UNIVERSITY OF DERBY

PSYCHOPHYSIOLOGICAL AND EMOTIONAL ANTECEDENTS OF CLIMBING PERFORMANCE

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i. Table of Contents

ii. List of Figures

iii. List of Tables

iv. Publications and Presentations

All research and writing contained within this thesis are my own, unless otherwise identified.

Within the thesis are several publications from a small group of researchers at the University of Derby, UK and collaborations with academics at other universities, including the University of Gloucester, UK; Charles University Prague, CZ; and, The University of Cadiz, ES. Where elements of this thesis have been published or are under review, this will be indicated at the start of the relevant section. All studies have received institutional ethical approval.

Preliminary methodological studies: Lead author

Giles, D., Taylor, N. Mitchell, J. & Draper, N. (2017). Self-reported ability and pre-competition anxiety in climbing competition performance. [*Under review Research Quarterly for Exercise and Sport*]

Giles, D., Fryer, S., Dickson, T. & Draper, N. (2017). The influence of height familiarity on psychophysiological response. [*Under review Scandinavian Journal of Medicine and Science in Sports*].

Giles, D., Draper, N., Gilliver, P., Taylor, N., Mitchell, J., Birch, L., Woodhead, J., Blackwell, G. & Hamlin, H. (2014). Current understanding in climbing psychophysiology research. *Sports Technology,* 7(3-4), 108-119. [doi: 10.1080/19346182.2014.968166].

Preliminary methodological studies: Member of team

Taylor, N., **Giles, D.,** Hoyle, D. and Draper, N. (2017). Development of a lead climbing performance analysis tool. [Manuscript in preparation].

Draper, N., **Giles, D.,** Schöffl, V., Fuss, F., Watts, P… & Abreu, E. (2016). Comparative grading scales, statistical analyses, climber descriptors and ability grouping: International Rock Climbing Research Association Position Statement. *Sports Technology,* 8(3-4), 88-94. [doi: 10.1080/19346182.2015.1107081]

Presentations associated with thesis

Giles, D., Draper, N., Gilliver, P., Taylor, N., Mitchell, J., Birch, L., Woodhead, J., Blackwell, G. & Hamlin, H. (2014). Current trends and the future progression of psychophysiology in climbing research. International Rock Climbing Research Congress, September 15th – 19th 2014, Pontresina, Switzerland. [Oral].

Additional publications during PhD process

Fryer, S., Sveen, J., Stone, K., Dickson, T., España-Romero, V., **Giles, D.,** Baláš, J., Draper, N. & Stoner, L. (2017). Differences in forearm strength, endurance and hemodynamic kinetics between male boulderers and sport rock climbers. *European Journal of Sports Science.* [doi: 10.1080/17461391.2017.1353135]

Giles, D. & Draper, N. (2017). Heart rate Variability: a comparison of artefact correction methods. *Journal of Strength and Conditioning Research.* [doi: 10.1519/JSC.0000000000001800]

Fryer, S., **Giles, D.,** Garrido Palomino, I., O Puerta, A. & España-Romero, V. (2017) Hemodynamic and cardiorespiratory predictors of sport rock climbing performance. *Journal of Strength and Conditioning Research.* [doi: 10.1519/JSC.0000000000001860]

Giles, D., Kelly, J. & Draper, N. (2016). Alterations in Heart Rate Variability Indices of Autonomic Cardiovascular Modulation in Response to Normobaric Hypoxia. *European Journal of Sports Science*, 16(8), 1023-31. [doi: 10.1080/17461391.2016.1207708]

Baláš, J., **Giles, D.,** Chrastinová, L., Kárníková, K., Kodejška, J. and Draper, N, (2016). The effect of potential fall distance on hormonal response in rock climbing. *Journal of Sports Sciences*, 35(10), 989-94. [doi: 10.1080/02640414.2016.1206667]

Fryer, S., Stone, K., **Giles, D.,** Sveen, J. Garrido, I. Stoner, L. & Espańa-Romero, V. (2016). Oxidative capacity in the dominant forearm flexor predicts sport climbing performance. *European Journal of Applied Physiology*, 116(8), 1479-84. [doi: 10.1007/s00421-016-3403-1]

Giles, D., España-Romero, V., Garrido, I., Castillo, M., Fryer, S. (2016). Differences in oxidative capacity between the dominant and non-dominant flexor digitorum profundus in rock climbers. *International Journal of Sport Physiology and Performance*, 12(1), 137-139. [doi: 10.1123/ijspp.2015-0651]

Giles, D., Draper, N. & Neil, W. (2016). Validation of the Polar V800 heart rate monitor to measure RR intervals at rest. *European Journal of Applied Physiology*, 118, 563-71. [doi: 10.1007/s00421-015-3303-9]

Balás, J., Michailov, M., **Giles, D.,** Kodejška, J., Panáčková, M., Fryer, S. (2015). Active recovery of the finger flexors enhances intermittent handgrip performance in rock climbers. *European Journal of Sports Science*, 16(7), 764-72. [doi: 10.1080/17461391.2015.1119198]

Panáčková, M., Baláš, J., Bunc, V. & **Giles, D.** (2014). Physiological demands of indoor wall climbing in children. *Sports Technology,* 7(3-4), 183-190. [doi: 10.1080/19346182.2014.968251]

v. Abstract

Recreational sport climbing is characterised by self-selected route choices, which place participants under both physiological and psychological stress. This thesis is comprised of four studies, each conducted with experienced climbers, exploring subjective psychological, objective psychophysiological and behavioural responses to anxiety-inducing stressors.

Studies One and Two explored the means of protecting a climber in the event of a fall and the relative difficulty of a route. Significant and meaningful differences in self-reported anxiety and climbing performance were found in both studies. However, notably, psychophysiological measures of anticipatory heart rate and cortisol did not result in meaningful differences. Results suggested that situations, atypical of participants' normal recreation sessions, with an increased likelihood of a climber falling or being unable to complete the route, were likely to be evaluated as threatening, elicit a negative emotional response and disrupt performance. However, the quantitative methods employed in *Studies One and Two* did not provide an explanation of the processes underlying participant's anxious response and disrupted performance.

Consequently, *Study Three* qualitatively explored individual experiences of climbers, with a focus on psychological factors that influence performance. The defining characteristics of lead climbing were discussed, as were the potential for taking falls, and/or the anticipation of falling. Further, interviewees described the choices they make, in order to increase or decrease the physical, psychological and technical challenges present. Critically, the choices made by a climber appear to potentiate or limit opportunities to perform optimally. Climber's decisions were mediated by a number of antecedents, including a climber's background in the sport, climbing partners and training status. Data suggests that while decisions made by the climbers allow them to engage with the sport on their own terms and exert a level of control over the challenges of their climbing sessions, it is often at the expense of performance. Interestingly, while interviewees were aware of techniques to reduce anxiety and improve performance, few regularly used these in training.

Study Four examined the effectiveness of clip drops and repeat practice to reduce anxiety. Results indicated that neither technique resulted in reduced anxiety or improved performance when compared to the control group. While there were small differences in the success rate of participants in the intervention groups, they were less anxious and interpreted their level of self-confidence as more positive, compared to control, it was not possible to differentiate between the two interventions. However, when the combined means were considered there were significant and meaningful differences observed in the post-intervention red-point ascent compared to the initial on-sight.

This thesis highlights the difficulty that arises in attempting to quantitatively examine anxiety. While there might not be (a) anxiety in climbers or (b) quantifiable differences between climbers of different abilities, it may be that what is possibly ‘noise’ in data arises due to weaknesses in the markers themselves. The findings of *Study Three* provide evidence of the true nature of anxiety for climbers, which was not evident from the quantitative markers; as well as the lengths climbers will go to, to avoid anxiety. Climbers’ responses to anxiety were individualised, consequently, generalised interventions may have a limited effect on reducing anxiety to a level which supports performance improvements. It may be that an individualised approach to anxiety reduction and avoidance behaviours has a more significant impact on performance improvement than any of the latest training programmes, equipment or nutritional strategies.

Keywords

Rock climbing; lead climbing; intermediate; advanced; psychophysiology; physiology; psychology; challenge and threat; cortisol; heart rate; anxiety

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vii. Abbreviations

The following abbreviations and acronyms are used throughout this thesis. Where possible acronyms are written out in full on their first appearance in each chapter and shortened subsequently.

Abbreviations: Scientific

°C	Degrees Celsius
µL	Microliter
ACTH	Adrenocorticotropin Hormone
AGQ	Achievement Goals Questionnaire
ANOVA	Analysis of Variance
ANS	Autonomous Nervous System
$b.min^{-1}$	Beats Per Minute
BLA	Basolateral Complex of the Amygdala
BNST	Bed Nucleus of the Stria Terminalis
BP	Blood Pressure
BPS	Biopsychosocial
C	Challenge
CBG	Corticosteroid-Binding-Globulin
CeA	Central Nucleus of the Amygdala
CH	Convex Hull
$CI_{95\%}$	95% Confidence Interval
CO	Cardiac Output
CPEI	Climbing Performance Evaluation Inventory
CRF	Corticotropin-Releasing Factor
CSAI-2R	Competitive State Anxiety Inventory
CTi	Challenge and Threat Index
DMN	Dorsal Motor Nucleus of the Vagus
$dyn{\cdot}s{\cdot}cm^{5}$	Vascular Resistance
ELISA	Enzyme-Linked Immunosorbent Assay
FDR	False-Discovery Rate
GABA	β-Aminobutyric Acid
GE	Geometric Entropy
Glu	Glutamate
HPA	Hypothalamic-Pituitary-Adrenal
HR	Heart Rate
HRM	Heart Rate Monitor
IAMS	Immediate Anxiety Measurement Scale
IS	Independent Sample
Kcal	Kilocalorie
kg	Kilogramme
L/min	Litres per Minute
LC	Locus Ceruleus
LH	Lateral Hypothalamus
LM	Line of Motion
LSD	Least Significant Difference
m	Metre
MANOVA	Multivariate Analysis of Variances
MAp	Mastery-Approach
MAP	Mean Arterial Pressure
MAv	Mastery-Avoidance
MD	Mean Difference
min	Minute
$mL{\cdot}kg^{-1}{\cdot}min^{-1}$	Millilitres per kilogram per minute
NA	Noradrenaline
NA	Nucleus Ambiguus
nm	Nanometre
nmol/L	Nanomoles per Litre
NTS	Nucleus Tractus Solitaries
PAC	Pituitary-Adreno-Cortical
PAG	Periaqueductal Gray
PAp	Performance-Approach

PAv	Performance-Avoidance
PBN	Parabrachial Nucleus
PFC	Prefrontal Cortex
POMS	Profile of Mood State
PVN	Paraventricular Nucleus
RCAI	Rock Climbing Anxiety Inventory
RPC	Caudal Reticulo Pontine Nucleus of the Reticular Formation
rpm	Revolutions per Minute
SAM	Sympathetic-Adreno-Medullary
SPSS	Statistical Package for the Social Sciences
STAI	State-Trait Anxiety Inventory
SV	Stroke Volume
T	Threat
TCTSA	Theory of Challenge and Threat States in Athletes
TPR	Total Peripheral Resistance
$\dot{V}O_2$	Volume of Oxygen
$\dot{V}O_{2max}$	Maximal oxygen consumption
ηp^2	Partial Eta Squared Effect Size

Abbreviations: General

+ve	Positive
♀	Female
♂	Male
Adv	Advanced Ability
CLL	Climbers Lead Limit
CLLminus	Below Climbers Lead Limit
CLLplus	Above Climbers Lead Limit
f	French difficulty grade
Int	Intermediate Ability
IRCRA	International Rock Climbing Research Association
LC	Lead-Climb
LCTR	Lead Climb with Top-Rope
LL	Lead Limit
Low	Low Ability
MIA	Mountaineering Instructor Award
OS	On-Sight
QD	Quickdraw
RP	Red-Point
SPA	Single Pitch Climbing Award
TR	Top-Rope
-ve	Negative
YDS	Yosemite Decimal Scale
UIAA	Union International des Associations d'Alpinisme

1

Introduction

The sport of rock climbing is an established pastime, having emerged as an alternate discipline from mountaineering during the 19th and 20th Centuries (Thompson, 2011). Initially, climbing served as a means of gaining the skills necessary for more ambitious objectives; whereas nowadays, the modern sport is most often a means to an end in itself (Thompson, 2011; Wilson, Pearson, & Pearson, 1975). Since the 19th Century, climbing has developed rapidly. While early pioneers took the lines of least resistance up mountains and crags, at first easy scrambles, then gullies, chimneys, ridges and arêtes, with the evolution of improved climbing equipment, training and skill, attention turned to more technical slabs and walls (Cram, 1986). Consequently, advances in performance during the 20th Century have been considerable and are likely to represent the largest seen in the sport (Thompson, 2011).

The combination of technological advancements and strong ethical and historical influences has resulted in three divergent disciplines: traditional, sport climbing and bouldering (Bisharat, 2009). While bouldering and sport climbing can be carried out indoors or outdoors, traditional climbing is entirely an outdoor activity. Traditional climbing, as an outdoor sport, is undertaken on natural rock with protection placed by the climber, while sport climbing relies on pre-placed protection (Bisharat, 2009). Bouldering is comprised of short, powerful, technical climbing, typically completed low to the ground above crash mats, which protect against a fall (Stiehl & Ramsey, 2005). The performance of climbers at their maximal level has progressed considerably during the past 100 years; **Figure 1.1** illustrates the progression in performance, taking the first route at every grade in the discipline of sport climbing and bouldering. Undoubtedly, we will continue to see improvements in the grades climbers achieve, but it does not appear that it will be at the same rate as the past 50 to 100 years.

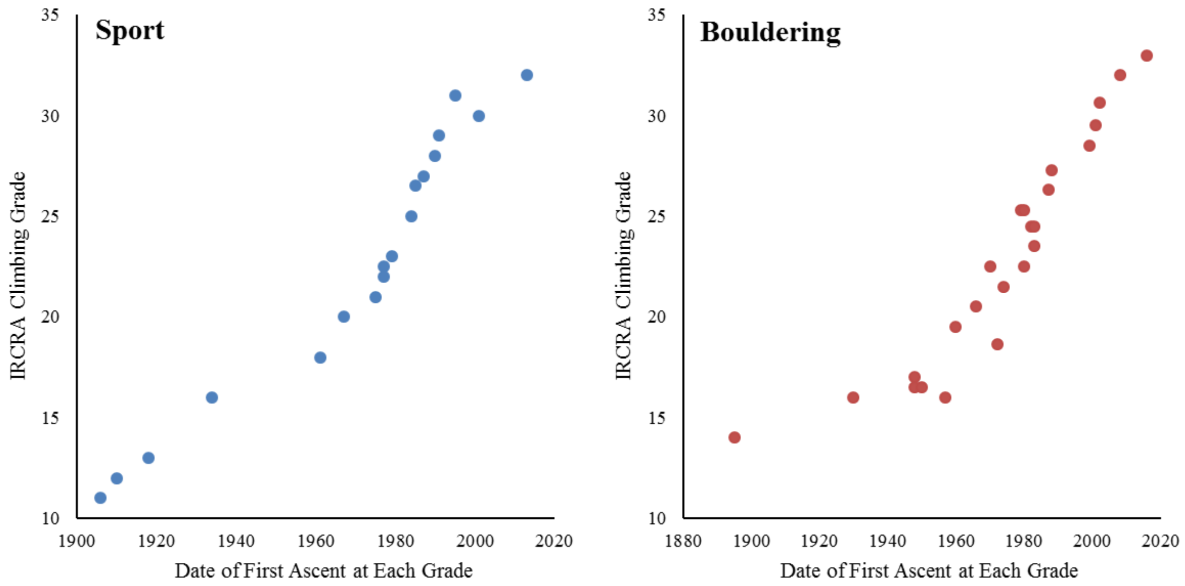


Figure 1.1: *The first route at every grade in the discipline of sport and bouldering. International Rock Climbing Research Association (IRCRA) grading scale used for comparison between different grading scales (15 = f6c / F5+; 20 = f7b / F7A; 25 = f8b / F7C+; 30 = f9a+ / F8B+; Draper et al., 2016).*

The rapid progression of climbing performance started in the post-war era of the 50's and 60's, the so-called age of the hard-men of British climbing (Thompson, 2011). The swift development occurred because of a combination of structured practice, a key exponent of which was the American former gymnast, come climber John Gill; along with technological developments in equipment, including improvements in the means of protecting climbers in the event of a fall and the development of sticky rubber on closely fitted climbing shoes (Niegl, 2009). Since the 1980's the sport's development continued with the arrival of indoor climbing gyms. In contrast to the large, clean and well-protected walls found across the country today, the first indoor walls were rudimentary with protruding bricks for holds (Mittelstaedt, 1997). Indoor climbing walls not only provided facilities for climbers living further from outdoor climbing, but also facilitate year-round training (Harrison & Erpelding, 2012).

From its recreational roots, indoor competitive climbing has developed in recent years (IFSC, n.d.). The first organised international lead climbing competition 'SportRoccia' was held in 1985, outdoors in Bardonecchia, Italy. Competitive climbing was recognised by the Union International des Associations d'Alpinisme (UIAA) in 1998, leading to a World Series and the first World Cup in speed and lead climbing in 1989. The late 20th century saw an increase in the number of competitions. The most recent development in the sport was the decision by the 129th International Olympic Committee in Rio de Janeiro to approve climbing as a new event for Tokyo 2020. In line with the Olympic motto of "Citius, Altius, Fortius" or "Swifter, Higher, Stronger" (Grasso, Mallon, & Heijmans, 2015, p. 442) the Olympic competition will consist of sport climbing, speed climbing and bouldering, a departure from the single discipline currently seen in adult international competitions (IOC, 2016).

This thesis is primarily concerned with indoor sport climbing, a key component of the Olympic discipline when climbing joins the Olympic family in Tokyo 2020. Furthermore, indoor climbing is becoming increasingly popular. Between 2010 and 2014 there was a 30% increase in the number of climbing walls in the United Kingdom and a concomitant increase in the number of wall visits (Gardner, 2015). According to Sport England's report, approximately sixty-one thousand individuals take part in the sport for at least 30 minutes each month (Sport England, 2015).

Climbing research has followed a similar progression to the sport. The earliest published climbing study examined the effects of the rope in rock climbing accidents (Barford, 1945). The proceeding work largely focused on personality and climbing (Edwards, 1967; Gray, 1967; Ogilvie, 1974) and the occurrence of accidents and injuries (Foray et al., 1981; Hubicka, 1977; Schussman & Lutz, 1982). With the arrival of climbing as a competitive sport attention focused on the anthropometric characteristics of climbers (Grant, Hynes, Whittaker, & Aitchison, 1996; Watts, Martin, & Durtschi, 1993), the physiological demands of the sport (Watts, Drobish, & Ringheim, 1992; Watts & Drobish, 1998) and climbing movement (Cordier, France, Bolon, & Pailhous, 1993; Cordier, France, Pailhous, & Bolon, 1994). Knowledge progressed with the development of sport-specific measures (West, Hicks, Clements, & Dowling, 1995) and training guidelines (Köstermeyer & Weineck, 1995). In current climbing research, there is a continuing focus on injuries, with approximately 40 - 50% of climbing studies published on the subject (Chang, Torriani, & Huang, 2016; Lion, Van Der Zwaard, Remillieux, Perrin, & Buatois, 2015; Schöffl, Popp, Küpper, & Schöffl, 2015). The sport specificity of the measurement techniques has improved, for example with advanced methods for the assessment of forearm endurance using near infrared spectroscopy (Fryer et al., 2015a; Fryer et al., 2015b) and, of particular interest to this thesis, the use of psychophysiological techniques to explore the psychological demands of the sport (Dickson, Fryer, Blackwell, Draper, & Stoner, 2012a; Draper et al., 2012; Fryer, Dickson, Draper, Blackwell, & Hillier, 2013; Hodgson et al., 2009).

Climbing is an activity with numerous intrinsic challenges and rewards, however, it also carries inherent dangers (Anwyl, 2010). The sport is frequently grouped with other risky sports, such as mountain biking and kayaking, which are often referred to as a lifestyle, alternative, adventure or extreme sport (Kerr & Mackenzie, 2012). A particular commonality of these sports are the environments in which they take place and the hazards they contain (Young, 2012). It is hard to talk about climbing without discussing the risks these hazards place on the personal safety of those taking part. Indeed, climbing literature, such as Eric Hörst's book on mental training for climbing, starts with the statement *"Warning: Climbing is a dangerous sport. You can be seriously injured or die."* (Hörst, 2010, p. VII). Equally, the British Mountaineering Council's participation statement is displayed in most, if not all, climbing walls in Britain and highlights, climbing, hill walking and mountaineering are activities that carry the risk of personal injury or death (Anwyl, 2010).

Undoubtedly, climbing does carry hazards not present in more typical mass participation sports, such as football, however, they should be put in context. In the 45 years between 1960 and 2005 there were 50 million climbing wall visits and during that period there was only one fatality indoors in England and Wales (Gardner, 2007). Injury incidence rates indoors are around 0.02 - 4.2 per 1000 hours climbing (Schöffl, Morrison, Schwarz, Schöffl, & Küpper, 2010; Schöffl, Hoffmann, & Küpper, 2013; Schweizer, 2012). The type of injuries differs between disciplines, while sport climbing indoors is more likely to result in chronic overuse injuries of the upper extremities, traditional climbing outdoors is more likely to result in injuries because of a fall, due to the need for the climber to place their own protection (Backe, Ericson, Janson, & Timpka, 2009; Schöffl et al., 2010). Despite these hazards, the injury risk is still considered lower than traditional sports such as football, for which typical injury incident rates are around 64 per 1000 match hours (Theron, Schwellnus, Derman, & Dvorak, 2013).

One of the primary challenges and choices made by climbers when ascending a route is the style of ascent, or how the climber is protected in the event of a fall. Typically, on all but the shortest of routes, climbers are either protected from above with a top-rope or they trail a lead rope which they attach to intermittent points of protection as they ascend (Bisharat, 2009). Lead climbing involves the potential for the climber to fall some distance before they are arrested by their belayer (Bisharat, 2009). Despite the low incidences of acute injuries, the potential for taking falls, and an associated perceived concern of injury, is considered a significant stressor for climbers (Macleod, 2010). Hurni (2003) describes a fear of falling as one of the most difficult fears within climbing to overcome, and Sagar (2001) *"fear is the root of many climbers' limitations"* (p. 114). Anecdotally, Macleod (2010) also reports *"I've observed it [fear of falling] as the primary weakness in over 50% of climbers I meet for coaching sessions"* (p. 95), and is one of the most *"insidious and unpleasant"* (p. 95) problems facing coaches.

Given the inherent relevance of fear and anxiety to the sport, it is unsurprising that the role and consequences of emotions have long been investigated in climbing research literature (Edwards, 1967; Hardy & Whitehead, 1984; Mace, 1979; Mace & Carroll, 1985; Williams, Taggart, & Carruthers, 1978). In recent years, a growing body of research has developed using psychophysiological techniques to explore the challenge present in climbing, particularly with differences in the style of ascent (Aras & Akalan, 2011; Dickson et al., 2012a; Draper, Dickson, Fryer, & Blackwell, 2011d; Draper et al., 2012; Draper, Jones, Fryer, Hodgson, & Blackwell, 2008; Draper, Jones, Fryer, Hodgson, & Blackwell, 2010; Fryer et al., 2013; Hodgson et al., 2009); along with route knowledge (Draper et al., 2008) and between successful and unsuccessful climbers (Draper et al., 2011d). Psychophysiology is concerned with the study of relations between psychological manipulations and resulting physiological responses (Andreassi, 2006); for example, changes in measures of heart rate and the stress hormone cortisol provide a means of quantifying mental and bodily processes, providing an objective assessment of a climbers state (Dickson et al., 2012a; Draper et al., 2012; Fryer et al., 2013).

The use of psychophysiological techniques in climbing are not new, having been used as early as Williams et al. (1978) with the measurement of changes in heart rate and catecholamine concentrations in response to an outdoor climbing task. However, psychophysiological techniques in climbing have seen limited use, possibly because of the complexity and time-consuming nature of data collection, cost of analysis and, in the case of Williams et al. (1978), the interaction of other stressors and environmental conditions: *"The rock was open, smooth, and dripping with rainwater and did not lend itself to isometric exertion as a mode of remaining on the face"* (p. 127). Regarding these challenges, Draper, Dickson, Fryer and colleagues research have made significant methodological advances, with the application of the measurement of plasma cortisol and heart rate in the complex environments climbing presents (Dickson et al., 2012a; Draper et al., 2012; Fryer et al., 2013). However, while significant advances have been made, their results have proved largely equivocal, despite the consternation by coaches and climbers of the demands of the stressors investigated (Hague & Hunter, 2011;

Hörst, 2010; Hörst, 2008; Hurni, 2003; Sagar, 2001). Variation and lack of meaningful differences in previous studies are likely to have occurred because of the interaction between known, and possibly as yet unknown stressors. Climbing is frequently described as multifaceted, consequently, it is unsurprising that psychophysiology research completed to date has highlighted the considerable intra-individual variability in results.

Not only are stressors in climbing potentially anxiety-inducing, they are also likely to have a significant impact on performance (Pijpers, Oudejans, Holsheimer, & Bakker, 2003). However, with the exception of Hardy and Hutchinson (2007) and Sanchez, Boschker, and Llewellyn (2010), there has been limited investigation into the effects of stressors on experienced climbers' performance. Indeed, Pijpers et al. (2003) speculated that the lack of performance measures was the reason why research on anxiety in sport has proved to be equivocal, and why there is limited evidence of predicted relationships (Jones, 1995). Instead, Pijpers et al. (2003) suggest research should adopt a process-oriented approach, which not only considers changes in outcomes, such as success and failure (Draper et al., 2011d), but also changes in the execution of movements that may, or may not, lead to changes in outcomes (Gould, Greenleaf, & Krane, 2002). Consequently, as with Pijpers et al. (2003), this thesis will employ detailed measures of performance in order to determine if behavioural changes occur alongside differences in self-report of state and psychophysiological measures.

Building upon the understanding gained from the work of Draper, Dickson Fryer and colleagues, this thesis continues to explore psychophysiological and emotional antecedents of climbing performance (Dickson et al., 2012a; Draper et al., 2011d; Draper et al., 2012; Draper et al., 2008; Draper et al., 2010; Fryer et al., 2013; Hodgson et al., 2009). To achieve this, this thesis aimed to make advances in several key areas: firstly, combining physiological measurements with detailed methods of performance assessment including geometric entropy (Cordier et al., 1993) and coaches assessment of performance; secondly, consideration of the potential interaction of stressors identified in preceding climbing psychophysiology research; thirdly, qualitatively explore experienced climbers' understanding of the challenges present within climbing and how they are managed; finally, explore the effectiveness of clip-drop fall practice techniques, as suggested anecdotally by the majority of climbing coaching textbooks for improving performance and reducing subjective emotions (Hague & Hunter, 2011; Macleod, 2010; Sagar, 2001). The thesis also aimed to advance understanding in regard to demand evaluations, in particular, those occurring because of perceptions of danger, as set out by Lazarus (1991). Currently, there is no empirical evidence supporting predictions of demand evaluations occurring because of perceived danger in challenge and threat research (Blascovich & Tomaka, 1996; Jones, Meijen, McCarthy, & Sheffield, 2009). Climbing potentially presents an effective means of instigating perceived danger demand evaluations in an experienced sporting population.

1.1 Thesis overview

The research completed for this thesis aims to build on the body of climbing psychophysiological research completed to date (Dickson et al., 2012a; Draper et al., 2012; Fryer et al., 2013). Specifically, the thesis contributes to the growing body of research in this field by exploring psychophysiological and emotional antecedents of climbing performance. This includes developing on the existing body of research with the addition of new-to-climbing cardiac psychophysiological markers, detailed climbing performance measures, consideration of the interaction of stressors, the qualitative investigation of intermediate participants' perceptions of stressors and the investigation of the effectiveness of clip-drop and red-point climbing interventions on pre-climb psychological state and performance.

The thesis is comprised of four main studies: *Study One* investigates changes in the safety protocol and its consequences. *Study Two* investigates the relationship between climber ability relative to the difficulty of a route, and their psychological, physiological and behavioural responses; *Study Three* explores participants' perceptions of stress in indoor sport climbing through semi-structured interviews; and *Study Four* examines the effectiveness of two interventions, the first red-point practice, the second a progressive fall exercise, for reducing psychophysiological response, perceived anxiety and improving climbing performance. The series of studies that make up this thesis are amongst the largest completed to date in the sport, particularly those investigating psychological factors such as fear and anxiety. The inclusion of detailed performance measures to assess inter-individual differences between participants and the psychophysiological and emotional antecedents develops on previous research.

1.2 Structure

The thesis is laid out as follows: Firstly, the literature review aims to critically analyse climbing psychophysiological research within a framework of theoretical understanding of stress in sport. To achieve this, *Chapter 2* provides context to the sport and the individuals who participate in it, along with research concerning the stress process, stressors and how and why performance is disrupted. *Chapter 3* discusses current climbing psychophysiology research and the implications on performance and behaviour. *Chapter 4*, to avoid repetition in the experimental chapters (*Chapters 5, 6 and 8*), provides details of the methods common to *Studies One, Two, and Four*; the general methods chapter is supported by several preliminary studies, which were conducted to explore the validity and reliability of the methodologies used in the main investigations. The results of the preliminary studies are discussed and full texts may be found in the appendices at the end of this thesis. *Chapters 5, 6, 7 and 8* are experimental chapters, where details of the specific methodological, procedures, analysis, results and findings of *Studies One, Two, Three and Four* are presented. *Chapter 9* concludes this thesis, discusses the main findings, their implications, applications and suggested areas for future study.

1.3 Purpose

The purpose of *Study One* was to investigate differences in the pre- to post-climb psychophysiological and behavioural responses of climbers to routes with differences in the means of protecting them from falling (style of ascent). The purpose of *Study Two* was to explore the mediating role of climbing experience and ability on indices of challenge and threat, psychophysiological markers pre-post climb and climbing performance for climbers attempting a route below, at, or above their maximum on-sighting ability. The purpose of *Study Three* was to determine potential sources of inter-individual variation in responses to the challenges of indoor lead climbing through exploring the individual perceptions of intermediate climbers. Finally, the purpose of *Study Four* was to establish the effectiveness of two interventions, designed to reduce perceived anxiety and improve climbing performance on indoor lead climbing routes, when compared to a control group.

2

Literature Review: Part One

Stressors, the stress process and the disruption of performance

The following chapter discusses the relationship between stressors, associated psychological, physiological and behavioural processes and their implications for climbing performance. This chapter begins by presenting an overview of the stressors present in the climbing environment. The proceeding sections explore stress as a process. Firstly, by discussing physiological and psychological responses to stressors, before exploring the role of cognitive interpretations of state. The importance of demand resource evaluations and challenge and threat states are considered. Finally, the performance implications and mechanisms of performance disruption are then explored. Reviewed literature has been drawn from psychology, sports psychology and climbing, in addition to research focused on the investigation of climbing specific stressors. An emphasis is placed on understanding the concomitant factors responsible for inter-individual variation in responses seen in previous climbing psychophysiology research.

2.1 Understanding the sport of climbing

There are many potential stressors within the climbing environment. A stress response may arise because of the physical and technical demands of the sport, including the difficulty, length and angle of a climb (Watts, 2004), and the considerable psychological demands including the style of ascent, competition, height, fear of falling and route knowledge (Hague & Hunter, 2011). Stress is a state of threatened disruption of homeostatic balance (Chrousos, Loriaux, & Gold, 2013), which has the potential to have a considerable impact on both physical and technical performance (Hatfield & Kerick, 2007). In one of the first climbing psychophysiology studies Williams et al. (1978) stated that climbing *"represents more of an anxiety-type of psychological stress than a physical stress and as such is likely to increase moral fibre rather than muscle fibre"* (p. 125). In contrast to the conclusions of Williams et al. (1978), coaches have described climbing performance as being comprised of a combination of *physical*, *technical* and *mental* aspects (Hörst, 2008). Hörst (2008) asserts that rock climbing is unique amongst sports, as it requires a near-equal balance between these three facets (**Figure 2.1a**). Magiera et al. (2013) findings provide empirical support for Hörst (2008) contention of the contribution to performance, although further research is needed.

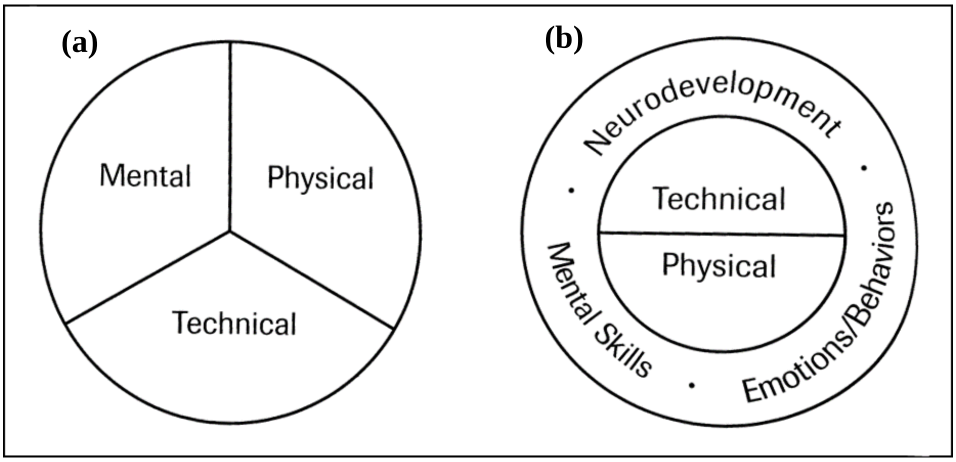


Figure 2.1: *A theoretical model of the relative contribution of mental, physical and technical components comprising skill in climbing. With (a) highlighting the near equal balance, and (b) their psychological underpinning [copyright Hörst (2010), reproduced with permission].*

The physical element of performance concerns the sport specific power, strength and endurance of the climber; the technical aspect is determined by the fundamentals of efficient movement, including coordination and technique; and the mental element concerns emotional control, behaviours, personality traits, temperament, locus of control and tactics (Hörst, 2008). While optimal performance in climbing may require an equal balance between the three elements, they often do not receive the same attention (Hörst, 2010). Expertise in the physical and technical components of the sport are essential, however, they are also underpinned by the psychological component, which should not be ignored (**Figure 2.1b**). Despite this, an emphasis on training the physical element is common, possibly because it is harder for individual climbers to assess personal levels of movement quality or mental skill, than their own physical aptitude (Hörst, 2010).

An essential characteristic of skilled athletic performance is the efficiency of movement, and the same holds true for climbing (Hatfield & Hillman, 2001; Lay, Sparrow, Hughes, & O'dwyer, 2002). Within the sport, technical skill has been described as the ability to *"rapidly and fluently transition between holds"* (Orth, Davids, & Seifert, 2016, p. 1). Skilled climbers are able to perform with minimal effort, as constrained by the difficulty of the route and the opportunities for action (Orth et al., 2016). Efficiency in climbing performance typically develops with experience. Hardy and Martindale (1982) found experienced climbers to have lower energy expenditure and could climb much further on a more challenging route than beginner climbers (proportional energy cost in beginners 23.98, and experts 7.41 $\dot{V}O_2$ per meter). Similarly, Balas et al. (2014) reported increased exercise economy with climbing ability. Self-reported ability was negatively correlated with both $\dot{V}O_2$ and heart rate (wall angle 90º, $\dot{V}O_2$ r = -0.82, heart rate r = -0.66; angle 105º, $\dot{V}O_2$ r = -0.84, heart rate r = -0.78); higher ability participants were able to offset the increased demands through improved exercise economy, which led to increased time to exhaustion (Balas et al., 2014). Furthermore, these characteristics have been shown to be trainable, with repetition of the same route over a ten week period Espana-Romero et al. (2012) reported a decrease in the time required to ascend a route (week 1, 2.02 ± 0.55 min; week 9, 1.38 ± 0.31 min) and energy expenditure (week 1, 17.16 ± 4.56 kcal; week 9, 11.59 ± 3.22 kcal).

With an increase in ability and efficiency, there is less complexity in the processes associated with motor control and a reduction in the degrees of freedom of relevant neural networks (Hatfield & Kerick, 2007). Reduced degrees of freedom leads to greater consistency in resulting motor performance due to less variability in the organisation and preparation of movement (Hatfield & Hillman, 2001). Further anecdotal evidence of the development of climbing movement efficiency is provided in coaching literature. Hörst (2010) states *"Beginners naturally lack the motor programs needed to execute many climbing moves, while cognitive focus centres mainly on dealing with fear and basic risk management",* while intermediate climbers *"exhibit increasingly smooth, more efficient movement and a calmer, more confident demeanour. Motor programs are refined and expanded as a function of hours invested in practising skills and exploring new types of climbing"* (pp. 14 – 15). Such evidence is consistent with the notion of three phases of automaticity in skilled motor behaviour, advanced by Fitts and Posner (1967). More recently, developing on the largely descriptive nature of the framework of Fitts and Posner (1967), the Adaptive Control of Thought-Rational (ACT-R) was advanced based on a simulation model of motor development (Anderson & Lebiere, 2014). In Anderson and Lebiere (2014) model, knowledge progresses from a declarative phase, where explicitly retrievable declarative knowledge is held in working memory and consciously attended to; to a procedural phase (or motor program), which does not require the same degree of attention and where the performer negotiates tasks or demands without conscious effort. The proceduralisation occurs through a process of knowledge compilation, where information is restructured into a new type of skill representation (Beilock & Carr, 2004).

In addition to technical skill, as previously eluded to, climbers require considerable psychological skill to respond appropriately and to produce behaviour indicative of an optimal performance (Macleod, 2010; Seifert et al., 2013). Such challenges are not so different from those experienced in other competitive sports:

> *Performing in professional competitive sport requires athletes to make split-second decisions, coordinate their limbs within multiple degrees of freedom, and maintain fine motor control under physical and mental fatigue- all while operating under the stress imposed by perceptions of the consequences of victory or defeat*. (Wilson, 2012, p. 173).

However, unlike competition, the choice climbers have when engaging with stressors within recreational sessions should also be considered. Climbers take part in the sport of their own volition, making choices that may increase the risk, including choosing to change the style, difficulty, risk and exposure of ascents. Enjoyment has been described as being unrelated to the associated fear, pain and strenuous muscular effort required (Hooper, Collins, & Eklund, 2011). Climbers of any ability may choose to take part in riskier ascents, where the consequences of mistakes are more severe, likely motivated by the opportunity for optimal experiences, rather than the risk itself (Schüler & Nakamura, 2013). It is believed competence, combined with hard effort, are decisively important factors, which leads to both successful ascents and the development of self-confidence in climbers (Papaioannou, Kourtesopoulou, & Konstandakatou, 2005). The relationship between performance and participants ability to respond to potentially evocative stressors effectively is a fundamental aspect of climbing

(Goddard & Neumann, 1993; Hörst, 2008). Consequently, a considerable amount of literature exists on the topic, its impact on performance and strategies surrounding psychological control (Hague & Hunter, 2011; Hurni, 2003; Macleod, 2010; Reeves, 2010). For example, Hague and Hunter (2011) describe anxiety as performance-robbing and assert that every climber should attempt to overcome it. In support of such statements, anxiety has been shown to disrupt most aspects of technical climbing performance, including visual attention, the perception of affordances, perceived reach distance and the fluency of movement (Nieuwenhuys, Pijpers, Oudejans, & Bakker, 2008; Pijpers, Oudejans, & Bakker, 2005). The disruption of performance will be discussed in detail later in the literature review (*see Section 2.8 Disruption of performance*).

One of the primary psychological stressors in climbing relates to the choice of how a route is protected in the event of a fall, which is termed as the *style of ascent*. With a change in the style of ascent, there is the potential for increased negative emotional response towards falling, indeed many authors of climbing and coaching literature acknowledge such challenges and their potential effect on performance (Hague & Hunter, 2011; Hurni, 2003; Macleod, 2010; Sagar, 2001). A fear of falling is a non-associative phobia, which may develop without the individual experiencing any direct or indirect trauma (Menzies & Clarke, 1993b). Typically, the initial fearful response to falling will diminish over time due to habituation; however, poor habituates and individuals who do not gain sufficient safe exposure may remain fearful (Clarke & Jackson, 1983). In a climbing context, Hörst (2008) speculates that it is not the falling itself that is feared, but not knowing what the fall will be like *"This explains why your first fall on a route is the scariest, while subsequent falls are often much less stressful"* (p. 37). Falling may be associated with physical injury, or a threat of physical harm, even indoors where the majority of climbing injuries occur because of chronic overuse of the upper extremities (Backe et al., 2009).

Alternatively, a fear of falling may develop because of a threat to self-efficacy as a result of a climber's perceived evaluation by others. Self-efficacy has the potential to play a significant role in how situations are approached, the emotions experienced and consequently how the climber performs (Bandura, 1997). While climbing success has been described as enhancing self-esteem and self-confidence (Stiehl & Ramsey, 2005), for recreational climbers, success is often dictated by whether the climber reaches the top of a route, or not. Furthermore, a fear of failure is associated with anticipation of shame in evaluative situations and a tendency to appraise situations as threatening (Conroy, Willow, & Metzler, 2002; Sagar & Lavallee, 2010).

It is conceivable then that failure, or the potential for failure, would have a negative impact on self-efficacy. Conversely, greater self-efficacy has been associated with participants being less likely to fear failure (Kontos, 2004). Similarly, in a climbing context, Llewellyn, Sanchez, Asghar, and Jones (2008) found greater self-efficacy were associated with participants taking greater calculated risks, attempting harder climbs and climbers having greater feelings of confidence in their ability.

A fear of falling, whether it is because of a fear of physical harm, or a threat to self-efficacy, is unlikely to affect all climbers to the same extent. With the development of expertise, particularly in traditional climbing, an emphasis is placed on cognitive skills required for risk management (Holland-Smith & Olivier, 2013). Within the sport, there is a strong emphasis on being in control and taking ownership of decisions (Holland-Smith & Olivier, 2013). Indeed, both Robinson (1985) and West and Allin (2010) found climbers defined themselves as rational risk managers, rather than reckless *adrenaline junkies*. Binney and McClure (2005) also suggest skilful climbing performance lies in being able to manage and differentiate between rational and irrational fear and perceived and actual risk. This is particularly important when anxiety has been demonstrated to have a significant detrimental effect on performance (Pijpers et al., 2003), less pleasure while participating in sport (Scanlan, Babkes, & Scanlan, 2005; Smith & Smoll, 1991) and can even result in discontinuation of sport participation (Gould, Feltz, Horn, & Weiss, 1982; Scanlan et al., 2005).

The intensity of the emotions experienced also varies between individuals, based on their interpretation of the demands of the task and the skills they possess to manage them (Lazarus, 1991). Anecdotally speaking, inter-individual differences in the willingness to take risks and ability to manage potentially debilitative stressors are observable. There are numerous examples in climbing media of athletes who can produce apparently superhuman performances, ascending hard routes with little or no protection, where the consequences of a mistake will, at best, result in life-changing injuries or, more likely, death. A particularly well-known example is the American climber Alex Honnold, famous for free soloing: ascending huge routes, that take other climbers days or even weeks, in a matter of hours with no protection to arrest a fall; *"Free soloing is almost as old as climbing itself, with roots in the 19th century. Climbers are continuing to push the boundaries. There are certainly better technical climbers than me. But if I have a particular gift, it's a mental one - the ability to keep it together where others might freak out."* (Honnold, 2014, p. 12). At the other end of the continuum, on a trip to a local climbing wall or crag, it would be possible to observe climbers avoiding taking falls on routes that, aside from changes in the style of ascent, would be well within their physical capabilities. While Honnold's ability to free solo is atypical, it highlights the range of confidence and control between individuals within the sport.

Understanding the impact of stressors typical of the recreational climbing environment, and their psychological and psychophysiological antecedents, has implications for coaches and climbers, climbing research, and wider research using climbing as a means of instigating psychological and physiological stress. For coaches and climbers, fear and anxiety are likely to have significant implications for performance, as well as long-term enjoyment and continued participation. For climbing research, studies exploring climbing stressors have proved equivocal, despite the consternation of climbers and coaches as to their significance. The lack of meaningful differences observed (*see Chapter 3*) may have occurred for several reasons, including the interaction of stressors present in the climbing environment; controlling for these factors, *Studies One and Two* aim to elucidate differences not previously *observed*. Finally, due to its psychological challenges, climbing has also been used as a medium for exploring psychological concepts, such as challenge and threat (Turner, Jones, Sheffield, Barker, & Coffee, 2014; Williams, Cumming, & Balanos, 2010), cognitive resource demands (Helton, Green, & de Joux, 2013) and processing efficiency theory (Hardy & Hutchinson, 2007). For wider research which uses climbing as a means of instigating stress, understanding the way in which participants respond, stressors interact and the magnitude of responses is essential.

In summary, climbing is a complex multifaceted sport in which participants choose to challenge themselves, selecting the stressors they are exposed to, their responses to which vary based on their experience and their interpretations of the consequences of poor performance. With an increase in the ability of the climber, not only are they physically fitter, with greater coordination and efficiency of movement, it is thought they are also better able to judge, rationalise and manage the challenges the climbing environment contains, including those related to psychological challenges, such as falling. While some climbers can effectively manage the psychological stressors, others find them all-consuming. As a result, fear and anxiety have the potential to have a significant detrimental effect on climbers' behaviour and consequently their performance.

2.2 Responding to stressors

Stress is a state of threatened disruption of homeostatic balance (Chrousos et al., 2013). In a sporting context, a demand is placed on an individual who is then required to cope to perform optimally (Jones, 1990). The term *stress* was first used in health literature by the eminent physiologist Hans Selye. Selye defined stress as "*the non-specific response of the body to any demand"* (Selye, 1974). The demands, or threats to homoeostasis, are termed *stressors* denoting any stimulus or demand that gives rise to a stress response (Chrousos et al., 2013). To re-establish homoeostatic balance when faced with a stressor *adaptive responses* occur, which may be either generalised or specific (Chrousos et al., 2013). Everly and Lating (2012) stated: *"stress is a physiological response that serves as a mechanism of mediation linking any given stressor to its target-organ effect or arousal"* (p. 17) (**Figure 2.2**). The stress response, as a physiological mechanism of mediation, can be characterised by a widely diverse collection of processes, which include neurological response pathways, neuroendocrine response mechanisms and endocrine response pathways (Everly & Lating, 2012).

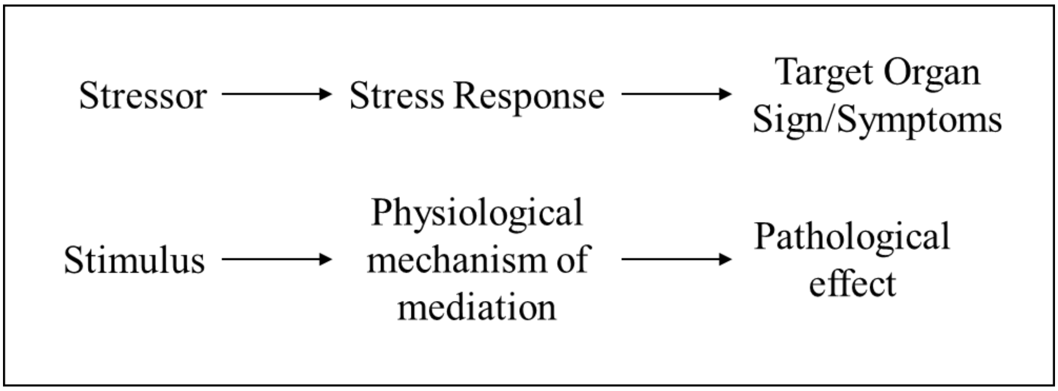


Figure 2.2: *The stress response as a physiological mechanism of mediation, based on the work of Everly and Lating (2012).*

There are two potential sources of stressors, those occurring because of psychosocial factors, and those because of bioenergetics (Girdano, Dusek, & Everly, 2012). Psychosocial stressors occur because of individuals' cognitive interpretation of an event and the meaning they assign to it (Lazarus, 1991). Psychosocial stressors rely on individual's either consciously or unconsciously perceiving them in the environment (Mellalieu, Hanton, & Fletcher, 2006). Bioenergetic stressors require no cognitive appraisal, as they possess an inherent stimulant quality, in order to cause physiological arousal (Widmaier, Raff, & Strang, 2014). The stimulant quality is found in substances such as caffeine and alcohol, but also of importance for sports psychophysiology research, with changes in temperature and physical exertion (Everly & Lating, 2012). It is worth noting that some stressors are inherently more stressful than others, leaving less potential variation for cognitive interpretation, while others are more dependent on individuals' interpretation (Everly & Lating, 2012). Cognitive interpretation plays a significant role in adjustment to the stressor and serves to augment or mitigate the resultant stress response; *"It's not what happens to you that matters, but how you take it."* (Seley n.d. in Everly & Lating, 2012, p. 28).

Climbers may manipulate several aspects to increase or alter the challenge of a given climb, these are undoubtedly psychosocial stressors and have received varying amounts of research attention. The most obvious psychosocial stressor is the style of ascent or the means in which climbers protect themselves in the event of a fall. While a top-rope will immediately arrest a fall, a lead of a route will result in the climber traveling further before coming to a stop; consequently, the style of ascent has received considerable research attention (Aras & Akalan, 2011; Dickson et al., 2012a; Draper et al., 2011d; Draper et al., 2012; Draper et al., 2010; Fryer et al., 2013; Hardy & Hutchinson, 2007; Hodgson et al., 2009). Differences in behaviour have been examined in novice climbers with alterations in height above the ground (Nieuwenhuys et al., 2008; Pijpers, Oudejans, Bakker, & Beek, 2006; Pijpers et al., 2003; Pijpers et al., 2005). The knowledge a climber possesses of the route they are ascending has also been investigated (Draper et al., 2008; Hardy & Hutchinson, 2007). Research concerning these factors will be discussed in the next chapter (*see Chapter 3, Literature Review: Part Two*).

The physicality of ascending routes is also a considerable stressor, requiring a significant contribution from both anaerobic and aerobic energy pathways (Watts, 2004). For example, a significant load is placed on the finger flexors and the forearms to intermittently grip holds, while the shoulder girdle, upper arms and chest, in tandem with the lower body provide upward locomotion (Giles, Rhodes, & Taunton, 2006). Flexibility within the hips and lower back, and stability within the shoulders, are essential qualities (Draper, Brent, Hodgson, & Blackwell, 2009). In addition to the physiological demands of the difficulty of the route, the relative difference between the climber and the difficulty route should be considered, this has received limited research attention, but is thought to be both a significant physiological and psychological stressor (Hardy & Hutchinson, 2007; Hardy & Whitehead, 1984; Janot, Steffen, Porcari, & Maher, 2000).

In response to stressors, including those in the climbing environment, to maintain allostasis, a series of orchestrated physiological and psychological events occur (Everly & Lating, 2012). Arousal is a critical component of the stress response, commonly referred to as undifferentiated energy without valence, which primes or prepares the body for immediate action (Gould et al., 2002; Hardy, 1996). The default response to threat, novelty or uncertainty is sympathoexcitatory preparation for action, the so-called fight or flight response, an adaptive excitation preparing the body with the aim of maximising survival (Thayer & Lane, 2009). Arousal is seen to vary on a continuum, from deep sleep to intense excitement, combining both the physiological and psychological components of the energetic systems (Malmo, 1957). Duffy (1962) linked the potential energy with behaviour *"the extent of release of potential energy, stored in the tissue of the organism, as this is shown in activity or response"* (p. 179). Further definitions of arousal have proposed three dimensions, comprised of autonomic, electrocortical and behavioural aspects (Lacey, 1967). Autonomic arousal is the biological response triggered by the nervous system, including raised heart rate, pupil dilation, changes in breathing, and may be measured using physiological indices such as galvanic skin response, heart rate or blood pressure. Electrocortical arousal is responsible for changes in brain functioning, with brain waves changing frequency, speeding up or slowing down, as measured in the cortex via electroencephalogram. Behavioural arousal may be observed in changes in overt behaviour, including restlessness, fidgeting, trembling or tension (Andreassi, 2006).

The neurophysiological mechanisms and processes responsible for adaptive responses to stressors are complex (Gray & McNaughton, 2003). Steimer (2002) provides an overview of the interrelationships between the various neurophysiological mechanisms and processes (**Figure 2.3**). Briefly, the stress process is coordinated by the limbic system, the central components of this functional circuit are the amygdalae and the bilateral and anterior of the hippocampi on the inferior and medial aspect of the temporal lobes (Bear, Connors, Paradiso, Bear, & Connors, 2006). On presentation of a stressor, a series of orchestrated events occur which together change athletes' mental and physical state in a profound manner (Hatfield & Kerick, 2007). Multiple sensory pathways including auditory, visual, olfactory and somatosensory stimuli are relayed by the thalamus to the basal lateral complex of the amygdalae and cortex and environmental events are immediately processed (Paré, Quirk, & Ledoux, 2004; Steimer, 2002). The basal lateral complex of the amygdalae also receives contextual information from the hippocampal formation. The amygdala, which has outputs to autonomic, endocrine and other physiological regulatory systems become active under threat and uncertainty and is largely responsible for the processing and memory of emotional reactions and the coordinated response to fear-eliciting stimuli (Bishop, 2007).

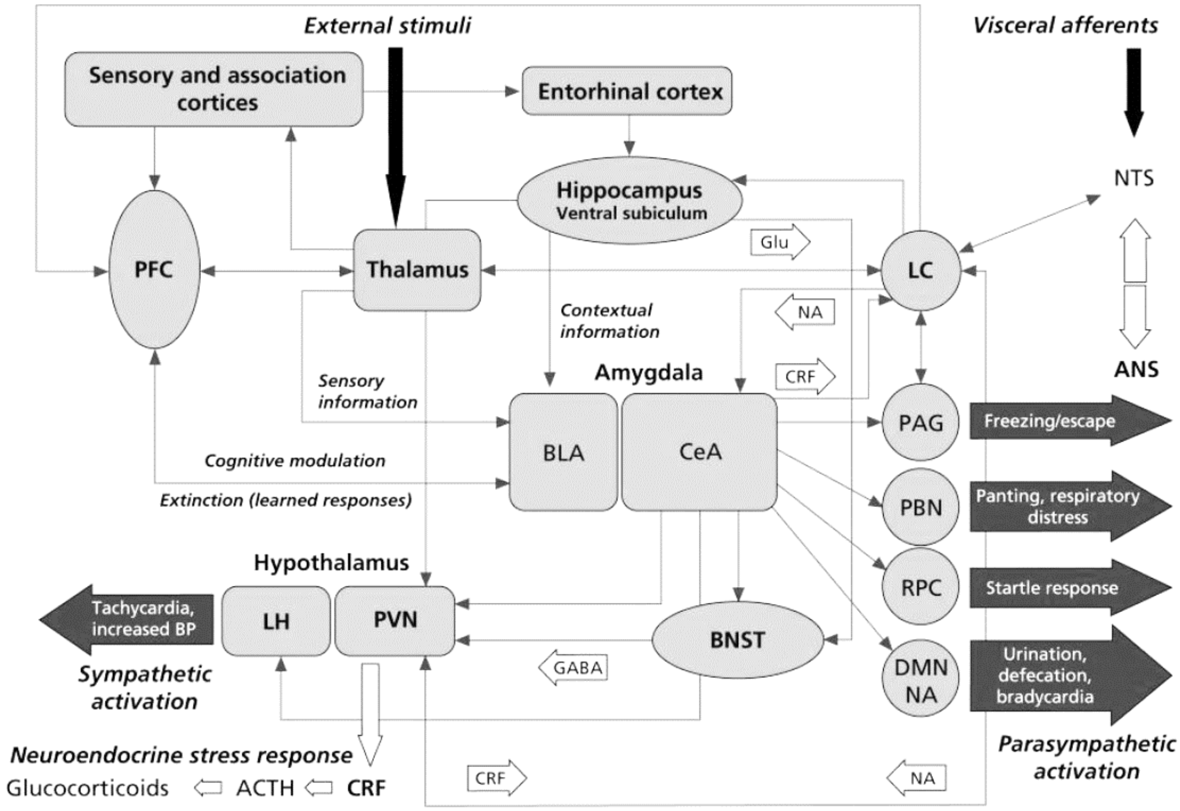


Figure 2.3: *The major brain circuits involved in fear and anxiety [reproduced from Steimer (2002) under the terms of the Creative Commons Attribution License]*. (*BLA, basolateral complex of the amygdala; LC, locus ceruleus; CeA, central nucleus of the amygdala; CRF, corticotropin-releasing factor; PVN, paraventricular nucleus; LH, lateral hypothalamus; BNST, bed nucleus of the stria terminalis; PAG, periaqueductal gray; PBN, parabrachial nucleus; RPC, caudal reticulopontine nucleus of the reticular formation; DMN, dorsal motor nucleus of the vagus; PFC, prefrontal cortex; ACTH, adrenocorticotropic hormone; ANS, autonomous nervous system; BP, blood pressure; GABA, β-aminobutyric acid; Glu, glutamate; NA, noradrenaline or nucleus ambiguus; NTS, nucleus tractus solitaries*).

Research suggests that, under conditions of uncertainty and threat, there is disruption of the amygdalae-prefrontal circuit, occurring because of enhanced amygdala activation and deficient recruitment of prefrontal control mechanisms (Hatfield & Kerick, 2007). Individuals under high stress will exhibit reductions in prefrontal asymmetry, which results in decreased frontal executive control over the medial frontal-mesolimbic circuit, behavioural changes and potentially disrupted performance (Hatfield & Kerick, 2007). A lack of control, or hyperactivity, of the amygdalae results in heightened emotional influence, interfering with attention and the motor loop connections to the motor cortex largely responsible for controlling the corticospinal outflow and the resultant quality of the motor unit activation (Grafton, Hari, & Salenius, 2000; Hatfield & Kerick, 2007). Further heightened amygdala activity and reduced prefrontal recruitment appears to result in undesirable alterations in information processing, with athletes' more likely to pay attention to threatening stressors and interpret emotionally ambiguous stimuli as threatening (Bishop, 2007). The implications of disruptions of attention will be discussed in sections *2.7 Attention and 2.8 Disruption of performance.*

Following intra-amygdala processing of the emotional stimuli, depending on its valence, the central nucleus of the amygdala activates critical forebrain, brainstem and endocrine structures that mediate the expression of emotions (Steimer, 2002). These structures include the locus ceruleus and central and peripheral noradrenaline systems via corticotropin-releasing factor neurones and the hypothalamus (paraventricular nucleus and lateral hypothalamus). The bed nucleus of the stria terminalis (part of the extended amygdala) is also a control centre for the neuroendocrine system, integrating information originating from both the hippocampus and the amygdala. In addition, the central nucleus of the amygdala directly activates various midbrain regions, which are responsible for increases in heart rate and blood pressure associated with emotional events (Steimer, 2002); these include the periaqueductal gray, responsible for motor responses freezing or escape, the parabrachial nucleus responsible for increased respiratory rate, caudal reticulon pontine nucleus of the reticular formation responsible for startle and the dorsal motor nucleus of the vagus in the medulla. The dorsal motor nucleus of the vagus in the medulla together with the lateral hypothalamus is responsible for sympathetic arousal and stimulation of stress hormones via the hypothalamic-pituitary-adrenal (HPA) axis. The cingulate cortex communicates with neocortical association regions, such as temporoparietal regions, with interconnections to pontine nuclei in the reticular formation, which results in increased overall arousal (Hatfield & Kerick, 2007).

Neuroendocrine and parasympathetic activation results in alterations in many physiological variables, which may be used for the non-invasive assessment of climbers' response to stressors (Dickson et al., 2012a; Draper et al., 2012; Fryer et al., 2013). Of interest to this thesis are alterations in the outflow of the central autonomic network, the HPA axis, sympathetic-adreno-medullary (SAM) activity and pituitary-adreno-cortical (PAC) activity (Seery, 2011). The various outputs of these systems have been highlighted to represent psychophysiological markers of the activity of critical neurophysiological mechanisms related to the stress response (Seery, 2011). The psychophysiological assessment provides a means of objectively indexing stress process, in response to cognitive evaluations that occur predominantly unconsciously (Seery, 2011). Previous climbing psychophysiology research this has consisted of the determination of serum cortisol and anticipatory changes in heart rate (Dickson et al., 2012a; Draper et al., 2012; Fryer et al., 2013). The research is discussed in *Chapter 3, Literature Review: Part Two*.

Moving on from the existing body of climbing psychophysiology research, this thesis will employ the measurement of cardiovascular indices of challenge and threat, namely heart rate, cardiac output and total peripheral resistance. Furthermore, the determination of cortisol concentrations in the present thesis will develop the body of research surrounding the predictions of Blascovich and Tomaka (1996) biopsychosocial (BPS) model of challenge and threat and Jones et al. (2009) theory of challenge and threat states in athletes (TCTSA). While the cardiovascular indices of heart rate, cardiac output, peripheral resistance and pre-ejection period (not possible to assess in this thesis) have been used to quantify challenge and threat states, cortisol has not (Blascovich, Seery, Mugridge, Norris, & Weisbuch, 2004; Jones et al., 2009; Mendes, Blascovich, Hunter, Lickel, & Jost, 2007; Moore, Vine, Wilson, & Freeman, 2012; Moore, Wilson, Vine, Coussens, & Freeman, 2013; Turner et al., 2013; Turner, Jones, Sheffield, & Cross, 2012). A threat response is characterised not only by an increase in SAM activity, as seen in a challenge response, but also an increase in PAC activity. The activation of the PAC axis results in the release of ACTH, causing the adrenal cortex to secrete corticosteroids into the bloodstream. As a consequence of the increase in concentrations of circulating cortisol during a threat state, there is no corresponding decrease in systemic vascular resistance, despite cardiac activity increases similarly to a challenge condition (Dienstbier, 1989). Given these hypotheses threat cardiovascular reactivity should be associated with elevated levels of cortisol. The methodological implications of psychophysiological measurements will be discussed in the general methods (*see 4.3.3* Cardiovascular reactivity).

2.3 The relationship between arousal and performance

Previous authors have attempted to define the relationship between arousal and performance through uni-dimensional arousal based theories. Broadhurst (1957) and Hebb (1955) proposed the relationship between arousal and performance may be explained by Yerkes and Dodson (1908) inverted-U hypotheses. They suggested heightened arousal enhanced performance to a certain point, after which continued increases in arousal would hinder performance (**Figure**

2.4). Similarly, Spence and Spence (1966) later drive theory stated that there was a positive linear relationship between drive or arousal and performance, as long as the learnt dominant responses was correct skill execution. Consequently, Broadhurst (1957) and Hebb (1955), Spence and Spence (1966) and others including Zajonc (1965) social facilitation theory, proposed that an individual's performance level was determined directly by his or her current level of arousal or drive.

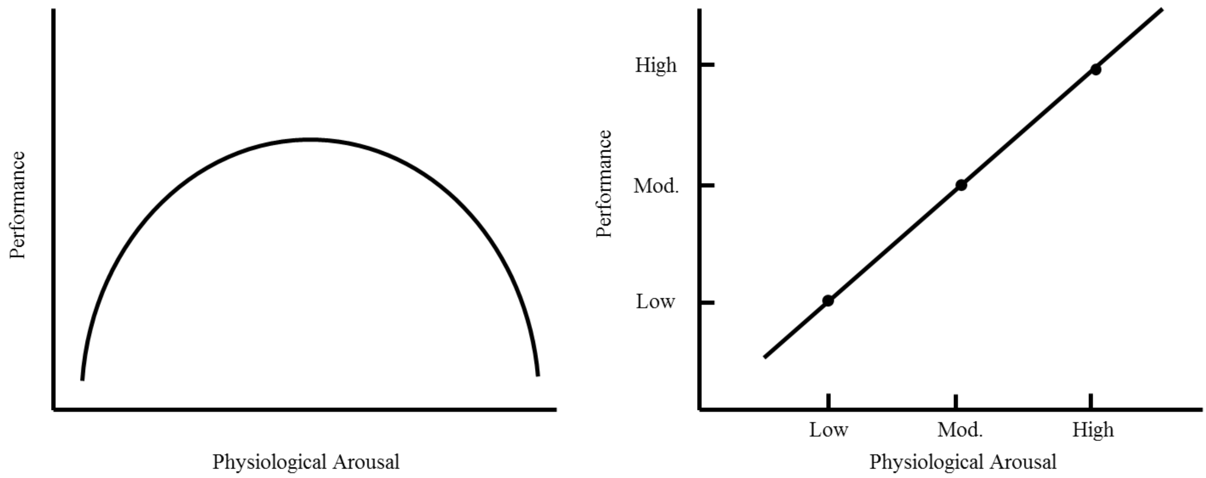


Figure 2.4: *The inverted-U hypothesis (Left) based on the work of Yerkes and Dodson (1908) and drive theory (right) based on the work of Spence and Spence (1966).*

A number of early climbing psychophysiology studies assessed physiological arousal, primarily recording alterations in heart rate (Hardy & Martindale, 1982; Hardy & Whitehead, 1984; Mace, 1979). Mace (1979) reported the effects of pre-training on arousal during an abseil task. Participants were comprised of a control group, experienced climbers and an experimental intervention group. Heart rate increased during the abseil task in all participants, however, in comparison to the experienced climbers, the response in the control and intervention groups to the initial abseil was significantly greater (control and experimental groups ~150 $b.min^{-1}$, experienced ~95 $b.min^{-1}$), despite the experimental group receiving additional preliminary training and instruction on a small abseil. In contrast, Hardy and Martindale (1982) reported that initial heart rates before an indoor traverse climbing task suggested experts were more physiologically aroused than beginners (beginners ~79 $b.min^{-1}$, experts ~94 $b.min^{-1}$); it appeared that arousal formed a necessary part of the expert's psychological preparation. The presumably low height of the traverse in Hardy and Martindale (1982) study may have contributed to the difference from the findings of Mace (1979), it is possible the increase in heart rate before the commencement of the task was an appropriate response. Hardy and

Whitehead (1984) also found participants exhibited elevated heart rate in response to a lead ascent of a traditional route at the climbers lead limit, compared to an easier route (easier route 78 $b.min^{-1}$, lead limit 83 $b.min^{-1}$) (Hardy & Whitehead, 1984). The authors stated that increased heart rate in the hardest condition supports Lacey (1967) view, heart rate increases when the subject is attempting to *reject* the environment.

The early climbing studies of Mace (1979), Hardy and Martindale (1982) and Hardy and Whitehead (1984) highlight the limitations of arousal-performance models discussed in more contemporary literature. There is agreement that arousal exists on a continuum, however, while intuitive, arousal does not serve to directly explain the relationship between a participants' state and their performance. Drive and arousal theories are consistent with pressure induced skill decrements in some situations, but they are generally limited in usefulness; they do not provide an explanation of the mechanisms for why performance failures occur (Beilock & Gray, 2007) and they cannot easily explain why athletes choke under pressure (Lavallee, Kremer, Moran, & Williams, 2012). It is also not possible to predict in advance the point of diminishing returns for the effects of arousal on skilled performance (Neiss, 1988), further, if an athlete goes *over the top,* it is not realistic to assume that the athlete would be able to get back to an optimal performance state as easily (Woodman & Hardy, 2001). Finally, they do not allow for individuals' cognitive appraisal of the situation (Lazarus, 1991).

Arousal is an undifferentiated product of the stress response, preparing the body for immediate responses to new stimuli (Gould et al., 2002; Hardy, 1996). Consequently, arousal does not serve as a direct explanation for alterations in performance. It is instead the complex interaction of physiological and psychological arousal and the cognitive interpretation/ appraisal of the state that are likely to determine performance. For example, the process model of Gould et al. (2002) is presented to illustrate the relationship between the environmental demand, arousal and anxiety and resultant changes in perception of state, psychophysiological markers and behaviour (**Figure 2.5**). The relationship proposed by Gould et al. (2002) is based on four stages: Stage 1, the athlete is placed under environmental demand; Stage 2, they perceive the environment as more or less threatening; Stage 3, an arousal response occurs to meet the demand, comprised of physiological arousal component and a cognitive interpretation; and Stage 4, specific performance outcomes occur. While Gould et al. (2002) model is presented here, there are a number of models that describe the temporal patterning of the emotion-arousal experience including those of James-Lange (Fehr & Stern, 1970), Cannon-

Bard (Cannon, 1927), Schachter-Signer (Schachter & Singer, 1962), discussion of which are beyond the scope of this thesis.

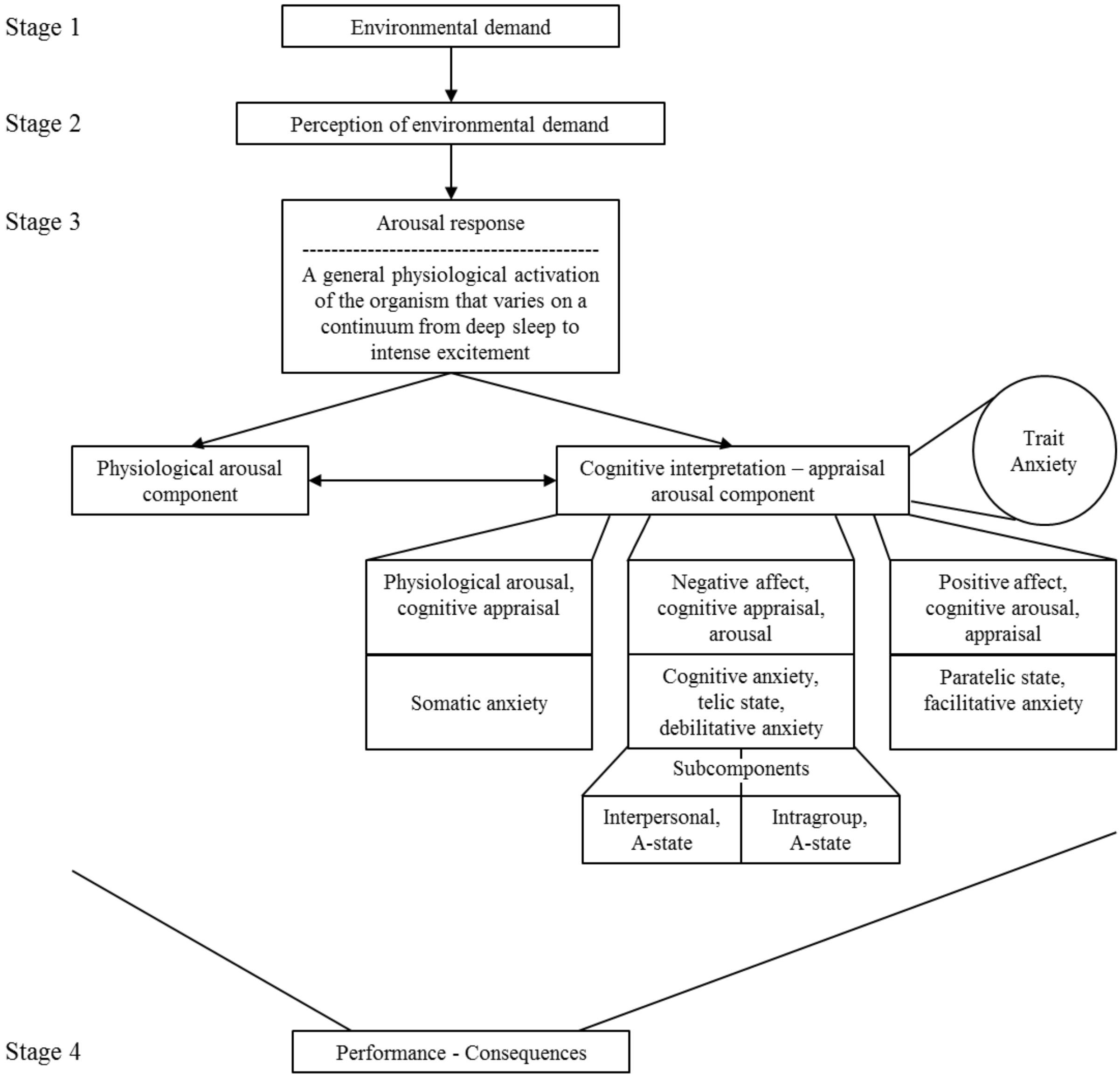


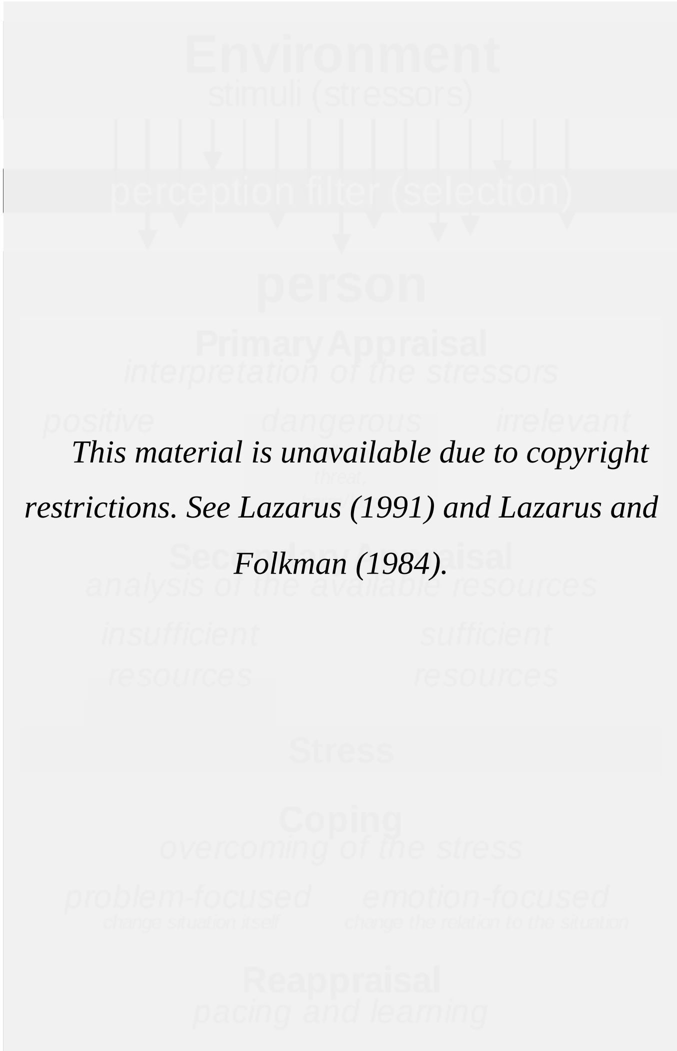
Figure 2.5: *Gould et al. (2002) model of the relationship between the stress process and arousal terminology [copyright Gould et al. (2002), reproduced with permission].*

Central to Gould et al. (2002) model is the cognitive interpretation-appraisal of the arousal component. An individual's interpretation of a stressor and self-appraisal of available coping resources are believed to be critical in determining how the individual responds (Lazarus & Folkman, 1984; Martens, 1977). Interpretation is a key component of the stress response and resultant performance in environments containing stressors, and may explain why no one climber's response is the same as the next; *"under similar environmental conditions, people perceive themselves differently, think differently, cope differently, and experience and display emotions differently"* (Lazarus, 1998, p. 213). Indeed, it is conceivable that differences in cognitive interpretation have been responsible for the considerable inter-individual variation seen in previous climbing psychophysiology research (*see Chapter 3*). As a consequence, developing on previously climbing psychophysiology research, the consideration of climbers' cognitive evaluation within this thesis, as described by Lazarus (1991), will provide further understanding of the antecedents and mechanisms for changes in emotional state and behaviour. The following section will discuss the role and importance of climbers' cognitive interpretation of their state.

2.4 Cognitive interpretation of state

Psychological stress and emotion are not intrinsically determined by factors in the environment or intrapsychic process. Instead, they are believed to be determined by the individual relationship between the person and the environment, which changes over time and in response to different circumstances (Lazarus, 1991; Lazarus & Folkman, 1984). Lazarus (1991) theory of resources appraisal proposed two levels of cognitive appraisal, acting as a perceptual mediator between stressor and stress response (**Figure 2.6**). The primary appraisal establishes how important the situation is to an individual and whether it will endanger their well-being. The secondary cognitive evaluation process concerns the coping options available. Although appraisals can sometimes occur consciously and deliberately, often appraisals occur rapidly and largely outside of conscious control (Uphill, 2015). The reappraisal is a successive evaluation based on external information obtained from the environment and the internal appraisal; the reappraisal differs from the primary appraisal only in that it follows an earlier cognitive evaluation (Lazarus, 1991).

Demand appraisals include the perception of danger, uncertainty and required effort in a situation. For example, a demand appraisal would be made if a climber perceives a fall may result in physical harm (danger of injury or humiliation), is unsure of how they may perform (uncertainty) and/or recognises the need for the physical and mental effort required to succeed (effort). Resource appraisals relate to the ability to cope with the demands of a situation and includes skills, knowledge, abilities; and dispositional factors including self-esteem, sense of control and external support availability (Blascovich, Mendes, Tomaka, Salomon, & Seery, 2003). Coping represents an individuals' cognitive, affective, and behavioural efforts to manage specific external and/or internal demands and may be either problem or emotion-focused (Lazarus & Folkman, 1984).



This material is unavailable due to copyright restrictions. See Lazarus (1991) and Lazarus and Folkman (1984).

Figure 2.6: *Illustration of Lazarus' Resource Appraisal Theory based on the work of Lazarus (1991) and Lazarus and Folkman (1984).*

Demands and resources are considered environmental variables which, combined with personality variables, are the antecedents which lead to appraisals, action tendencies and coping (Lazarus, 2006). If there is an imbalance in the transaction between the environmental demands and the individual's resources, then the emotions experienced will reflect the appraisal (Lazarus & Folkman, 1984). Coping is experienced when individual's secondary appraisal perceives they have sufficient or near sufficient coping potential to meet situational demands. Conversely, stress is experienced when secondary appraisal indicates an individual's coping potential is not sufficient to meet situational demands, thus deeming harm potentially imminent (Lazarus, 1991). Disparity between the cognitive evaluation of the situational demands and coping resources present in the climbing environment may be responsible for differences between climbers' emotional state and performance outcomes. Individual climbers' evaluations are likely to be critically important in determining their response to stressors. If there is an imbalance in the transaction, between the environmental demands and the individual's resources, then the emotions experienced will reflect the appraisal.

In a sporting context, building from Lazarus (1991) theory of resources appraisal, the TCTSA (Jones et al., 2009) is presented as a unifying theory, a potential explanation for individual differences in the stress response and an explanation of the link between emotional, physiological, neurophysiological and behavioural factors, with a growing body of literature examining the sporting performance consequences of each state (Blascovich et al., 2004; Moore et al., 2012; Moore et al., 2013; Turner et al., 2013; Turner et al., 2012). Consequently, the experimental studies of this thesis integrate the TCTSA. Differences in the cognitive evaluation of climbers present a potential explanation for the anxious response of climbers and coaches in occurring toward stressors present in the environment. Research testing the predictions of theories of challenge and threat have explored situations believed to elicit differences in perceptions of uncertainty and effort, however, little evidence has been presented for situations eliciting differences in perceptions of danger. Climbing, or more specifically perceptions of danger brought about because of climbing, afford the opportunity to explore demand evaluations occurring as a result. Theories of challenge and threat, and supporting evidence, are discussed in the following section.

2.5 Challenge and threat states

The Theory of Challenge and Threat States in Athletes (TCTSA), proposed by Jones et al. (2009), provides a secondary sports-focused framework for Blascovich and Tomaka (1996) biopsychosocial (BPS) model of Challenge and Threat, which has its roots in the earlier work of Lazarus and Folkman (1984) and Dienstbier (1989). Fundamental to the TCTSA is the belief that some athletes excel in motivated performance situations whereas others fail to perform (Jones et al., 2009). The two contrasting motivational states of challenge and threat reflect how individuals engage in meaningful motivated performance situations, such as sporting competitions (Blascovich & Mendes, 2000). Both the BPS model and TCTSA are underpinned by Lazarus (1991) theory of cognitive appraisal, which acts as a perceptual mediator between stressor and stress response. A challenge state is considered an adaptive approach associated with superior performance, and threat a maladaptive approach related to inferior performance (Blascovich et al., 2004; Moore et al., 2012; Turner et al., 2013; Turner et al., 2012). For the two motivational states, there are two possible series of potential emotional, physiological and performance consequences, which lead to either performance outcomes being positively or negatively affected (**Figure 2.7**).

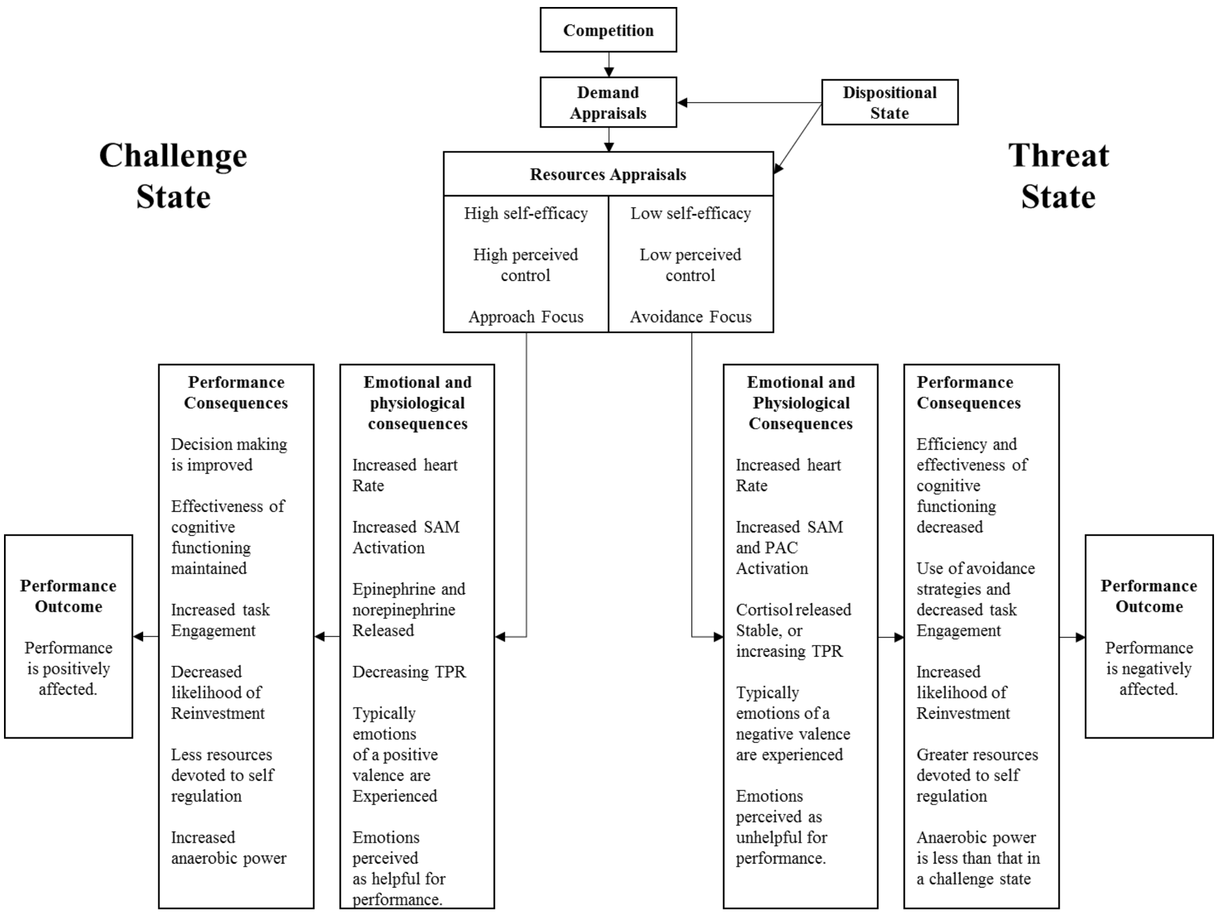


Figure 2.7: *Theory of Challenge and Threat States in Athletes, adapted from Jones et al. (2009). (SAM sympathetic-adreno-medullary; PAC pituitary-adreno-cortical; TPR total peripheral resistance) [copyright Jones et al. (2009), reproduced with permission].*

The demands of a situation may not differ for an athlete experiencing a challenge or threat state, instead, it is the athlete's evaluation of their available coping resources relative to the demand of the task that leads to a specific state, as discussed in the previous section (*see 2.4 Cognitive Interpretation of State)*. Evaluation of demands and resources occur predominantly unconsciously, without awareness of the evaluation process (Seery, 2011). Consequently, challenge and threat states are best indexed objectively through the observation of distinct patterns of cardiovascular and neuroendocrinal responses (Seery, 2011). A challenge appraisal is believed to be characterised by increased catecholamine output (adrenaline and noradrenaline), indicating SAM activity, which results in increased cardiac output and reduced total peripheral resistance, the product of vasodilatation. A threat appraisal also elicits increased SAM activity, as well as increased PAC activity. Pituitary-adreno-cortical activation releases adrenocorticotrophic hormone, which results in corticosteroids being secreted by the adrenal cortex into the bloodstream. The combination of SAM and PAC activation is characterised by smaller-than-challenge increases in heart rate, stroke volume and resulting cardiac output; no change or a small increase in total peripheral resistance along with increases in cortisol (Jones et al., 2009).

There is a growing body of research supporting the predictions of the TCTSA. Blascovich et al. (2004) examined the relationship between pre-performance motivational states in college baseball and softball players. Cardiovascular indices of cardiac output and total peripheral resistance, recorded while imagining giving a speech about a specific baseball or softball playing situation were identified as significant predictors of athletic performance during the subsequent season. Similarly, in a netball shooting task, under competition conditions, cardiovascular reactivity indicative of a challenge state predicted superior performance in comparison to cardiovascular reactivity associated with a threat state (Turner et al., 2012). More recently, Turner et al. (2013) established that challenge cardiovascular reactivity predicted superior performance in a cricket batting test, compared with threat cardiovascular reactivity. Interestingly, neither Turner et al. (2012) or Turner et al. (2013) found relationships between cardiovascular reactivity and self-reported psychological and emotional responses. It has been reported on a number of occasions that self-report of pre-task emotions via questionnaires provides a poor means of assessing how individuals process consciously available evaluations and does not provide a means of assessing individual’s unconscious processes, such as the immediate evaluation of a stressor (Blascovich & Mendes, 2000; Ledoux & Bemporad, 1997). Furthermore, there is also evidence that the subconscious awareness of evocative stimuli results in the bypassing of measurable cognitive evaluations and only a psychophysiological response (Weisbuch-Remington, Mendes, Seery, & Blascovich, 2005). Consequently, the assessment of cardiovascular reactivity provides a means of obtaining an objective insight into the participant's demand and resource evaluation (Jones et al., 2009).

In order to outline the emotional and psychophysiological constructs that underpin athlete's responses to motivated performance situations, the TCTSA draws on Skinner and Brewer (2004) model of adaptive approaches to competition and Jones (1995) control model of debilitative and facilitative competitive states (Jones et al., 2009). The TCTSA also proposes how personality traits can affect the likelihood of athletes responding to goal-relevant performance situations with either challenge appraisal or threat appraisal. A challenge state is theorised to be characterised by increased self-efficacy, individuals' belief in their capability to organise and execute an action to produce given attainments (Bandura, 1997); perceived control, individuals cognitive appraisal of the degree of influence over coping and goal attainment (Jones, 1995); approach goals, which govern achievement beliefs and guide subsequent decision making and behaviour in achievement contexts (Duda, 2005); and positive emotions and a facilitative interpretation of emotions before performance (Jones et al., 2009; Skinner & Brewer, 2004). Conversely, a threat state is characterised by decreased levels of self-efficacy, lower perceived control, avoidance goals, more negative emotions and a more debilitative interpretation of emotions (Jones et al., 2009; Skinner & Brewer, 2004). Finally, the TCTSA proposes emotions in a challenge state to be perceived as helpful for upcoming performance, while in a threat state emotions will be interpreted as unhelpful (Skinner & Brewer, 2004).

Differences in performance with challenge and threat states in studies conducted to date have likely resulted because of a combination of interpretation of emotional state and attentional control. While changes in behaviour have not been exhaustively tested, threat states appear to result in maladaptive behaviour (*see 2.7 Attention*). Those challenge and threat studies that have investigated behaviour have found threat states to be characterised by greater freezing, avoidance posture and less smiling (Mendes et al., 2007); less effective attentional control, measured with shorter quiet eye durations (Mann, Williams, Ward, & Janelle, 2007; Moore et al., 2012; Vine, Moore, & Wilson, 2014); focus on non-task relevant cues (Blascovich et al., 2004; Jones et al., 2009); reduced quality of task-relevant movements (Moore et al., 2012); and greater muscular tension. Challenge and threat states may be associated with one or more of the previous characteristics, which may or may not affect performance. For example, participants' challenge and threat state was manipulated in a golf putting task, using two sets of task instructions, in novice (Moore et al., 2012) and experienced golfers (Moore et al., 2013). In both cases, the participants in the challenge conditions displayed greater success rate, lower performance error and more favourable emotions in the putting task. However, while the inexperienced challenge participants of Moore et al. (2012) displayed more efficient gaze activity, putting kinematics, and muscle activity, mediation analysis did not find this to significantly influence performance. Furthermore, in the more experienced participants of Moore et al. (2013), there were no differences in such factors.

To summarise, cognitive appraisal is a key component of responses and resultant performance in environments containing stressors. The TCTSA proposes a set of distinct cardiovascular markers that occur depending on the appraisal. Consequently, through the assessment participants' cardiovascular responses to task instructions, it is possible to gain an objective insight into the climber's demand and resource evaluation as a potential explanation of the antecedents of alterations in performance (Jones et al., 2009). Cardiovascular assessment of the responses of climbers will be employed in this thesis. A growing number of studies have demonstrated differences in athletes performance between challenge and threat reactivity, including cricket batting (Turner et al., 2013), golf putting (Moore et al., 2012; Moore et al., 2013) and netball free throws (Turner et al., 2012). A commonality of studies completed to date, testing the prediction of the BPS and TCTSA, are the type of demands employed. Demand appraisals include the perception of required effort and uncertainty, but have not included perceptions of danger (Blascovich & Mendes, 2000). As a result, the studies that make up this thesis will develop on the existing body of challenge and threat research, through exploring cardiovascular reactivity, self-report of cognitive evaluations and behaviour outcomes in response to tasks that may bring about demand evaluations because of perceptions of danger, as well as perceived effort and uncertainty. Anxiety, attention and the disruption of performance will be discussed in more detail in the proceeding sections.

2.6 The relationship between anxiety and performance

Anxiety is an unpleasant negative emotional response, associated with vague but persistent feelings of apprehension and dread (Cashmore, 2008; Mellalieu et al., 2006; Uphill, 2015). From a cognitive psychological perspective, anxiety is characterised by a negative affect that impairs performance occurring as a result of threat, and is related to the subjective evaluation of a situation (Eysenck, 1996; Neiss, 1988). The main function of anxiety is to act as a signal of danger, threat, or motivational conflict and to trigger an appropriate adaptive response (Steimer, 2002). Anxiety is a multifaceted response, comprised of physiological, behavioural, linguistic and cognitive elements (Uphill, 2015). Within climbing, because of the presence of real physical danger, some authors discuss fear rather than anxiety (Morris, 1997; Spielberger, 1966). Fear is more specific, both are altering signals preparing the body for different actions, while anxiety is generalised and vague, fear is focused on a known external danger (Morris, 1997; Spielberger, 1966). However, as the source of the emotions experienced by climbers are often only inferred, it is not possible to say if they occur because of perception of danger, or for example a threat to esteem. Therefore, in accordance with Pijpers et al. (2003), fear and anxiety will be considered synonymously in this thesis.

Anxiety may be classified as situationally dependent state anxiety, or an aspect of personality that influences behaviour, trait anxiety (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). State anxiety is a consciously appraised feeling of apprehension and tension, which is accompanied by or associated with physiological arousal. Conversely, trait anxiety is a behavioural disposition that predisposes an individual to perceive non-dangerous circumstances as threatening and to respond to them disproportionally with greater state anxiety, in comparison to a lower trait anxious athlete (Spielberger, 1966). Low and high trait anxious individuals may interpret pressure in fundamentally different ways. In stressful situations, it has been shown that high trait anxious athletes use different and often non-productive coping behaviours, in comparison to low trait anxious athletes (Giacobbi & Weinberg, 2000). Furthermore, high trait anxious individuals will perceive more situations as threatening and will react with greater state anxiety in a wider range of situations than those with lower trait anxiety (Gould et al., 2002).

Anxiety is believed to be a multidimensional construct comprised of two distinguishable components of cognitive anxiety and somatic anxiety (Morris, Davis, & Hutchings, 1981; Schwartz, Davidson, & Goleman, 1978). Cognitive anxiety represents the mental component describing thoughts athletes experience in stressful situations, such as worries, negative expectations and apprehensions about performance (Hanton, Thomas, & Mellalieu, 2009). Somatic anxiety describes the individual perceptions of physiological arousal state in a stressful environment, including muscular tension, butterflies in the stomach, increased heart rate and perspiration (Hanton et al., 2009). It should be noted that, while somatic anxiety refers to the individuals' *perceptions* of physiological arousal, physiological arousal refers directly to measured physiological changes (e.g., heart rate, skin conductance and cortisol concentrations) (Woodman & Hardy, 2001). Cognitive and somatic anxiety are symptoms of the anxiety response rather than causal variables in the stress-performance relationship (Hardy & Hutchinson, 2007).

Athletes experience a range of emotions in relation to competition and other motivated performance situations (Hanin, 2000; Uphill & Jones, 2007). However, research has predominantly focused on anxiety, which while undoubtedly important, is only part of a range of emotions that may affect performance (Hanin, 2007; Uphill, 2015). The focus on anxiety is also true of climbing research (Green & Helton, 2011; Hardy & Hutchinson, 2007; Hodgson et al., 2009; Nieuwenhuys et al., 2008; Pijpers et al., 2006). In sporting contexts, the most important emotions are usually personally relevant, task-specific, and functionally helpful or harmful. It has been argued that emotions conceptualised as negatively related to performance, such as anxiety, can sometimes be beneficial (Woodman & Hardy, 2001). For example, experienced athletes may be able to deliberately use relatively high anxiety to their advantage and expert performers often perceive anxiety as facilitative (Jones, 1995). Similarly, pleasant emotions are not always beneficial, sometimes leading to a poor performance due to complacency, underestimation of task demands, insufficient focus and dysfunctional energy levels (Hanin, 2000).

Within climbing research, participants interpretation of anxiety has not been assessed, although improved climbing performance has been reported to occur alongside increased somatic anxiety on traditional climbs when an experienced climber leads near their limit (Hardy & Hutchinson, 2007). Similarly, Sanchez et al. (2010) found, even when differences in baseline ability were accounted for, successful climbers reported higher levels of pre-performance somatic anxiety and positive affect, which correlated positively with the final route scores in a national climbing competition. However, it is possible that the positive affect in Sanchez et al. (2010) was the determining factor, rather than the somatic anxiety itself, as it has previously been stated that successful athletes can maintain a more positive affective state before competition than those who are less successful (Lox, 1996). Similarly, Draper et al. (2011d) found, when investigating differences between successful and unsuccessful climbers, while there were no significant differences in the subjective feelings of somatic or cognitive anxiety, there were significant differences in reported self-confidence. Greater feelings of self-confidence before attempting a climb may improve route planning decisions and the choice of technique and tactics employed, directly improving climbing performance (Draper et al., 2011d).

There are several theories and models that attempt to explain the relationship between anxiety and performance. In contrast to theories of arousal (Broadhurst, 1957; Spence & Spence, 1966) and unidimensional state anxiety models (Martens, Burton, Rivkin, & Simon, 1980), multidimensional anxiety theories hypothesise that the antecedents of cognitive and somatic anxiety are different, and differentially related to performance (Woodman & Hardy, 2001). Multidimensional anxiety theories state that self-confidence has a positive linear association with performance, cognitive anxiety a negative linear relationship and somatic a quadratic or inverted-U relationship (**Figure 2.8**) (Martens, Burton, Vealey, Bump, & Smith, 1990). The basis of the theorised somatic anxiety inverted-U appears to be an extension of the previously discussed inverted-U relationship of Broadhurst (1957); although, as previously discussed, a distinction should also be made between perceptions of physiological arousal and psychological arousal (Woodman & Hardy, 2001). While the predictions of the multidimensional anxiety theory are intuitive, the support for Martens et al. (1990) predictions are largely equivocal, and meta-analysis of the relationships between the three factors and performance are largely inclusive, with only self-confidence predicting performance well and even then with a weak relationship (Craft, Magyar, Becker, & Feltz, 2003). Finally, a major criticism of Martens et al. (1990) multidimensional anxiety theory has been that it attempts to explain the additive rather than interactive effects of anxiety on performance (Hardy, 1996).

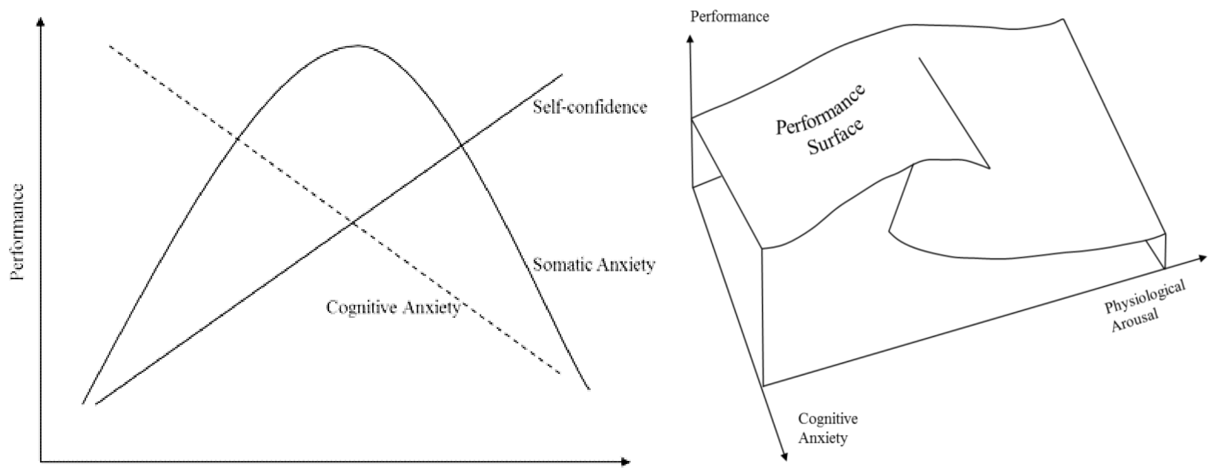


Figure 2.8: *Left, multidimensional anxiety [based on the work of Martens et al. (1990)]; right, two surfaces catastrophe model (Hardy & Fazey, 1988) [copyright Hardy, Jones, and Gould (1996), reproduced with permission].*

Catastrophe models of anxiety-performance attempt to address the limitations of the multidimensional anxiety theory, not only acknowledging performance anxiety as a multifaceted construct but also that performance depends on a complex interaction between these components (Hardy & Fazey, 1988). One of the limitations of the previously discussed multidimensional anxiety model is that it tries to explain a complex four-dimensional relationship between cognitive anxiety, somatic anxiety, self-confidence and performance in a series of independent two-dimensional relationships (Woodman & Hardy, 2001). Consequently, the catastrophe model (Hardy & Fazey, 1988) was developed to allow the interaction between anxiety and performance to be illustrated (**Figure 2.8**) (Woodman & Hardy, 2001). Briefly, according to Hardy and Fazey (1988), cognitive anxiety can have positive performance consequences but it is tied to physiological arousal. In the model, cognitive anxiety is termed the splitting factor and physiological arousal is termed the asymmetry factor. The splitter determines whether the effect of the asymmetry factor will be smooth and small, large and catastrophic, or somewhere in between. The increases in cognitive anxiety will be beneficial to performance when physiological arousal is low, but detrimental if it is high. With low cognitive anxiety, changes in physiological arousal result in small changes in performance in the form of an inverted-U. Under high cognitive anxiety, physiological arousal can either be facilitative or debilitative. Furthermore, under high cognitive anxiety, depending on whether physiological arousal is increasing or decreasing, large discontinuous changes in performance can result. With elevated cognitive anxiety and physiological arousal increases in performance will also increase up to a point, however, if anxiety increases beyond this stage then performance will suffer catastrophically.

Unfortunately, there is little evidence in regard to the specific aspects predicted by the previously presented models, including the cusp-catastrophe (Hardy, Beattie, & Woodman, 2007). Despite catastrophe models of anxiety being extensively reported in sports psychology literature (Gould et al., 2002; Uphill, 2015), they have received little empirical support, outside of the work of Hardy and colleagues (Woodman & Hardy, 2001). While examples of the cusp-catastrophe model's effects on performance have been found, with high cognitive anxiety and increased physiological arousal, physiological arousal has been manipulated through exercise, not anxiety (Hardy et al., 2007). It is possible the physiological arousal recorded in these studies reflected the physical effort required to perform the task rather than anxiety-induced physiological arousal, confounding reported findings. Furthermore, other authors including Cohen, Pargman, and Tenenbaum (2003) have not found any support for the cusp-catastrophe model with an indiscriminate dart-throwing task, stating the model *"lacks the sound framework necessary to examine the effects of multidimensional anxiety and physiological arousal on motor performance . . . the model fails to provide a tool for accurately describing performance catastrophes"* (p. 155). Finally, while the models presented in this section are useful for explaining the interaction between variables, they do not explain how performance is disrupted. More recently, attentional theories have been presented that provide an explanation for how alterations in performance occur.

2.7 Attention

Arousal-performance and anxiety-performance models describe the interaction between the two factors. However, they do not answer *how* performance is disrupted. Conversely, attentional theories provide an explanation for alterations in performance, based on the premise that successful task performance relies on the ability to attend to task-relevant information at the right time, while ignoring task-irrelevant information (Eysenck, Derakshan, Santos, & Calvo, 2007; Janelle, 2002; Masters & Maxwell, 2008; Nieuwenhuys & Oudejans, 2012). Disruptions to performance caused by anxiety have primarily been attributed to the way in which they interfere with attention and working memory (Wilson, 2012). Until recently there were two contrasting mechanisms both developed as possible explanations regarding how anxiety affects perceptual-motor performance: distraction and execution theories (Carson & Collins, 2016; Decaro, Thomas, Albert, & Beilock, 2011).

The attentional control theory (Eysenck et al., 2007) is based on the earlier cognitive interference theory (Sarason, 1988) and processing efficiency theory (Eysenck & Calvo, 1992). Anxiety manifests as impaired attentional control, which leads to decreases in performance in tasks involving the central executive of the working memory system (Eysenck et al., 2007), Attention is regulated by both goal-directed and stimulus-driven attentional systems (Eysenck et al., 2007). The top-down goal-directed attentional system is made up of knowledge, current goals and expectations, while the bottom-up stimulus-driven system is sensitive to salient environmental stimuli. Worry inhibits performers' ability to resist distraction from task-irrelevant stimuli, causing an imbalance between the two systems (Carson & Collins, 2016). Anxiety is proposed as modulating the balance between the two systems, with high anxiety causing an increase in the influence of the stimulus-driven and decrease in the goal-directed attentional system, and vice versa (Eysenck et al., 2007).

It is the disruption of the inhibition and shifting functions that cause attention to be diverted from goal-directed to stimulus-driven attentional stimuli, reducing processing efficiency. Performance is affected as a result of adjustments to movement taking place based on perceptual information; movement becomes less accurate and more attempts may be needed to successfully complete a task (Eysenck & Derakshan, 2011). Anxious individuals can respond by using compensatory or alternative processing strategies to limit decrements in performance, at the expense of processing efficiency (Eysenck et al., 2007). Attentional control theory also suggests two executive functions, those of inhibition and shifting, which allow individuals to minimise disruption from task-irrelevant stimuli, allowing the goal-directed attentional system to continue to function, allowing for the effortful maintenance of performance (Eysenck & Derakshan, 2011). To achieve this increased processing resources and storage capacity of the working memory may be invested (Carson & Collins, 2016).

Research presented by Hardy and Hutchinson (2007) supports the processing efficiency theory in a climbing context; in line with the predictions of Eysenck and Calvo (1992), anxious responses in climbers were accompanied by dual motivational and attentional effects. Specifically, increased anxiety was associated with increased effort and enhanced or maintained performance. However, there were several differences in the findings of Hardy and Hutchinson (2007) and the theoretical research of Eysenck and Calvo (1992), likely arising because of the laboratory basis of the theory. For example, while Eysenck and Calvo (1992) reported somatic anxiety as relatively unimportant, Hardy and Hutchinson (2007) found increased somatic anxiety, rather than increases in cognitive anxiety were associated with increased effort and performance. The threat of physical harm is probably a major determinant of somatic anxiety when climbers are leading, a threat of physical harm has been found to lead to high somatic anxiety, but no elevation of cognitive anxiety (Morris et al., 1981). Consequently, it is likely that increased somatic anxiety was a major component of the anxiety response for Hardy and Hutchinson (2007) participants.

Execution focused models, including the conscious processing hypothesis (Masters & Maxwell, 2008), are based on reinvestment theory (Masters, 1992) and the explicit monitoring hypothesis (Beilock & Carr, 2001). Explicit monitoring and self-focus theories suggest pressure situations raise self-consciousness and anxiety about performing correctly inducing conscious processing during skill execution (Baumeister, 1984). Masters (1992) and later Beilock and Carr (2001) suggested that the consciously monitoring or controlling of technique through reinvestment leads to its eventual breakdown. It is argued that increases in anxiety and self-consciousness cause an increase in the attention paid to skilled processes and their step-by-step control (Eysenck et al., 2007). The increase in attention causes a disruption to performance due to an effortful increase in conscious awareness and allocation of attention to otherwise proceduralised skills (Masters & Maxwell, 2008). Such conscious awareness reverses the normally automatic processes governing well-learned execution to a dysfunctional state: a temporary regression to an earlier stage of perceptual-motor learning (Anderson & Lebiere, 2014; Fitts & Posner, 1967).

Both distraction theories and self-focus theories assume the key to successful task performance is an ability to attend to task-relevant information, while ignoring irrelevant information (Eysenck et al., 2007; Janelle, 2002; Masters & Maxwell, 2008; Nieuwenhuys & Oudejans, 2012). However, both offer different predictions: while distraction theories suggest a shift in attention away from the task, self-focus theories suggest too much attention is shifted toward the execution of a skill (Eysenck et al., 2007; Masters & Maxwell, 2008). It has been argued both are relevant and that there are at least two ways in which anxiety can induce disruptions of performance (Wilson, 2012). This has the potential to create a situation where both influence behaviour and performance, depending on the way a task is represented and implemented (Beilock & Gray, 2007; Decaro et al., 2011).

The findings of Decaro et al. (2011), drawn from a series of four laboratory based categorical learning tasks, suggest *both* distraction and explicit monitoring theories of choking under pressure are correct. However, the diversion of attention away from, or towards the task depends on the characteristics of the performance situation, along with the attentional demands of the task being performed. Skills that rely heavily on working memory, such as the problem-solving and decision-making involved in route reading, will fail when pressure consumes resources (Boschker, Bakker, & Michaels, 2002). Pressure-induced worries about the situation and its consequences reduces available working memory capacity, as proposed by distraction theories (Beilock & Gray, 2007; Beilock, Kulp, Holt, & Carr, 2004). Equally, at the same time, pressure prompts individuals to attempt to control movement execution to ensure optimal performance in line with explicit monitoring theories (Beilock & Gray, 2007; Beilock et al., 2004). Proceduralised skills that are run largely outside of working memory will fail when pressure induced attention brings such processes back into conscious awareness.

Furthermore, if skills rely on both working memory and proceduralised skills outside of working memory, they may be susceptible to both distraction and explicit monitoring. For example, pressure co-opts working memory when individuals are performing demanding cognitive tasks, whereas it induces attention to skill process during proceduralised motor skill execution (Decaro et al., 2011). However, Decaro et al. (2011) argue that it seems strange that the high-pressure situation would exert different effects *"simply depending on whether one is holding a pencil or a baseball bat in one's hands"* (p. 391). This is also salient in climbing as the sport is both a demanding cognitive task – route finding, selection of appropriate movements, placing protection – as well as also involving the execution of proceduralised motor skills. As such, it is difficult to see how one theory or the other explains a deterioration in climbing performance.

The sole importance of working memory has also been questioned, as not all tasks rely on working memory resources. In highly automatic performance, such as those of experts, limited attentional resources cannot explain adverse effects of performance, as proceduralised high-level motor skills do not require online attentional control and are thought to run outside of working memory (Anderson & Lebiere, 2014; Beilock & Carr, 2001; Fitts & Posner, 1967). Consequently, proceduralised skill should be robust to distractions that consume working memory resources. This relies on the fact that expert performances are run without conscious control, which is the generally held belief, however, there is limited research to suggests this is not the case (Ericsson & Lehmann, 1996). Conversely, novice performance is thought to be supported by declarative or explicit knowledge held within working memory and attend to in a step-by-step fashion (Anderson & Lebiere, 2014; Fitts & Posner, 1967). If novices were exerting conscious control due to anxiety then novices, who are already performing tasks with explicit attentional control, would not be affected in the same way as experts. However, this has not been shown to be the case, with novice performance being affected as well (Beilock & Carr, 2001).

To address these issues Nieuwenhuys and Oudejans (2012) integrated the contrasting models of distraction and investment, developing on the work of Decaro et al. (2011). Nieuwenhuys and Oudejans (2012) model extends the scope of distraction and investment models, which both primarily focus on movement execution, and do not consider how the environment is interpreted and its behavioural effects. Nieuwenhuys and Oudejans (2012) integrative model states the imbalance between top-down and bottom-up processes not only affects attentional control (Eysenck et al., 2007), but also affects interpretational processes (Bishop, 2007; Blanchette & Richards, 2010) and facilitates specific behavioural responses (Schutter, Hofman, & Van Honk, 2008; Stins et al., 2011). Underpinning Nieuwenhuys and Oudejans (2012) integrative model is an embodied approach to perceptual-motor behaviour, visual stimuli are believed to be inherently meaningful, however, attention is still required to detect information and to guide their actions (Proffitt, 2006). Participants must attend to the correct information to successfully calibrate and adjust movements in relation to a target. In a climbing context, there are also likely to be many possibilities for action in the environment, and likely to be several stimuli that compete for attention. For a climber to perform optimally, relevant information for the preferred action should be selected and used to perform the actions, while also ignoring irrelevant information (Pijpers et al., 2006).

Nieuwenhuys and Oudejans (2012) integrative model states that anxiety may affect goal-directed action on three levels, extending the work of Eysenck et al. (2007) and Masters and Maxwell (2008); not only does it affect perceptual-motor performance during movement execution, but also exerts its influences during the perception and selection of action possibilities, which are depicted as perception-selection-action cycle (**Figure 2.9**). Through describing information regarding the behavioural possibilities of the environment, perceptual-motor behaviour can be conceptualised as a process of perceiving task-relevant information, selecting action opportunities and executing the action (Nieuwenhuys & Oudejans, 2012). The demands of the task will determine which is more salient, tasks requiring a great deal of visual control will be strongly affected at the attentional level, tasks involving a great amount of uncertainty will be strongly affected at the interpretational level and tasks mainly executive will be strongly affected at the behavioural level (Decaro et al., 2011). These will be discussed separately in the following section (*see 2.8 Disruption of performance*).

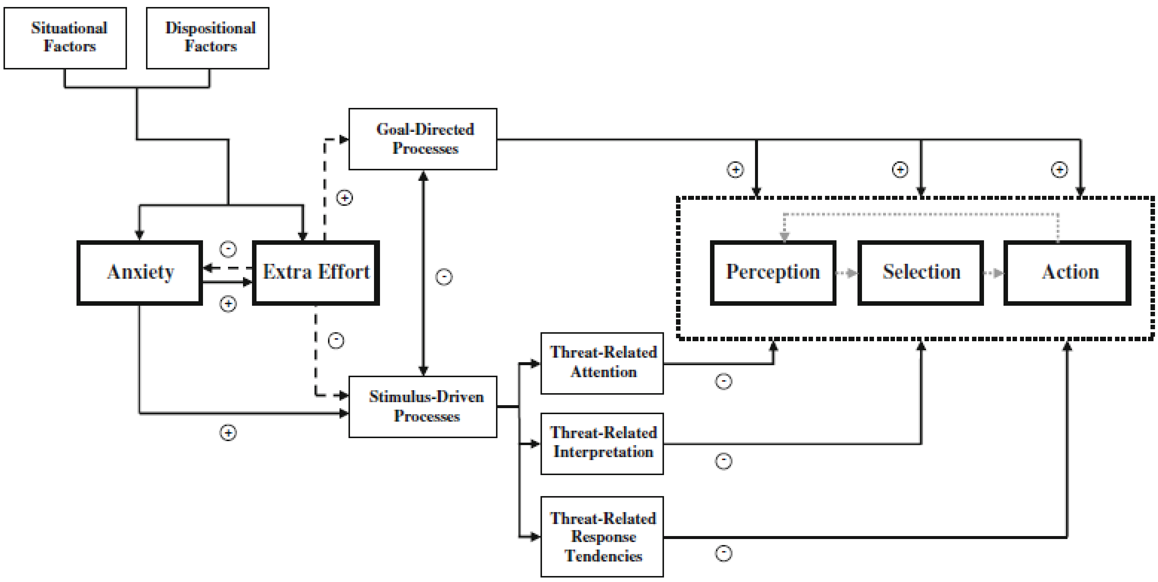


Figure 2.9: *Nieuwenhuys and Oudejans (2012) integrated model of anxiety and perceptual-motor performance [copyright Nieuwenhuys and Oudejans (2012), reproduced with permission].*

The level or levels that anxiety eventually affects behaviour, along with the strategies employed to maintain performance are dependent on situational and dispositional factors. Decaro et al. (2011) reported stressors, the level anxiety affects behaviour and the strategies used to compensate for negative effects, to be dependent on situational factors (task characteristics, environmental constraints) and dispositional factors (trait anxiety, state or action orientation, dispositional reinvestment). These are similar to Lazarus (1991) two levels of cognitive appraisal, which act as a perceptual mediator between stressor and stress response, as discussed previously (*see 2.4 Cognitive interpretation of state*). The primary appraisal establishes how important the situation is to an individual and whether it might endanger their well-being. The secondary cognitive evaluation process concerns the coping options available to the individual. Combined, athletes are more likely to be affected by the most salient aspects of a pressure situation and will react to situations in a manner that fits with their previous experiences and actions (Lazarus, 1991; Lazarus & Folkman, 1984).

While anxiety may affect performance negatively, anxiety may also serve as a motivational function enabling athletes to try and maintain performance through increases in mental effort (Eysenck et al., 2007). Nieuwenhuys and Oudejans (2012) model demonstrates how extra mental effort may help to maintain performance, the effectiveness and appropriateness of the methods are likely to rely on time available. It may be possible to reinforce or maintain task-relevant processes and concentrate fully on the task, instead of thinking about the consequences. Through strategically deploying conscious attention, specific skills are still executed automatically, but the general psychological state is more consciously regulated, with increased effort and concentration (Geeves, Mcilwain, Sutton, & Christensen, 2014). Furthermore, it may be possible to deliberately stop thinking about or attending to threat-related sources of information, although, ironically, this may also draw attention to towards it. Finally, if the task requires little attention, distraction strategies may help to increase execution focus (Decaro et al., 2011).

This thesis does not set out to test the assumptions of Nieuwenhuys and Oudejans (2012) integrated model of anxiety and perceptual-motor performance, instead it is presented as an explanation of the mechanisms for potential differences in performance seen in response to difference in the style of ascent (*Study One*), relative route difficulty (*Study Two*) and in response to differences in interventions (*Study Four)*. The following section discusses examples of the disruption of performance, with specific reference to the sport of climbing.

2.8 Disruption of performance

Nieuwenhuys and Oudejans (2012) model develops significantly on the earlier work of Eysenck et al. (2007) and Masters and Maxwell (2008) in describing how anxiety not only affects perceptual-motor performance during movement execution but also exerts its influences during the perception and selection of action possibilities. While Nieuwenhuys and Oudejans (2012) present evidence for changes in performance at each of these levels, there is significant overlap between each. Goal-directed action may be affected by alterations in the detection of task-relevant information. Visual scanning behaviour may become less efficient and individuals more easily distracted by task-irrelevant information, making more fixations of shorter duration (Janelle, 2002). For example, Pijpers et al. (2006) found novice climbers to make shorter explorative fixations on many more handholds during a high over low traverse condition, leading to slower less fluent movement. Threatening stimuli also attract extra attention and are harder to disengage from, possibly affecting the perception of action possibilities and task-relevant information through attending to different, threat-related information (Proffitt, 2006). Finally, if attention is drawn away from task-relevant information, towards threat-related information, athletes are more likely to interpret their environment as threatening (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & Van Ijzendoorn, 2007).

Even if the correct information is attended to, anxiety may affect the perception of action possibilities, by altering how the environment is perceived and interpreted (Derryberry & Reed, 2002). If the information is perceived differently or misinterpreted, the selection of a threat related interpretation may be more likely, strengthening the output of the threat evaluation mechanism and inhibiting the influence of prefrontal control mechanisms (Bishop, 2007; Blanchette & Richards, 2010). Consequently, the different interpretation may affect the perceived costs associated with performing an action or alter the perception of task-specific variables (Proffitt, 2006). For example, Pijpers et al. (2006) found anxious novice climbers to have both reduce perceived and actual maximal reaching height. Furthermore, with a decrease in perceived reaching ability, the number of climbing holds participant used also increased, indicating reduced efficiency of climber’s movement (Pijpers et al., 2006).

Perceptual information is necessary to establish the coordination patterns and muscle activity guiding movements and make actions possible (Nieuwenhuys & Oudejans, 2012). In goal-directed action, the amount of time athletes spend looking at the target appears to be directly related to performance (Vickers, 2007). Target fixation time is significantly reduced under anxiety, allowing athletes less time to fine-tune movements from visual information, causing a decrease in performance (Causer, Holmes, Smith, & Williams, 2011). Disruption of fixation time is likely to be of limited importance to climbers, although dynamic whole-body movements are likely to be affected in this way. There is also an increased tendency for athletes to produce emotionally congruent behavioural responses (Nieuwenhuys & Oudejans, 2012). While a positive stimulus facilitates approach movements, a threat stimulus facilitates avoidance movements. Emotionally congruent behaviour interferes when the intended behaviour is not in line with the emotion experienced, this may make it hard to initiate emotionally-incongruent approach movements towards a threatening stimulus (Stins et al., 2011). For example, in a climbing context, a climber committing to an irreversible move while high above the last piece of protection, with no opportunity to climb back down to the last safe point, may find such a situation to emotionally incongruent.

As with the conscious processing theory, too much attention to a task can disrupt the otherwise automatic execution of a task, leading to slower less efficient, more rigid movement behaviour and reduced performance (Masters & Maxwell, 2008). Movement efficiency may be disrupted as excitement of the corticospinal motor track is increased, leading to higher levels of muscle activation, more force production and increased heart rate, blood pressure, breathing frequency, muscle activity and energy expenditure; while excitement potentially enables quicker responses to threat, it can also disrupt motor performance (Grafton et al., 2000; Hatfield & Kerick, 2007). For example, Pijpers et al. (2003) showed greater muscle activation, or co-activation, greater levels of fatigue and higher blood lactate concentrations in climbers on a high traverse. Similarly, Nibbeling, Daanen, Gerritsma, Hofland, and Oudejans (2012) found when running on an elevated treadmill there was a reduction in running efficiency. Such changes in activation are likely to impact on both physical and technical climbing performance.

In summary, there are a number of differing mechanisms that may be independently, or jointly, responsible for differences in climbing performance seen in response to stressors, such as the style of ascent, or route difficulty. Nieuwenhuys and Oudejans (2012) integrative model states that not only may anxiety affect perceptual-motor performance during movement execution, but also exerts its influences during the perception and selection of action possibilities. The work of Pijpers and colleagues have reported high over low traverse in novice climbers to result in increased muscular tension and a reduction in the degrees of freedom of the climbers movement (Pijpers et al., 2003); increased movement entropy and climbing time (Pijpers et al., 2003); increased explorative movements (Pijpers et al., 2005); differences in gaze behaviour, (Pijpers et al., 2006); and, slower less fluent movement and increases in eye fixation duration (Nieuwenhuys et al., 2008). Again, this thesis does not set out to explore the mechanisms for changes in performance occurring in response to stressors, however, it will provide a detailed assessment of climbers' performance. With the exception of Hardy and Hutchinson (2007), there has been limited investigation into the effects of stressors on experienced climbers' performance. This thesis, as suggested by Pijpers et al. (2003), takes a process-oriented approach, which not only considers changes in outcomes, such as success and failure (Draper et al., 2011d), but also changes in the execution of movements that may, or may not, lead to changes in outcomes (Gould et al., 2002). This consists of both quantitative measures of climbing time and geometric entropy and qualitative coaches' assessment of performance. The methods employed are described in detail in section *4.2 Climbing performance measures*.

2.9 Summary

There are many potential sources of stress in the climbing environment, including factors climbers choose to manipulate to increase or alter the challenges of a climb, such as route difficulty, route knowledge and the style of ascent. On presentation of a stressor, a series of orchestrated events occur which together alter athletes' mental and physical state in a profound manner (Hatfield & Kerick, 2007). It is believed individual climber's interpretation of the demands stressor and their resources determine the emotional response and resultant technical and physiological performance consequences (Lazarus, 1991).

The challenge and threat states of the TCTSA (Jones et al., 2009) and BPS (Blascovich & Tomaka, 1996), based on Lazarus' theory of cognitive appraisal (Lazarus, 1991), provide a potential explanation of how some athletes are able to perform in motivated performance situations, while others fail to perform; they also outline distinct patterns of cardiovascular reactivity for the objective determination of cognitive appraisal. Further, several theories and models have been proposed that attempt to explain the relationship between arousal and anxiety occurring as a result of an individual's cognitive appraisal and performance (Broadhurst, 1957; Hardy & Fazey, 1988; Martens et al., 1980; Spence & Spence, 1966). However, with the exception of attentional theories, few explain how anxiety disrupts performance. Nieuwenhuys and Oudejans (2012) integrative model of anxiety and perceptual motor performance states that the imbalance between top-down and bottom-up processes not only affects attentional control

(Eysenck et al., 2007), but also affects interpretational processes (Bishop, 2007; Blanchette & Richards, 2010) and facilitates specific behavioural responses (Schutter et al., 2008; Stins et al., 2011).

The research contained within this thesis aims to develop on the body of climbing psychophysiological research completed to date (Dickson et al., 2012a; Draper et al., 2012; Fryer et al., 2013). A growing body of work has been completed exploring psychophysiology of climbing, this research is discussed in the following section (*Chapter 3*). This thesis combines the previous research and its advances and limitations with understanding of Lazarus's cognitive appraisals, resultant challenge and threat states as described by the TCTSA and performance outcomes as set out in Nieuwenhuys and Oudejans (2012) integrative model of anxiety and perceptual motor performance. Notably, existing climbing psychophysiology research has not considered the performance implications of the stressors explored. A such, this thesis combines physiological measurements with detailed methods of performance assessment including geometric entropy (Cordier et al., 1993) and coaches assessment of performance. The consideration of climber's performance is important, as it will both provide a more detail understanding of participants responses to stressors and elucidate differences not seen in previous climbing psychophysiology research. This thesis also includes psychophysiological and self-reported methods of determining the cognitive evaluation of participants, as described in the BPS and TCTSA (Blascovich & Mendes, 2000; Jones et al., 2009). The cognitive evaluation of climbers presents a potential explanation for differences in the anxious response of climbers in reaction to stressors present in the environment. While climbing psychophysiology research to date has provided a description of the subjectively experienced anxiety of participants and objective measures of heart rate and cortisol, they provide little explanation of the antecedents of these outputs.

The research contained within this thesis not only has implications for understanding the impact of stressors on climbers' performance and climbing psychophysiology research, but also from a theoretical perspective, particularly for the BPS and TCTSA. Challenge and threat studies completed to date have explored demand appraisals include the perception of required effort and uncertainty, but have not included perceptions of danger (Blascovich & Mendes, 2000). As discussed at the start of this chapter, stressors within the climbing environment have the potential to bring about fear and anxiety because of danger or perceived danger to participants (Hague & Hunter, 2011; Hurni, 2003; Macleod, 2010; Sagar, 2001). Consequently, this thesis will contribute to the understanding of cardiovascular reactivity, self-report of cognitive evaluations and behaviour outcomes in response to tasks that may bring about perceptions of danger in participants. Finally, cardiovascular reactivity has been used to quantify challenge and threat states extensively in previous research, while alterations in concentrations of the stress hormone cortisol have not. The BPS model based on Dienstbier (1989) work predicts, as a consequence of the increase in concentrations of circulating cortisol, during a threat state there is no corresponding decrease in systemic vascular resistance despite cardiac activity increases similarly to a challenge condition. Consequently, threat indicative cardiovascular reactivity should be accompanied by an increase in cortisol concentration, this thesis will be the first to test this hypothesis.

3

Literature Review: Part Two

Climbing Psychophysiology

The following chapter reviews the literature concerning psychophysiological and psychological responses to climbing specific stressors. To date, climbing psychophysiology research has focused on three aspects, which are explored in the first three sections of this chapter. Section *3.1* discusses the safety protocol and protection of the climber in the event of a fall; section *3.2* route knowledge; and section *3.3*, route difficulty. Finally, section *3.4* explores differences in climbing height, the findings of which are of methodological significance. Through the psychophysiological analysis of stressors, researchers are provided with a unique insight into affective states arising from the demands of the sport (Draper et al., 2008; Hodgson et al., 2009).

Giles, D., Draper, N., Gilliver, P., Taylor, N., Mitchell, J., Birch, L., Woodhead, J., Blackwell, G. & Hamlin, H. (2014). Current understanding in climbing psychophysiology research. *Sports Technology*, 7(3-4), 108-119. [doi: 10.1080/19346182.2014.968166].

3.1 The safety protocol

One of the primary stressors in climbing arises from the means of protecting the climber in the event of a fall, known as the style of ascent or the safety protocol. Because of its significance in the sport, the style of ascent has received considerable research attention (Aras & Akalan, 2011; Dickson et al., 2012a; Draper et al., 2011d; Draper et al., 2012; Draper et al., 2010; Fryer et al., 2013; Hardy & Hutchinson, 2007; Hodgson et al., 2009). Briefly, ascents may be protected by a *top-rope* or *led.* While a top-rope will immediately arrest a climber's fall, leading a route will result in falling a greater distance (Bisharat, 2009). When leading, there are two potential stressors compared to an equivalently graded top-rope. The first arises because of the physiological demand brought about by having to clip quickdraws to protect the climber. The second, because of differences in the consequences in the event of a fall.

The need to attach the rope to intermittent points of protection (quickdraws) requires the adoption of controlled isometric positions (Hurni, 2003). In effect, the need to clip quickdraws adds one or more additional movements per point of protection on the route, increasing the physiological demands of the task. In support of this, Aras and Akalan (2011) found greater energy expenditure and oxygen consumption when lead climbing, in comparison to a top-rope ascent. Similarly, Draper et al. (2010) reported lead climbing to be physically and mentally more demanding, requiring more effort, although differences in heart rate and $\dot{V}O_2$ did not reach statistical significance, likely because of differences in climbing time. Conversely, Fryer et al. (2013) did not find any significant difference between lead and top-rope conditions for $\dot{V}O_2$ or blood lactate concentration, although during the lead climb heart rate was significantly elevated for the last part of the route. It is likely that differences in the physiological response to leading are due, at least in part, to participants' ability. The participants of Draper et al. (2010) and Aras and Akalan (2011) were of lower and intermediate ability, compared to the intermediate and advanced ability of Fryer et al. (2013). With increased climber experience, there are improvements in both physical fitness and technique (Balas et al., 2014). For example, the position climbers choose to attach the rope to quickdraws, can affect the demands of the task and the fall potential. Pulling enough rope to clip a quickdraw at, or above head height can cause several problems, in comparison to clipping at waist height. Firstly, the climber must pull additional rope, which can cause a longer fall if the climber does not succeed; secondly, it may force the climber to place the rope in the mouth; and thirdly, it can also force the climber clip from a potentially more strenuous locked off position rather than efficiently with a straight arm (Hurni, 2003).

The potential for falling and an associated perceived concern of injury is often considered a stressor for climbers, one of the most difficult for them to overcome and a limitation for many (Hurni, 2003; Macleod, 2010; Sagar, 2001). To date, the majority of style of ascent studies have compared the contrasting conditions of lead and top-rope indoors, although there are several notable exceptions. Aras and Akalan (2011) and Hodgson et al. (2009) both examined top-rope and a contrived top-rope with a trailing lead rope; additionally, Hardy and Hutchinson (2007) conducted their research outdoors, on natural rock. **Table 3.1** highlights current climbing style of ascent research, including the route difficulty and the design of the studies. Based on the summarised studies it is possible to gain an overview of climbers' responses to differences in the style of ascent across a range of abilities. Since the earliest studies by Hardy and Hutchinson (2007) and Hodgson et al. (2009), the effects have been examined in a range of ability groups from low (French 4+; YDS 5.8) through to advanced ability (French 7b+, YDS 5.12c), these studies will be considered together. To aid comparisons mean differences and 95% confidence intervals (CI_{95}), were calculated. With the exception of Hardy and Hutchinson (2007) who used the Rock Climbing Anxiety Inventory (RCAI) state anxiety was assessed with the Competitive State Anxiety Inventory (CSAI-2R).

Table 3.1: *Overview of the style of ascent psychophysiology research completed to date. Sorted by climber ability. Both Dickson (2013) and Fryer (2013) examined a range of ability groups, these are shown separately.*

Ability Group	**Author & Date**	**Mean Grade**	**No. of Participants**			**Independent Groups?**	**Notes**
			TR	LCTR	LC		
Lower ability	Aras and Akalan (2011)	f4+	26	26		N	½ OS, ½ RP
	Dickson (2013)	f4+	7		3	Y	
	Hardy and Hutchinson (2007)	f6a	24		24	N	LC-OS, TR-RP
Intermediate	Draper et al. (2012)	f6a	11		8	Y	
	Dickson (2013)	f6a	7		5	Y	
	Fryer (2013)	f6a	5		7	Y	
	Hodgson et al. (2009)	f6b	12	12	12	N	RP: Familiarisation
	Draper et al. (2010)	f6b	9		9	N	½ OS, ½ RP
	Fryer (2013)	f6b+	9		10	Y	
	Fryer et al. (2013)	f6c	9		9	Y	
Advanced	Dickson (2013)	f7a	10		9	Y	
	Dickson et al. (2012)	f7b+	7		8	Y	
	Fryer (2013)	f7b+	7		5	Y	
	Dickson (2013)	f7b+	7		4	Y	

Notes: Low low ability; Int intermediate ability; Adv advanced ability; TR top-rope; LC lead-climb; LCTR lead climb with top-rope; OS on-sight; RP red-point

Somatic anxiety describes the perception of autonomic arousal and unpleasant feelings such as nervousness and tension (Hanton et al., 2009). **Figure 3.1** outlines mean differences (CI_{95}) in somatic anxiety between top-rope and lead conditions (lead with top-rope; Aras & Akalan, 2011). A threat of physical harm has been described as a major determinant of performance anxiety and has been found to result in elevated somatic anxiety, but not cognitive anxiety (Morris et al., 1981). Conceivably, as Hardy and Hutchinson (2007) stated, if a threat of physical harm is likely to be a major determinant of performance anxiety when lead climbing, it would be expected that leading would result in greater somatic anxiety. However, with the exception of the lower grade climbers of Aras and Akalan (2011) and Hardy and Hutchinson (2007 S3) the majority of studies did not find significant or meaningful differences between the conditions (Dickson, 2013; Dickson et al., 2012a; Draper et al., 2012; Draper et al., 2010; Fryer, 2013; Fryer et al., 2013). Indeed, only Aras and Akalan (2011) and Hardy and Hutchinson (2007 S3) found somatic anxiety to be greater in the lead condition. Furthermore, when the actual values were considered there was no notable difference between the studies, with values of somatic anxiety reported using the CSAI-2R ranging between 14 - 16 in low, 13 - 20 in the intermediate and 15 - 16 in the advanced ability groups.

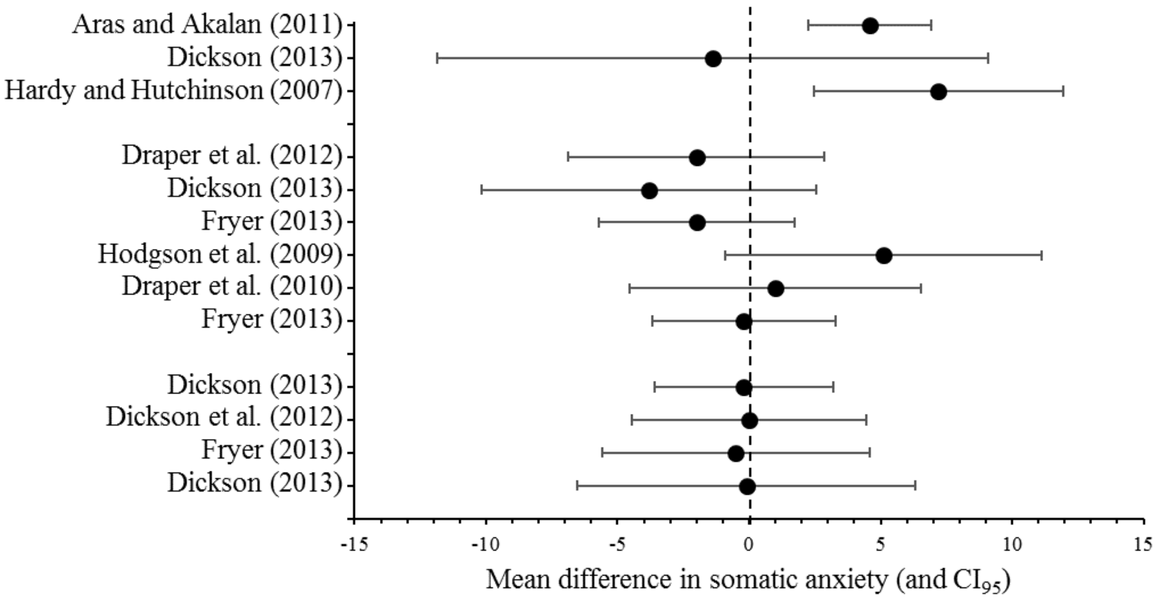


Figure 3.1: *Mean differences in somatic anxiety and 95% confidence intervals with style of ascent. Positive values denote greater somatic anxiety in the lead condition.*

Differences in somatic anxiety may be dependent on the ability of the climbers. Meaningful differences in somatic anxiety were found in two lower grade studies; while, the studies involving more experienced, intermediate and advanced ability, climbers had very small mean differences, suggesting greater consistency in participants' response to the two conditions (Dickson, 2013; Dickson et al., 2012a; Fryer, 2013). Another factor that has received little attention is whether anxiety is actually detrimental to performance (Jones, 1995). It is possible that anxiety may not always have a negative effect; for example, greater somatic anxiety in the lead condition of Hardy and Hutchinson (2007 S3) was associated with increased effort and enhanced or maintained performance. Similarly, Sanchez et al. (2010) found successful climbers to have significantly greater somatic anxiety and more fluent movement, than unsuccessful climbers. It has been argued that emotions conceptualised as negatively related to performance, such as anxiety, can sometimes be beneficial (Woodman & Hardy, 2001). For example, experienced athletes may be able to deliberately use relatively high anxiety to their advantage and expert performers often perceive anxiety as facilitative (Jones, 1995). However, as performance was only assessed by Hardy and Hutchinson (2007 S3), it is not possible to determine if this was the case.

Cognitive anxiety describes the negative perception of expectations and cognitive concerns about the situation at hand and its potential consequences (Hanton et al., 2009). **Figure 3.2** outlines mean differences (CI_{95}) in cognitive anxiety between top-rope and lead conditions. Like somatic anxiety, cognitive anxiety varied considerably. Furthermore, when the values from the lead condition were considered there were no notable differences between the studies, with values of cognitive anxiety ranging between 16 - 19 in low, 16 - 18 in the intermediate and 15 - 18 in the advanced ability groups. Consequently, it may be said that no meaningful differences in cognitive anxiety have been found in previous climbing style of ascent research (Aras & Akalan, 2011; Dickson, 2013; Draper et al., 2012; Draper et al., 2010; Fryer, 2013; Fryer et al., 2013; Hardy & Hutchinson, 2007 S3; Hodgson et al., 2009).

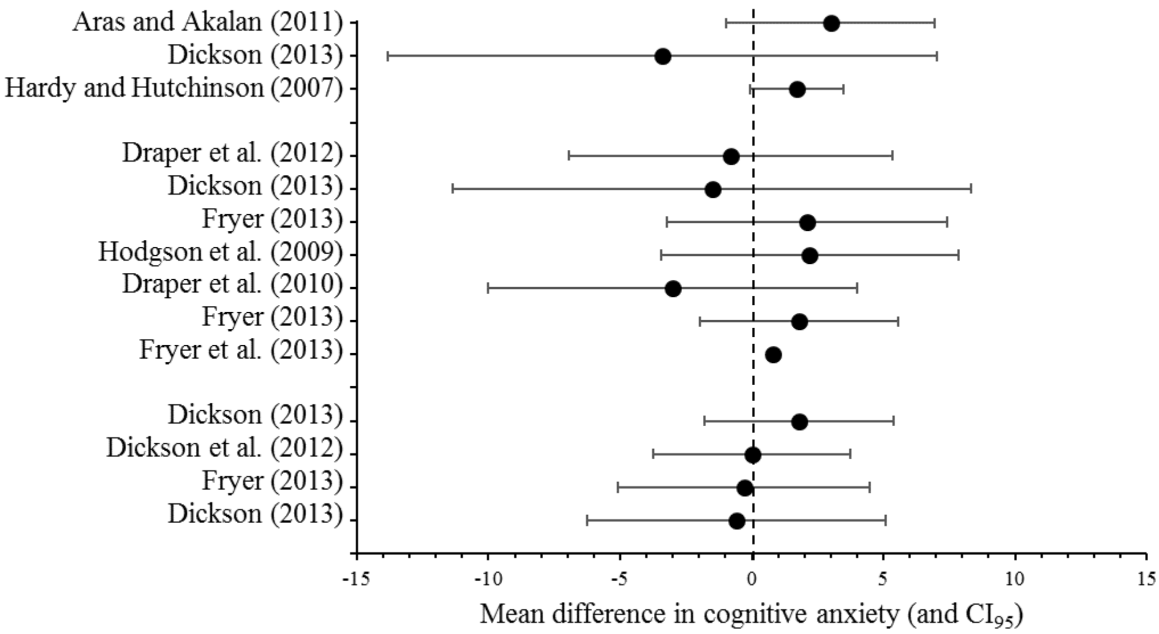


Figure 3.2: *Mean differences in cognitive anxiety and 95% confidence intervals with style of ascent. Positive denotes greater cognitive anxiety in the lead condition.*

The lack of differences in cognitive anxiety does not support the anecdotal experiences of coaches, who describe differences in the mind-set of experienced climbers with alterations in the style of ascent (Dickson et al., 2012a). For example, it may have been expected to see differences in cognitive anxiety with ability and experience, as more experienced climbers have been described as better able to judge, rationalise and manage the challenges of the climbing environment, including those related to psychological challenges, such as falling (Binney & McClure, 2005; Holland-Smith & Olivier, 2013; West & Allin, 2010). Climbers' ability to differentiate between rational and irrational fear and perceived and actual risk, is a skill that develops over time (Binney & McClure, 2005). Such assertions are not supported by the cognitive anxiety results of the summarised style of ascent studies.

Finally, there were meaningful differences in self-confidence in several studies (**Figure 3.3**), with greater values found in the top-rope condition in five (Aras & Akalan, 2011; Dickson et al., 2012a; Fryer, 2013; Hodgson et al., 2009). However, there were also an equal number with no meaningful differences. Self-confidence was lower when leading in the more experienced climbers of Dickson et al. (2012a), Fryer (2013) and Dickson (2013). There were no notable difference in reported values, with values of self-confidence ranging between 24 - 27 in the low, 26 - 30 in the intermediate and 24 - 26 in the advanced ability groups. Self-confidence has been termed a moderating variable with athletes achieving fine performances when being both anxious and self-confident (Hardy, Woodman, & Carrington, 2004; Woodman & Hardy, 2003). Consequently, it is unsurprising self-confidence has previously been reported as a particularly important factor in climbing performance. Indeed, both Draper et al. (2011d) and Sanchez et al. (2010) found successful participants to have significantly greater self-confidence than their unsuccessful counterparts. Such findings are typical of more traditional sports settings, a meta-analysis of anxiety and self-confidence conducted by Woodman and Hardy (2003) found athletes achieved greater performance when being both anxious and self-confident. Self-confidence has been said to improve route planning decisions and the choice of technique and tactics employed, and vice versa (Draper et al., 2011d). However, it is not possible to tell if the climber's performance also changed in line with self-confidence in the studies summarised in **Figure 3.3**, as with the exception of Hardy and Hutchinson (2007, Study 3) it was not assessed.

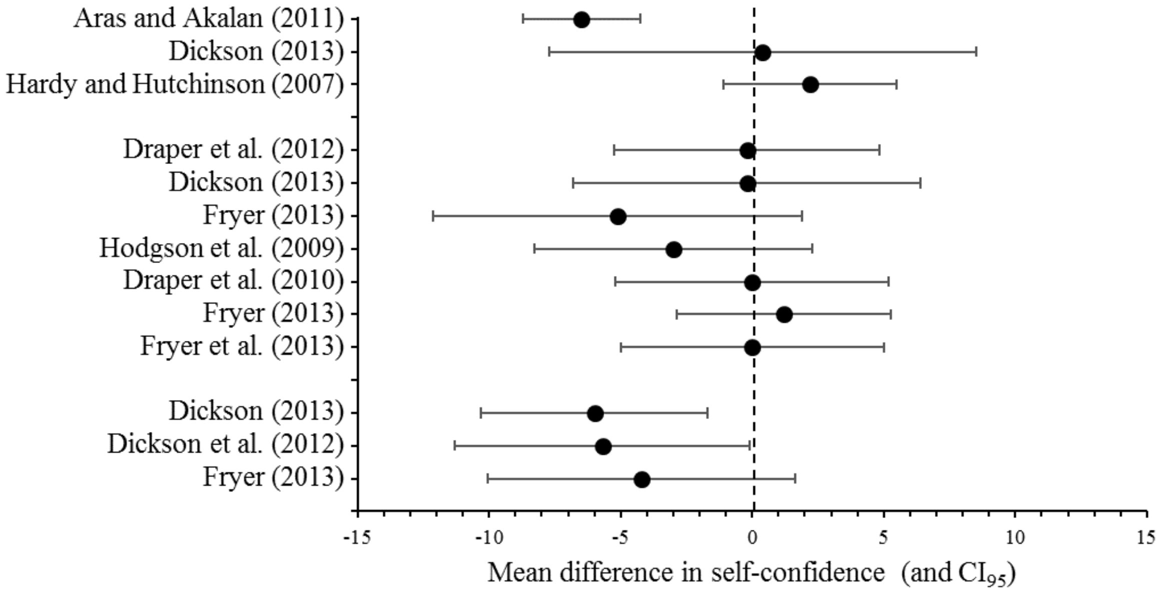


Figure 3.3: *Mean differences in self-confidence and 95% confidence intervals with style of ascent. Positive represents greater self-confidence in the lead condition.*

Self-report anxiety and self-confidence results do not support the assertion by coaches and authors that lead climbing and the anticipation of falls are anxiety inducing (Hague & Hunter, 2011; Hurni, 2003; Macleod, 2010; Sagar, 2001). However, meaningful differences may have been obscured and variability introduced due to the interaction of several stressors, particularly route knowledge, which will be discussed in *section 3.2*. Equally, the environment is also likely to be a factor, Hardy and Hutchinson (2007, Study 3) study was completed outdoors; the objective dangers of outdoors lead climbing are potentially greater than those of artificial indoor routes of the other studies cited (**Table 3.1**). Furthermore, it is possible that differences in the timing of the administration of the CSAI-2R may have affected the values observed (McNally, 2002). Hodgson et al. (2009), unlike all other style of ascent studies discussed, asked participants to retrospectively report anxiety following completion of the climb, which may have influenced the participants' responses, possibly making them more likely to report feelings towards the lead climb as positive.

Many of the style of ascents studies also reported psychophysiological variables. Through the psychophysiological analysis of the stressors, researchers are provided with a unique insight into affective states arising from the demands of the sport (Andreassi, 2006), predominantly these have been plasma cortisol and heart rate. Cortisol is the most commonly used biochemical marker for the assessment of the function of the hypothalamic-pituitary-adrenal (HPA) axis, which plays a significant role in the body's rapid and specific responses to a wide range of environmental and internal stressors (Kirschbaum & Hellhammer, 2000; Wittert, Livesey, Espiner, & Donald, 1996). Concentrations of plasma cortisol have been sampled at two time points, pre-climb and post climb. Pre-climb cortisol has been found to be greater prior to top-rope climbs (not shown) and pre-post climb delta values, greater in response to lead climbing (**Figure 3.4**). With the exception of the lower grade climbers of Dickson (2013) no significant or meaningful differences were reported.

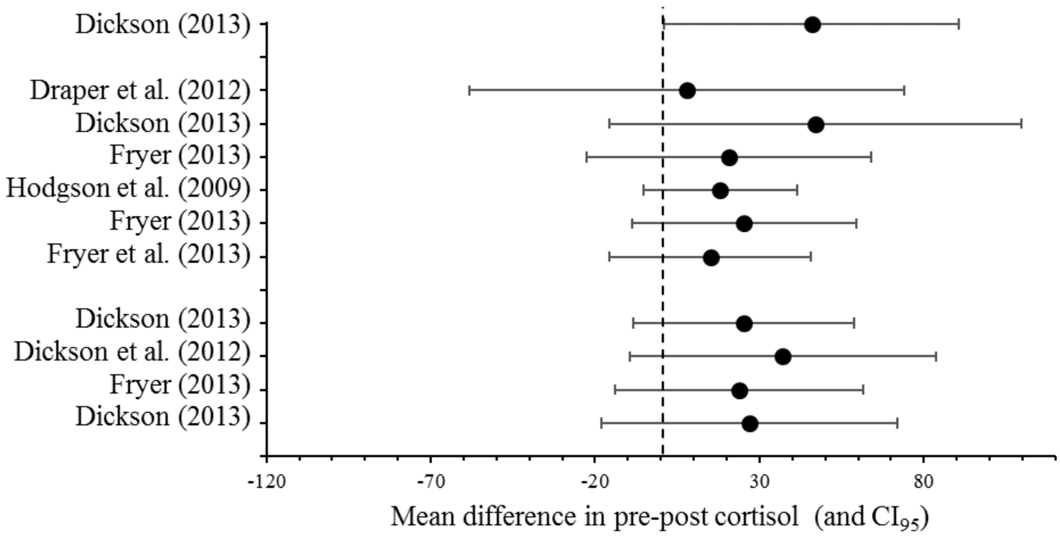


Figure 3.4: *Mean differences in pre-post cortisol concentration and 95% confidence intervals with style of ascent. Positive denotes greater pre-post cortisol concentration in the lead condition.*

Cortisol secretion is known to increase in response to both physical exertion (Jacks, Sowash, Anning, McGloughlin, & Andres, 2002; McGuigan, Egan, & Foster, 2004; Sherk, Sherk, Kim, Young, & Bemben, 2011) and psychological stress (Giles, Fryer, Dickson, & Draper, 2017a; Owens et al., 2014; Peckins, Susman, Negriff, Noll, & Trickett, 2015; Thompson et al., 2012). It is believed that post-climb changes in cortisol secretion predominantly occur due to the psychological challenge, rather than the physical loading. Due to the short duration and moderate nature of the climbing tasks, demonstrated by previous studies at around 60% $\dot{V}O_{2max}$ (Fryer et al., 2012; Giles et al., 2017a), increases are unlikely to be due solely to physical exertion; for increases in cortisol secretion to occur, exercise must be intense (>70% $\dot{V}O_{2max}$)

and longer lasting (>40 min) (Hill et al., 2008; Jacks et al., 2002). Consequently, it is likely the increases in cortisol seen may be attributed to psychological stress, as opposed to physiological stress alone.

A potential explanation for the lack of significance seen in cortisol concentrations are habituation to the climbing task. Elevated concentrations of cortisol have been shown to occur when situational factors of performance or competition have been manipulated (Fernandez-Fernandez et al., 2015; Filaire, Sagnol, Ferrand, Maso, & Lac, 2001; Quested et al., 2011; Rohleder, Beulen, Chen, Wolf, & Kirschbaum, 2007). Furthermore, in a laboratory setting, cortisol reactivity has been found to be reduced with repeated exposures, as a result of habitation to stressors (Kirschbaum et al., 1995). It is conceivable that, because of the nature of the task the participants were asked to complete being typical of their normal recreational indoor climbing sessions, the participants were habituated to the task. An earlier pilot study supports this assertion, as salivary cortisol was able to differentiate between non-climbers (59 ± 39% increase from rest) and an experienced group of climbers (18 ± 48% increase from rest) when attempting an indoor 20-meter wire ladder climb (Giles et al., 2017a). However, cortisol does not appear to be sensitive enough to differentiate between the responses of climbers completing a task they are habituated to (**Figure 3.4**).

Heart rate response has been used extensively in climbing psychophysiology research (Dickson, 2013; Dickson et al., 2012a; Fryer, 2013; Fryer et al., 2012). Climbers' heart rate response to changes in the style of ascent have been assessed at two time points. Firstly, anticipatory changes at rest immediately prior to attempting a route, calculated as the difference from resting heart rate. Secondly, heart rate during the ascent. No meaningful differences in either pre-climb heart rate (**Figure 3.5**) or heart rate during the ascent (*not shown*) have been found. Although, both were generally greater in lead climbing conditions, with the exception of the lower ability climbers of Dickson (2013). Anticipatory rises in heart rate prior to attempting a climb, in the absence of a physical stressor, have been attributed to increased preparatory psychological arousal (Hardy & Martindale, 1982; Janot et al., 2000). Heart rate was marginally lower in the low ability group than the advanced, with heart rate of 107 $b.min^{-1}$ in the low, ranging between 108 - 128 $b.min^{-1}$ in the intermediate and 116 - 132 $b.min^{-1}$ in the advanced ability groups. Conversely, elevated heart rate during the climb may be attributed to a combination of physiological and psychological factors, which it is not possible to separate. Consequently, heart rate measurements while climbing were less definitive, with significant variability, due to differences in the difficulty, routes angle, climbing speed and the number of quickdraws (Mermier, Robergs, McMinn, & Heyward, 1997; Watts & Drobish, 1998).

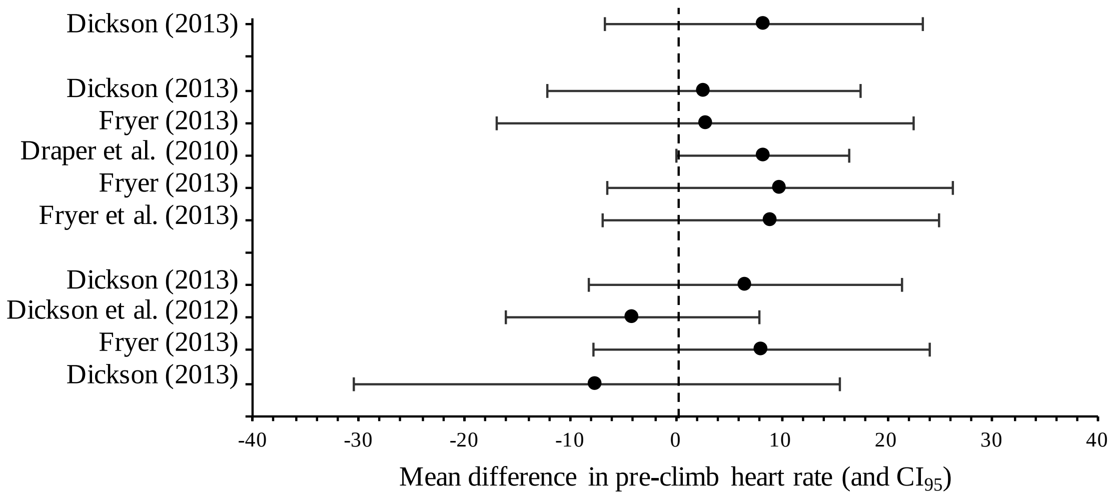
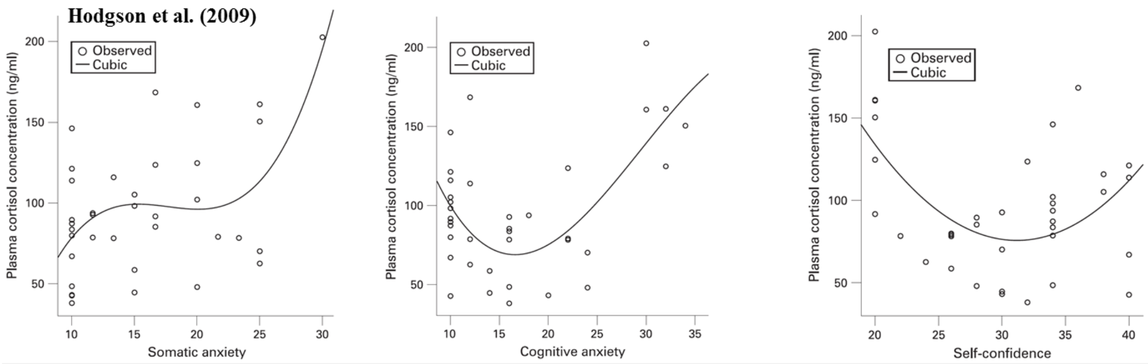


Figure 3.5: *Style of ascent research, mean change in pre-climb heart rate and 95% confidence intervals. Positive denotes greater pre-climb heart rate in lead conditions.*

Psychophysiological measures of cortisol and heart rate were more directional than those of self-reported anxiety (**Figure 3.4** and **Figure 3.5**), although there was still considerable variation. Further analysis of the relationship between subjective self-reported anxiety and objective cortisol concentrations also highlights conflicting, weak interactions (**Figure 3.6**). Regression analyses by Hodgson et al. (2009) demonstrated a cubic relationship between plasma cortisol concentrations and self-confidence (R^2 = 0.281), somatic (R^2 = 0.268) and cognitive anxiety (R^2 = 0.425). However, more recently Draper et al. (2012) found the relationships between plasma cortisol concentrations and subjective anxiety (somatic R^2 = 0.049; cognitive R^2 = 0.253) and self-confidence (R^2 = 0.267) were linear rather than cubic. Finally, Fryer et al. (2013) analysis revealed no significant relationships between anxiety or self-confidence and cortisol concentrations. Taken together, there does not appear to be a meaningful relationship between cortisol and self-reported anxiety. It is possible, differences in the relationship between the studies occurred because of inter-individual variance in both subjective self-report and objective physiological markers, as previously discussed. The sample size of both Hodgson et al. (2009), Draper et al. (2012) and Fryer et al. (2013) are likely to have compounded this, with small sample sizes of 12, 19 and 9 participants, respectively.



This material is unavailable due to copyright restrictions. See Draper et al. (2012) figures 1, 2 and 3.

Figure 3.6: *The relationship between cortisol concentration and somatic and cognitive anxiety and self-confidence [copyright Hodgson et al. (2009), reproduced with permission].*

Considering both self-reported anxiety and psychophysiological measures of cortisol and heart rate it may be said that there were no clear meaningful differences in climbers' responses with alterations in the style of ascent. Such a finding goes against anecdotal evidence from climbers and coaches that lead climbing, and the potential for falls, are anxiety inducing (Hague & Hunter, 2011; Hurni, 2003; Macleod, 2010; Sagar, 2001). The lack of meaningful differences in heart rate and cortisol are unsurprising, considering the inter-individual variation present in all studies with large standard deviations and confidence intervals.

Differences between self-reported state anxiety and psychophysiological measures may have occurred for several reasons, beyond those associated with changes in the style of ascent. In addition to the previously mentioned timing of the administration of the CSAI-2R questionnaires, the emotions experienced before climbing may be more complex than may be represented by the questions presented in the CSAI-2R, or even the climbing specific RCAI (Hardy & Hutchinson, 2007). It has been stated that self-report questionnaires provide a poor means for the assessment of how individuals process consciously available evaluations and do not provide any assessment of individual's unconscious processes, such as the immediate assessment of a stressor (Blascovich & Mendes, 2000; Ledoux & Bemporad, 1997). Finally, there is also evidence that, in some cases, the subconscious awareness of evocative stimuli results in the bypassing of measurable cognitive evaluation and only elicits a psychophysiological response (Weisbuch-Remington et al., 2005).

Previous studies designs may have been a factor in their lack of significance, particularly climbers' route knowledge. While many of the style of ascent studies completed to date have used independent samples, with participants randomly assigned an on-sight ascent of either lead or top-rope climbs (Dickson, 2013; Dickson et al., 2012a; Draper et al., 2012; Fryer, 2013; Fryer et al., 2013). Other studies have used a repeated measures design, with participants completing both top-rope and lead ascents, on the same route. One of the most significant contributions of psychophysiology research completed to date, has been the understanding gained of the potential interaction of stressors, route knowledge is an example of this (see *section 3.2*). It is known for a repeat red-point of a route the physiological and psychological demands will be less than those of the initial on-sight because of familiarity with the route.

To address route knowledge a number of different methods have been used, Hodgson et al. (2009) employed a familiarisation task; conversely, Hardy and Hutchinson (2007) participants completed the lead climb on their first attempt and top-rope their second and both Aras and Akalan (2011) and Draper et al. (2010) used a counterbalanced design. While an independent sample design ensures all climbs are completed on-sight (*see section 3.2*), such designs do not allow for the comparison of the relative change in factors, such as self-reported anxiety, or cortisol concentrations, which may in part be responsible for some of the variation seen. Consequently, the experimental studies of this thesis, particularly *Study One*, carefully consider the interaction of stressors. For example, *Study One* uses a repeated measures design with three novel routes to control for the impact of route familiarity. A repeated measures design, with each condition completed on-sight allowing for the comparison of differences, without the need for independent groups, familiarisation, or differences in route knowledge.

To summarise, many climbing psychology and psychophysiology studies completed to date have examined alterations in the style of ascent, however, considered together the results of the studies are largely equivocal. Psychophysiological measures of delta cortisol and anticipatory heart rate were consistently elevated in the lead over top-rope conditions, self-reported anxiety did not display such a relationship and variability obscured significance. There were considerable inter-individual differences in both self-reported and psychophysiological responses. While significant methodological advances have been made, particularly by Draper, Dickson, Fryer and colleagues, their research has highlighted the complexity of climbing stressors, and their potential interaction, particularly with route difficulty and knowledge. Given the consternation of climbers and coaches about the significance of lead climbing and its impact on performance, despite the lack of significance found in previous research, there would be benefit for future research in this area. Two key aspects items are apparent for future style of ascent research, firstly, a repeated measures design, while considering climbers route knowledge will help control for individual variation; secondly, the performance implications of changes in the style of ascent should be assessed. These are addressed in *Study One.*

3.2 Route knowledge

Regardless of the style of ascent, the knowledge a climber possesses, and the amount of practice a climber has had before leaving the ground, is thought to have a significant impact on performance (Cordier et al., 1994; Draper et al., 2008; Hardy & Hutchinson, 2007). **Figure 3.7** outlines nomenclature for climbers' knowledge and practice of a route. While a red-point involves a climber ascending a pre-practised route, usually at their maximum climbing grade, an on-sight of a climb challenges them against an unknown and unfamiliar route (Hague & Hunter, 2011). Like an on-sight, a flash ascent is completed with external information, possibly gained from a guide book or peer, but without physical practice. An on-sight is often considered the purest form of ascent, although it is speculated that a red-point ascent may prove to be a greater physiological and psychological challenge in some cases (Hague & Hunter, 2011). Red-point, flash, and on-sight ascents of a route have their own challenges and physiological and psychological implications (Draper et al., 2008).

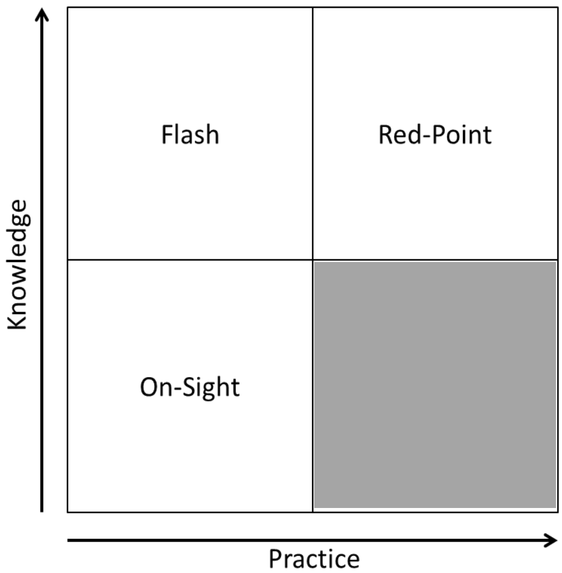


Figure 3.7: *Terminology relating to route knowledge and route practice.*

Routes present climbers with complex problem-solving tasks. The correct perception of affordances plays a significant role in the success of an ascent (Pijpers et al., 2006). Affordances, in a climbing context, describe the link between the visual properties of hand and footholds and the more general climbing environment and the action, or actions, which may be performed with them (Gibson, 2014). Links may be based on stored information about a particular hold, but this is not always necessary (Humphreys & Riddoch, 2001). Because of the challenges of reading and planning movements while managing fatigue, typically an experienced climber's red-point ability will be between one and two grades greater than their on-sight ability (Hörst, 2011). During an on-sight attempt, not only should the climber complete the physical movements, but they must also read and plan their ascent (Hörst, 2010). The ability to read routes while climbing is a complex cognitive task (Boschker & Barker, 2002) and anxiety is known to have significant implications for attention (*see 2.7* Attention). Consequently, a climber’s emotional state plays a major role in the perception and realisation of affordances and performance outcomes (Pijpers et al., 2006).

Figure 3.8: *Difference in ease of perceiving affordances while climbing routes (a) indoors with coloured holds, (b) outdoors on pale limestone and (c) with obvious chalk stains on sandstone.*

Significant differences in route reading ability have been demonstrated with experience (Boschker et al., 2002). Experienced climbers can recall more information, clusters of information and tend to fixate on the functional aspects of a climbing wall pertinent to the successful ascents of a route. Inexperienced climbers focus more on the holds themselves (Boschker et al., 2002). Furthermore, while pre-climb visual inspection does not appear to be significant in determining the success or failure of climbers, Sanchez, Lambert, Jones, and Llewellyn (2012) found that it did influence performance. Following visual inspection, climbers made fewer, shorter stops, with experts benefiting the most from the visual inspection. The complexity of the visual perception of climbing affordances may be compounded outdoors by the reduction in the distinction of holds, in comparison to the coloured indoor holds (**Figure 3.8**), although due to the use of chalk outdoors, this may also vary (Luebben, 2004).

Unlike an on-sight, a repeat red-point ascent of the same route does not require the same commitment of energy, or time, to work out the sequence of movements needed to complete the climb (Draper et al., 2008; Hardy & Hutchinson, 2007). Quantifying this effect, Cordier et al. (1994) examined climber's movement fluency by calculating the geometric entropy of the climber's centre of mass. Following ten successive ascents of a route, it was possible for the fluency of a climber's trajectory to describe the learning process on a route (**Figure 3.9**). Furthermore, the results also illustrate differences with climbing experience, the time taken for stability to be achieved varied with experts achieving a stable trajectory after the 3rd trial, while this did not occur until the 6th trial for the non-experts. A similar effect with practice was found in novice climbers by both Espana-Romero et al. (2012) and Wescott (1992), who reported decreased climbing time and total energy expenditure with repetition of the same route over a 10 and seven week period, respectively.

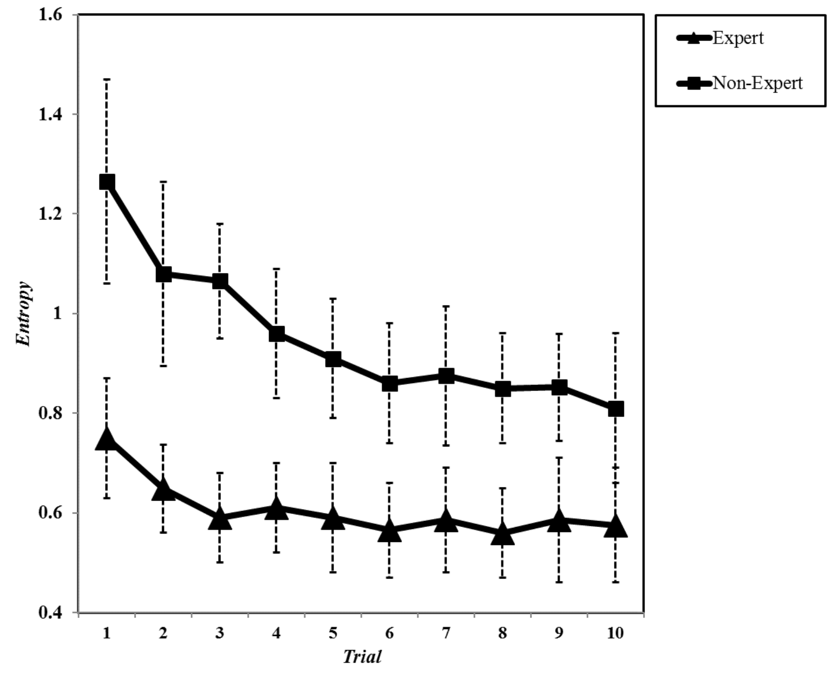


Figure 3.9: *Mean entropy and standard deviations of learning trajectories for non-experts and experts [copyright Cordier et al. (1994), reproduced with permission].*

To date, only Draper et al. (2008) have made a direct comparison between an on-sight lead and a subsequent red-point of the same route. The combined knowledge and practice gained through a repeat ascent of a short ~10-meter route resulted in a significant 14-second reduction in ascent time (on-sight 213 ± 46 sec vs. red-point 199 ± 33 sec). However, the reduced climbing time was not accompanied by any changes in mean $\dot{V}O_2$ (↓0.56 $mL \cdot kg^{-1} \cdot min^{-1}$) or heart rate (↓2 $b \cdot min^{-1}$). However, significant reductions in state anxiety were recorded prior to the red-point ascent, with both somatic (↓3.4 point) and cognitive (↓3.6 point) anxiety decreasing significantly, while self-confidence saw only a small non-significant reduction (↓0.4 point). Differences in climbing time between the two ascents are likely to have occurred due to the need for route planning during the first ascent and climbers' familiarity with the route during the second (Draper et al., 2008). It is also possible that differences in climbing time occurred because of anxiety, due to several factors including less fluent movement, hesitation, and greater explorative fixations and movements (Nieuwenhuys et al., 2008; Pijpers et al., 2006; Pijpers et al., 2003; Pijpers et al., 2005).

Hardy and Hutchinson (2007) studied changes in anxiety with repetition of a route, however, unlike Draper et al. (2008), climbers were asked to lead and top-rope two routes and then subsequently top-rope the same routes again. The findings demonstrated, regardless of whether the initial ascent was completed on a top-rope or lead, there were reductions in heart rate, ratings of perceived exertion and physical and mental effort in the repeat ascent. The reduction in effort was at least partially attributed, as Draper et al. (2008) would also later conclude, to the unfamiliar sequences of movements during the on-sight ascent of the route and a learning effect. Furthermore, Hardy and Hutchinson (2007) found cognitive anxiety was significantly lower (lead to top-rope ↓ 1.7 points; top-rope to top-rope ↓ 1.75 points) and activation significantly increased (lead to top-rope ↑ 2.25 points; top-rope to top-rope ↑ 1.96 points), regardless of the initial style of ascent. However, somatic anxiety was only significantly reduced between lead and top-rope (lead to top-rope ↓ 7.2 points; top-rope to top-rope ↓ 1.87 points). Hardy and Hutchinson (2007) concluded an on-sight ascent elicits a similar anxiety response regardless the style of ascent. Additionally, the response does not appear to be altered based on experience or ability level. It should be noted, in contrast to Draper et al. (2008), Hardy and Hutchinson (2007) research was completed outdoors, on traditional lead climbs, where the consequences of a leader fall were potentially greater (Schöffl et al., 2010).

The findings of Hardy and Hutchinson (2007) and Draper et al. (2008) contribute to our understanding of the physiological and psychological consequences of differences in route knowledge. However, they do not explain why the participants of Draper et al. (2008) and Hardy and Hutchinson (2007) found on-sight conditions to be more anxiety-inducing. Neither study provided an explanation for the differences beyond the observations made. It is possible to speculate, as a key tenant of on-sight climbing is the uncertainty about the holds, sequences of movements and whether the climber can execute them, that these are likely to be important factors. This is supported by the uncertainty of outcomes being known to be a contributing factor to anxiety (Fisher & Zwart, 1982; Martens et al., 1990). The familiarity provided by the repeat red-point addresses these factors, reducing anxiety and improving performance.

The growing body of psychophysiology research has highlighted potential interactions between stressors. Differences in the response provoked by repeat ascents may be responsible for some of the variation seen in the previous style of ascent studies (*see 3.1 The safety protocol*), specifically those by Aras and Akalan (2011), Draper et al. (2010) and the second study in Hardy and Hutchinson (2007). These studies investigated anxiety in randomised conditions of lead and a subsequent ascent of either a top-rope or a top-rope with a trailing lead rope; however, unlike Hodgson et al. (2009), no familiarisation trial was used. Thus, participants climbed either the lead or top-rope condition on-sight, before randomly repeating the same route in the alternative condition, as a red-point. As previously discussed, from the findings of Draper et al. (2008) and Hardy and Hutchinson (2007), route knowledge is known to affect the physiological and psychological response of climbers. It is speculated differences in route knowledge may have obscured trends that may otherwise have been found. The consideration of the interaction of stressors is not only important for the studies contained within this thesis, but also research using climbing as a means of instigating physiological and psychological stress (Hardy & Hutchinson, 2007; Helton et al., 2013; Turner et al., 2014; Williams et al., 2010). Researchers should carefully consider the stressor(s) participants are exposed to, including the style of ascent, route difficulty and knowledge as they appear to have significant additive and interactive consequences for climbers' responses.

In summary, it may be stated that with a repeat ascent of a route there is a significant learning effect (Cordier et al., 1994). The second repetition of a route typically results in decreased climbing time for both indoor sport routes (Draper et al., 2008) and traditional outdoor routes (Hardy & Hutchinson, 2007). Decreased climbing time were also accompanied by reduced perceptions of cognitive and somatic anxiety (Draper et al., 2008; Hardy & Hutchinson, 2007).

The learning effect and its physiological and psychological consequences are used by the climbers to their advantage, typically an experienced climber's red-point grade, will be one to two grades greater than their on-sight (Draper et al., 2016; Hörst, 2011). From research completed to date, it is not clear why on-sight conditions are more anxiety-inducing, however, it is likely to be related to the unknown challenges of the ascent (Fisher & Zwart, 1982; Martens et al., 1990). Differences in route knowledge may explain variations seen in a number of previous style of ascent studies, for example between the repeated measures design of Aras and Akalan (2011) and the independent samples design of Draper et al. (2012).

3.3 Route difficulty

Grades provide a subjective estimation of the difficulty of a route and consequently an indication of effort and skill required to ascend them (Draper et al., 2016). Several factors influence route difficulty, including the length, angle, size, and frequency of the holds, opportunities for protecting the climb (sport and traditionally protected routes) and the inclusion of obscure or unusual movements. Personal preference may also play a role in climbers' choice and responses, particularly as climbers have free choice of the routes they ascend. For example, while one climber may excel at off-vertical slab climbs, another may excel at steep overhanging routes; it is speculated that a climbers' performance outcomes may differ significantly depending on which they are on.

Route difficulty and the physiological demands of climbing have been investigated by a number of authors including Mermier et al. (1997), Watts and Drobish (1998) and Janot et al. (2000). Mermier et al. (1997) reported significant increases in mean heart rate (↑21 $b.min^{-1}$), $\dot{V}O_2$ (↑ 4.2 $ml\cdot kg\cdot min^{-1}$), energy expenditure (↑ 0.222 $kJ\cdot kg\cdot min^{-1}$) and blood lactate (↑ 1.56 mmol/L) with increases in route difficulty, created through alterations in the angle of a route (vertical to overhanging). Similarly, Watts and Drobish (1998) reported an increase in the physiological demand placed on the climber with changes in the angle of the route while climbing on a mechanical rotating treadwall; a decrease in the angle resulted in non-significant increase in heart rate and blood lactate response. The increased physiological demands with the decrease in the angle of a route are likely to have occurred as the shoulder girdle, arms, and forearms are required to support a greater proportion of the climbers' weight, while reducing the contribution provided by the legs (Mermier et al., 1997). Finally, Janot et al. (2000) found a difference in physiological performance with alterations in route difficulty, while the angle remained the same. Performance of novice climbers was assessed on two 10-meter routes, while difficulty was changed through the route setting (rather than angle). In line with the findings of Watts and Drobish (1998) and Mermier et al. (1997) heart rate responses and perceived exertion were greater when attempting the harder of the routes (Janot et al., 2000).

In addition to physical aptitude, climbing is also characterised by technical skill (Hörst, 2008). Balas et al. (2014) reported improvements in exercise economy with greater climbing ability. As with Watts and Drobish (1998) and Mermier et al. (1997), there was a relationship between the inclination of a wall and the physiological demands of the climbing task. Self-reported ability was negatively correlated with both $\dot{V}O_2$ and heart rate (wall angle 90º, $\dot{V}O_2$, r = -0.82; heart rate, r = -0.66; angle 105º, $\dot{V}O_2$, r = -0.84; heart rate, r = -0.78); higher ability participants were able to offset the increased demands of the steeper climb through improved exercise economy, which led to increased time to exhaustion (Balas et al., 2014). Similarly, Hardy and Martindale (1982) found experienced climbers had lower energy expenditure and were able to climb much further on a more difficult route than beginner climbers (mean proportional energy cost per meter in beginners ~24, and experts ~7.5 $\dot{V}O_2$ per meter). As previously discussed, significant differences in route reading ability have also been demonstrated with experience (Boschker et al., 2002).

An increase in route difficulty not only increases the physiological demands, it may also increase the likelihood of a negative emotional response. Increased difficulty of a route, relative to the ability of the climber, reduces the likelihood they will be successful on their first attempt. If the climber is unable to complete the route, they will either fall or have to ask to be taken tight on the rope. Despite the low incidences of acute injuries, the potential for taking falls and an associated perceived concern of injury is considered a significant stressor for climbers (Hurni, 2003; Macleod, 2010; Sagar, 2001). Not only may the fall potential be anxiety inducing, but the anxiety the climber may experience may also affect their performance and limit their ability to complete the route they are attempting (Hague & Hunter, 2011). Anxiety has been shown to disrupt most aspects of technical climbing performance, including visual attention, the perception of affordances, perceived reach distance and the fluency of movement (Nieuwenhuys et al., 2008; Pijpers et al., 2005). To date, only Hardy and Whitehead (1984) and Hardy and Hutchinson (2007) have investigated climbers responses to differences in route difficulty.

Hardy and Whitehead (1984) explored differences in route difficulty, relative to the ability of experienced climbers. Routes were selected at a climbers' lead limit (LL), minus one grade (LL-1) and minus two grades (LL-2). Pre-climb alterations in heart rate and oral temperature were reported, with a significant decrease in oral temperature and a significant increase in heart rate resulting from baseline measures in the harder LL-1 and LL conditions. Furthermore, subjective assessments of affect described significant increases from baseline in cognitive anxiety, somatic activation and somatic anxiety, but not cognitive activation. With the same premise, Hardy and Hutchinson (2007) also compared two outdoor lead ascents and then top-ropes of traditional routes at LL and LL-2. The results occurred in the same direction as Hardy and Whitehead (1984), with the harder climb resulting in significantly greater cognitive anxiety (↑9.7 points), somatic anxiety (↑18.7 points) and activation (↑14.3 points). There was also a significant difference in the measures of effort, with increases in heart rate (↑15.5 $b.min^{-1}$), perceived exertion (↑5.4 points) and perceived mental effort (↑4.2 points). Finally, the belayer's rating of the climber's performance was greater (↑1.2 points); superior performance was seen during the harder ascent, despite the significance of cognitive and somatic anxiety. Interestingly, a similar effect was found by Sanchez et al. (2010), who reported a successful competitor in a national competition had greater somatic anxiety, which was significantly correlated with performance, along with positive affect. Hardy and Hutchinson (2007) concluded the threat of physical harm from falling, which accompanies leading harder routes, was a major determinant of anxiety; however, the anxiety was not necessarily detrimental to climbing performance.

As with route knowledge, it is conceivable that the difficulty of the route relative to the ability of participants was a source of variability in previous climbing psychophysiology research. Discussed studies highlight that route difficulty has implications for both the physiological demands (Janot et al., 2000; Mermier et al., 1997; Watts & Drobish, 1998) and the psychological response (Hardy & Hutchinson, 2007; Hardy & Whitehead, 1984). The results of Hardy and Whitehead (1984) and Hardy and Hutchinson (2007), which both explicitly manipulated the grade of the route relative to climber ability, found considerable differences in responses when leading a route at a climbers' on-sight and limit, compared to a submaximal route. However, they did not consider climbers response to an attempt of a supramaximal route, likely because of the greater risks associated with falling while leading outdoors on climber placed traditional protection. Developing on this previous research, *Study Two* of this thesis not only considers route below and at climber's maximum grade, but also an attempt of a route beyond the climber's self-reported ability. Future studies should carefully consider the ability of participants, the difficulty of routes and the potential interaction of the two factors. It is also conceivable that differences in the relative ability of participants recruited for previous studies, such as those exploring the style of ascent, may be responsible for some variation in the results seen.

In summary, with an increase in the difficulty of a route, relative to a climber’s ability, there are an increase in the physiological demands (Billat, Palleja, Charlaix, Rizzardo, & Janel, 1995; Hardy & Whitehead, 1984; Mermier et al., 1997; Watts & Drobish, 1998). Increased climber ability offsets these challenges through a number of adaptations, including improved exercise economy (Balas et al., 2014) and route reading ability (Boschker et al., 2002; Boschker & Barker, 2002). The psychological demands also differ, both Hardy and Whitehead (1984) and Hardy and Hutchinson (2007) demonstrated an increase in anxiety may be expected the closer the difficulty of a climb is to the leaders limit. It is speculated such an effect occurs because of the threat of physical harm from the increased likelihood of falling that accompanies harder routes. Particularly as falling is thought to be a potential source of stress and to have a debilitative effect on performance (Hurni, 2003; Macleod, 2010; Sagar, 2001).

3.4 Height above ground

Success in climbing, with the exception of traverses, requires the climber to ascend to height, until either the top of the route is reached or they can no longer continue. While bouldering is completed low to the ground and protected with spotters and crash mats, sport and traditional climbs may be of almost any length and are protected with a trailing rope and protection placed by the climber or pre-placed bolts (Bisharat, 2009). An increase in the distance from the ground when bouldering increases the risk of injury, particularly when movements involve placing the feet high. Conversely, if the protection is sound and it will not fail when shock loaded, an increase in the height from the ground when lead climbing may be considered safer, as the chance of a ground fall is reduced (Burbach, 2005).

Differences in climbers’ responses to the height of routes have not been investigated; however, Pijpers and colleagues, have investigated traverses of routes at differing heights (Nieuwenhuys et al., 2008; Pijpers et al., 2006; Pijpers et al., 2003; Pijpers et al., 2005). To investigate manifestations of anxiety at the subjective, physiological, and behavioural level

Pijpers and colleagues conducted a series of studies with novice climbers traversing a wall at different heights. Specifically, the protocol involved two top-roped traverses: the mean height of the footholds for the lower traverse was between 0.3 – 0.4 meters and the higher traverse 3.6 - 5.1 meters (**Figure 3.10**).

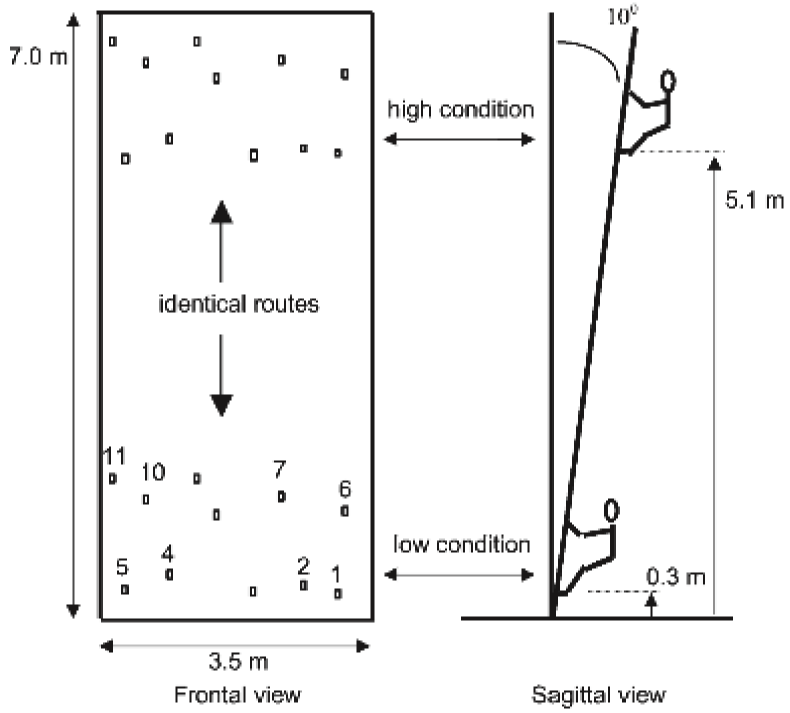


Figure 3.10: *Visual representation of two identical traverses, one low to the ground (0.3 to 0.44 meters) and one higher (3.6 to 5.1 meters) [copyright Pijpers et al. (2003), reproduced with permission].*

Participants responses to the traverse task were assessed with heart rate, self-reported anxiety and climbing time (**Table 3.2**). Without exception, across all the studies, the novice participants reported feeling more anxious on the higher of the two traverses, as measured by an increase in the mean anxiety scores (Nieuwenhuys et al., 2008; Pijpers et al., 2006; Pijpers et al., 2003; Pijpers et al., 2005). Anxiety was measured with a simple unidirectional anxiety thermometer, allowing participants to quickly indicate their perceived anxiety, however, this did not allow participants to report their cognitive and somatic anxiety, as the CSAI-2 would (Martens, Vealey, & Burton, 1995). Heart rate was also recorded during the traverse task of the four studies (with the exception of Pijpers et al. (2006) second and third studies) (Nieuwenhuys et al., 2008; Pijpers et al., 2006; Pijpers et al., 2003; Pijpers et al., 2005). In all cases, the difference in heart rate between the low and high traverses were reported as significant, although, the difference in heart rate ranged between 10.2 and 19.6 $b.min^{-1}$. The mean values in the two conditions also varied, with heart rates in the low condition between 108.9 to 146.1 $b.min^{-1}$ and in the high condition between 119.1 and 164.8 $b.min^{-1}$ (**Table 3.2**).

Table 3.2: *Heart rate ($b.min^{-1}$), climbing time (sec) and self-reported anxiety recorded in studies with high and low traverse conditions (Mean ± SD).*

			Heart Rate ($b.min^{-1}$)		Anxiety		Climbing Time (sec)	
Author (Date)		***n =***	**Low**	**High**	**Low**	**High**	**Low**	**High**
Pijpers et al. (2003)	**S1**	13	146.1 ± 18.1	164.8 ± 14.1	1.5 ± 1.3	4.3 ± 2.4		
	S2	17	112.4 ± 18.2	130.4 ± 18.8	2.1 ± 1.1	4.6 ± 1.7	29.5 ± 6.7	43.1 ± 12.1
Pijpers et al. (2005)	**S1**	8	143.3 ± 9.7	157.3 ± 14.6	0.7 ± 0.4	2.7 ± 1.9	56.6 ± 34.2	89.5 ± 46.5
	S2	15	126.3 ± 18.4	145.9 ± 19.3	3.4 ± 2.0	6.5 ± 2.4	62.1 ± 12.0	76.1 ± 11.0
Pijpers et al. (2006)		12	108.9 ± 17.0	119.1 ± 16.6	1.7 ± 1.6	4.5 ± 2.5		
Nieuwenhuys et al. (2008)		12	114.6 ± 13.0	127.9 ± 14.1	1.2 ± 0.8	4.9 ± 2.3	29.4 ± 4.8	45.5 ± 12.8

Notes: $b.min^{-1}$ beats per minute; sec seconds; S study

Differences in heart rate between studies were likely due to the procedures used, particularly traverse height, the number of repetitions and climbing time. The greatest heart rate were observed during the first study of Pijpers et al. (2003), which involved 6.5 traverses of a 3.5-meter wall at a set pace of 20 seconds per traverse, while the second part of the study only required two traverses of the wall and, as such, heart rate was lower. At the opposite end of the spectrum, the lowest heart rate values were observed by Nieuwenhuys et al. (2008) and Pijpers et al. (2006), who did not ask their participants to perform a physically demanding task, with the respective protocols consisting of a perception of reach task, and a self-paced traverse. It was speculated the change in heart rate in the high condition were due to the increase in climbing time, which was significantly greater in the high condition in all studies, rather than anxiety which was consistently greater (Nieuwenhuys et al., 2008; Pijpers et al., 2006; Pijpers et al., 2003; Pijpers et al., 2005). As previously discussed, anxiety was unlikely to be the main factor responsible for elevated heart rate during the climb, instead, it may be attributed to a combination of both physiological and psychological factors.

In addition to the assessment of the effect of traverse height on self-reported anxiety and heart rate, Pijpers and colleagues also explored behavioural changes (Nieuwenhuys et al., 2008; Pijpers et al., 2006; Pijpers et al., 2003; Pijpers et al., 2005). Climbing behaviour, except for the analysis by Hardy and Hutchinson (2007) and Sanchez et al. (2010) has seen limited investigation, particularly in response to potential anxiety-inducing stressors. Pijpers and colleagues, throughout their series of studies, demonstrated notable changes in performance in the high traverse, including increased muscular tension and a reduction in the degrees of freedom of the climbers movement with increased movement entropy and climbing time (Pijpers et al., 2003); the effect of anxiety on visual attention through increased eye fixation duration (Nieuwenhuys et al., 2008); anxiety-induced changes in climbing behaviour with increased explorative movements (Pijpers et al., 2005); and, differences in the perceiving and realising affordances *(Pijpers et al., 2006) (see section 2.8 for a detailed discussion of changes in performance*).

Considered together, the psychological and physiological changes observed by Pijpers and colleagues demonstrate that for novice climbers' height above the ground presents as a significant evocative stressor (Nieuwenhuys et al., 2008; Pijpers et al., 2006; Pijpers et al., 2003; Pijpers et al., 2005). A fear of heights in more experienced climbers could be considered a paradox as, with few exceptions, an increase in the height from the ground is accompanied by a decrease in the likelihood of a potentially injury-inducing ground fall (Burbach, 2005). It is possible that the emotional response of participants of Pijpers and colleagues represented a disparity in perception of risk perception and reality. It is speculated the more experienced climbers would have a more rational assessment of the risk of traversing at height, while protected with a top-rope (Binney & McClure, 2005). The lack of research exploring increases in height and in groups other than the novices, limits conclusions that may be drawn about general climbing populations.

Pijpers and colleagues have made a significant contribution to understanding responses to stressors, particularly through the assessment of climber behaviour. Outside of the work of Pijpers and colleagues, there has been limited use of fine-grained methods for the assessment of performance. Previous climbing psychophysiology has largely focused on differences in potentially anxiety-inducing conditions, such as changes in the safety rope protocol. Pijpers et al. (2003) speculated that the lack of performance measures is the reason why research on anxiety in sport has proved to be equivocal and why there is limited evidence of predicted relationships (Jones, 1995). Because of the focus on differences between contrasting conditions, it is likely differences have been missed that would otherwise have been observed. Moving climbing psychophysiology research forward, studies should take a process-oriented approach, considering changes in the execution of movements that may or may not lead to variations in the outcome (Gould et al., 2002). Through the consideration climbers' behavioural response to potential anxiety-inducing conditions, such as the style of ascent (*Study One*) and route difficulty (*Study Two*), it is expected it will be possible to elucidate differences in responses not seen previously.

To summarise, with an increase in novice climbers' height above ground there was greater state anxiety, heart rate and climbing time. There were also changes in movement behaviour in the climbers in the high conditions, with increased muscle fatigue and geometric entropy; explorative movements and grasping the holds longer and moving slower from hold to hold; reduced perceived maximum reach height; and an increase in the number and duration of gaze fixations. However, the results are limited in their applicability to general climbing populations because of the novice nature of the participants and the top-rope traverse conditions. The research of Pijpers and colleagues highlights the need for performance measures in climbing psychophysiology research, an aspect that is particularly underdeveloped. Consequently, this thesis will employ both quantitative and qualitative means of determining climber performance, these are described in detail in section *4.2 Climbing performance measures*.

3.5 Summary

Research using psychophysiological techniques to explore the challenges present within the sport of climbing has developed significantly in the past 10 years. Research completed, highlights the multi-faceted stressors faced by participants, including the style of ascent, route knowledge, route difficulty and height above the ground. To date, the style of ascent has received the most attention, based on the consternation of climbing coaches of its significance (Hague & Hunter, 2011; Hurni, 2003; Macleod, 2010; Sagar, 2001). However, the results of summarised studies suggest there are few meaningful differences between top-rope and lead climbs (Aras & Akalan, 2011; Dickson et al., 2012a; Draper et al., 2011d; Draper et al., 2012; Draper et al., 2008; Draper et al., 2010; Fryer et al., 2013; Hardy & Hutchinson, 2007; Hodgson et al., 2009). It is speculated that the equivocal results could have occurred because of a combination of methodological differences and inter-individual variation.

The studies examined in this chapter highlight that responses to climbing stressors may, or may not, have a detrimental effect on performance depending on several factors, including climber ability and experience (Draper et al., 2011d; Sanchez et al., 2010). There is likely to be interaction between stressors including route difficulty (Hardy & Hutchinson, 2007; Hardy

& Martindale, 1982) and knowledge (Draper et al., 2008; Hardy & Hutchinson, 2007) and even height on a route (Nieuwenhuys et al., 2008; Pijpers et al., 2006; Pijpers et al., 2003; Pijpers et al., 2005). Furthermore, elevated anxiety is not necessarily detrimental to climbing performance, indeed both Hardy and Hutchinson (2007), and Sanchez et al. (2010) reported performance to be associated with elevated somatic anxiety. Finally, with the exception of Hardy and Hutchinson (2007), there has been limited investigation into the effects of stressors on experienced climbers performance.

This thesis continues to refine psychophysiological methods, to develop our understanding of the challenge facing climbers and their responses; particularly considering the consternation of climbing coaches of stressors of significance, despite equivocal results found to date (Hague & Hunter, 2011; Hurni, 2003; Macleod, 2010; Sagar, 2001). The thesis aimed to explore psychophysiological and emotional antecedents of climbing performance. To achieve this, the methods used developed on previous studies, particularly Draper, Dickson, Fryer and colleagues (Dickson et al., 2012a; Draper et al., 2012; Fryer et al., 2013); as well as through the inclusion of detailed performance measures, including geometric entropy (Cordier et al., 1993) and coaches assessment of performance; the identification of stressors through discussion with climbers; and, finally, consideration of the potential interactions of stressors. The methods common to *Studies One, Two and Four* will be discussed in the following chapter.

4

General Methods

The following chapter provides an overview of the methods and procedures pertinent to the studies presented in *Chapters 5, 6 and 8*, referred to as *Studies One*, *Two* and *Four*. This chapter is broadly divided into five sections; the first is concerned with the recruitment, safety and description of participants; the second provides details of the objective and subjective tools used for the description and analysis of climbing performance; the third and fourth describe the psychophysiological and psychological tools used to assess climbers state, respectively. The final section refers to common data and statistical analysis methods. This chapter should be referred to where appropriate when reading the experimental chapters. Experimental design, methods, data analysis and statistical analysis unique to each of the studies are presented in their respective chapters.

4.1 Participant preparation

4.1.1 Participants

Participants were recruited from the climbing community local to Awesome Walls Climbing Centre, Sheffield. The studies were advertised locally in Sheffield, using posters, targeted advertisements placed on social media and word of mouth. All contact with participants was made directly; no third parties were involved in communication. Participation was sought voluntarily and no inducement was offered for taking part. All recruited participants were over the age of 18 on the first day of testing, normotensive and reported being in good health. Participants were recruited based on being competent lead climbers, familiar with the equipment, processes and techniques required for lead climbing indoors. Participant's eligibility was assessed against the recruitment criteria for each of the studies set out in **Table 4.1**.

Table 4.1: *Participant climbing experience recruitment requirements.*

Study	**Sex**	**Age** (years)	**Competent lead climber?**	**On-sight Climbing ability**	**Notes**
Study 1	♀ or ♂	18-55	yes	f6b/+	Single session
Study 2	♀ or ♂	18-55	yes	f6a – f6c+	Approximately 20 participants per whole letter grade (3 divisions), 60 total. Single session
Study 4	♀ or ♂	18-55	yes	f6b/+	Two sessions, on two consecutive days

Notes: ♀ Female; ♂ Male; f French difficulty grade

On arrival at the start of each session, participants received a detailed verbal explanation of the procedure and an opportunity to ask any questions they may have had. They were then provided with the relevant participant information sheet and as much time as they needed to consider the materials. Following ensuring participants were aware of all aspects of the study, procedures and what was required of them, they were asked to complete the declaration of informed consent and health history questionnaire. No deception of any form was employed and the participants were aware of all aspects of the study; although, participants were not provided with exact details of the routes they were to climb until they received the audiotaped route instructions. All questions were answered in full when asked. Participants had the right to withdraw from the project at any time, including withdrawal of any information provided up to two weeks after data collection, with no need for an explanation. The anonymity and confidentially of the data was emphasised, participants were informed that data may be published in journals and presented at conferences, in addition to within this thesis.

Participants were asked not to alter their training regime in the run-up to the study, and to choose sessions that allowed for adequate rest. Additionally, prior to sessions, all participants were asked to refrain from strenuous exercise for 24 hours, consuming food within two hours of the sessions and drinking any alcohol or caffeinated beverages within 24 hours. As salivary samples were collected, in accordance with Gonzalez, Del Mar Bibiloni, Pons, Llompart, and

Tur (2012), all participants were instructed not to brush their teeth 30 minutes before attendance, not to consume water five minutes before any sample, and not to consume food before arrival at the laboratory. If testing involved two sessions (*Study Four*) participants were asked to wake up at the same time of day, and consume similar food for the 24 hours prior. Participants understanding of the instructions was checked when recruited and confirmed on each day of testing.

Participants were recruited based on their self-reported competence as an indoor lead climber. While the level of experience of participants for *Studies One, Two and Four* varied between on-sight grades of f6a to f6c+ (**Table 4.1**), all were competent lead climbers who were aware of the risks the sport presented. As a precaution, as part of the warm-up for *Studies One, Two and Four,* participants completed an easy lead of a route graded f5-f6a (depending on their on-sight ability), to provide an indication of their competency. If during or following the easy on-sight lead it was apparent the climber was not competent or safe at lead climbing they were withdrawn from the study and were unable to continue; it was not necessary to exclude any participants for these reasons. Participants used their own harness, shoes and chalk for each ascent.

All initial ascents were on-sight, participants were not provided with any information on the routes they were to attempt, other than the colour of holds and which quickdraws they were to clip. Except for the warm-up, participants were instructed to climb until they either reach the top of the route or fell. If the participant fell, weighted the rope or took a hold that was not part of the route they were attempting then their attempt was over. Participants were informed they may stop at any time before or while on the climb.

4.1.2 Anthropometrics and warm-up

Anthropometric data were collected from all participants during the first session of each study, which was comprised of age, height and body mass. Height was measured as follows. Hair ornaments were removed, and braids were undone, the participant stood on the stadiometer (Seca 866; Seca, Gmbh & Co. Germany) with bare feet placed slightly apart and the back of the head, shoulder blades, buttocks, calves, and heels touching the vertical board. Legs were kept straight and the feet flat. The head was positioned so a horizontal line drawn from the ear canal to the lower edge of the eye socket ran parallel to the baseboard. The headboard was pulled down to rest firmly on top of the head to compress the hair. Height readings were taken to the last completed 0.5 centimetre. Body mass was recorded as follows, the participant stood still in the centre of the platform of the scale (Seca 866; Seca, Gmbh & co. Germany) without support, with the body weight evenly distributed between both feet. Light underclothes were worn, excluding shoes, long trousers and thick coats and tops. Mass was recorded to the nearest 0.01 kilogramme.

The climbers completed a thorough warm-up, comprised of five minutes of pulse raising activity (walking, jogging skipping etc.), five minutes of mobilising exercises and five minutes of gentle climbing, including leading a route graded f6a or below. The prescribed warm-up was adapted from the methods previously set out by Binney and McClure (2006), Gresham (2007) and Tenke and Higgins (1999) and used by a number of previous studies including Draper et al. (2011c) and Dickson et al. (2012b). The pulse raising activity was of a moderate intensity, raising heart rate to a maximum of 50% heart rate maximum (based on age prediction: 220 – age). Mobilisation systematically worked from hands, wrists, elbows, shoulder, back, neck to the hips and legs, working the joints through their normal range of motion. The gentle climbing and leading of a route were also used as an assessment of the climber's ability to lead a route safely, as previously described.

4.1.3 Protection of climbers

During the climbing tasks, participants were protected from ground falls using a climbing harness, a lead climbing rope or top-rope and a belayer and belay device (Petzl Gri-Gri). The anchors for the safety rope were already semi-permanently installed in place by a qualified person and were regularly inspected by climbing centre staff. All equipment used for the protection of climbers were regularly inspected, and records kept. In the case of an incident, the participant may have been rapidly lowered back to the ground. Participants were required to complete a separate disclaimer provided by the Awesome Walls climbing centre (Electronic, completed on arrival at the wall). The climbing trials were supervised by an experienced and competent person holding the SPA (Mountain Leader Training England Single Pitch Award), under the guidance of a MIA (Mountaineering Instructor Award), experienced and proficient in the running and management of such an activity. The climbing trials were completed with the full cooperation of Awesome Walls climbing centre and staff and fully complied with their standard operating procedures and safety policies.

4.1.4 Ethical approval

Ethical approval was granted for the studies by the University of Derby's College of Life and Natural Sciences Research Ethics Committee (**Table 4.2**). Confirmation of approval may be found in *Appendix A*. Ethics applications for the four studies were combined in two pairs, based on a combination of the ability of the participants to be recruited, the need for routes to be set and the similarity of methods.

Table 4.2: *Details of ethical approval granted for methods papers and main studies.*

Title	Study(s)	Ref Number	Date Submitted	Date Granted
Exploring determinants of climbing performance and the effectiveness of specific coaching interventions.	Study 1 Study 4	LSREC_1516_06	12/10/15	09/02/16
A psychophysiological and behavioural comparison of on-sight lead climbing and the role of participant ability.	Study 2 Study 3	LSREC_1516_07	07/12/15	21/07/16

As with any form of exercise, there was a minimal, but potentially significant risk to participants, which was explained fully on the information sheets and verbally prior to the first session. As well as being able to withdraw at any-time participants were supervised at all times during the protocol, if at any-time participants' safety was at risk testing was immediately halted and appropriate measures were taken. Participants were screened via a health history questionnaire. Furthermore, as the assessment of cortisol is both used as diagnostic tests for several conditions (e.g. Cushing's syndrome, Addison's disease), there was potential for the identification of values that would require further investigation by a qualified medical professional. If abnormal (e.g. excessively high or low) concentrations of cortisol emerged during the analysis of the data the participant's data was identified, removed from the analysis and they were contacted and recommended to visit a doctor. Any relevant information was provided for presentation. This was not necessary.

4.1.5 Data protection

Participants' confidentiality and anonymity were maintained, and their personal privacy protected. The collection, storage, disclosure and use of research data complied with the Data Protection Act 1998. The data were held securely and was only accessible by David Giles and Professor Nick Draper: data with identifying information (physical paper copies) were stored in the locked office of Professor Nick Draper; anonymised data were stored on David Giles' personal computer (encrypted and password protected). Participant's identity will never be made public. Video recordings were made of the climbers for performance analysis, the recordings were viewed by the research team for analysis. Following analysis, all copies were deleted, and a single copy will be stored on David Giles' personal computer (encrypted and password protected), for a maximum of 6 years.

4.1.6 Location

Data collection was performed at a single location. Anthropometric and descriptive data were collected in a quite isolated classroom while all indoor climbing was also completed at Awesome Walls climbing centre, Sheffield.

4.1.7 Route design

The routes used for each of the climbing studies were set by professional route setters, familiar with setting routes from recreational to world-cup level. Details of each of the routes, grade, number and style of ascent are provided in **Table 4.3**. The climbing routes were set using Core® (Core Climbing Ltd, Sheffield, UK) modular climbing holds. The routes were set such that both hands and feet could be used on the holds; the feet could also be smeared on the wall. The route was 14.1 meters' high, with a 1.6-meter overhang. The three routes for *Studies One and Four* were graded French 6a+ (12 IRCRA; 5.10c YDS), and for *Study Two* were graded French 6b (13 IRCRA; 5.10d YDS), which was confirmed by four expert climbers prior to the commencement of each study (**Table 4.3**).

Table 4.3: *Location, style of ascent, grade and number of climbs set of each study.*

Study	Location	Styles of Accent	Knowledge	Grade of climbs	Number of routes
Study One	Climbing Wall	Top Rope Lead Climb Lead Climb with Run-Out	OS	f6a+ (12 IRCRA; YDS 5.10c)	3
Study Two	Climbing Wall	Lead Climb	OS	f6b (13 IRCRA; YDS 5.10d)	1
Study Four	Climbing Wall	Lead Climb	OS and then RP	f6a+ (12 IRCRA; YDS 5.10c)	2

Notes: OS on-sight; RP red-point; f French grade scale; IRCRA international rock climbing research association; YDS yosemite decimal system

The style of ascent describes the way in which climbers were protected in the event of a fall. The three conditions used in the studies were top-rope, lead or lead run-out. For the top-rope, a rope was attached to the climber from the top of the wall, in the event of a fall the rope immediately arrested the climber. The lead condition required the climber to ascend the route trailing a climbing rope; the climber attached the rope to quickdraws, in the event of a fall the climber travelled a short distance before being arrested by the belayer and the trailing rope. The lead run-out condition was identical in principle to the lead condition, except at the top of the route the distance between quickdraws was 2.93 meters, rather than 1.45 and 1.38 meters. For the lead conditions, to protect climbers in the event of a fall quickdraws were fixed at intermittent points on the route. After the first quickdraw at 3.05 meters, the distance between the next nine quickdraws was 1.21 ± 0.13 meters (**Figure 4.1**). The initial three meters of the route were unprotected unless the climber was using a top-rope. In the event of a fall on the lower unprotected section, the floor of the wall was covered in dense rubber crumb matting, the belayer also ‘spotted’ the climber, to ensure if they did fall they would land on their feet. Once the first point of protection was clipped this was no longer necessary.

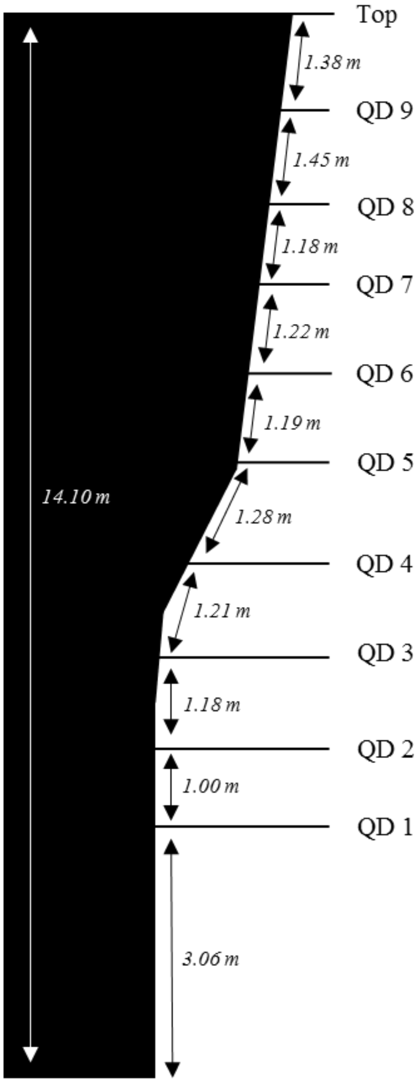


Figure 4.1: *Profile of route and distribution of points of protection, quickdraws, on the routes of Studies One, Two and Four. Distance in meters. QD quickdraw; m meter.*

A climber's prior knowledge of a route, impacts the way in which the ascent is completed, along with altering the relative psychological load (Draper et al., 2008). The principal forms of ascent are *on-sight*, without any prior knowledge on the first attempts, or a *red-point* repeat ascent of a whole or partially climbed route (Goddard & Neumann, 1993). Except for *Study Four*, all routes were completed without prior knowledge (**Table 4.3**). Where possible participants were asked to refrain from watching preceding participants attempting the climbs, to limit the amount of information participants had about the climb and the success or failure of previous participants. As all routes were set on a public climbing wall, participants were instructed to avoid climbing on certain panels (Awesome Walls Sheffield Panels number 101, 102, 103), until after the study to ensure the route was novel.

4.2 Climbing performance measures

Considerable methodological advances have been made in recent climbing psychophysiology research, particularly by Draper, Dickson, Fryer and colleagues (Dickson et al., 2012a; Draper et al., 2011d; Fryer et al., 2013). However, while significant advances have been made their results have proved largely equivocal, despite the consternation by coaches and climbers of the demands of the stressors investigated (Hague & Hunter, 2011; Hörst, 2010; Hörst, 2008; Hurni, 2003; Sagar, 2001). Pijpers et al. (2003) speculated that the lack of performance measures was the reason why research on anxiety in sport has proved to be equivocal, and why there is limited evidence of predicted relationships. The same is true of climbing research, with the exception of the analysis of novice climbers' performance by Pijpers and colleagues (Nieuwenhuys et al., 2008; Pijpers, Oudejans, & Bakker, 2007; Pijpers et al., 2006; Pijpers et al., 2003; Pijpers et al., 2005), and the limited analysis of expert climbers by Hardy and Hutchinson (2007), there has been inadequate investigation into the effects of stressors on performance.

Climbers' behaviour and performance were considered one of the most important aspects of climber's responses assessed in *Studies One, Two and Four*. Not only are behavioural responses quantifiable, they also provide detailed practical information for coaches and climbers. The following section outlines performance measures designed to quantify participants' behavioural response to the climbing tasks. These include self-reported ability (Draper et al., 2016), geometric entropy (Cordier et al., 1993; Cordier et al., 1994) and coaches performance assessment.

4.2.1 Self-reported ability and experience

Draper, N., **Giles, D.,** Schöffl, V., Fuss, F., Watts, P… & Abreu, E. (2016). Comparative grading scales, statistical analyses, climber descriptors and ability grouping: International Rock Climbing Research Association Position Statement. *Sports Technology*, 8(3-4), 88 - 94.

Giles, D., Taylor, N. Mitchell, J. & Draper, N. (2017). Self-reported ability and pre-competition anxiety in climbing competition performance. [*Under review Research Quarterly for Exercise and Sport*]

A climbing routes difficulty is dictated by the frequency, size and quality of hand and footholds and the length and angle of the route itself (Watts, 2004). Differences in the style of ascent and the amount of knowledge a climber possesses of a route are also likely to influence the challenges a climb presents (Draper et al., 2008; Draper et al., 2010). In order to gauge a climber's ability, quantify the difficulty of routes, measure progress and facilitate climbers' choice of routes, climbs are graded (Draper et al., 2016). There are many different grading scales that have developed largely independently around the world; for this reason, the International Rock Climbing Research Association (IRCRA) climbing grade scale was created (Draper et al., 2011a; Draper et al., 2016). The IRCRA grade scale provides a consensus on the conversion between grade scales, the standardised division of experience and their use in statistical analysis (*Appendix B).*

A climber's capability to report their past and present ability is not only important within the sport, but also in research, as many studies use self-reported grades as the primary independent variable; for example, recent research has used self-reported grades while exploring differences in the forearm oxidative capacity of intermediate and advanced climbers (Fryer et al., 2015b), the classification of climbers ability to determine injury trends (Schöffl et al., 2015) and the correlation between ability and finger strength (Baláš, Mrskoč, Panáčková, & Draper, 2015). Consequently, it is important that climbers can accurately and reliably assess and recall their previous ability. An understanding of climbing grades is a fundamental skill, which climbers are introduced to early on in their time in the sport; it is also typical of climbers to have a good understanding of their local grading scale (Draper et al., 2016).

To assess the validity of self-reported climbing grades Draper et al. (2011b) asked 29 competitive rock climbers of varying abilities to self-report their best on-sight performance before then being asked to climb a competition style route. The route used increased in difficulty and the distance achieved by the climbers denoted the grade achieved; a style similar to scoring used in competition. Despite minor over- and underestimations in male and females respectively, there were no significant or meaningful differences between self-reported grade and the grade achieved. Self-reported ability assessment was able to explain ~72% of the variation in climbing performance. Similarly, Giles, Taylor, Mitchell, and Draper (2017b) assessed the relationship between self-reported climbing grades and performance in a national bouldering competition (*n* = 153). It was found that six-month self-reported ability could explain ~65% of competition scores achieved. The results of the both studies suggest climbers self-reported grades provide a valid and accurate reflection of a climbers ability (Draper et al., 2011b; Giles et al., 2017b).

For the reporting of climbers ability in research, Draper et al. (2016) proposed a 3:3:3 rule: climbers' highest red-point grade for which they have completed three successful ascents on three different routes (at the grade) within the previous three months. Giles et al. (2017b) proposed a modification of the 3:3:3: rule, suggesting that 3:3:6 would be more appropriate, with the 6-month reported grade being less susceptible to short-term variation. As such, for the purpose of this thesis, climbers reported grades achieved in the six months prior to data collection. In addition to climbing ability, climbers' experience, in terms of the number of years they have been taking part in the sport and their preferred climbing discipline are import and come together to describe a climber. Participant experience was collected based on the IRCRA guidelines (Draper et al., 2016; Giles et al., 2017b).

4.2.2 Video recording of climbs

Each of the ascents in *Studies One, Two and Four* were video-recorded (Panasonic HD V720 digital video camera) for later analysis of geometric entropy and coaches' assessment of performance. Due to the challenges of recording in a climbing wall, it was not possible to set the camera up at half route height (7.05 meters). Consequently, the camera was set up 10 meters from the base of the route, at 1.5 meters' height. The placement of the camera at the base of the route necessitated the correction of the perspective of the video files prior to their digitisation for the calculation of geometric entropy. Had the video files been left in their raw, unedited form, the digitalisation would have overemphasised the size and velocity of the movements in the lower half of the route and underemphasised the movements in the upper half of the route. The videos perspective were corrected in Adobe Photoshop (Adobe Systems Software Ireland Ltd.) using a template, before being exported for analysis.

Following correction, it was possible to digitise the x and y coordinates of the climbers' position throughout their ascent of the route. A single point on the middle back of the harness was chosen as an approximation of the climber's centre of mass to represent the climbers' displacement over the entire route (Watts, Drum, Kilgas, & Phillips, 2016). Several previous studies have used the single-point path of the centre of mass (Cordier et al., 1993; Cordier et al., 1994; Pijpers et al., 2003; Sanchez et al., 2010; Watts et al., 2016). The chosen point was manually digitalised into x and y coordinates using Tracker (Version 4.92; Open Source Physics). A one-meter marker was used at the top and the bottom of the route to calibrate distance in the Tracker software. The slow nature of climbing, with each climb lasting between one minute eleven seconds and five minutes, and the need for manual digitalisation necessitated the use of a 5 Hz sampling frequency. From the recorded videos several variables were calculated, including climbing time, geometric entropy and the coaches' assessment of performance.

4.2.3 Geometric entropy

Taylor, N., **Giles, D.,** Mitchell, J. Panáčková, M., Hoyle, D. and Draper, N. (2017). Development of a lead climbing performance analysis tool. [*Manuscript in preparation*].

Skilled climbing performance has been described as the ability to *"rapidly and fluently transitioning between holds"* (Orth et al., 2016, p. 1). Skilled climbers can perform with minimal effort as constrained by the difficulty of the route and the opportunities for movement available to them (Orth et al., 2016). It is possible to quantify the fluency of movement through the analysis of the path of the centre of mass of a climber over the course of an ascent, the geometric index of entropy quantifies the paths relative complexity (Cordier et al., 1993; Cordier et al., 1994). An increase in geometric entropy indicates a less smooth displacement of the climber's centre of mass, characteristic of less skilled climbing behaviour (Cordier et al., 1993; Cordier et al., 1994). Geometric entropy has been shown to decrease (improve) relative to experience, with learning (Cordier et al., 1993; Cordier et al., 1994). The shape of the entropy curve has been demonstrated to occur as a function of the climber's level of expertise (Cordier et al., 1993; Cordier et al., 1994). Following ten successive ascents of a route, it was established that changes in the fluency of a climber's trajectory could describe the learning process on a route (Cordier et al., 1993). Furthermore, the time taken for stability to be achieved varied with the experience of the climber, with experts achieving a stable trajectory after the 3rd trial, while this did not occur until the 6th trial for the non-experts (Cordier et al., 1993). **Figure 4.2a** illustrates changes in the path with learning for a single climber, each line representing a single attempt at the route (Cordier et al., 1994). It is possible to notice the reversal in the path of the centre of mass at point (i) and the reduction in the complexity higher up in the route (ii), following practice. Differences in geometric entropy have also been found with anxiety. Pijpers et al. (2003) reported significantly greater anxiety in a high traverse condition, compared to a low-to-ground condition. The increase in anxiety was also accompanied by an increase in movement entropy with a noisier movement pattern a more rigid, jerkier and less efficient movement pattern (**Figure 4.2b**). This increase in entropy occurred alongside greater climbing time (Pijpers et al., 2003); eye fixation duration (Nieuwenhuys et al., 2008); increased explorative movements (Pijpers et al., 2005); and differences in the perceiving and realising affordances (Pijpers et al., 2006).

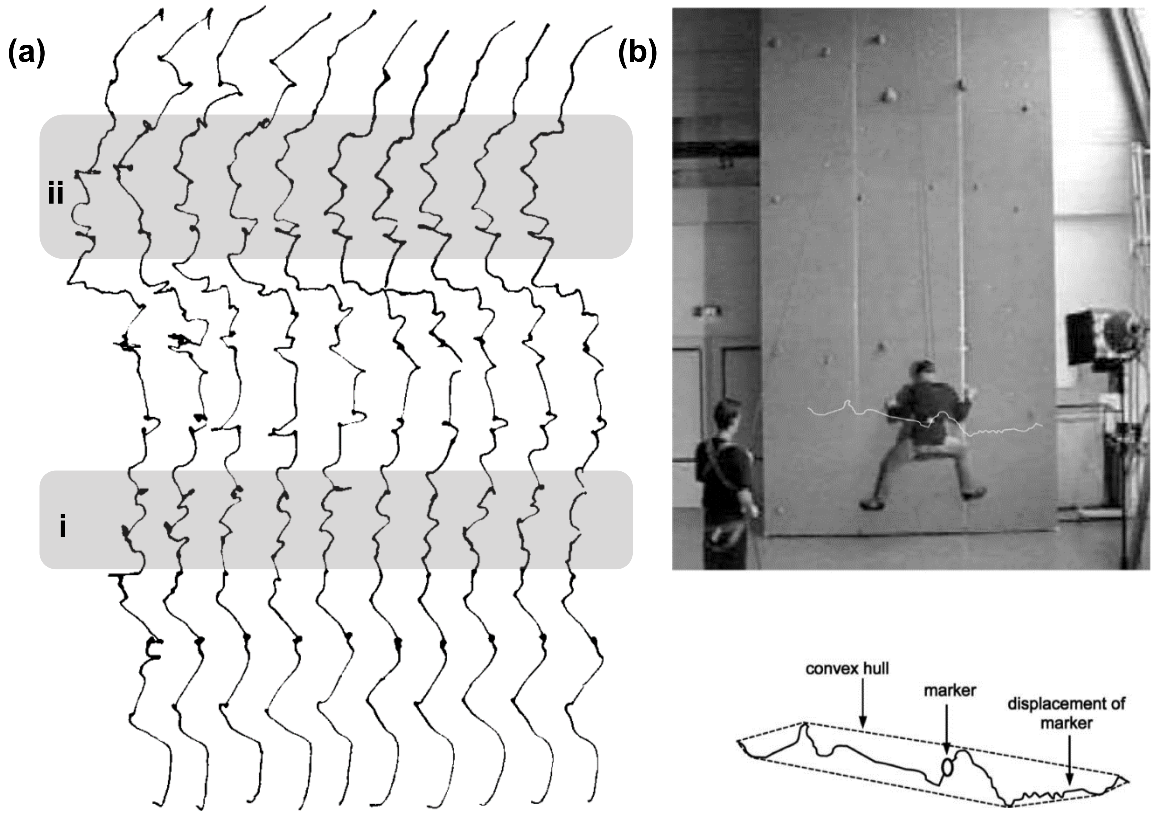


Figure 4.2: *(a) Family of 10 successive trajectories reaching a stable state [reproduced from (Cordier et al., 1994) with permission]. (b) Front view of the climbing wall with the marker curve [copyright Pijpers et al. (2003), reproduced with permission].*

The geometric entropy of the climbers' path was calculated from the digitised x and y coordinates of the displacement of the centre of mass, as set out by Cordier et al. (1993). Two variables were calculated, the line of motion (LM) and the convex hull (CH). Geometric entropy (GE) was expressed as the natural logarithm of two times the LM divided by the CH:

$$GE = \log\left(\frac{2 \times LM}{CH}\right)$$

The convex hull was calculated as the value of the perimeter around the LM (Cordier et al., 1993; Cordier et al., 1994). Geometric entropy was calculated from the x and y data coordinates stored in .csv files in Matlab using code adapted from the work of Marc Boschker (Boschker & Barker, 2002); the code may be found in *Appendix C*. An increase in geometric entropy resulted with a noisier less fluent path of the centre of mass, while lower values represented fluency and stability of the path.

4.2.4 Coaches performance assessment tool

Taylor, N., **Giles, D.,** Mitchell, J. Panáčková, M., Hoyle, D. and Draper, N. (2017). Development of a lead climbing performance analysis tool. [*Manuscript in preparation*].

Recreational climbing performance is typically determined by the dichotomic conditions of success or failure. When leading, an ascent is considered successful when the climber has managed to clip the rope through the last quickdraw (the chains, in climbing nomenclature) without weighting the rope on their ascent. If the climbers falls, weights the rope, touches a hold of a different colour or fails to clip the last quickdraw, then they are considered to have been unsuccessful. In contrast, competition performance is determined by how far participants achieve on an ascent of a route, receiving points for distance travelled, and the number of holds used (IFSC, 2016).

To date the majority of climbing psychophysiology studies have assessed differences between conditions, such as lead or top-rope and on-sight or red-point; there has been limited use of performance measures. Success and failure and competition points have been used as indications of performance in a small number of studies (Draper et al., 2011d; Sanchez et al., 2010). The research of Draper et al. (2011d) and Sanchez et al. (2010) both explored the antecedents of successful climbing performance, and while the consideration of differences between success and failure and competition points allows for antecedents to be explored, they do not provide an explanation for climbers' behaviour.

The only study to have investigated psychological and behavioural responses in experienced climbers are Hardy and Hutchinson (2007). The authors investigated anxiety and behavioural responses to lead and top-rope ascents of routes. The performance instrument used was termed the Climbing Performance Evaluation Inventory (CPEI), and was constructed based on 10 salient factors in traditional lead climbing performance, identified by 30 experienced climbers. Consequently, because of the traditional basis of the scale, five of the ten items referred to factors concerned with the protection of routes, such as the appropriate use of gear placements, rope management and setting up belays. The other five items related to climbing performance, including remaining focused and controlled, demonstrating good strength and stamina, being graceful in their movements, economy of effort and the ability to read the route. Participants of Hardy and Hutchinson (2007) were scored by their belayer on the five characteristics that they felt were most important to their performance. Such an approach is limited in several respects, not least because of the lack of theoretical basis for the items, the potential for climbers choosing factors that they believed others would score them highly on and the need for the belayer to score the climber, while belaying.

Considering the lack of a thorough climbing performance measures, there was a need for the development of a scale that considered the technical aspects of performance. Consequently, as preliminary work for this thesis, a group of expert coaches and elite climbers set out to develop an observational instrument that scored of climbers on important elements of their technical and tactical performance. Importantly, the score needed to identify the quality of performance and was not tied to specific moves (e.g. rock over), which may, or may not, be present in a given performance or appropriate for a given climb or climber. Rather, the performance scale needed to describe factors common to all movements, differentiating between those that are inappropriately selected and poorly executed and those that were both appropriate and well executed.

The performance scale was developed in consultation with an expert panel of climbing coaches (coaching both local and national climbers) with between 5 and 20 years of coaching experience. Initially, coaches were contacted with the aim of identifying variables that together contribute to the quality of a climber's performance. This resulted in the creation of an extensive list of possible variables. Ambiguous variables were defined, duplicates were then removed, and the variables were then categorised into key common areas. To confirm the findings of the expert panel and to provide an indication of the importance of the identified variables, coaches were asked to rank each of the variables in each category in order of their perceived importance. The variables were rated against the following definition of skill in climbing, *"the ability to coordinate a series of complex, whole body, movements to ascend a predefined route with an economy of movement"*. To assess skill against the definition, the identified list of variables from the initial consultation that described the level of skill were assessed based on the rankings provided.

The final scale was comprised of five themes and 14 items:

Base of Support (*accuracy and precision | adjustments*): Climbers interface with the holds on routes with both their hands and feet, which form the climber's base of support. Accurate and precise placements without readjustments to facilitate efficient economical climbing movement.

Transitioning Movement (*dynamic balance | fluidity and linking | exploratory movements | sequencing*): Ascending a route requires climbers to use momentum to link moves between positions while remaining in balance. Fluidly in transitions between movements allows the maintenance of momentum. To facilitate these movements, the climber should observe and execute sequences of movements without mistakes, hesitation or the need to reach out and feel hand and foot holds.

Coordination (*movement initiation | extension and body tension*): The climber should coordinate the whole body in the correct sequence throughout whole movements, while extending and maintaining body tension, without unnecessary movement, to keep weight over the base of support.

Technique (*repertoire of movement skills and techniques*): The climber should select appropriate movements for the routes, skilfully apply techniques, employ the most biomechanically advantageous form of movement to complete a given move and route.

Tactics (*tempo* | *commitment and confidence* | *rests* | *clipping*): While ascending the route, the climber should make a number of tactical decisions, including the selection of pace appropriate to the difficulties of the route, ascending without hesitation, and select appropriate rest positions and clipping positions that minimise unnecessary energy expenditure.

Finally, a score sheet was developed and for each variable a unique descriptor for a poor or non-existent component (1) and a flawless demonstration of skill (5) were produced (*Appendix D*). From the scale, it was then possible to calculate an average score for each of the categories of base of support, transitioning, coordination, technique and tactics. An overall score for the climber's performance over the entire route was also produced.

To assess the validity and reliability of the final coaches' performance assessment scale, the performance of 60 climbers were assessed. The climbers completed an on-sight lead ascent of a single route, set on a slightly overhanging wall at Awesome Walls climbing centre, Sheffield. Following an explanation of the methods, participants provided informed consent and health history. Institutional ethical approval was granted. The participating climbers ranged in ability from f6a to f6c+ (IRCRA 11 to 16; 5.10b to 5.11c). The climb was video recorded for analysis. Four experienced climbing coaches scored each of the climbers' ascents of the routes, using the developed coaches' performance assessment scale. The inter-rater reliability was calculated along with the relationship between the subjective assessments of climber's skill, climbing time and geometric entropy. Differences across the six ability groups were assessed with a series of one-way ANOVAs (significance $p < 0.05$, effect size η_p^2); the relationship between total coaches score and geometric entropy (see *4.2.3 Geometric entropy*) and climbing time (see *4.2.2 video recording of climbs*) were determined using Pearson's product-moment correlations.

The inter-rater coefficient of variation was 0.82 (95% Confidence interval = 0.42, 0.94), demonstrating good reliability of the scale. There was a strong positive relationship between climbers self-reported ability and the total coaches' subjective assessment of their performance of the route (R^2 = 65%). When the coaches' subjective assessment of the climber's skill was further broken down into the five categories it was possible to determine their relative contribution to performance (**Table 4.4**). All five variables were significant, connection points ($p < 0.005$, $\eta_p^2 = 0.630$), transitioning ($p < 0.005$, $\eta_p^2 = 0.662$), coordination ($p < 0.005$, η_p^2 =

0.569), technique ($p < 0.005$, $\eta_p^2 = 0.568$) and tactics ($p < 0.005$, $\eta_p^2 = 0.561$). There was a significant ($p < 0.05$) negative relationship between both climbing time ($r = -0.65$) and geometric entropy ($r = -0.38$), with greater coaches score significantly associated with slower climbing time and more fluid displacement of the climbers' centre of mass.

Table 4.4: *Breakdown of climbing performance score for each of the five categories of connection points, transitioning, coordination, technique, tactics as well as the total score (mean ± SD).*

	Ability						*One-way ANOVA*		
Category	**f6a**	**f6a+**	**f6b**	**f6b+**	**f6c**	**f6c+**	$F_{(5,55)}$ =	***p*** =	η_p^2
Base of support	2.5 ± 0.6	2.9 ± 0.4	2.9 ± 0.4	3.5 ± 0.6	3.9 ± 0.3	4.3 ± 0.6	18.714	< 0.005	0.630
Transitioning	2.3 ± 0.8	2.6 ± 0.6	2.6 ± 0.6	3.1 ± 0.4	3.8 ± 0.5	4.3 ± 0.4	21.554	< 0.005	0.662
Coordination	2.4 ± 0.7	2.8 ± 0.7	2.9 ± 0.6	3.4 ± 0.5	3.8 ± 0.4	4.3 ± 0.5	14.509	< 0.005	0.569
Technique	1.9 ± 0.6	2.2 ± 0.5	2.4 ± 0.5	2.8 ± 0.5	3.4 ± 0.6	4.0 ± 0.5	21.117	< 0.005	0.658
Tactics	2.7 ± 0.7	3.0 ± 0.8	3.2 ± 0.6	3.7 ± 0.4	4.1 ± 0.4	4.5 ± 0.5	14.085	< 0.005	0.561
TOTAL	**33.6 ± 8.0**	**38.0 ± 7.3**	**39.5 ± 6.3**	**46.5 ± 5.5**	**53.3 ± 5.9**	**60.0 ± 6.3**	**23.855**	**< 0.005**	**0.684**

Note: f french climbing grade scale; ANOVA analysis of variance

The coaches' assessment affords a detailed assessment of climbers' performance, complementing existing measures of climbing time and fluency of movement. The developed coaches' assessment tool provides a reliable means for the assessment of key performance indicators. The results demonstrated the scales good inter-rater reliability. The relationship between self-reported ability and coaches' performance score was also significant, explaining 65% of the relationship. Considering the relationship between self-reported ability and assessed ability seen previously in lead (Draper et al., 2011b) and bouldering (Giles et al., 2017b), the percentage of explained variance is as expected. Importantly, the coaches' performance assessment allows for the identification of coachable characteristics, complementing geometric entropy and climbing time. Each ascent of a route in the thesis will be scored using the coaches' assessment of performance, with a component score and total score produced. Scores were calculated for each of the climbers on each of the routes independently by two investigators.

4.3 Psychophysiological measures

Through quantifying the psychophysiological responses to stimuli, it is possible to gain an objective insight into climbers' psychological performance (Andreassi, 2006). Several psychophysiological variables were calculated (**Table 4.5**). Heart rate was recorded at rest;

cardiac output, peripheral resistance and heart rate and cortisol were collected pre, during and post participants receiving the audio recorded instructions. Heart rate and salivary cortisol were recorded prior to, during and post climb. Additionally, heart rate was recorded continuously during the climb, to assess the relative physiological load. Cortisol was sampled pre- and post-climb using a salivette; heart rate was recorded using Polar heart rate monitor and blood pressure was recorded at rest using Finapress Portapres sphygmomanometer. The following section provides a detailed overview of each of the physiological measures, their techniques, processing, and interpretation.

Table 4.5: *Key physiological and psychophysiological dependent variables*

Rest	Response to instructions	Response to Climb	Physical
Resting Heart Rate ($b.min^{-1}$)	**Heart Rate Response** (Pre to post instruction; $b.min^{-1}$) **Cardiac Output** (Pre to post instruction; L/min) **Total Peripheral Resistance** (Pre to post instruction; $dyn.s.cm^{5}$) **Cortisol** (Post instruction; nmol/L)	**Anticipatory Heart Rate** (Baseline to pre-climb; %) **Cortisol Reactivity** (Pre to Post-climb; %)	**Peak Heart Rate** ($b.min^{-1}$) **Average Heart Rate** ($b.min^{-1}$)

Notes: $b.min^{-1}$ beats per minute; L/min litres per minute; $dyn.s.cm^{5}$ vascular resistance; nmol/L nanomoles per litre

4.3.1 Salivary cortisol

Giles, D., Fryer, S., Dickson, T. & Draper, N. (2017). The influence of height familiarity on psychophysiological response. [*Under review Scandinavian Journal of Medicine and Science in Sports*].

The glucocorticoid steroid hormone cortisol (hydrocortisone) is the most commonly used biochemical marker for the assessment of the function of the hypothalamic-pituitary-adrenal (HPA) axis (Wittert et al., 1996). The HPA axis plays a significant role in body's ability to maintain allostasis, providing rapid and specific responses to a wide range of environmental and internal stressors (Kirschbaum & Hellhammer, 2000). Consequently, cortisol has been used as a biomarker for stress, anxiety and depression in many studies (Owens et al., 2014; Peckins et al., 2015; Thompson et al., 2012). Within climbing psychophysiology research, plasma cortisol has been extensively used as a marker of stress, for example, with manipulation of the style of ascent (Dickson, 2013; Dickson et al., 2012a; Draper et al., 2012; Fryer, 2013; Fryer et al., 2013; Hodgson et al., 2009). Similarly, cortisol has been used to assess group differences in BASE jumpers (Monasterio et al., 2016), judo athletes in competition (Filaire et al., 2001) and paragliders (Filaire, Rouveix, Alix, & Le Scanff, 2007).

Cortisol is synthesised and secreted into the circulating blood by the adrenal glands following stimulation by adrenocorticotropin hormone (ACTH). Within the blood, a significant proportion of cortisol is bound to carriers, including corticosteroid-binding-globulin (CBG), albumin and erythrocytes. A smaller proportion remains unbound (free), accounting for between 5 and 15 percent of cortisol (Robin, Predine, & Milgrom, 1978). Unbound cortisol appears in all bodily fluids, including saliva, as it is a highly liquid soluble molecule. Cortisol enters saliva via rapid passive diffusion through acinar cells and other non-active mechanisms and, consequently, is unaffected by saliva flow rates (Lewis, 2006). Salivary cortisol is often used as a surrogate assay for free plasma cortisol (Levine, Zagoory-Sharon, Feldman, Lewis, & Weller, 2007). Salivary sampling of cortisol provides an easily assessed non-invasive means of assessing the function of the HPA axis in climbers. The assessment of salivary cortisol, over capillary or venepuncture, offers the opportunity to collect the samples stress-free, without medical personnel, and in a multitude of environments (Hellhammer, Wüst, & Kudielka, 2009).

The validity of salivary cortisol, compared to venepuncture, has previously been established both at rest (Westermann, Demir, & Herbst, 2004) and in response to maximal exercise (Fryer et al., 2014). Furthermore, the ability for salivary cortisol to differentiate between climbers' responses was determined in a pilot study (Giles et al., 2017a). The pilot study aimed to determine psychophysiological responses in rock climbers and non-height familiar controls to a 20-meter wire ladder-climbing task (*Appendix G*). Fifteen rock-climbers and 14 controls, completed an ascent of a free-hanging wire ladder. Self-reported anxiety, heart rate (HR), salivary cortisol and oxygen uptake ($\dot{V}O_{2PEAK}$) were recorded. The control group climbed slower ($p < 0.005$; Mean Difference = 60.3 sec 95% Confidence Intervals 19.9, 100.6) and achieved a greater % of HR_{MAX} ($p = 0.010$; MD = 6.3%, $CI_{95\%}$ 1.7, 11.0), but not % $\dot{V}O_{2PEAK}$ ($p = 0.572$; MD = 3.6%, $CI_{95\%}$ -9.6, 16.8). The control group were more cognitively anxious ($p = 0.042$; MD = 3.1 $CI_{95\%}$ 0.1, 6.0), had lower self-confidence ($p = 0.019$; MD = 4.6 $CI_{95\%}$ 0.8, 8.3), had greater peak cortisol ($p = 0.010$; MD = 3.5 nmol/L $CI_{95\%}$ = 0.9, 6.1) and anticipatory heart ($p = 0.008$; MD = 14.0% $CI_{95\%}$ 3.9, 24.2). It appears the control group found ascending the 20-meter free hanging a greater stressor than the height-familiar rock climbers. The findings suggest the lower anxiety and psychophysiological response of experienced climbers occurred because of habituation to the challenge of ascending to height. Furthermore, the time taken for salivary cortisol to reach peak following the ladder-climbing, occurred 15 minutes' post completion of the task. The study demonstrated saliva samples ability to differentiate participants psychophysiological response. With good agreement between salivary and capillary sampling methods (Fryer et al., 2014; Westermann et al., 2004), and its ability to differentiate between groups salivary sampling is suitable in situations where venepuncture or capillary sampling are not suitable or convenient.

All saliva samples were collected using salivettes (Sarstedt, Germany). The sample timing and frequency is described individually in each methods section. Participants placed the Sarstedt Cortisol Salivette in their mouth, without touching it with their hands. Participants then moved the sponge around their mouth collecting the saliva sample, before then returning the saturated cotton swab back into the tube. Participants were instructed not to brush their teeth 30 minutes before attendance, not to consume water 5 minutes before any sample, and not to consume food before arrival at the session (Gonzalez et al., 2012). After each salivary sample was taken it was immediately frozen and stored at –20 °C for subsequent cortisol analysis.

The saliva samples were analysed for cortisol concentration using an enzyme-linked immunosorbent assay (ELISA) Kit (Saliva RE52611, Plasma RE52061, IBL International, Germany) as described and validated by (Westermann et al., 2004). Prior to analysis all reagents and samples were allowed to reach room temperature (18-25 °C), saliva samples were centrifuged Hermel Z326K centrifuge (Labnet International Ltd, USA) at 1000 g for 2 minutes. All standards, controls, and samples were analysed in duplicate on the same plate. The ELISA test procedure was as follows: Firstly, 50 µL of each Standard, Control and the sample was pipetted into the respective wells of the microtiter plate (**Figure 4.3**). Using a multi-pipette 100 µL of Enzyme Conjugate was then added to each well. The plate was then covered with adhesive foil and incubated for two hours at room temperature (18-25°C) on an orbital shaker (400 – 600 rpm). Following incubation, the adhesive foil was removed, incubation solution discarded and the plate was washed four times with 250 µL of diluted Wash Buffer. The excess wash solution was removed by tapping the inverted plate on a paper towel. After washing and drying 100 µL of TMB Substrate Solution was pipetted into each well and then incubated for a further 30 min at room temperature (18-25°C) on the orbital shaker (400 – 600 rpm). Finally, the substrate reaction was stopped by adding 100 µL of TMB Stop Solution into each well using a multi-pipette and then shaken briefly.

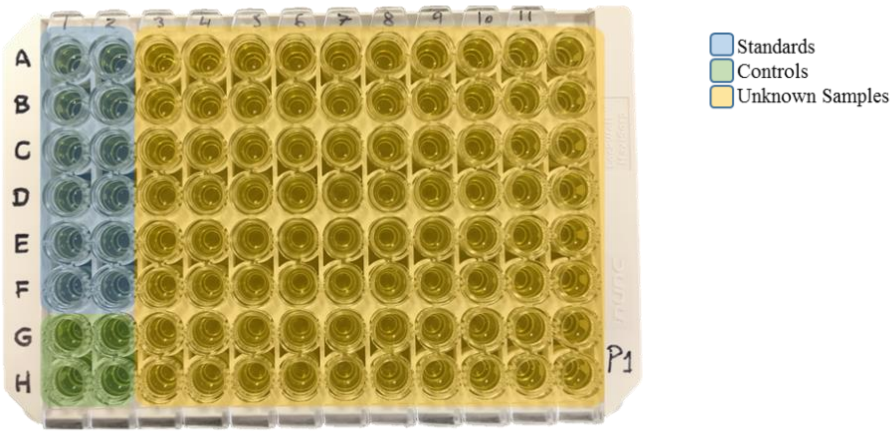


Figure 4.3: *Example well plate setup for ELISA saliva assay.*

The optical density of each well was read with a photometer at 450 nm (Reference-wavelength: 600-650 nm) within 15 min of pipetting of the Stop Solution. Cortisol concentrations were calculated from the average absorbance values for each pair of standards, controls and unknown samples. A standard curve was constructed by plotting the mean absorbance obtained from each of the standards against its known concentration with absorbance value on the y-axis and concentration on the x-axis, a cubic spline, four parameter logistics curve fit was then added. The concentration of the samples were read directly from this standard curve with the mean absorbance value for each sample. It was not necessary to dilute any saliva cortisol samples. Using these techniques Westermann et al. (2004) demonstrated cortisol recovery for saliva samples using IBL ELISA kits of 98% (range 89 - 114%). Intra-assay coefficients of variation were 3.95% and 4.68% for the low and high saliva controls, respectively. Cortisol concentrations were expressed as nmol/L.

4.3.2 Heart rate

Giles, D., Draper, N. & Neil, W. (2016). Validation of the Polar V800 heart rate monitor to measure RR intervals at rest. *European Journal of Applied Physiology*. [doi: 10.1007/s00421-015-3303-9]

Heart rate has been used extensively in climbing research to both quantify task demands and physiological arousal (Aras & Akalan, 2011; Dickson et al., 2012a; Draper et al., 2012; Fryer et al., 2013; Hardy & Hutchinson, 2007). Heart rate recorded during climbs are typically used to provide a relative estimate of the physiological load of climbing (Fryer et al., 2012). Anticipatory changes in heart rate have been used extensively in climbing psychophysiology research (Dickson, 2013; Dickson et al., 2012a; Fryer, 2013; Fryer et al., 2012). The anticipatory rise in heart rate, pre-climb despite the absence of a physical stressor has been attributed to increased psychological arousal in preparation for a climbing task (Hardy & Martindale, 1982; Janot et al., 2000).

Measurements of heart rate were made continuously during each session. Heart rate was recorded using a V800 Polar heart rate monitor (HRM) with a Polar H7 chest strap (Polar, Finland). The validity of the Polar V800 for the recording of heart rate has previously been established (Giles & Draper, 2017). To maximise detection of R-waves, an appropriately sized strap for the participant was chosen. The electrode belt was dampened and placed following Polar's guidelines, tightly but comfortably just below the chest muscles. Environmental sources of interference were minimised by checking the correct pairing of the HRM and the chest strap and avoiding other wireless networks. During resulting recordings, the Polar V800 watch was positioned in front of the participant, during climbs the watch was attached to the harness of participants to the side, to avoid interfering with the climber and getting caught on climbing holds. Raw, unfiltered heart rate data was exported from the Polar Flow web service as a space delimited .txt file, artefacts were corrected following the procedure of Giles and Draper (2017).

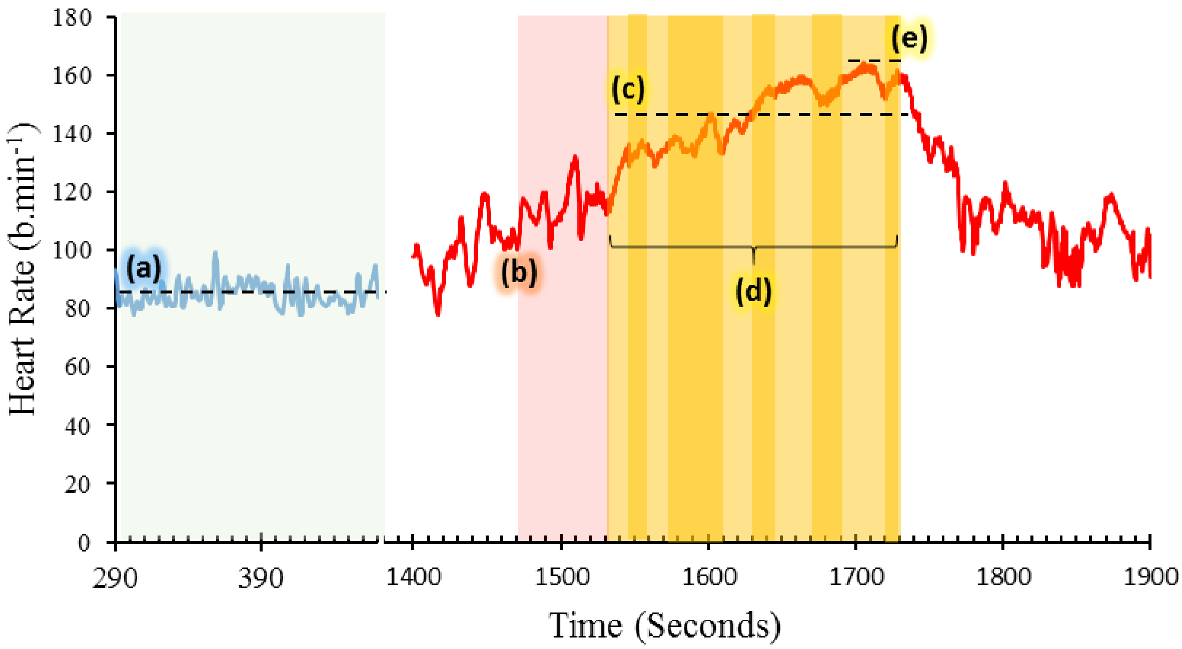


Figure 4.4: *Heart rate data visualisation, heart rates presented at (a) rest; (b) one min pre-climb; (c) average; (d) each quickdraw; (e) peak.*

Several dependent variables were calculated from the heart rate data. The values are illustrated in **Figure 4.4**. Resting heart rate was averaged over 180 seconds, during the rest period, prior to the presentation of task instructions, while seated in a quiet dark room (a). Task engagement was assessed through calculating heart rate change pre-post instruction (not shown). Anticipatory changes in heart rate were recorded one minute prior to commencing the climb (b). Average and peak heart rate were recorded for the whole climb (c & e), and at each quickdraw on the route (d). Results were presented as either beats per minute ($b.min^{-1}$) or, for anticipatory heart rate, as a percentage increase from rest.

4.3.3 Cardiovascular reactivity

The Theory of Challenge and Threat States in Athletes (TCTSA) proposed by Jones et al. (2009), provides a secondary, sports-focused framework for Blascovich and Tomaka (1996) biopsychosocial (BPS) model of Challenge and Threat. Challenge and threat occur depending on the athletes' appraisal of a situation and the relationship between the task demand and individuals coping resources (Lazarus, 1991). A challenge state is considered an adaptive approach associated with superior performance and threat, a maladaptive approach related to inferior performance (Blascovich et al., 2004; Moore et al., 2012; Turner et al., 2013; Turner et al., 2012). Evaluation of demands and resources occur predominantly unconsciously, without awareness of the evaluation process (Seery, 2011). Consequently, challenge and threat states are best indexed objectively using through the observation of distinct patterns of cardiovascular and neuroendocrinal responses (Dienstbier, 1989; Seery, 2011).

For both challenge and threat, specific patterns of cardiovascular reactivity are proposed, which occur depending on the athletes' appraisal of a situation and the relationship between their resources and task demand (Jones et al., 2009). A challenge appraisal is believed to be characterised by increased catecholamine output (adrenaline and noradrenaline), indicating sympathetic-adreno-medullary (SAM) activity, which results in increased cardiac output and reduced total peripheral resistance, the product of vasodilatation. A threat appraisal also elicits increased SAM activity, as well as increased pituitary-adreno-cortical (PAC) activity. This PAC activation releases adrenocorticotrophic hormone, which results in corticosteroids to be secreted by the adrenal cortex into the bloodstream. The combination of SAM and PAC activation is believed to be characterised by smaller-than-challenge increases in heart rate, stroke volume and resulting cardiac output, no change or a small increase in total peripheral resistance along with increases in cortisol (Jones et al., 2009). There is a growing body of literature demonstrating the performance consequences of participants with challenge and threat cardiovascular reactivity patterns (Blascovich et al., 2004; Moore et al., 2012; Moore et al., 2013; Turner et al., 2013; Turner et al., 2012).

Blood pressure was measured using a Finapres Portapres Model-2 (Finapres Medical Systems B.V., Amsterdam, The Netherlands). Finger arterial pressure was recorded continuously using an appropriately sized Finapres finger cuff, applied to the mid-phalanx of the middle finger of the left hand. Heart rate reactivity to the presented task instructions was assessed to determine task engagement, an important prerequisite for the analysis of challenge and threat cardiovascular reactivity (Blascovich, Vanman, Mendes, & Dickerson, 2011). Although both heart rate and pre-ejection period are both considered markers of task engagement (an increase in heart rate and a decrease in the pre-ejection period), only heart rate was used as the Portapres does not allow the pre-ejection period to be measured (Seery, 2011). For the entirety of the cardiovascular data collection, the participants' arm was rested on a table, next to the participant, at heart level and the participant was required to sit still, quiet and upright, legs facings forwards, bent at a 90-degree angle.

Blood pressure signals were analysed with BeatScope software (Version 1.1a) to calculate the three cardiovascular indices used to differentiate challenge and threat states: heart rate, cardiac output and total peripheral resistance (**Table 4.6**). Cardiovascular reactivity scores were calculated for cardiac output and total peripheral resistance by subtracting the raw cardiovascular responses for the last minute of baseline from the average raw cardiovascular responses across 1-minutes post presentation of task instructions. Average cardiac output and total peripheral resistance reactivity were combined into a single challenge and threat index (Moore et al., 2013; Turner et al., 2013; Turner et al., 2014). The challenge and threat index was calculated by converting average cardiac output and average total peripheral resistance reactivity values into z scores and summing them. Cardiac output was assigned a weight of +1 while total peripheral resistance was assigned a weight of -1 so that larger values reflected challenge reactivity.

Table 4.6: *Calculated cardiovascular variables.*

Measure	**Calculation**	**Unit**
Heart Rate		$b.min^{-1}$
Difference in heart rate	$HR_{POST} – HR_{PRE}$	$b.min^{-1}$
Cardiac Output	CO = SV x HR	L/min
Cardiac Output reactivity	$CO_{POST} – CO_{PRE}$	L/min
Total Peripheral Resistance	(MAP / CO) x 80	$dyn.s.cm^5$
Total Peripheral Resistance reactivity	$TPR_{POST} – TPR_{PRE}$	$dyn.s.cm^5$
Challenge and Threat Index (CTi)	$CO_{REACTIVITY}$ Z-SCORE + ($TPR_{REACTIVITY}$ Z-SCORE × -1)	

Notes: HR heart rate; CO cardiac output; SV stroke volume; TPR total peripheral resistance; CTi challenge and threat index; MAP mean arterial pressure

4.4 Psychological measures

The following sections provide details of the psychological inventories used to assess participants' mood and personality, these are summarised in **Table 4.7**. On arrival to each session participants completed the profile of mood state (POMS), trait anxiety questionnaire (STAI A-TRAIT) and achievement goals questionnaire (AGQ). Following the presentation of the climbing task instructions, participants completed a combined questionnaire assessing self-efficacy, cognitive evaluation, perceived control, task importance, demand resource evaluation and achievement goals. Finally, immediately prior to each climb, participants completed subjective measures of cognitive and somatic anxiety self-confidence and pre-climb emotions.

Table 4.7: *Self-report variables, their scales and the calculation of reported items.*

Item	Scale	Score Calculation
POMS		
Total Mood Disturbance	Likert Scale 0 - 4	Depression + Confusion + Tension + Anger + Fatigue – Vigour
Depression		Σ 8 items
Vigour		Σ 6 items
Confusion		Σ 5 items
Tension		Σ 6 items
Anger		Σ 7 items
Fatigue		Σ 5 items
TSAI	Likert Scale 1 - 4	Σ 20 items (9 positive, 11 negative)
AGQ		
MAp	Likert Scale 1 - 7	Σ 3 items
MAv		Σ 3 items
PAp		Σ 3 items
PAv		Σ 3 items
Self-efficacy	Likert Scale 1 - 7	$\bar{x}$ 2 items
Cognitive Evaluation	Likert Scale 1 - 7	Σ Challenge – Threat
Perceived Control	Likert Scale 1 - 7	1 item
Task Importance	Likert Scale 1 - 7	1 item
Demand Resource Evaluation	Likert Scale 1 - 7	Σ Resources – demand
Achievement Goals		
MAp	Likert Scale 1 - 7	1 item
MAv		1 item
PAp		1 item
PAv		1 item
Somatic Anxiety	**Intensity**	Measured distance (mm) for x and y axis
Cognitive Anxiety	80 mm x-axis **Direction (valence)**	
Self-confidence	30 mm +ve; 30 mm -ve y axis	

Note: POMS profile of mood states; TSAI trait anxiety inventory; AGQ achievement goal questionnaire; MAp mastery-approach; MAv, mastery-avoidance; PAp performance-approach; PAv performance-avoidance; Σ sum; $\bar{x}$ arithmetic mean; mm millimetres; +ve positive; -ve negative

4.4.1 Profile of mood states

The Profile of Mood State questionnaire short form (POMS; McNair, Lorr, & Droppleman, 1971) measures participants' perception of fatigue, vigour, anger, depression and tension. The shortened 37 item POMS-SF questionnaire (Shacham, 1983) was completed by participants upon arrival at each testing session to assess participants' mood state. The POMS-SF is typically used in a clinical setting and has been used in a wide range of groups (Baker, Denniston, Zabora, Polland, & Dudley, 2002; Koven, Cadden, Murali, & Ross, 2013; Trunzo & Pinto, 2003), as well as sport (Chase & Hutchinson, 2015; Lagos, Thompson, & Vaschillo, 2013). The shortened POMS-SF showed very high correlations with the full version of the scale, with correlations above $r = 0.95$ for all items (Shacham, 1983). The POMS inventory is designed to assess current *'right now'* mood states and mood changes. Mood state can influence physiological performance and consequently have an effect on climbing performance (Beedie, Terry, & Lane, 2000). The POMS is common in climbing psychophysiology literature and has primarily been used to ensure participants mood states do not vary significantly during multi-day testing and between groups (Draper et al., 2011d; Draper et al., 2010; Fryer et al., 2012).

The inventory measures participants' perception of tiredness and weariness (fatigue), readiness to partake in physical/mental work (vigour), aggression or hostility (anger), worthlessness (depression) and restlessness (tension) on a Likert scale of 0-4 (0; Not at all, 1; A little, 2; Moderately, 3; Quite a bit, 4; Extremely). Total mood disturbance was calculated as the sum of depression, confusion, tension, anger and fatigue, subtracting vigour. The greater the score, the greater the total mood disturbance. Individual total for each subscale were calculated by summing related items (**Table 4.7**).

4.4.2 Trait anxiety inventory

Trait anxiety represents a general disposition to respond to a variety of situations with heightened levels of state anxiety (Uphill, 2015). The A-Trait component of Spielberger et al. (1983) Trait-State Anxiety Inventory (Y form) was used for participants to indicate the intensity of feelings of trait anxiety. Spielberger et al. (1983) described trait anxiety as a personality trait and is defined as a disposition to experience state anxiety frequently, through interfering with the cognitive appraisal of threatening internal or external stimuli. The scale was completed by participants upon arrival at the first testing session to assess their trait anxiety. The STAI has been used in a wide variety of populations, including musicians (Kenny, Davis, & Oates, 2004), psychotherapy patients (Durham et al., 1994) and athletes (Leddy, Lambert, & Ogles, 1994; Ravaldi et al., 2003), including climbers (Pijpers et al., 2006; Pijpers et al., 2003; Pijpers et al., 2005). The A-Trait is comprised of a 20-item inventory; each item being scored on a Likert scale of 1 to 4. The trait anxiety score for each participant was calculated by summing the 20 items (nine positive items scores reversed), so that higher scores indicate greater anxiety (**Table 4.7**).

4.4.3 Achievement goal questionnaire

The Achievement Goals Questionnaire (AGQ; Conroy, Elliot, & Hofer, 2003) measured mastery-approach goals (MAp), mastery-avoidance goals MAv), performance approach goals (PAp), and performance avoidance goals (PAv). Achievement goal theory assumes individuals are intentional, goal-directed organisms who operates in a rational manner and achievement goals govern achievement beliefs and guide subsequent decision making and behaviour in achievement contexts (Duda, 2005). The AGQ has been used in a variety of contexts, including education (Roussel, Elliot, & Feltman, 2011) and in sport (Morris & Kavussanu, 2008; Stoeber, Uphill, & Hotham, 2009). The 2 x 2 achievement goal framework is comprised of four distinct achievement goals, two definitions of competence (mastery/task versus performance/ego) and two valences of strivings (approaching competence versus avoiding incompetence). Participants were asked how they felt on a 7-point Likert scale ranging from 1 (not at all true) to 7 (very true). The three items that comprised each of the four subscales were summed creating individual scores for MAp, MAv, PAp and PAv (**Table 4.7**).

4.4.4 Post-instruction

A combined scale of self-efficacy, cognitive evaluation, perceived control, task importance, demand resource evaluation and achievement goals were collected following the presentation of task instructions (**Table 4.7**). The TCTSA proposes athlete's personality traits can affect the likelihood of athletes responding to goal-relevant performance situations with either challenge appraisal or threat appraisal. A challenge state is theorised to be characterised by increased self-efficacy, perceived control, approach goals, positive emotions and a facilitative interpretation of emotions before performance (Jones et al., 2009; Skinner & Brewer, 2004). While a threat state is characterised by decreased levels of self-efficacy, lower perceived control, avoidance goals, more negative emotions and a more debilitative interpretation of emotions (Jones et al., 2009; Skinner & Brewer, 2004). The following items have been used in several sport studies (Moore et al., 2013; Turner et al., 2013; Turner et al., 2014).

Self-efficacy. Two items were used to measure self-efficacy, developed in line with the suggested guidelines of Bandura (2006). The two items were: (1) *"To what extent do you feel* *confident that you can complete the route?"*; and, (2) *"To what extent do you feel confident that you can make the right route reading decisions?"*. The participants respond by rating the item on a 7-point Likert-scale ranging from 1 (not at all) to 7 (very much so). A self-efficacy score was calculated by averaging the two items.

Cognitive evaluation. Based on previous research (Turner et al., 2014), in order to explore the relationship between self-reported challenge and threat states, participants completed two items indicating *"How challenged do you feel about the upcoming climb?"* and *"How threatened do you feel about the upcoming climb?"*. Participants responded on a 7-point Likert-scale ranging from 0 (not at all) to 7 (very much so). A cognitive evaluation score was calculated by subtracting threat from challenge (range -6 to +6) a more positive score reflecting a challenge state and a more negative score reflecting a threat state.

Perceived control. Participants completed a single item in relation to the climb, adapted from the Academic Control Scale (Perry, Hladkyj, Pekrun, & Pelletier, 2001). Participants were asked to rate how much they agree with *"The more effort I put into the upcoming climb the better I will do"*. The item was recorded on a 7-point Likert-scale ranging from 1 (not at all) to 7 (very much so).

Task importance. Participants completed a single item indicating *"How important is doing well on the climb to you?"* on a 7-point Likert-scale ranging from 0 (not at all) to 7 (very much so).

Demand resource evaluation. Demand and resource evaluations of the participants, in relation to each ascent of a route, were measured using two items from the cognitive appraisal ratio (Tomaka, Blascovich, Kelsey, & Leitten, 1993). Climb demands were assessed by asking, *"How demanding do you expect the upcoming climb to be?"* while personal coping resources were measured by asking, *"How able are you to cope with the demands of the upcoming climb?"*. Both items were rated on a 7-point Likert-scale scored between 1 (not at all) and 7 (very much so). A demand resource evaluation score was calculated by subtracting demands from resources (range -6 to +6) a more positive score reflecting a state with sufficient resources and a more negative score reflecting insufficient resources (Moore et al., 2013; Tomaka et al., 1993).

Achievement goals. A shortened, four item Achievement Goals Questionnaire (AGQ; Conroy et al., 2003) measured mastery-approach goals *"It is important to me to perform as well as I possibly can"*, mastery-avoidance goals *"I worry that I may not perform as well as I* *possibly can"*, performance approach goals *"It is important to me to do well compared to others"*, and performance avoidance goals *"I just want to avoid performing worse than others"*. The AGQ was reduced to four of the items described in *4.4.3* (one item for each subscale). Participants were asked how they felt about the imminent climb on a 7-point Likert scale ranging from 1 (not at all true) to 7 (very true), prior to each climb.

4.4.5 Pre-climb emotions

Following a visual inspection of the route, the participant completed the self-report emotional measures in relation to the upcoming climbing task.

Subjective measure of anxiety and self-confidence. Participants provided an indication of their subjective appraisal of their anxiety and self-confidence prior to each ascent. The immediate anxiety measurement scale (IAMS; Thomas, Hanton, & Jones, 2002) was used to measure participants' intensity and directional interpretations of cognitive and somatic anxiety symptoms and self-confidence. The IAMS provides a much quicker means of participants reporting their state anxiety, particularly compared to the CSAI-2 which requires approximately 10 minutes to complete (Thomas et al., 2002). The validity of the IAMS has been determined by Thomas et al. (2002) compared to the CSAI-2 with good agreement (r = 0.61 to 0.70, 30 minutes prior to event). Furthermore, the IAMS has been used extensively within challenge and threat literature (e.g. Moore et al., 2012; Moore, Vine, Wilson, & Freeman, 2014; Moore et al., 2013; Williams et al., 2010).

A 'thermometer' style scale was used to record both the intensity and valence of participants perceived emotion on an x and y scale (Houtman & Bakker, 1989). The thermometer style scale is quick to administer, with participants marking their individual level of perceived anxiety on a horizontal axis, and the valence on the vertical axis. A similar unidimensional scale was used by Pijpers and colleagues' due to its validity and ease of use (Nieuwenhuys et al., 2008; Pijpers et al., 2007; Pijpers et al., 2006; Pijpers et al., 2003; Pijpers et al., 2005). After reading definitions of cognitive and somatic anxiety and self-confidence, participants were asked to mark the intensity on the horizontal axis *"To what extent are you experiencing [cognitive anxiety | somatic anxiety | self-confidence] right now?"* and direction on the vertical axis *"What effect do you think this [cognitive anxiety | somatic anxiety | self-confidence] will have on your upcoming performance on the task?"*. The distance in mm between the axis and the participant's mark was used as a measure of the reported emotion.

Other pre-climb emotions. To ensure anxiety was not the only focus of the anxiety and self-confidence scales, four other scales were randomly administered from the Emotion Regulation Questionnaire (ERQ; Uphill, Lane, & Jones, 2012). They were anger, dejection, excitement and happiness, as with anxiety and self-confidence, they were also scored for both intensity and the direction.

4.5 Procedures, and data and statistical analysis

This chapter provides an overview of the methods and procedures pertinent to the studies presented in ***Chapter 5, 6 and 8***, referred to as *Study One*, *Study Two* and *Study Four*. Experimental design, methods, data analysis and statistical analysis that are unique to each of the studies are presented in their respective chapters. Data was analysed using SPSS (Version 22; Chicago, IL).

5

Study One

Psychophysiological and emotional antecedents of on-sight climbing performance with alterations in the style of ascent

5.1 Introduction

The sport of climbing is characterised by self-selected pressurised situations, such as on-sight lead climbing, which place a climber under both physical and psychological stress (Draper et al., 2011d). Despite the low incidences of acute injuries indoors, the potential for falling when climbing is considered a significant stressor (Bisharat, 2009; Macleod, 2010). Climbing coaching authors report a fear of falling and a perceived concern of injury as sources of anxiety and fear for many (Hurni, 2003; Macleod, 2010), and a significant limiting factor for performance (Hague & Hunter, 2011; Macleod, 2010; Sagar, 2001). Anxiety and fear are speculated to originate from an inability to differentiate between rational and irrational fear and perceived and actual risk, which must be overcome by climbers to perform optimally (Binney & McClure, 2005). Climbers require a considerable amount of skill and experience to respond to potentially evocative stimuli effectively and maintain performance (Goddard & Neumann, 1993; Hörst, 2008). If stress is not managed correctly, it has the potential to have an adverse effect on performance (Draper et al., 2011d; Sanchez et al., 2010), including movement behaviour (Pijpers et al., 2003).

During their sessions, climbers make choices about the safety protocol, otherwise known as the style of ascent, which refers to the means of protecting the climber in the event of a fall. Indoor routes are protected by either a *top-rope*, with which a fall is immediately arrested, considerably reducing the consequences or climbers may *lead* a route, where a fall results in travelling some distance before being arrested by a trailing rope, attached to intermittent preplaced quickdraws (Bisharat, 2009). An increase in the distance between the points of protection is known as a *run-out* (Bisharat, 2009). Although run-outs are not typically experienced indoors, many climbing wall designs allow for an increase in the distance between the points of protection as the climber gets higher and the chance of a ground fall decreases (CEN12572-1, 2007).

Climbing psychophysiology research conducted to date has primarily focused on changes in the safety rope protocol, assessing differences between the two contrasting conditions of top-rope and lead (Dickson et al., 2012a; Draper et al., 2010; Fryer et al., 2013; Hodgson et al., 2009). While anecdotally it may be said lead is a greater stressor than top-rope climbing, due to the increased fall potential (Hague & Hunter, 2011; Hurni, 2003; Macleod, 2010; Sagar, 2001), this has not been supported by research to date (Aras & Akalan, 2011; Dickson et al., 2012a; Draper et al., 2011d; Draper et al., 2012; Draper et al., 2010; Fryer et al., 2013). Psychophysiological measures of cortisol and anticipatory heart rate have been found to be consistently elevated in the lead over top-rope conditions, although differences were not significant; conversely, self-reported anxiety varied considerably and meaningful differences may have been obscured by large amounts of variation (*see 3.1 The safety protocol*).

There are several potential explanations why climbing psychology and psychophysiology literature to date has not supported the assertions of climbing coaches. These relate to both methodological and conceptual issues. Considering issues relating to the self-reporting of anxiety, it has previously been stated that the self-report of pre-task emotions via questionnaires provides a poor means of assessing how individuals process consciously available evaluations and do not provide a means of assessing individual's unconscious processes, such as the immediate evaluation of a stressor (Blascovich & Mendes, 2000; Ledoux & Bemporad, 1997). Evidence suggests a subconscious awareness of evocative stimuli results in the bypassing of measurable cognitive evaluations and only a psychophysiological response (Weisbuch-Remington et al., 2005). Furthermore, the lack of significance may be due to the Competitive State Anxiety Inventory (CSAI-2R), rather than participants' state anxiety. Individual responses to anxiety are speculated to be more complex than may be represented by the CSAI-2R (Giles et al., 2014).

While significant methodological advances have been made, particularly by Draper, Dickson, Fryer and colleagues, their research has also highlighted the complexity of climbing stressors and their potential interaction, particularly with route knowledge and difficulty (Dickson et al., 2012a; Draper et al., 2010; Fryer et al., 2013). Differences in the style of ascent have been assessed with either independent designs, participants climbing either lead or top-rope on the same route (Dickson, 2013; Dickson et al., 2012a; Draper et al., 2012; Fryer, 2013; Fryer et al., 2013), or repeated measures with climbers completing both lead a top-rope on the same route (Aras & Akalan, 2011; Draper et al., 2010; Hardy & Hutchinson, 2007; Hodgson et al., 2009). Independent designs have been used to avoid the interaction of route knowledge, which is known to influence both the physiological and psychological challenges (Draper et al., 2008; Hardy & Hutchinson, 2007). However, independent designs do not allow for the consideration of differences between climbers' responses. Consequently, a repeated measures design, on three different routes completed on-sight would overcome many of the limitations of previous studies.

Critical in determining if a participant will cope with a stressor, such as an on-sight lead climb, are their appraisal of the task demands and their coping resources (Lazarus, 1991). The Theory of Challenge and Threat States in Athletes (TCTSA; Jones et al., 2009) proposes that, in such motivated performance situations, demand evaluations are made about climbers' perceptions of danger (physical or esteem), uncertainty, and effort (physical and psychological). Resource evaluations determine whether the climber perceives they have sufficient coping resources to meet the apparent demands of the task. Based on the evaluation, responses occur on a continuum from challenge to threat (Seery, 2011). While research testing the predictions of theories of challenge and threat have explored situations believed to elicit differences in perceptions of uncertainty and effort, little evidence has been presented for situations eliciting differences in perceptions of danger. Climbing potentially presents a medium for the exploration of challenge and threat states occurring in response to such demand appraisals.

Resulting from the cognitive evaluation are two contrasting states: Challenge cognitive appraisal states are experienced when individual's secondary appraisal perceives they have sufficient or near sufficient coping potential to meet situational demands. Conversely, threat states are experienced when their secondary appraisal indicates an individual's coping potential are not sufficient to meet the situational demand, perceiving physical or psychological harm as potentially imminent (Blascovich & Mendes, 2000; Blascovich & Tomaka, 1996; Lazarus, 1991). Evaluation of demands and resources occur predominantly unconsciously, without awareness of the evaluation process (Seery, 2011). Consequently, challenge and threat states are best indexed objectively through the observation of distinct patterns of cardiovascular and neuroendocrinal responses (Seery, 2011).

5.1.1 Summary and aims

The purpose *Study One* was to investigate differences in psychophysiological, emotional and performance factors with a difference in style of ascent. To achieve this, *Study One* developed on existing methods used in climbing psychophysiology research (Dickson et al., 2012a; Draper et al., 2012; Fryer et al., 2013), through employing the assessment of cardiovascular reactivity, a repeated measures design and the detailed assessment of climbers performance (Pijpers et al., 2003). Assessments were made in response to changes in the style of ascent, namely top-rope, lead climb and a lead climb with a run-out. The novel lead run-out condition was included to determine participants' responses to a condition atypical of their normal recreational sessions, while not being far removed from a task they would be used to completing. While previous style of ascent research has proved largely equivocal, despite the consternation of coaching text authors (Hague & Hunter, 2011; Macleod, 2010; Sagar, 2001), the methods employed in the present study should facilitate exploration of performance differences and inter-individual variation. Therefore, the aim of *Study One* was to examine psychophysiological and emotional antecedents of climbing performance in responses to on-sight climbing with alterations in the safety protocol.

5.1.2 Hypotheses

H1: Climbers will experience (a) less cognitive and (b) less somatic anxiety and (c) will be more confident in the top-rope condition, compared to the lead and again the lead run-out ascents.

H2: The climbers will have less of a psychophysiological response, as measured with (a) anticipatory heart rate and (b) salivary cortisol in the top-rope condition, compared to the lead and again the lead run-out ascents.

H3: Climbing performance will be (a) faster, (b) smoother and less hesitant with (c) better assessed performance in the top-rope condition, compared to the lead and again the lead run-out ascents.

H4: Climbers cardiovascular reactivity will indicate relatively (a) greater cardiac output, (b) lower peripheral resistance and (c) lower cortisol concentrations in the top-rope condition indicative of challenge with lower cardiac output, greater peripheral resistance and cortisol concentrations in the lead condition and again the run-out conditions, indicative of threat state.

H5: The climbers' pre-climb demand-resource evaluation will indicate that (a) coping resources outweigh demand in the top-rope condition indicative of challenge, but will indicate lower evaluation of coping resources in the lead condition and again in the run-out condition, indicative of threat state.

5.1.3 Strengths of the study

- The current study is the largest repeated measures style of ascent investigation completed to date.
- It is the only repeated measures study in which the participants' have completed ascents on-sight.
- It is the first study to examine in detail behavioural changes occurring with differences in the safety rope protocol.
- A homogenous group of participants, with on-sight lead grades within one grade of the difficulty of the route, were recruited.
- The routes were set by a highly-experienced route setter, who has set at a world-cup level, to ensure the routes allowed all style of ascent to be completed on-sight while providing the same opportunities for rest, clipping and style of climbing.

5.1.4 Delimitations

- Data are representative and specific to the individual route profiles, the length of route and spacing of quickdraws used within the study.
- Findings of the current study are specific to the relative difficulty of the route to the best on-sight grade of the intermediate climbers
- The results are only representative of on-sight lead climbing indoors.

5.1.5 Assumptions

- All participants refrained from strenuous training 48 hours prior to testing and observed a period of complete rest for at least 12 hours before each testing session.
- All participants refrained from either inspecting or attempting the route prior to their testing session as requested.
- Self-reported climbing grades relied on participants accurately and honestly reporting their on-sight and red-point performance (Draper et al., 2011b).
- The word of participants was taken that they had not consumed alcohol or caffeine prior to the session.

5.1.6 Limitations

Despite careful consideration of the methodologies employed and numerous pilot studies, there were still certain limitations within *Study One*:

- The climbs took place in a public climbing wall, as such it may have affected climbers' responses.
- Successive evaluations may have meant participants who perform poorly on a task may be more likely to evaluate the task as threatening in subsequent ascents.
- The study was difficult to perform because of the nature of the methodology and costs, limiting the sample size.

5.2 Methods

This section provides details of the participants and an overview of the experimental design, procedures for the session, data and statistical analysis. Throughout these methods, references are made to the *General Methods* chapter, which should be referred to where applicable.

5.2.1 Participants

Thirty-four rock climbers (8 Female and 26 Male) completed the study (**Table 5.1**). The climbers were classified as intermediate (Draper et al., 2016) with self-reported on-sight ability ranging from French 6a+ to 6b+ (IRCRA 12 to 14; YDS 5.10c to 5.11a) and red-point ability ranging from French 6b to 6c (IRCRA 13 and 15; YDS 5.10d to 5.11b; *see 4.2.1 Self-reported ability and experience*). No inducement was offered to participants for taking part. Participants volunteered and met the recruitment set out in Chapter 4 (*4.1.1 Participants*).

Table 5.1: *Participants anthropometric and climbing experience characteristics for combined and male and females (mean ± SD).*

	Combined (n = 34)	**Male** (n = 26)	**Female** (n = 8)
Anthropometrics			
Age (years)	29.8 ± 6.7	30.8 ± 6.9	26.5 ± 5.3
Height (m)	1.75 ± 0.07	1.77 ± 0.05	1.66 ± 0.06
Mass (kg)	71.3 ± 9.1	74.4 ± 7.1	60.5 ± 7.5
Experience			
Years Climbing	7.0 ± 5.5	7.7 ± 6.0	4.5 ± 2.2
Sessions a week	2.3 ± 1.2	2.1 ± 1.2	3.0 ± 1.1
Grade			
Indoor OS (IRCRA)	13.2 ± 0.7	13.3 ± 0.7	12.9 ± 0.7
Indoor RP (IRCRA)	13.9 ± 0.8	14.0 ± 0.8	13.6 ± 1.0

Note: m metres; kg kilogramme; OS on-sight; RP red-point; IRCRA international rock climbing research association.

5.2.2 Experimental design

All participants attended a single afternoon session at Awesome Walls climbing centre, Sheffield. Participants were asked to adhere to the pre-testing guidelines set out in *4.1.1 Participants*. Adherence to the guidelines was confirmed verbally before the commencement of the testing session. Anthropometrics were recorded in a quiet classroom (*4.1.2*); while the routes were set on the climbing wall at the same centre (*4.1.7 Route design*). The sessions were conducted in the afternoon to minimise the influence of circadian rhythm, particularly on salivary cortisol concentrations (*4.3.1*). Prior to each climb heart rate (*4.3.2*), blood pressure reactivity (*4.3.3*) and cortisol concentrations (*4.3.1*) were assessed in response to pre-recorded task instructions. During the climbing phase of the session, participants were required to attempt randomised on-sight ascents of three routes set on an artificial climbing wall (*4.1.7*). The routes varied in the style of ascent, protected by either a top-rope, lead or lead with a run-out; participants received audiotaped instruction concerning the style of ascent prior to each.

5.2.3 Climbing wall and route setting

Three routes were set, allowing for each of the attempts with a different style of ascent to be completed on-sight (*4.1.7 Route design*). The routes were of a consistent grade over their length, and of consistent style and grade with each other, in this respect consideration was made to the type of holds, the style of the climbing and the difficulty. The three routes were graded French 6a+ (12 IRCRA; YDS 5.10c), which was confirmed by four expert climbers before the commencement of the study. Where possible participants were asked to refrain from watching preceding participants attempting the climb to limit the amount of route information.

5.2.4 Safety protocol

The primary independent variable in *Study One* was the safety protocol. Differences in the safety protocol are described in detail in the literature review (*3.1 The safety protocol*) and in the general methods (*4.1.7 Route design*). Except for the top-rope, with which participants were immediately arrested in the event of a fall, climbers were protected with preplaced quickdraws, to which the climber attached a dynamic lead climbing rope. After the first quickdraw at 3.05 meters, the distance between the next nine quickdraws was 1.21 ± 0.13 meters (*4.1.7 Route design*). The lead conditions required the climber to ascend the route trailing a climbing rope; the climber attached the rope to all quickdraws. In the event of a fall, the climber travelled a short distance before being arrested by the belayer and the trailing rope. The lead run-out condition was identical in principle to the lead condition, except the participant missed the last quickdraw, resulting in a gap between the last quickdraw and the top of the route of 2.83 meters; in the event of a fall, the climber would travel further.

5.2.5 Procedure – pre and warm-up

Figure 5.1 represents the procedures carried out over the single testing session. Following the explanation of the procedures, ascertaining heath history and fitness to participate and informed consent participants completed the Profile of Mood States (POMS; *see 4.4.1*), Achievement Goal Questionnaire (AGQ; *4.4.3*) and the State-Trait Anxiety Inventory (STAI; *4.4.2*). Participants were then equipped with a climbing sit harness and fitted climbing shoes. Participants completed a thorough warm-up, comprised of five minutes of pulse raising activity (walking, jogging skipping, etc.), five minutes of mobilising exercises and five minutes of moderate climbing (*see 4.1.2 Anthropometrics and warm-up*). Following the warm-up, participants were provided with 10 minutes of seated recovery time.

5.2.6 Procedure – climbing

Following the rest period, prior to each of the climbs, participants completed a nine-minute cardiovascular data recording, comprising of five minutes of rest, one minute of instruction and three minutes of mental preparation. Participants were equipped with a Polar H7 chest strap and V800 heart rate monitor (HRM; Polar, Finland) and, once seated, the Finapres Portapres Model-2 (Finapres Medical Systems B.V., Amsterdam, The Netherlands). Finger arterial pressure was recorded continuously using an appropriately sized Finapres finger cuff, applied to the mid-phalanx of the middle finger of the left hand (*4.3.3 Cardiovascular reactivity*). Participants were informed they would be required to sit still and quiet, upright, with their arm

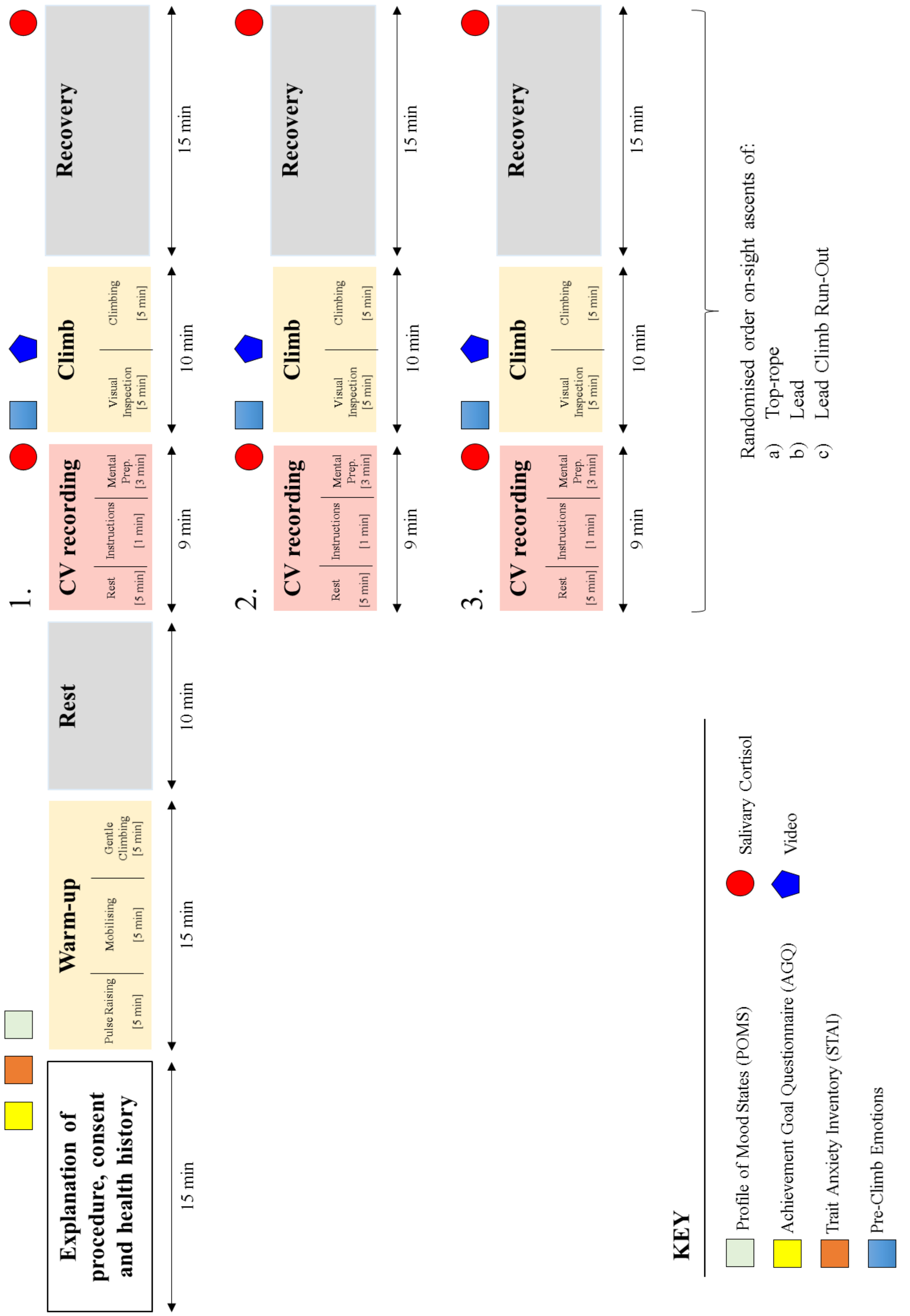


Figure 5.1: *Timeline for anthropometrics, resting and climbing measurements for top-rope, lead and run-out conditions.*

supported at the level of their heart and legs facings forwards, bent at a 90-degree angle. After five minutes of data collection, participants were presented with audio instructions concerning the upcoming climbing task via a set of headphones (QC 25, Bose). The audiotaped instructions were randomly assigned and described the upcoming climb (Top-rope; Lead; Lead Run-Out). Recordings of heart rate and blood pressure were made during this time.

The audio instructions lasted for one minute (*Appendix E Audio transcripts*). The instructions promote the high task demands of the conditions, typical of a motivated performance situation. Participants were informed that the task was difficult *"The climb is designed to be close to your on-sight lead grade."* (thus, requiring physical and mental effort), with the novel *"on-sight"* nature of the climb aimed at promoting perceptions of uncertainty regarding performance. As well as promoting task demands, the instructions contained the physical and emotional danger manipulation, in the form of changes in the length of potential fall, in line with the theory of resource appraisals put forth in the TCTSA (Jones et al., 2009). The top-rope conditions simply stated, *"You are required to top-rope the route"*, while the lead route stated, *"You are required to lead climb the route, clipping every quickdraw"*, finally the lead run-out condition *stated, "You are required to lead climb the route, clipping every quickdraw except the last before the lower off (marked with red tape)"*. Attention was drawn to the run-out section of the route *"The task that you are about to complete is designed to assess your lead climbing performance on a route with a run-out"*. The final part of the task instructions asked participants to mentally prepare for the upcoming climbing task by thinking about their performance for three minutes. This was followed by a pre-climb salivary cortisol sample. Following the presentation of the climbing task instructions, participants completed combined self-efficacy, cognitive evaluation, perceived control, task importance, demand resource evaluation and achievement goals inventories (*4.4.5 Pre-climb*).

After the cardiovascular data collection, participants moved out onto the climbing centre floor and were shown the route they were to attempt. Following a visual inspection of the route, the participant completed the Immediate Anxiety Measurement Scale (IAMS) in relation to the upcoming climbing task (*4.4.5 Pre-climb*). Participants then attempted the assigned route, climbing until they either reached the top of the route or fell. If desired, the participants could use climbers' chalk to dry their hands, contained within a chalk-bag carried at the rear of the harness. Participants began climbing when ready, ascending at their own pace, protected from falling using a standard climbing harness, rope and an experienced belayer (*4.1.3 Protection of climbers*). During the climb, heart rate was recorded continuously. Saliva cortisol was sampled on returning to the ground after a 15-minute passive recovery period. The process was repeated for the remaining two climbs.

5.2.7 Data analysis

Baseline to pre-climb and pre-climb to post climb delta values were calculated for several dependent variables. The collection, processing and calculation of variables from individual measures are presented in *General Methods* chapter and should be referred to where appropriate.

5.2.8 Statistical analysis

All statistical analysis was conducted using SPSS (version 22; Chicago IL) and Microsoft Excel (Version 2015; Redmond WA) software. Outlier analysis was first conducted; univariate outliers were first identified based on being more than 3.3 standard deviations from the mean (Tabachnick, Fidell, & Osterlind, 2001). Following identification, as in Moore et al. (2012), outliers were identified and winsorized by changing the deviant raw score to a value 1% larger or smaller than the next most extreme score, this was necessary for three participants cardiovascular data. Normal distribution and homogeneity of variance were then assessed through visual inspection of the frequency histogram, Shapiro-Wilk's tests and by examining variance around the mean with the use of box plots (if the maximum variance was less than three times the mean then equal variance was assumed). This is the normally accepted rule to determine whether the analysis of variance (ANOVA) test is reliable. Descriptive statistics were calculated for all variables; all values are reported as Mean ± SD.

Gender differences were investigated using independent samples *t*-tests. Pre-post instruction changes in HR were investigated using paired samples *t*-tests. To investigate differences occurring between conditions (top-rope, lead, lead run-out) and to control for increasing error rate due to multiple testing conceptually linked independent variables were tested together using a multivariate analysis of variances (MANOVA). Repeated measures analysis of variance (ANOVA) were used to follow up significant MANOVAs, and for all other comparisons. Post-hoc least significant difference (LSD) tests were used to explore the source of the differences in the means between conditions for each significant ANOVA. Pearson’s product moment correlations assess the relationship between the challenge and threat index and physiological, performance, emotions and self-report characteristics.

For all analysis, the critical α-level was set at 0.05; corrections for multiple comparisons were made using Benjamini and Hochberg (1995) false-discovery rate (FDR) method, which has been supported for use in place of Bonferroni adjustments (Glickman, Rao, & Schultz, 2014). Unadjusted and adjusted *p* values were calculated and, where necessary, presented to provide an indication of the likelihood of type I and type II error rates; given it has been previously argued that reducing the possibility of type II error is preferable in exploratory research (Hoad & Monks, 2011; Perneger, 1998). Effects sizes were determined using η_p^2 for multiple comparisons and Cohen's *d* for comparisons between two groups.

5.3 Results

Participants who were unable to complete any of the assessed routes were excluded from the analysis (climbers who fell on all three routes); of the 34 participants that took part in the study two were excluded, one male, one female.

5.3.1 Participant climbing experience and anthropometrics

The experience and ability (mean ± SD) of the remaining 32 participants (25 male, 7 female) are presented in (**Table 5.2**). A series of independent samples *t*-tests were used to investigate gender differences, climbing experience and ability; no significant differences were found.

Table 5.2: *Participants climbing experience and ability level (mean ± SD).*

	Combined (*n* = 32)	**Male** (*n* = 25)	**Female** (*n* = 7)	**IS *t*-test** $t_{(30)}$ =	***p* =**	***ES (d)***
Experience						
Years Climbing (years)	7.0 ± 5.5	7.7 ± 6.0	4.5 ± 2.2	1.379	0.178	0.24
Sessions a week (sessions)	2.3 ± 1.2	2.1 ± 1.2	3.0 ± 1.1	1.769	0.087	0.31
Discipline						
% Sport	41.0 ± 33.3	40.1 ± 37.2	48.6 ± 14.6	0.583	0.564	0.11
% Trad	17.3 ± 30.3	21.3 ± 33.2	12.8 ± 19.8	0.636	0.530	0.12
% Boulder	39.2 ± 30.5	35.4 ± 33.2	38.6 ± 15.7	0.243	0.810	0.04
In/out						
% Indoor	74.8 ± 28.9	70.8 ± 30.7	89.1 ± 15.0	1.514	0.140	0.27
% Outdoor	25.2 ± 28.9	29.2 ± 30.7	10.9 ± 15.0	1.514	0.140	0.27
Grade						
Indoor OS (IRCRA)	13.2 ± 0.7	13.3 ± 0.7	12.9 ± 0.7	1.453	0.157	0.26
Indoor RP (IRCRA)	13.9 ± 0.8	14.0 ± 0.8	13.6 ± 1.0	1.429	0.163	0.25

Note: OS on-sight; RP red-point; IRCRA international rock climbing research association; IS independent sample; ES effect size

Anthropometric characteristics are presented in **Table 5.3**. Gender differences were investigated with a series of independent samples *t*-tests between male and female participants. Significant differences in height ($p < 0.005$) and mass ($p < 0.005$) were found. Female climbers were shorter (Mean Difference = 0.11 m, 95% Confidence Interval = 0.07, 0.17) and had lower mass (MD = 13.8 kg, CI_{95} = 7.6, 20.1). Such gender differences are typical of climbers (Watts, 2004), and were to be expected in a representative sample of intermediate climbers.

Table 5.3: *Participant's anthropometric characteristics (mean ± SD).*

	Combined (*n* = 32)	**Male** (*n* = 25)	**Female** (*n* = 7)	**IS *t*-test** $t_{(30)}$ =	***p* =**	***ES (d)***
Age (years)	29.8 ± 6.7	30.8 ± 6.9	26.5 ± 5.3	1.502	0.144	0.26
Height (m)	1.75 ± 0.07	1.77 ± 0.05	1.66 ± 0.06*	4.919	**< 0.005**	**0.67**
Mass (kg)	71.3 ± 9.1	74.4 ± 7.1	60.5 ± 7.5*	4.518	**< 0.005**	**0.64**

Notes: m metres; kg kilogramme; IS independent samples; ES effect size
** significant gender differences p < 0.05*

Trait anxiety was assessed with the STAI, achievement goals with the AGQ (2x2 framework), and mood state with POMS, all are presented in **Table 5.4** for combined, and male and female participants (mean ± SD). There were no significant gender differences in STAI, POMS or any of the four dimensions of the AGQ, as assessed with a series of independent samples *t*-tests.

Table 5.4: *Response to trait anxiety, achievement goals and mood state questions for male and female participants (mean ± SD).*

	Combined (*n* = 32)	**Male** (*n* = 25)	**Female** (*n* = 7)	**IS *t*-test** $t_{(30)}$ =	***p* =**	***ES (d)***
STAI	39.6 ± 8.9	38.5 ± 8.1	43.3 ± 9.7	1.321	0.197	0.23
AGQ						
MAp	17.5 ± 2.6	17.5 ± 2.5	17.4 ± 3.2	0.080	0.937	0.01
MAv	14.5 ± 3.9	14.0 ± 3.9	16.4 ± 3.3	1.517	0.140	0.27
PAp	11.5 ± 5.2	10.7 ± 5.4	14.3 ± 3.4	1.655	0.108	0.29
PAv	10.3 ± 5.1	9.8 ± 5.3	12.1 ± 4.3	1.070	0.293	0.19
POMS						
Total Mood Disturbance	29.2 ± 15.7	27.9 ± 15.4	33.8 ± 17.3	0.880	0.386	0.37
Depression	9.9 ± 3.6	9.7 ± 3.8	10.4 ± 2.8	0.457	0.651	0.08
Vigour	17.0 ± 3.6	17.3 ± 3.4	15.9 ± 4.2	0.951	0.349	0.17
Confusion	7.6 ± 2.7	7.6 ± 2.8	7.9 ± 2.5	0.255	0.801	0.05
Tension	11.0 ± 3.9	10.5 ± 3	13.0 ± 5.9	1.556	0.130	0.27
Anger	8.5 ± 3.2	8.2 ± 2.8	9.7 ± 4.5	1.117	0.273	0.20
Fatigue	9.2 ± 3.8	9.3 ± 4.1	8.7 ± 2.8	0.339	0.737	0.06

Notes: STAI state-trait anxiety inventory; AGQ achievement goal questionnaire; MAp mastery approach; MAv mastery-avoidance; PAp performance approach; PAv performance avoidance; POMS profile of mood states; IS independent samples; ES effect size

The following sections present the results of *Study One*. The results have been grouped into the following four sections: (5.3.2) the physical demands of the task; (5.3.3) performance differences; (5.3.4) cardiovascular, endocrine and subjective responses to task instructions; (5.3.5) objective and subjective pre-climb assessment.

5.3.2 Climbing task demands

The on-sight lead climbing task was within the on-sight ability of all participants who took part and were included in the analysis (two excluded, as previously described). Despite this several participants were unsuccessful on the route. One participant fell on the top-rope climb, seven on the lead climb and seven on the lead with run-out.

Physical demand

Table 5.5 presents climbing time and average and maximum heart rate data recorded continuously throughout each of the climbs. Differences were assessed with a series of repeated measures ANOVAs. Climbing time differed significantly with the style of ascent ($p < 0.005$, $\eta_p^2 = 0.672$). Post-hoc LSD were significant and indicated climbing time differed significantly between top-rope and lead (MD = 47.7 sec, CI_{95} = 38.3, 57.1), top-rope and run-out (MD = 34.4 sec, CI_{95} = 24.6, 44.2) and lead and top-rope (MD = 13.3 sec, CI_{95} = 4.8, 21.7). There were no meaningful differences in participants' average heart rate or maximum heart rate.

Table 5.5: *Climbing time and average and maximum heart rate for each of the three styles of ascent (mean ± SD).*

	Top-Rope	**Lead Climb**	**Run-out**	**Repeated Measures ANOVA**		
				$F_{(2, 62)}$ =	*p* =	η_p^2
Climb Time (Sec)	101.0 ± 19.0	148.7 ± 31.3*	135.4 ± 24.5*ǂ	**59.374**	**< 0.005**	**0.672**
Average Heart Rate ($b.min^{-1}$)	150.0 ± 21.8	153.4 ± 18.5	149.9 ± 23.6	0.666	0.517	0.022
Maximum Heart Rate ($b.min^{-1}$)	163.0 ± 24.0	165.0 ± 25.1	161.1 ± 32.0	0.380	0.685	0.014

Notes: ANOVA analysis of variance; Sec seconds; $b.min^{-1}$ beats per minute
** significant from top-rope p < 0.05; ǂ significant from lead-climb p < 0.05*

In addition to the average and maximum heart rate, **Figure 5.2** shows the heart rate for each ascent immediately prior to the climb and at each quickdraw and is provided to describe the demands of the climb. As described previously, there were no significant differences in average or maximum heart rate, despite differences in climbing time, this is clearly illustrated.

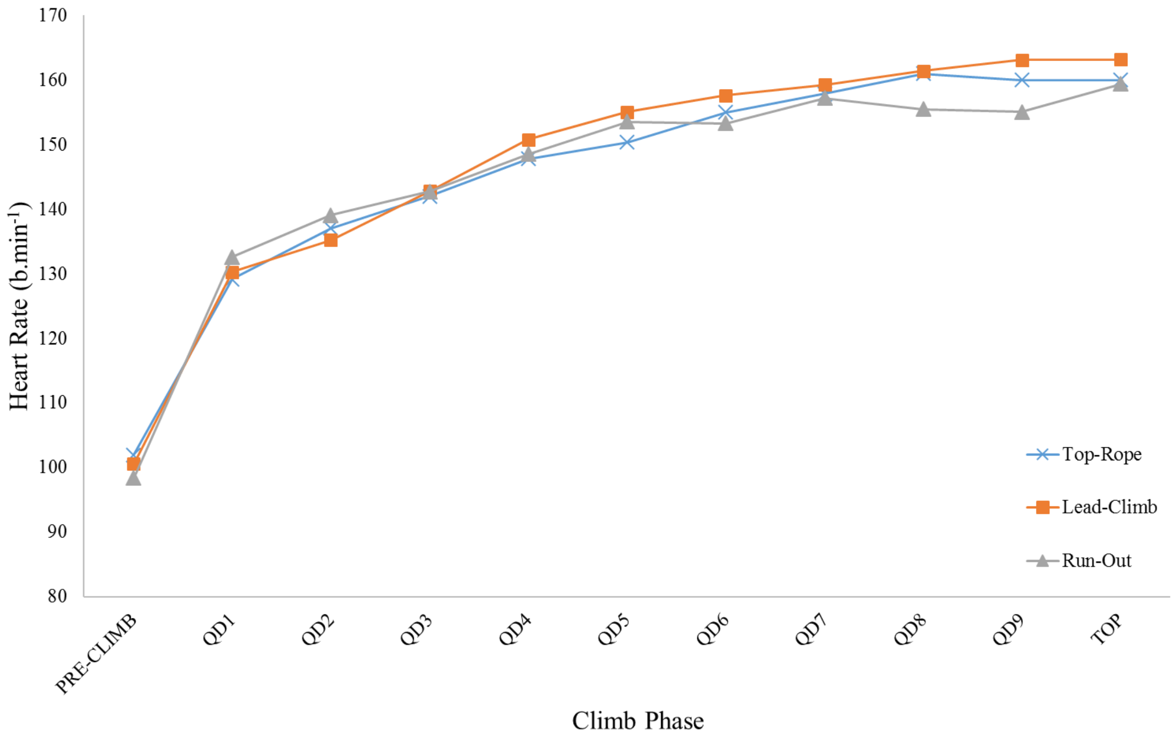


Figure 5.2: *Average heart rate (b.min^{-1}) for top-rope, lead climb and run-out pre-climb and across the climb (QD Quickdraw).*

5.3.3 Climbing performance

Climbers' performances were assessed for each of the ascents (**Table 5.6**). A one-way repeated measures MANOVA was run to determine the effect of the style of ascent on climbers' performance. Two dependent variables were assessed, geometric entropy and total coaches' performance score. The difference between conditions on the combined dependent variables was statistically significant ($p < 0.005$, $\eta_p^2 = 0.641$, Wilks' $\Lambda = 0.267$). Follow-up one-way ANOVAs showed significance ($p < 0.005$) for each dependent variable. Post-hoc LSD were significant and indicated geometric entropy was greater for lead climbs (less fluent movement) than the top-rope to the lead (MD = 0.14, CI_{95} = 0.08, 0.20) and lead run-out (MD = 0.11, CI_{95} = 0.05, 0.17). Similarly, the total coaches score decreased significantly from the top-rope to the lead (MD = 5.1, CI_{95} = 3.6, 6.6) and lead run-out (MD = 6.4, CI_{95} = 4.6, 8.3). The total coaches' score was further broken down to the five characteristics of the performance score. A series of one-way repeated measures ANOVAs showed significance for all dependent variables ($p < 0.005$), except for the base of support. Post-hoc LSD were significant and indicated there were meaningful differences between all three styles of ascent for coordination; while for transitioning, technique and tactics, significant differences existed between the top-rope and lead and between top-rope and run-out, but not between the lead and run-out.

Table 5.6: *Geometric entropy, coaches' score and movement analysis for each of the three styles of ascent (mean ± SD).*

	Top-Rope	Lead Climb	Run-out	MANOVA	RM ANOVA			
					$F_{(2,62)}$ =	*p* =	η_p^2	*FDR*
Geometric Entropy	0.75 ± 0.11	0.89 ± 0.10*	0.87 ± 0.12*	***p* < 0.005**	**22.074**	**< 0.005**	**0.540**	
Total Coaches' Score	57.3 ± 5.6	52.1 ± 7.2*	50.8 ± 5.4*	**η_p^2 = 0.641**	**30.618**	**< 0.005**	**0.513**	
Base of Support	3.6 ± 0.7	3.4 ± 0.6*	3.3 ± 0.5*		5.543	0.006	0.156	0.004
Transitioning	3.8 ± 0.5	3.5 ± 0.5*	3.5 ± 0.3*		**8.303**	**0.001**	**0.217**	**0.001**
Coordination	3.6 ± 0.7	3.3 ± 0.6*	3.1 ± 0.6*ǂ		**27.246**	**< 0.005**	**0.476**	
Technique	3.4 ± 0.6	2.9 ± 0.6*	2.9 ± 0.5*		**23.236**	**< 0.005**	**0.436**	
Tactics	4.5 ± 0.3	3.8 ± 0.6*	3.7 ± 0.5*		**60.162**	**< 0.005**	**0.667**	

Notes: MANOVA multivariate analysis of variance; RM ANOVA repeated measures analysis of variance; FDR false discovery rate

* *significant from top-rope p < 0.05;* ǂ *significant from lead-climb p < 0.05*

5.3.4 Task instructions

Task engagement

Heart rate reactivity (**Table 5.7**) to the presented task instructions was assessed to determine task engagement, an important prerequisite for the analysis of challenge and threat cardiovascular reactivity (Blascovich et al., 2011). A one-way repeated measures ANOVA reported a significant difference in heart rate reactivity between conditions ($p < 0.005$, η_p^2 = 0.343). Paired samples *t*-tests for pre- and post-instruction heart rate indicated a significant increase in heart rate for top-rope (MD = 1.5 b.min^{-1}, CI_{95} = 0.4, 3.0), lead climb (MD = 3.5 b.min^{-1}, CI_{95} = 2.0, 4.9) and run-out ascents (MD = 5.4 b.min^{-1}, CI_{95} = 3.9, 7.3). Additionally, although a one-way ANOVA did not find a significant difference between the style of ascent (p = 0.165, η_p^2 = 0.057), participants indicated success on the route was important to them with task importance scores of > 4.5. Finally, the manipulation check indicated all participants engaged in task-relevant thoughts about the upcoming climbing task, supporting the heart rate and task engagement data in asserting all three styles of ascent represented motivated performance situations.

Table 5.7: *Engagement to task instruction assessed with task importance and pre-post heart rate reactivity (b.min^{-1}) (mean ± SD).*

	Top-Rope	Lead Climb	Run-out	RM ANOVA		
				$F_{(2, 62)}$ =	*p* =	η_p^2
Heart Rate Reactivity (b.min^{-1})	1.5 ± 3.3	3.5 ± 3.8	5.4 ± 4.7	**14.076**	**< 0.005**	**0.343**
Task Importance	4.5 ± 1.8	4.9 ± 1.7	5.0 ± 1.7	1.857	0.165	0.057

Notes: RM ANOVA repeated measures analysis of variance; b.min^{-1} beats per minute

Cardiovascular markers

Alterations in the cardiovascular markers of cardiac output and peripheral resistance were assessed continuously at rest, prior to, during and post presentation of the task instructions (**Table 5.8**). Due to equipment problems, the cardiovascular data from two participants could not be recorded and was excluded from analysis. Cardiovascular reactivity, the difference in cardiac output and peripheral resistance pre-post instruction, were assessed with a one-way repeated measures MANOVA, with the two dependent variables of cardiac output and total peripheral resistance reactivity. The difference between conditions on the combined dependent variables was statistically significant ($p < 0.005$, $\eta_p^2 = 0.218$, Wilks' $\Lambda = 0.435$). Follow-up one-way repeated measures ANOVAs demonstrated significance for both the greater cardiac output ($p < 0.005$, $\eta_p^2 = 0.288$) and the lower in total peripheral resistance ($p = 0.001$, $\eta_p^2 = 0.278$). Post-hoc LSD were significant and indicated cardiac output differed significantly between top-rope and run-out (MD = 0.57 L/min, CI_{95} = 0.30, 0.83) and lead climb and run-out (MD = 0.39 L/min, CI_{95} = 0.14, 0.64), but not between the top-rope and lead. Total peripheral resistance was significantly different between top-rope and lead climb (MD = 63.3 dyn.s.cm^5, CI_{95} = 21.9, 104.6) and top-rope and run-out (MD = 98.2 dyn.s.cm^5, CI_{95} = 64.5, 131.9), but not between the lead climb and run-out. The combined challenge and threat index varied considerably and did not differ by a meaningful amount ($p = 0.938$, $\eta_p^2 = 0.002$). Resting post instruction alterations in cortisol were not found to be significant ($p = 0.456$, $\eta_p^2 = 0.025$).

Table 5.8: *Cardiac output and total peripheral resistance cardiovascular markers pre-post task instructions (mean ± SD).*

	Top- Rope	Lead Climb	Run-out	Multivariate ANOVA	ANOVA $F_{(2, 58)}$ =	p =	η_p^2
Cardiac Output							
Pre-Instruction (L/min)	6.4 ± 1.0	6.1 ± 1.3	6.1 ± 1.3				
Post-Instruction (L/min)	6.8 ± 1.2	6.7 ± 1.6	7.0 ±1.6				
Peripheral Resistance							
Pre-Instruction (dyn.s.cm^5)	1044 ± 256	1163 ± 345	1190 ± 365				
Post-Instruction (dyn.s.cm^5)	1038 ± 233	1090 ± 324	1085 ± 353				
Reactivity							
Cardiac Output (L/min)	0.4 ± 0.5	0.5 ± 0.4	0.9 ± 0.5*ǂ	**$p < 0.005$**	**12.359**	**< 0.005**	**0.288**
Peripheral Resistance (dyn.s.cm^5)	-15.7 ± 60.0	-83.9 ± 105.9*	-115.0 ± 72.5*	**$\eta_p^2 = 0.218$**	**10.904**	**0.001**	**0.278**
Challenge and Threat Index							
Index	0.09 ± 1.70	0.15 ± 1.66	0.26 ± 1.76		0.064	0.938	0.002
Cortisol							
Cortisol Concentration (*nmol/L*)	5.40 ± 4.56	4.47 ± 4.31	4.51 ± 5.21		0.796	0.456	0.025

Notes: ANOVA Analysis of Variance; dyn.s.cm^5 vascular resistance; L/min litres per minute; nmol/L nanomoles per litre
** significant from top-rope $p < 0.05$; ǂ significant from lead-climb $p < 0.05$*

Self-report measures

A series of one-way repeated measures ANOVAs were used to assess differences in self-efficacy, cognitive evaluation, perceived control and demand resources (**Table 5.9**). Self-efficacy was statistically significant (p = 0.004, η_p^2 = 0.165). Post-hoc LSD were significant and indicated self-efficacy was significantly greater in the top-rope condition than the lead run-out (MD = 0.55, CI_{95} = 0.18, 0.92) and between the lead and run-out conditions (MD = 0.41, CI_{95} = 0.11, 0.71). Cognitive evaluation was lower in lead conditions, but on average still positive and statistically significant (p < 0.013, η_p^2 = 0.130). Post-hoc LSD were significant and showed significance for run-out than the top-rope (MD = 0.53, CI_{95} = 0.12, 0.94) and the lead climb (MD = 0.41, CI_{95} = 0.13, 0.69). There were no significant differences in perceived control with changes in the style of ascent (p = 0.299, η_p^2 = 0.040).

Demand resource evaluation was statistically significant (p < 0.005, η_p^2 = 0.301). Post-hoc LSD were significant and showed demand to be significantly lower in the run-out than the top-rope (MD = 1.69, CI_{95} = 1.00, 2.38) and the lead climb (MD = 1.06, CI_{95} = 0.42, 1.71). Achievement goals were assessed with a one-way MANOVA, comprised of four dependent variables, mastery approach, mastery avoidance, and performance approach and performance avoidance. The difference between conditions on the combined dependent variables was not statistically significant (p = 0.145, η_p^2 = 0.095, Wilks' Λ = 0.187).

Table 5.9: *Self-efficacy, cognitive evaluation, perceived control, demand resource and achievement goals assessed post instructions for each of the three styles of ascent (mean ± SD). For cognitive evaluation, a more +ve score indicates challenge state, -ve more threatening; for demand resources, more +ve indicates coping resources outweigh demands.*

	Top-Rope	**Lead Climb**	**Run-out**	**MANOVA**	**RM ANOVA**			
					$F_{(2, 62)}$	p =	η_p^2	*FDR*
Self-Efficacy	5.0 ± 1.0	4.8 ± 1.0	4.4 ± 0.9*ǂ		**6.114**	**0.004**	**0.165**	**0.025**
Cognitive Evaluation	1.2 ± 1.1	0.8 ± 1.1	0.6 ± 1.1*ǂ		**4.629**	**0.013**	**0.130**	**0.038**
Perceived Control	6.2 ± 1.2	6.3 ± 0.9	6.2 ± 1.0		1.304	0.279	0.040	0.050
Demand Resource	0.9 ± 1.7	0.3 ± 1.4	-0.8 ± 1.6*ǂ		**13.361**	**< 0.005**	**0.301**	**0.013**
Achievement Goals								
MAp	5.4 ± 1.8	5.5 ± 1.5	5.3 ± 1.7					
MAv	3.8 ± 1.8	3.8 ± 1.8	3.7 ± 1.8	p = 0.145				
PAp	3.3 ± 2.1	3.1 ± 1.9	3.0 ± 2.0	η_p^2 = 0.095				
PAv	3.2 ± 2.2	3.0 ± 2.0	2.9 ± 2.0					

Notes: MANOVA multivariate analysis of variance; RM ANOVA repeated measures analysis of variance; MAp mastery approach; MAv mastery-avoidance; PAp performance approach; PAv performance avoidance
** significant from top-rope p < 0.05; ǂ significant from lead-climb p < 0.05*

Challenge vs. threat

Correlations between weighted challenge and threat index and psychophysiological, performance, emotions and self-report characteristics for top-rope, lead and run-out climbs are presented in **Table 5.10**. There were no significant correlations between challenge and threat index and any characteristics reported in the top-rope condition; greater challenge and threat index in the lead condition was significantly correlated with lower concentrations of cortisol (r = -0.417) and lower self-efficacy (r = -0.386). For the run-out condition, challenge and threat index only correlated with lower somatic intensity (r = -0.437) and more positive interpretation of somatic anxiety (r = 0.375).

Table 5.10: *Bivariate correlations between weighted challenge and threat index (+ve = challenge, -ve = threat) and psychophysiological, performance, emotions and self-report characteristics for top-rope, lead and run-out climbs.*

	Top-rope	Lead	Run-Out
n =	C 17 | T 14	C18 | T 13	C 17 | T 14
Physiology			
Heart Rate %	0.294	0.265	-0.108
Cortisol %	-0.229	-0.417 *	-0.208
Performance			
Coaches Assessment	-0.261	-0.253	-0.028
Geometric Entropy	0.245	0.008	-0.289
Emotions			
Somatic Intensity	-0.243	-0.184	-0.437 *
Somatic Direction	0.098	0.123	0.375 *
Cognitive Intensity	-0.257	0.045	0.233
Cognitive Direction	0.103	0.266	-0.009
Confidence Intensity	-0.001	0.047	0.271
Confidence Direction	0.181	0.115	-0.113
Self-report			
Self-Efficacy	-0.163	-0.386 *	0.164
Cognitive Evaluation	0.152	0.052	-0.083
Perceived Control	0.176	0.368	-0.323
Demand Resource	0.007	-0.266	0.222

Notes: C challenge; T threat
* *denotes significance $p < 0.05$*

5.3.5 Pre-Climb

Emotions

Subjective assessment of the intensity and direction of anxiety and self-confidence were assessed immediately prior to the climbs with the IAMS (**Table 5.11**). Differences between the style of ascent were assessed through a series of one-way repeated measures ANOVAs. Significant increases in the intensity of cognitive and somatic anxiety and decreased self-confidence were found (p = 0.011, η_p^2 = 0.136; p = 0.002, η_p^2 = 0.187; and p = 0.001,

η_p^2 = 0.219, respectively). Post-hoc LSD were significant and showed significantly greater somatic anxiety in the run-out than the top-rope (MD = 9.5, CI_{95} = 1.6, 17.4) and lead climb (MD = 8.3, CI_{95} = 2.2, 14.4). Similarly, cognitive anxiety was greater in the run-out than the top-rope (MD = 12.7, CI_{95} = 5.0, 20.4) and lead climb than the top-rope (MD = 13.4, CI_{95} = 6.2, 20.6). Self-confidence was significantly greater in the top-rope than the run-out (MD = 10.4, CI_{95} = 3.8, 17.0) and lead climb (MD = 8.4, CI_{95} = 2.3, 14.5). While differences in the interpretation of somatic and cognitive anxiety occurred in the hypothesised direction, only self-confidence was significant (p = 0.025, η_p^2 = 0.120). Post-hoc LSD were significant and showed significantly more positive interpretation of level of self-confidence in the top-rope than the run-out (MD = 6.8, CI_{95} = 0.2, 13.4) and the lead than the run-out (MD = 6.1, CI_{95} = 0.1, 12.0).

Table 5.11: *Pre-climb emotional state, assessed immediately prior to climbing for each of the three styles of ascent (mean ± SD).*

		Top-Rope	**Lead Climb**	**Run-out**	**Repeated Measures ANOVA**			
					$F_{(2, 62)}$ =	***p* =**	**η_p^2**	***FDR***
Somatic Anxiety	Intensity	21.5 ± 15.0	22.7 ± 13.4	31.0 ± 16.9*ǂ	**4.897**	**0.011**	**0.136**	**0.011**
	Direction	-4.1 ± 19.2	-4.4 ± 15.7	-9.6 ± 13.4	1.658	0.199	0.051	
Cognitive Anxiety	Intensity	14.0 ± 10.4	27.4 ± 17.3*	26.8 ± 17.0*	**7.119**	**0.002**	**0.187**	**0.017**
	Direction	-2.6 ± 17.6	-5.3 ± 15.0	-4.9 ± 19.2	0.247	0.782	0.008	
Self-Confidence	Intensity	41.4 ± 12.7	39.8 ± 11.2	31.3 ± 12.3*ǂ	**8.124**	**0.001**	**0.219**	**0.042**
	Direction	15.6 ± 15.9	14.9 ± 11.6	8.8 ± 16.4*ǂ	**3.936**	**0.025**	**0.120**	**0.025**

Notes: ANOVA analysis of variance; FDR false discovery rate
* *significant from top-rope $p < 0.05$;* ǂ *significant from lead-climb $p < 0.05$*

Psychophysiological markers

Alterations in the psychological components of anticipatory heart rate and delta cortisol concentrations were assessed with a one-way repeated measures MANOVA, with the two dependent variables (**Table 5.12**). The difference between conditions on the combined dependent variables was not statistically significant (p = 0.275, η_p^2 = 0.045, Wilks' Λ = 0.912).

Table 5.12: *The psychological components of anticipatory heart rate (% increase from rest) and delta cortisol concentrations for each of the three styles of ascent (mean ± SD).*

	Top-Rope	**Lead Climb**	**Run-out**	**RM MANOVA**
Anticipatory Heart Rate (%)	48.6 ± 30.0	47.2 ± 30.4	41.9 ± 30.4	*p = 0.275*
Cortisol % Pre-Post	22.0 ± 58.4	36.9 ± 160.5	63.4 ± 161.8	*η_p^2 = 0.045*

Notes: RM MANOVA repeated measures multivariate analysis of variance

5.4 Discussion

The aim of *Study One* was to investigate differences in objective psychophysiological and subjective emotional responses to a randomised series of on-sight climbs with changes in the style of ascent. To achieve this, 32 intermediate climbers completed ascents of three separate routes, which were identical in difficulty, completed without any prior knowledge, but varied in the safety protocol: protected by either a top-rope, lead or lead with run-out. The routes were within one grade of the climbers' maximum self-reported indoor on-sight grade, ensuring the climbing was difficult for all participants and falling from the route was a real possibility. Climbers were informed of the task via pre-recorded instructions presented to them within 15 minutes of the start of their ascent. Responses to the task were measured before and after receiving the task instructions; and pre, during and post climb, for each of the ascents. The analysis explored subjective psychological, objective physiological and behavioural differences between conditions.

The main findings of *Study One* showed that, compared to a top-rope, lead and lead run-out ascents were characterised by (a) reduced performance quality, with less fluent, more hesitant movement; (b) significantly increased cognitive anxiety in both lead ascents and reduced self-confidence, and greater somatic anxiety specifically in the run-out ascent; (c) no meaningful, or significant differences in salivary cortisol or pre-climb heart rate from baseline; (d) cardiovascular reactivity to task instructions in line with challenge reactivity, despite and in contrast to the emotional and performance differences seen. The results demonstrated that intermediate climbers' performance was significantly affected by differences in the style of ascent, possibly because of greater cognitive anxiety as a result of greater perceived task demands during both lead ascents. While there were differences between lead and lead run-out ascents for somatic anxiety, self-confidence, self-efficacy, cognitive evaluation and demand resources, these were not associated with decrements in climbing performance.

A growing body of research explores the physiological and subjective challenges of the style of ascent within climbing (*see 3.1 The safety protocol*). The advances made in recent years, particularly by Draper, Dickson, Fryer and colleagues, refining methodologies and applying psychophysiological techniques to the climbing environment have been considerable (Dickson, 2013; Dickson et al., 2012a; Draper et al., 2012; Fryer, 2013; Fryer et al., 2013). Despite these advances, their results have been largely inconclusive (Aras & Akalan, 2011; Dickson et al., 2012a; Draper et al., 2012; Draper et al., 2008; Draper et al., 2010; Fryer et al., 2013; Hardy &

Hutchinson, 2007; Hodgson et al., 2009). Considering the significant understanding gained from the previous climbing style of ascent research, the present study continues to advance methodologies used in the climbing environment. This is the largest single study completed to date investigating climbers' responses to on-sight lead climbing with changes in the style of ascent. More importantly, it was the first study to employ a repeated measures design, while also ensuring the routes ascended by participants were completed on-sight. The task of setting similarly graded routes that were distinctly different in nature, thus maintaining an on-sight condition, while still being comparable in terms of opportunities for rest, the difficulty of the crux and clipping positions necessitated the use of a highly-experienced route setter, familiar with setting such routes. Furthermore, it was also the first to use detailed performance measures to assess differences between participants' performance. Finally, *Study One* developed on the existing body of challenge and threat research, firstly, through exploring cardiovascular reactivity, self-report of cognitive evaluations and behaviour outcomes in response to a task that may bring about perceptions of danger in participants. Secondly, through the determination of cortisol concentrations, which have yet to be assessed. The results of *Study One*, considering previous research, will be discussed in the following section.

5.4.1 Anthropometric and demographic data

The anthropometric and demographic characteristics of the climbers in *Study One* are presented in **Table 5.2** and **Table 5.3**. Recruited participants were considered healthy and normal and were not taking any medications that may have affected measurements made. The participants were similar to the intermediate climbers of Dickson (2013) and Draper et al. (2012) in terms of height, mass, years climbing, and on-sight and red-point climbing ability. Participants were more experienced in terms of years climbing and ability than those of Draper et al. (2011d). Participants on-sight ability ranged between f6a+ to f6b+ (IRCRA 12 to 14; YDS 5.10c to 5.11a), and red-point between f6b to f6c (IRCRA 13 and 15; YDS 5.10d to 5.11b). The difficulty of the routes were set at f6a+ (IRCRA 12; YDS 5.10c). Participants self-reported red-point grades were on average a grade greater than their self-reported best on-sight grade, this was lower than would be expected of climbers on average, and likely occurred due to the intermediate ability of the participants.

There were no meaningful, or significant differences between male and female participants for years climbing experience, the percentage of time in each discipline, time spent indoors or out and on-sight and red-point grade (**Table 5.2**). Further, there were no meaningful differences in total mood disturbance, or its subcomponents, achievement goal disposition or trait anxiety

(**Table 5.3**). However, unsurprisingly, there were significant differences in the height and mass of male and female climbers. The female climbers were shorter in stature and had lower body mass than their male counterparts. Despite these differences, gender was not considered a covariate in the analysis for several reasons. Firstly, there was no conceptual relationship between the assessed measures, be it psychophysiological, psychological or behavioural, and height or body mass. Secondly, participants were recruited based on their self-reported on-sight lead climbing grade and, while it was possible that height and mass may influence this, as participants were recruited based on this factor it is unlikely to have impacted on performance. Furthermore, recent studies have shown that body fat percentage and mass may not be a prerequisite for a high level of climbing performance, being just one of several attributes (Macdonald & Callender, 2011). Finally, the repeated measures design of the study reduced the significance of such inter-individual factors.

The achievement goal disposition of the participants was towards mastery, particularly, mastery-approach goals (MAp, 17.5 ± 2.6; MAv, 14.5 ± 3.9), while performance goals were lower (PAv 10.3 ± 5.1; PAp 11.5 ± 5.2) (**Table 5.3**). The results of the present study support the findings of Robinson (1985), describing climbers’ motivation for taking part in the sport. In particular, Robinson (1985) found, because high achievement in climbing with few exceptions does not offer any extrinsic material rewards, participants were motivated to a greater extent by friendships and the achievement of intrinsically set goals. Similarly, a meta-analysis of achievement goals in sport demonstrated that approach goals correlated significantly and positively with performance attainment, whereas avoidance goals were found to be unrelated to performance (Van Yperen, Blaga, & Postmes, 2014). Within indoor recreational climbing, it would appear the participant's goals represent striving to approach absolute or intrapersonal competence, with a focus on performing a task as well as possible or surpassing a previous performance (Duda, 2005). While the participants of *Study One* also reported greater MAv, representing striving to avoid absolute or intrapersonal incompetence, this was likely to have been intrinsic, with the participants less concerned about appearing incompetent in comparison with others (Duda, 2005).

Despite the thorough recruitment process for participants it was necessary to exclude two participants from the analysis. The two participants (one male, one female) met the recruitment criteria, were competent lead climbers and had a self-reported ability within one grade of the target route grade, however, they did not complete any of the three routes. While it was expected that some of the participants would be unable to climb all three of the routes, as the difficulty of the route relative to the on-sight lead climbing ability of the climbers were chosen so they represented a challenging condition, it was expected participants would be able to ascend at least one of the three routes at that grade. Furthermore, authors have noted a significant difference in route success (Draper et al., 2011d; Sanchez et al., 2010). The validity of self-reported climbing grades has been established (Draper et al., 2011b), however, it was possible these climbers misreported their climbing grade. This may not have been deliberate and may have been due to an unreported injury, a recent drop in frequency of climbing or fatigue prior to attending the session.

5.4.2 Climbing task demands

All ascents were completed on-sight, participants were not provided with any information on the routes they were to attempt, other than the colour of holds and which quickdraws they were to use. The three routes were set on the same part of the wall, the same length, angle and with similar holds, while the routes were not identical, they very closely resembled one another. The physical demands of the route were not the primary focus of *Study One*. However, the routes were set so the requirements of each, regardless of the style of ascent, were similar. To this end, participants' heart rate was recorded continuously throughout each of the climbs to provide an indication of the relative physiological load. Heart rate data may be found in **Table 5.5** and **Figure 5.2**. All other variables considered, the requirements of the lead climbing conditions may have resulted in an increase in physiological demands due to the need to assume isometric positions to clip quickdraws (Aras & Akalan, 2011; Draper et al., 2010; Fryer et al., 2013).

Climbers in the present study climbed slower in the lead conditions, likely because of the need to stop for longer to clip quickdraws (top-rope 101 ± 19, lead 149 ± 31, run-out 135 ± 25 seconds). Consequently, it was also expected that the lead climb condition would be more physically demanding, this was not the case in the present study. There were no meaningful differences in the style of ascent in either average (top-rope 150 ± 22; lead climb 153 ± 19; run-out 150 ± 24 $b.min^{-1}$) or maximum heart rate (top-rope 163 ± 24; lead climb 165 ± 25; run-out 161 ± 32 $b.min^{-1}$), or at each of the quickdraws (**Figure 5.2**). These results support that the physiological task demands were similar for each ascent, despite the difference in their means of protection.

5.4.3 Climbing behaviour and performance

Participants' success on the three routes were recorded, in line with assessed performance, just one participant was unsuccessful on the top-rope. Conversely, for both the lead and lead run-out, there were seven unsuccessful participants. Previous style of ascent research has speculated differences in participants success and failure on routes have occurred because of the greater physical and technical demands of lead climbing, in comparison to a top-rope (Dickson, 2013). This was not supported by the current study, while the physiological demands did not differ with the style of ascent, there were significant differences in performance, demonstrating the change in the style of ascent had a significant impact on climbers' behaviour and consequently participants' success or failure.

In contrast to the majority of style of ascent research completed to date, climbing performance in the current study was assessed through both quantitative and qualitative methods. The use of a detailed assessment of climbing performance allowed for the comparison of changes with the style of ascent. Climbing performance for the routes attempted by the participants are shown in **Table 5.6**. The markers of geometric entropy and coaches' score were considered together and were found to differ significantly between ascents. Further differences were apparent in all sub-components of coaches' performance score (base of support not significant). Both the lead climb and run-out showed significantly reduced performance in comparison to the top-rope route, but there were no significant differences between the lead climb and the run-out. Lead ascents were characterised by reduced economy of movement brought about by a combination of relatively less efficient hand and foot placements; less fluid movements, which were often out of sequence and lacking momentum; decreased coordination of whole body movement; inappropriate or less efficient choices of movement sequences; and poorer tactical decision making, particularly concerning commitment, climbing tempo and choice of rests.

Differences in climbing performance observed are interesting considering the lack of significance in self-report measures and the inconsistency in psychophysiological measures seen in previous style of ascent research (Aras & Akalan, 2011; Dickson et al., 2012a; Draper et al., 2011d; Draper et al., 2012; Draper et al., 2010; Fryer et al., 2013; Hardy & Hutchinson, 2007; Hodgson et al., 2009). Indeed, the lack of difference in the pre-climb physiological and psychological assessment of state, in a wide range of ability climbers examined in the thesis of Dickson (2013) led the author to conclude *"Indoor on sight climbing, set at a difficulty relative to self-reported best on-sight lead performance appears to elicit a similar psychological and* *physiological response pre-climb, irrespective of ascent style"* (p. 201). While this finding may be accurate in terms of the physiological and psychological response presented in previous research, the lack of assessment of climbing performance limits the conclusions that may have been drawn. In contrast, the detailed description afforded by the performance markers in the present study provide insight into the effect of style of ascent on behaviour, supporting the assertion by coaches that changes in the style of ascent can be a significant limiting factor for climbers (Hague & Hunter, 2011; Macleod, 2010; Sagar, 2001).

Research examining changes in climbing performance with alterations in the style of ascent are limited. The results of geometric entropy and coaches assessment of performance support coaches assertions that lead climbing has implications for performance (Hague & Hunter, 2011; Macleod, 2010; Sagar, 2001). Furthermore, these differences in performance occurred in the same direction as self-reported emotions (*see 5.4.4*). However, the findings conflict with those of Watts et al. (2016), who assessed differences in geometric entropy between lead and top-rope ascents of a familiar route and reported that, while geometric entropy decreased for three of the six participants, there were no significant differences between the lead and top-rope conditions. Differences between Watts et al. (2016) findings and the results of the present study may have occurred because of the low number of participants; however, it is likely the use of an initial top-rope familiarisation, followed by top-rope and lead in a randomised order was the more salient factor.

In contrast to the results of the present study, Hardy and Hutchinson (2007) found climbers performed significantly better when leading than when top-roping either the same route (repeat red-point) or another novel on-sight of a similar grade. Furthermore, improved performance occurred alongside greater cognitive and somatic anxiety, unlike the present study (*see section 5.4.4*). In light of the findings of Hardy and Hutchinson (2007), it was not clear why participants in *Study One* were unable to maintain their performance in the lead climb run out condition, while the participants of Hardy and Hutchinson (2007) were able to effortfully improve their performance. One possible explanation was the location of the climbing, while *Study One* was conducted indoors, Hardy and Hutchinson (2007) completed their research outdoors on traditionally protected climbs. Climbing outdoors included the potential for a fall on protection placed by the climber, along with greater objective dangers (Schöffl et al., 2010). Furthermore, differences in the physical difficulty and the ability of the participants of Hardy and Hutchinson (2007) are likely to have been greater than those used in the present study, as traditional climbs are graded both on the physicality and the subjective exposure of the climb (Draper et al., 2016). It may be the climbers of Hardy and Hutchinson (2007) were able to bring about an effortful improvement in their performance because their climbing ability exceeded the difficulty of the route, in comparison to the small difference in the climber's ability in the present study.

To date, Hardy and Hutchinson (2007) and Watts et al. (2016) are the only authors to have examined changes in climbers' performance with the alterations in the style of ascent. However, Pijpers and colleagues have determined climbing performance in novice climbers on horizontal traverses (Nieuwenhuys et al., 2008; Pijpers et al., 2006; Pijpers et al., 2003; Pijpers et al., 2005). Pijpers and colleagues found the difference in height resulted in increased muscular tension and a reduction in the degrees of freedom of the climbers movement (Pijpers et al., 2003), increased movement entropy and climbing time (Pijpers et al., 2003), increased explorative movements (Pijpers et al., 2005) and increase in eye fixation duration (Nieuwenhuys et al., 2008). In the present study, increased movement entropy in lead conditions may have resulted because of differences in gaze behaviour, Pijpers et al. (2006) reported similar changes in movement behaviour because of shorter explorative fixations on more handholds, leading to slower less fluent movement. The decrease in sequencing ability and a greater number of explorative movements may have resulted because of threatening stimuli, in the case of the lead climb the potential for a large fall, diverting attention and being harder to disengage from. This possibly affected the perception of action possibilities and task-relevant information, through participants attending to different, threat-related information (Proffitt, 2006).

Less efficient movement patterns were also observed in the present study, participants were more likely to initiate movements with the upper body, bend their arms, have poor body tension and use a reduced repertoire of movements. Similarly, Pijpers et al. (2006) reported changes in movement efficiency, anxious novice climbers had both reduced perceived and actual maximal reaching height, the decrease in perceived reaching ability under anxiety also affected the number of holds participants used. It has been stated that there is an increased tendency for athletes to produce emotionally congruent behavioural responses when anxious (Nieuwenhuys & Oudejans, 2012). While positive stimuli facilitate approach movements, threat facilitates avoidance movements. Emotional congruent behaviour interferes when the intended behaviour is not in line with the emotion experienced, this may make it hard to initiate emotionally-incongruent movements towards a threatening stimulus (Stins et al., 2011). Lack of commitment and a participant choosing to be taken tight on the rope, rather than fall are examples of such behaviour, however, these were not assessed in the present study.

Finally, as set out in the conscious processing hypothesis, too much attention to a task can disrupt its otherwise automatic execution, leading to slower, less efficient, more rigid movement behaviour and reduced performance (Masters & Maxwell, 2008). The changes observed in geometric entropy support disruption of movement behaviour, along with the previously described coaches' assessment of performance. Geometric entropy was significantly greater (less fluent movement) for lead ascents than top-rope (MD = 0.16, CI_{95} = 0.11, 0.22) and lead run-out compared to top-rope (MD = 0.13, CI_{95} = 0.08, 0.18). However, climbing time and geometric entropy are known to be closely related (Cordier et al., 1993; Cordier et al., 1994). As a result, difference in geometric entropy in the present study are likely, at least in part, to have been influenced by the need for the participants to stop and clip quickdraws to protect themselves as they progressed on the route. However, considering the results of Draper et al. (2011d), who found unsuccessful intermediate climbers ascended a route significantly slower than successful climbers, it is unlikely that the need to clip quickdraws was solely responsible for the difference between the conditions and differences also resulted because of anxiety in the lead conditions.

To summarise, while the physical demands of the three routes were comparable, there were considerable differences in the climbers' success and failure and performance between top-rope ascent and both lead conditions. The climbers selected for participation were amongst the most homogeneous groups used in such research to date and were all experienced indoor lead climbers. The differences in performance observed may be attributed solely to the means of protecting the climber in the event of a fall, as the participants completed all three ascents in a randomised order, blinded to the condition until they received the task instructions and all ascents were completed on-sight, without prior knowledge. These results are particularly important considering the limited use of performance measures in previous research. Given the results of the present study, it is likely that differences between conditions were overlooked in previous style of ascent research. Furthermore, of significance for climbers and coaches, the performance differences highlight the challenges of leading. Differences in performance do not occur solely because of the physical demands of assuming isometric positions to clip quickdraws, they also occur in intermediate climbers because of psychological factors associated with climbing with intermediate points of protection. This highlights potentially significant avenues for improved performance in intermediate climbers. To explore the antecedents of participants' responses to the change in the style of ascent both objective psychophysiological and emotional responses were recorded.

5.4.4 Task instructions cardiovascular reactivity

Developing on previous climbing psychophysiology research, and research exploring challenge and threat conditions in sport, participants cardiovascular reactivity was assessed in response to the presentation of task instructions concerning the style of ascent (Moore et al., 2014; Moore et al., 2013; Turner et al., 2013). The current study is likely to be the first to assess differences in cardiovascular reactivity to the presentation of tasks with differing demands, elicited through alterations in the description of the upcoming style of ascent. Furthermore, it is also likely to be the one of the first to demand resource evaluation outcomes in response to a task that may bring about perceptions of danger in participants. Consequently, not only do the measures of challenge and threat employed provide an objective (cardiovascular and neuroendocrine) and subjective (self-report) of participants cognitive evaluation in response to the differing styles of ascent, but they also provide insight into previously unexplored danger demand evaluations.

The TCTSA (Jones et al., 2009) is presented as an explanation of the link between emotional, physiological, neurophysiological and behavioural factors, with a growing body of literature examining the sporting performance consequences (Blascovich et al., 2004; Moore et al., 2012; Turner et al., 2013; Turner et al., 2012). While challenge and threat states can be measured via self-report, these have been criticised (Blascovich et al., 2004), predominantly because of potential issues with individuals being unwilling to report they have doubts about their performance and not being able to reflect accurately on their inner states (Nisbett & Wilson, 1977). Objective physiological measures avoid such issues as they are covert and difficult to consciously control (Blascovich et al., 2004). Consequently, the present study used both subjective self-report and objective cardiovascular measures to index challenge and threat states.

The majority of challenge and threat research completed to date has manipulated states through the instructional set given to participants and found associated changes in performance. For example, the golf putting tasks of Moore et al. (2012) and Moore et al. (2013) presented novice and expert participants with challenge and threat themed instructions. Participants who received challenge instructions displayed more efficient gaze activity, putting kinematics and muscle activity, although mediation analysis did not find these to significantly influence performance. Similarly, in a netball shooting task under competition conditions, cardiovascular reactivity indicative of a challenge state predicted superior performance in comparison to cardiovascular reactivity associated with a threat state (Turner et al., 2012). Alternatively, another branch of TCTSA research has grouped participants based on their cardiovascular reactivity; for example, Turner et al. (2013) examined differences in elite level cricketers batting performance between participants with challenge and threat cardiovascular reactivity, finding that challenge state predicted superior performance, compared with threat cardiovascular reactivity.

In contrast to previous TCTSA research, the present study utilised cardiovascular reactivity to quantify differences in participant's responses to task instructions concerning alterations in the style of ascent. Consequently, the analysis of cardiovascular reactivity in the present study was based on the corollary of the findings of previous research (Blascovich et al., 2004; Moore et al., 2012; Turner et al., 2013; Turner et al., 2012); specifically, the assumption that in response to the presentation of task instructions if participants evaluated they had insufficient coping resources then threat cardiovascular reactivity patterns would be observed, while if they believed their resources matched or exceeded the demands of the task then challenge cardiovascular reactivity would be observed. Furthermore, as challenge states are considered an adaptive approach they were also expected to be associated with superior performance and threat a maladaptive approach related to inferior performance (Blascovich et al., 2004; Moore et al., 2012; Turner et al., 2013; Turner et al., 2012). Given the performance results already presented, challenge reactivity would be expected in the top-rope condition and threat reactivity in the lead conditions.

The cardiovascular data revealed significant differences in cardiac output and peripheral resistance reactivity (**Table 5.8**). To summarise, the relative differences in the increase in cardiac output were greater, and peripheral resistance reactivity were lower, in the lead condition compared to the top-rope. Cardiac output reactivity increased in response to all three conditions, however the increase was significant only for the run-out, compared to both the top-rope (0.57 L/min, CI_{95} = 0.30, 0.83) and lead climb (0.39 L/min, CI_{95} = 0.14, 0.64). In contrast, differences in peripheral resistance reactivity were significant between both the lead and top-rope (63.3 dyn.s.cm^5, CI_{95} = 21.9, 104.6) and the run-out and top-rope (98.2 dyn.s.cm^5, CI_{95} = 64.5, 131.9). Finally, the calculated challenge and threat index varied considerably, but was positive across all three conditions, indicative of challenge reactivity, supporting individual reactivity results.

Participants did not experience threat cardiovascular reactivity in the lead conditions and challenge reactivity in the top-rope conditions as hypothesised. An increase in cardiac output and a decrease in peripheral resistance reactivity indicates sympathetic-adreno-medullary (SAM) activity, suggesting relatively greater challenge reactivity in the lead condition than the top-rope (Jones et al., 2009). Increases in both SAM and pituitary-adreno-cortical (PAC) activity are associated with threat conditions, resulting in smaller-than-challenge increases in cardiac output and no change, or a small increase in peripheral resistance reactivity (Jones et al., 2009). However, while peripheral resistance did not increase in the top-rope condition, the reactivity was notably less than both lead and run-out conditions. Considered together, it may be said the participants found the top-rope condition to be relatively more threatening than the lead and the lead with run-out. However, the lack of an increase in total peripheral resistance reactivity and the increase in cardiac output reactivity suggest the top-rope also represented a challenge state, when results of previous challenge and threat research are considered (Blascovich et al., 2004; Moore et al., 2012; Turner et al., 2013; Turner et al., 2014; Turner et al., 2012).

Performance outcomes, and the climbers' resultant behaviour and emotional responses to their state, are likely to be mediated by several factors, including perceived control (Jones, 1995), self-efficacy (Bandura, 1997) and achievement disposition (Duda, 2005), as described in the TCTSA (Jones et al., 2009). Consequently, along with cardiovascular reactivity, participants provided a subjective self-reported evaluation of their state; responses indicated significant and meaningfully lower relative differences in self-efficacy, cognitive evaluation score and the demand to resources evaluation score, between the run-out and both the top-rope and lead climb conditions, but not between the top-rope and lead. Self-efficacy differed by 0.55 units between top-rope and run out (CI_{95} = 0.18, 0.92), cognitive evaluation score by 0.53 units (CI_{95} = 0.12, 0.94) and demand resource score by 1.06 units (CI_{95} = 0.42, 1.71). It would appear differences were significant because of the run-out condition, possibly through a combination of the uncertainty of the unique task and the perceived danger because of the prospect of a greater fall. Like the performance scores and self-reported anxiety, the differences in style of ascent occurred in the opposite direction to those of cardiovascular reactivity, with participants indicating lower self-efficacy, the task as more threatening and demands to outweigh coping resources. Changes in the self-report measures in the present study occurred in the same direction as performance, rather than reactivity. It is not clear why such an effect was observed, particularly as while self-report measures have been criticised, the criticisms were thought of in the opposite direction, with participants moderating their responses, unlike the findings of the present study (Blascovich et al., 2004).

Building upon previous challenge and threat research, cortisol concentrations were determined post presentation of the tasks (and in response to the climbing task, discussed in the following section). A threat response is characterised not only by an increase in SAM activity, as seen in a challenge response, but also an increase in PAC activity. The activation of the PAC axis results in the release of adrenocorticotropin hormone (ACTH), causing the adrenal cortex to secrete corticosteroids into the bloodstream. As a consequence of the increase in concentrations of circulating cortisol during a threat state, there is no corresponding decrease in systemic vascular resistance, despite cardiac activity increases similarly to a challenge condition (Dienstbier, 1989). Consequently, differences in cortisol concentrations would be expected alongside the cardiovascular reactivity data. In line with such hypothesis, while there were no significant or meaningful differences in post instruction cortisol concentrations between the three conditions, concentrations were greater in the top-rope condition. Post instruction resting concentrations of salivary cortisol support the cardiovascular reactivity indicative of a challenge state observed.

Previous research has demonstrated the appraisal process, specifically, whether a task is appraised as a challenge or threat, can influence concentrations of secreted cortisol (Gaab, Rohleder, Nater, & Ehlert, 2005; Jones et al., 2009; Quested et al., 2011). It has also been reported through meta-analysis of studies exploring the use of cortisol, that responses are strongest in situations individuals evaluate as threatening (Dickerson & Kemeny, 2004). This assertion is supported by the TCTSA, which states the activity of the hypothalamic-pituitary-adrenal (HPA) axis is understood to be triggered by perceptions of threat, but un-stimulated by challenge states, as in the present study (Jones et al., 2009). While cardiovascular reactivity has not been assessed in previous climbing psychophysiology research, the lack of significant or meaningful differences in pre-climb cortisol secretion may indicate that challenge states are typical in such a population. Blunting of the response may have resulted because of familiarity with climbing in general (Kirschbaum et al., 1995). Or it may have occurred more immediately because of the repeated measures design and successive evaluations of the task (Kelsey et al., 1999). For example, participants who perform poorly on a task may be more likely to evaluate the task as threatening in the future (Moore et al., 2013). The amount exposure to a task can suppress cardiovascular reactivity and previous exposures can affect subsequent demand and resource evaluations (Kelsey et al., 1999; Quigley, Barrett, & Weinstein, 2002). Indeed, it should be remembered that all of the participants of the present study regularly choose to lead during their recreational sessions and were recruited on this basis.

Challenge states may be expected to result in superior performance by promoting more favourable emotional responses and interpretations of emotions (Mendes et al., 2007; Moore et al., 2012; Moore et al., 2013; Turner et al., 2014). Differences in performance may occur because of more effective attention in challenge states (Blascovich et al., 2004; Jones et al., 2009; Skinner & Brewer, 2004), particularly greater quiet eye durations, important in gaze behaviour and attentional control in aiming tasks, such as more dynamic climbing movements (Mann et al., 2007); it is also suspected that muscular tension is greater during a threat state than a challenge state, although empirical support is limited (Blascovich et al., 2003; Moore et al., 2012; Moore et al., 2013). While the present study cannot directly ascertain whether these predictions are correct, performance observed in the present study occurred in the opposite direction. In the case of the present study geometric entropy and coaches assessed performance score were found to be greater in the top-rope condition the opposite to the results expected, given the cardiovascular reactivity data presented. Differences in performance occurred in line with the differences in self-reported pre-climb emotions, and reported demand resource and cognitive evaluation.

Challenge states are thought to be associated with both positive and negative emotions and facilitative interpretation, whereas threat states are associated with only negative and emotions interpreted as debilitative (Jones et al., 2009; Moore et al., 2012; Skinner & Brewer, 2004). However, differences in anxiety and performance observed in the present study appeared to occur in the opposite direction to those of cardiovascular reactivity. Greater negative emotions were interpreted as more debilitative in the run-out lead condition, in comparison to the top-rope (*see 5.4.5 Psychophysiological and psychological measures*). Correlations between the weighted challenge and threat index and psychophysiological, performance, emotions and self-report characteristics were considered, in order to explore relations between factors with each of the styles of ascent. Weak non-significant relationships were found between most characteristics (**Table 5.10**). There were no significant correlations for challenge and threat index for any characteristics in the top-rope condition; greater challenge and threat index in the lead condition correlated with lower concentrations of cortisol (r = -0.417) and lower self-efficacy (r = -0.386). For the run-out condition challenge and threat index only correlated with lower somatic intensity (r = -0.437) and more positive direction (r = 0.375). While the correlations of challenge and threat index with cortisol and self-efficacy in the lead condition and somatic anxieties intensity and direction in the run-out occurred in the expected direction, it is unclear why they were not significant across all three styles of accent.

The cardiovascular reactivity findings are incongruent with previous challenge and threat research, which have demonstrated challenge states to be associated with higher levels of performance than threat states (Mendes et al., 2007; Moore et al., 2012; Moore et al., 2013; Turner et al., 2014). From the results, it is not clear why cardiovascular reactivity indicative of challenge states were observed, particularly considering the relatively poorer performance, reduced movement fluency in the lead and lead-climb with run-out conditions, than the top-rope (**Table 5.6**). It is possible to speculate that it occurred because of the task the climbers were asked to complete. While a lead climb may be associated with greater subjective anxiety, physiological response and reduced performance, the participants were asked to complete a task they would normally attempt during their recreational sessions. Furthermore, the achievement goal disposition of the participants and previous research on climbers personality suggest the climbers are focused on mastery goals, friendship and intrinsic achievements, rather than performance (Robinson, 1985). Such an assertion is supported by the blunted psychophysiological response, reactivity is thought to be greatest for tasks with low situational control, or high socio-evaluative threat, unlike the present studies' lead climbing tasks (Dickerson & Kemeny, 2004). Indeed, for some climbers, attempting to top-rope a route may be the more unusual of the conditions. Previously Hardy and Hutchinson (2007) have stated: *"It is not difficult to see how participants could perceive considerable ego threat in top-roping a climb at their leading limit in front of a relative stranger (the experimenter)"* (p. 159). It is conceivable the participants found the prospect of attempting a top-rope of a route close to their limit more threatening because of the greater chance of failing and the evaluation of others. However, this is not supported by the participants' self-efficacy, or perceived demand of the task, reporting they felt more confident towards the top-rope task and perceived it be less demanding and better able to cope (**Table 5.9**). Indeed, climbers with greater self-efficacy have been found to take greater calculated risks, attempt harder climbs and have greater feelings of confidence in their ability (Llewellyn et al., 2008).

Another explanation may relate to the ability and experience of the participants, who were of an intermediate ability and had been taking part in the sport for 7.0 ± 5.5 years, climbing on average 2.3 ± 1.2 sessions per week. For all participants, lead climbing was a typical aspect of their climbing sessions, and although leading represented a motivated performance situation, it was not unusual. Such familiarity may have habituated the climbers to the task, blunting cardiovascular and cortisol reactivity (Kelsey et al., 1999; Kirschbaum et al., 1995; Quigley et al., 2002). Finally, the conflicting results may be due to the applied nature of the present study, in comparison to previous research, which has been largely laboratory-based, typically using task instructions that alter perceptions of participants resources to manipulate evaluations (Turner et al., 2014). In contrast, the present study relied on participants own appraisal of their resources, relative to the changing demands of the task, as with the cricketers of Turner et al. (2013), however, participants were not grouped on their challenge and threat index, as with Turner et al. (2013), but on the task. While the results may have been investigated based on challenge and threat reactivity, this would not have met the aim of the study; furthermore, the correlations observed suggest the results would have been largely equivocal (**Table 5.10**).

To summarise, despite significant and meaningful differences in climbing performance and emotional response to the climbing tasks, there were only small differences in cardiovascular reactivity. The reactivity results presented suggest participants were experiencing challenge appraisal states in the lead run-out condition and relatively more threatening, but still challenge reactivity in the lead and top-rope condition. These findings conflict with previous challenge and threat research and occur in the opposite direction than expected given observed performance. From a wider TCTSA and BPS perspective, the findings of *Study One* are also of note. While it was hypothesised the greater perceived danger of the lead, and in particular the lead run-out condition would elicit a cognitive evaluation and cardiovascular and self-report indicative of a threat state, this was only true of the self-report measures. It is possible this occurred due to habituation to the tasks, as leading is a typical part of the intermediate climbers' recreational session, and the top-rope condition being unusual and more ego-threatening than the lead. However, this is not entirely supported, as self-report evaluation of pre-climb emotions indicated participants had greater anxiety and lower self-confidence prior to the lead ascents. It may be differences in the evaluation process and salience of factors occurring consciously and those unconsciously, without awareness that resulted in these differences. From the results of *Study* One, differences in the style of ascent are unlikely to be the best way to bring about cognitive evaluations occurring as a result of perceptions of danger. Finally, while cortisol concentrations were determined and small differences in the same direction as cardiovascular markers did exist, there was considerable variability. Cardiovascular reactivity would appear to be the most efficient, and least costly means of objectively determining challenge and threat states in such situations.

5.4.5 Psychophysiological and psychological measures

As with previous style of ascent research, alterations in both participants heart rate one minute prior to climbing and pre-post climb cortisol were assessed (Dickson, 2013; Draper et al., 2012; Draper et al., 2010; Fryer, 2013; Hodgson et al., 2009). Activation of the SAM axis is associated with short-term physiological responses, such as increases in heart rate; while the HPA axis is a slower acting mechanism of which cortisol is the primary hormonal endpoint (*see 2.2 Responding to stressors*). Alterations in cortisol and heart rate allow for the assessment of both short (heart rate) and longer (cortisol) responses to the task occurring to facilitate the mobilisation of physiological resources to respond appropriately to a stressful stimulus.

There were increases in salivary cortisol concentration pre-post climb for each ascent, however, large standard deviations obscured any meaningful differences between conditions (top-rope 22 ± 58%; lead climb 37 ± 161%; run-out 63 ± 162%). Similarly, heart rate was significantly elevated prior to each ascent, despite the lack of a significant physiological stressor pre-climb (top-rope 102 ± 20; lead climb 101 ± 23; run-out 98 ± 17 $b.min^{-1}$), however, again there were no meaningful differences in heart rates increase from rest (top-rope 49 ± 30%; lead climb 47 ± 30%; run-out 42 ± 30%). The findings of the present study are in line with current understanding of physiological changes associated with alterations in the style of ascent. No meaningful differences have been found in either pre-climb heart rate (Dickson, 2013; Dickson et al., 2012a; Fryer, 2013; Fryer et al., 2013), or cortisol (Dickson, 2013; Dickson et al., 2012a; Draper et al., 2012; Fryer, 2013; Fryer et al., 2013). With the exception of the lower grade climbers of Dickson (2013) for plasma cortisol concentrations.

Cortisol secretion is known to increase in response to both physical exertion (Jacks et al., 2002; McGuigan et al., 2004; Sherk et al., 2011) and psychological stress (Giles et al., 2017a; Owens et al., 2014; Peckins et al., 2015; Thompson et al., 2012). Post climb changes in cortisol secretion with the style of ascent may occur due to increases in physical load and longer ascent times in the lead condition. However, due to the short duration and moderate nature of the climbing task, demonstrated by previous studies to be around 60% $\dot{V}O_{2max}$ (Fryer et al., 2012; Giles et al., 2017a), increases are unlikely to be due solely to physical exertion. For increases in cortisol secretion to occur, exercise must be intense (>70% $\dot{V}O_{2max}$) and longer lasting (>40 min) (Hill et al., 2008; Jacks et al., 2002). Consequently, it is likely the increases in cortisol seen in the present study, and those previously, may be attributed to psychological stress as opposed to physiological stress alone. However, this does not explain the lack of meaningful differences observed.

As previously discussed, the lack of significance in differences between the three conditions may have occurred because of habituation to the task. For example, cortisol reactivity has been found to be reduced with repeated exposures following habitation to laboratory stressors (Kirschbaum et al., 1995). It is conceivable, because of the nature of the task the participants were asked to complete being typical in their normal recreational indoor climbing sessions, they were habituated to the task. While the inclusion of the somewhat novel run-out task may have been expected to cause a significant increase in cortisol, previous research that has assessed differences in catecholamines concentrations with a run-out climbing task did not find significant differences in cortisol concentrations either (Balas et al., 2016). The lack of differences are in line with the conclusions of a previous meta-analysis of task-induced stress, which suggested cortisol reactivity is greatest for tasks with low perceived situational control, or high socio-evaluative threat (Dickerson & Kemeny, 2004). However, as these were not measured it is only possible to speculate as to their contribution.

Several authors have suggested that the inability of psychophysiological responses to differentiate between styles of ascent may be due to the novel, on-sight, nature of the climbs (Dickson, 2013; Hardy & Hutchinson, 2007). The stress of completing climbs on-sight may be of greater importance and obscure the influence of ascent style on the psychophysiological response of the participants (Dickson, 2013). For example, Hardy and Hutchinson (2007) reported, when attempting an unknown route, climbers described similar levels of anxiety before an on-sight ascent, regardless of the safety protocol. Draper et al. (2008) also found reduced physical demands and significant reductions in state anxiety prior to the red-point ascent, compared to an initial on-sight ascent. However, the results of the present study are unlikely to have occurred solely due to route knowledge, as all routes were completed on-sight and there was still a significant and meaningful difference in the climbers' self-reported emotions and performance, despite the lack of significant or meaningful differences in psychophysiological variables. The on-sight nature of the climbs is likely to have created a degree of uncertainty for the participants in all the conditions, despite differences in the style of ascent.

Participants cognitive and somatic anxiety, self-confidence intensity and direction were reported using the modified IAMS (Thomas et al., 2002). In contrast to previous style of ascent research, there were significant differences found in somatic anxiety, cognitive anxiety and self-confidence (**Table 5.11**). Differences occurred between the run-out and both the top-rope and lead conditions for somatic anxiety; between top-rope and both lead conditions for cognitive anxiety; and between top-rope, lead and lead run-out conditions for self-confidence.

The differences in somatic anxiety were in line with previous style of ascent research, in that there were no meaningful differences between top-rope and lead conditions (Dickson, 2013; Dickson et al., 2012a; Draper et al., 2012; Draper et al., 2010; Fryer, 2013; Fryer et al., 2013). However, the novel run-out condition, compared to both the top-rope and the lead climb brought about significantly greater somatic anxiety (top-rope 22 ± 15; lead 23 ± 13; run-out 31 ± 17). Cognitive anxiety, in contrast to somatic anxiety, was significantly greater in both lead conditions, in comparison to the top-rope (top-rope 14 ± 10; lead 27 ± 17; run-out 27 ± 17). Greater cognitive anxiety in both lead conditions implies the demands of leading were the salient factor, rather than the run-out, bringing about the increase in anxiety. However, it is not clear why there was significance in cognitive anxiety in the present study, despite no meaningful differences in earlier style of ascent research (Aras & Akalan, 2011; Dickson, 2013; Draper et al., 2012; Draper et al., 2010; Fryer, 2013; Fryer et al., 2013; Hardy & Hutchinson, 2007 S3; Hodgson et al., 2009). The interpretation of somatic and cognitive anxiety was negative in all cases, but did not differ by a significant or meaningful amount.

These findings provide support for the theory that a threat of physical harm is a determinant of performance anxiety when leading, resulting in greater somatic anxiety, but not cognitive anxiety (Morris et al., 1981). Hardy and Hutchinson (2007) stated they believe a threat of physical harm was likely to be a major determinant of performance anxiety, where anxiety when leading and top-roping an unknown route were compared, as with the present study. Taken together it is suggested the run-out condition elicited greater feelings of somatic anxiety, but not cognitive anxiety, because of the perceived risk of the run-out. Despite the potential for a greater fall, the location at the top of the route means the fall, while possibly greater, was unlikely to lead to an increased risk to the participant (CEN12572-1, 2007), and such emotional responses may be considered irrational or at least disproportionate. This is particularly interesting as an element of skilful climbing performance has been reported as being able to manage and differentiate between rational and irrational fear and perceived and actual risk (Binney & McClure, 2005).

As with somatic anxiety, self-confidence decreased significantly only between the top-rope and lead run-out, rather than the lead condition (top-rope 41 ± 13; lead 40 ± 11; run-out 31 ± 12). Participants also interpreted low self-confidence as considerably less helpful for their climbing performance. Lower self-confidence in lead conditions has been reported by a number of authors (Aras & Akalan, 2011; Dickson et al., 2012a; Fryer, 2013; Hodgson et al., 2009). Although, the lack of significance in the lead condition was in line with many authors exploring the demands on intermediate climbers (Dickson, 2013; Draper et al., 2012; Fryer, 2013; Fryer et al., 2013). Significance in participant's interpretation of lower self-confidence implies its importance to them; indeed, self-confidence has been termed a moderating variable, regulating the interactive effects of cognitive and somatic anxiety, allowing athletes to achieve fine performances while being both anxious and self-confident (Hardy et al., 2004; Woodman & Hardy, 2003). Draper et al. (2011d) reported differences between successful and unsuccessful climbers and while there were no significant differences in their appraisal of somatic or cognitive anxiety, there were significant differences in reported self-confidence. Greater confidence before a climb may improve route planning decisions and the choice of technique and tactics employed and, as a result, was possibly responsible for the greater performance seen in the top-rope ascent of the present study (Draper et al., 2011d). Greater confidence may also increase tolerance to the effects of increased somatic anxiety before participants experience performance loss (Hardy et al., 2007). However, differences in confidence do not explain why lower levels of performance were observed during the lead condition as self-confidence only differed by a meaningful amount in the run-out condition.

To summarise, as with previous climbing style of ascent psychophysiology research, the ability of the objective psychophysiological measures of heart rate and cortisol to differentiate participants were limited (Dickson, 2013; Dickson et al., 2012a; Fryer, 2013; Fryer et al., 2012). The lack of significance in heart rate and cortisol are in line with previous research. The results do not provide support for the use of cortisol, it does not appear sensitive enough to differentiate between participants of similar ability and is likely to only be of use when exploring the response of groups of differing ability, as with the ladder study of Giles et al. (2017a). Furthermore, heart rate and cortisol results also contrast with the significant changes in climbing performance and self-reported cognitive, somatic anxiety and self-confidence observed. This may be partially attributed, in the case of somatic anxiety, to the inclusion of the run-out condition. A threat of physical harm appears to result in greater somatic anxiety and lower self-confidence, while cognitive anxiety was elevated for both lead conditions (Morris et al., 1981). It is speculated that greater cognitive anxiety resulted because of the challenges associated with lead climbing, rather than the run-out. Elevated levels of cognitive anxiety may be responsible for performance difference seen with the style of ascent.

Consequently, further research should concentrate on the sources of cognitive anxiety in intermediate climbers in order to determine the factors responsible for its elevation and the associated disruption of performance. This would help guide interventions of coaches in designing interventions to reduce anxiety with the aim of improving climbers' performance.

5.5 Perspectives

Lead climbing has been speculated to be a significant source of stress for climbers (Hague & Hunter, 2011; Macleod, 2010; Sagar, 2001). Such stress is believed to occur as a result of the potential for and the perceived consequences of, a lead fall (Bisharat, 2009; Hörst, 2011). Because of the reported effects of style of ascent on performance, a considerable amount of research has been completed on the topic (Dickson, 2013; Dickson et al., 2012a; Draper et al., 2012; Fryer, 2013; Fryer et al., 2013). However, the results of previous research examining differences in the style of ascent have proved largely equivocal. Building on the significant body of research and methodological advances previously made by Draper, Dickson and Fryer, *Study One* aimed to examine the objective physiological and subjective emotional responses of participants to on-sight ascents with changes in the style of ascent. Critically, participants' performance was assessed on the routes with a repeated measures design with three novel routes, ensuring participants completed each route on-sight, without any prior knowledge.

As with the previous style of ascent research, there were no meaningful differences in heart rate or cortisol concentrations, possibly due to habituation and familiarity with the assessed tasks. Similarly, cardiovascular reactivity to task instructions were in line with challenge reactivity, despite and in contrast to the emotional and performance differences seen. It was speculated that the nature of the lead climbing, in particular, demand appraisals occurring in response to perceived danger in the lead conditions, would result in threat cognitive evaluations. This was true only of the subjective self-report measures, not the cardiovascular reactivity data. It is possible differences in self-report and cardiovascular reactivity occurred due to habituation to the tasks, as leading is a typical part of the intermediate climbers' recreational session, and the top-rope condition was perhaps more unusual and more ego-threatening than the lead. It may be differences in the evaluation process and salience of factors occurring consciously and those unconsciously, without awareness that resulted in these differences. Further research is necessary to establish the implications of danger evaluations; however, care should be taken to ensure the salience of such evaluations. Finally, while cortisol concentrations were determined and minor differences in the same direction as cardiovascular markers existed, there was considerable variability. Cardiovascular reactivity would appear to be the most efficient, and least costly means of objectively determining challenge and threat states in such situations.

Participants were more cognitively anxious and performance quality was reduced in the lead conditions with less fluent, hesitant movement and lower assessed coaches score. Performance differences may have been brought about by significantly increased cognitive anxiety in both lead ascents, and reduced self-confidence and greater somatic anxiety in the run-out ascent. The findings of *Study One* support coaches' assertions of the challenges of lead climbing for intermediate climbers, despite participants' familiarity with the task. The results suggest that cognitive anxiety in the lead conditions was at least partially responsible for differences in performance seen. Consequently, it is conceivable that interventions addressing anxiety resulting from leading should concentrate on reducing cognitive anxiety and improving self-confidence, in order to reduce deterioration in performance occurring in intermediate climbers and improve enjoyment (see *Study Four*). Secondly, while this finding has implications for coaches and climbers wishing to improve lead climbing performance, there would be a significant benefit to understanding factors underlying greater cognitive anxiety occurring when leading (*see Study Three*). A more nuanced understanding of the concomitant factors would help with the specificity of the interventions to improve performance.

Despite advances made in the present study, there was still considerable variation in the results. A potential confounding factor may be route difficulty. It is not clear what effect relative differences in the difficulty of a route have on psychophysiological responses and participants demand resource evaluation. Route difficulty is one of the primary decisions made by climbers during their session to determine the challenge of the route. While ability has been linked with exercise economy (Balas et al., 2014) and relative energy expenditure (Hardy & Martindale, 1982), differences in route difficulty have only been investigated in terms of participants subjective experiences and were conducted outdoors on traditional climbs (Hardy & Hutchinson, 2007; Hardy & Whitehead, 1984). Consequently, *Study Two* will examine differences between climber ability relative to the difficulty of a route, and their subjective psychological, objective physiological and behavioural responses.

6

Study Two

Climber ability and differences in psychological, physiological and behavioural responses to an on-sight lead climb

6.1 Introduction

The premise of climbing is simple: ascend a route without falling, or weighting the rope. The challenge lies in the choices climbers make in regard to the routes they ascend, the means of their protection in the event of a fall, the difficulty and the climber's knowledge of the route (Draper et al., 2012; Fryer et al., 2013; Hardy & Hutchinson, 2007). When taken together, the nature of these characteristics alter both the likelihood and the consequences of failure; not only by contributing to the physiological demands, but also the psychological challenges (Goddard & Neumann, 1993). If the climber is leading and unable to complete the route, then they will either fall, which is a potentially physically threatening situation, or will have to back off and ask to be taken tight on the rope, which is potentially ego-threatening (Hurni, 2003). If the climber does not respond appropriately, stressors have the potential to have a significant deleterious effect on climbers' state and performance (Hardy & Hutchinson, 2007; Pijpers et al., 2005). Consequently, a significant aspect of the sport is the management of stress in order to maintain performance and ultimately reach the top of a climb (Hörst, 2010).

According to climbing coaching literature, the nature of lead climbing and the potential for falling mean it is often considered a stressor and a limiting factor for many (Hurni, 2003; Macleod, 2010; Sagar, 2001). *Study One* investigated climbers' objective physiological, behavioural and subjective psychological responses to differences in the safety protocol. Ideally, other factors aside (primarily, route knowledge and difficulty), a change in the safety protocol should not result in an alteration in climbers' performance. However, *Study One* demonstrated this not to be the case, with reduced performance quality associated with greater cognitive anxiety in the lead condition, compared to the top-rope; along with greater somatic anxiety and decreased self-confidence in the run-out condition, without any further decreases in performance. The findings support coaches' assertion of the psychological challenges of lead climbing. In particular, the potential for and perceived consequences of a lead fall appears to be associated with a perceived risk of physical injury, even indoors, where the majority of climbing injuries occur because of chronic overuse, as opposed to more acute injuries associated with falling (Backe et al., 2009).

In contrast to the style of ascent, route difficulty is responsible for changes in regard to the physical demands placed on the climber, while the consequences of failure remain the same (Janot et al., 2000; Mermier et al., 1997; Watts & Drobish, 1998). The physical demands are largely dictated by the length and angle of the wall, coupled with the size and frequency of the holds (Watts, 2004). Increased difficulty of a climb results in an increase in the physiological demands being placed on the climber (Janot et al., 2000; Mermier et al., 1997; Watts & Drobish, 1998). Furthermore, an increase in the difficulty, relative to the ability of a climber, results in a greater likelihood of the climber being unable to complete the route on their first attempt; the chance of failure changing as a function of the difficulty of the route. Therefore, relative route difficulty is likely to be a significant stressor for climbers.

Not only may the potential for a fall be anxiety inducing, the anxiety a climber experiences may limit their ability to complete the route (Hague & Hunter, 2011). An increase in the grade of a route, relative to the ability of the climber, creates a state in which the perceived demands of the task may exceed their coping resources (Lazarus, 1991). Cognitive evaluation theory proposes two levels of cognitive appraisal, which act as a mediator between stressors and the individual's stress response (Lazarus, 1991). The primary appraisal establishes how important the situation is to an individual and whether it might endanger their well-being. These demand evaluations are made about climbers' perceptions of danger (physical or esteem), uncertainty, and effort (physical and psychological). Research has explored situations believed to elicit differences in perceptions of uncertainty and effort, little evidence has been presented for situations eliciting differences in perceptions of danger. It was hypothesised in *Study One* that the nature of lead climbing, in particular, demand appraisals occurring in response to perceived danger in the lead conditions, would result in threat cognitive evaluations. However, this was true only of the subjective self-report, not the cardiovascular reactivity. Differences in the relative difficulty of the route may be another means of instigating such danger appraisals.

The nature of the task in *Study Two*, with differences in the relative difficulty of on-sight attempts, and conceivably differences in the likelihood of participant's success, are also hypothesised to bring about differences in demand evaluations because of perceptions of danger. It may be expected that participants attempting a route at or below their ability experience a *'challenge'* cognitive appraisal state when secondary appraisal perceives they have sufficient, or near sufficient, coping potential to meet the situational demands. Conversely, those attempting a route beyond their ability experience a *'threat'* state when secondary appraisal indicates an individual's coping potential is not sufficient, thus deeming harm potentially imminent (Lazarus, 1991). Perceptions of coping ability, performance outcomes and the climbers' resultant behaviour and emotional response to their state are likely to be dictated by several factors, these include perceived control (Jones, 1995), self-efficacy (Bandura, 1997) and achievement disposition (Duda, 2005), as described in the Theory of Challenge and Threat States in Athletes (TCTSA) (Jones et al., 2009). Put simply, if the climber has doubts about their ability to cope with the demands of a stressor arising because of perceived danger, uncertainty and effort, then feelings of anxiety are likely to result, and performance is likely to be affected.

Research examining the effects of the psychological demands and behavioural changes with alterations in route difficulty are limited. For example, Hardy and Hutchinson (2007), in line with the earlier work of Hardy and Whitehead (1984), reported an increase in anxiety might be expected when a climber is attempting a route at, or toward, the top end of their ability. The participants of Hardy and Hutchinson (2007) ascended routes at their lead limit and at one and two grades below their limit outdoors on traditional climbs. With an increase in the difficulty, there was significantly greater cognitive and somatic anxiety and activation. There was also a significant difference in the measures of effort, with increases in heart rate, perceived exertion and perceived mental effort. Interestingly, the belayer' rating of the climber's performance also increased, with superior performance seen during the harder ascents. However, as these ascents were completed outdoors with the greater objective danger of outdoor traditional lead climbing, the participants were not asked to attempt routes beyond their on-sight ability.

6.1.1 Summary and aims

An increase in the difficulty of a route, relative to the ability of a climber, creates a situation where the consequences of a failure are identical, however, the likelihood of the climber failing to complete the climb increases. The purpose of *Study Two* was to investigate the role of ability on the resultant psychophysiological, emotional and behavioural changes to an on-sight of a route below, at, or above the climber's self-reported indoor on-sight ability. The same assessment techniques set out in *Study One* were employed. Assessment of participants' cognitive evaluation in response to task instructions were made via cardiovascular reactivity and self-report inventories. Climbers' perception of their emotional state and psychophysiological responses were also assessed, along with climbing performance. Therefore, the aim of *Study Two* was to examine differences between climber ability relative to the difficulty of a route, and their subjective psychological, objective physiological and behavioural responses.

6.1.2 Hypotheses

The greater the difficulty of the route, relative to the ability of the climber:

H1: the lower the likelihood of the climber successfully completing the ascent, the lower the coaches' assessment of performance and the less fluid the displacement of mass will be.

H2: the greater cognitive and somatic anxiety and the lower self-confidence will be.

H3: the greater the rise in anticipatory heart rate will be. Given the results of *Study One* and previous psychophysiology research, it is unlikely that cortisol will differ significantly.

Further:

H4: An ascent of a route below a climber's on-sight ability will be considered ego-threatening, resulting in threat reactivity, greater stress response and reduced performance when compared to that of a route set at a climber's on-sight ability.

H5: A climber's challenge and threat index will be positively related to climbing performance, lower and more positive interpretations of cognitive anxiety, greater positive self-confidence, greater self-efficacy, challenge interpretation, greater demand resources and greater mastery focused achievement goals.

H6: The coaches' assessment of performance will be related to lower and more positive cognitive anxiety, greater positive self-confidence and somatic anxiety, lower anticipatory heart rate; greater self-efficacy, challenge interpretation, greater demand resources and greater mastery focused achievement goals.

6.1.3 Strengths of the study

- The current study is the largest climbing psychophysiology related study completed to date.
- It is the first study to examine participants' responses to a route with alterations in the difficulty of the climb, relative to the ability of the climber.
- A highly-experienced route setter, who has set at a world-cup level, set the routes.
- The use of a route that increases in difficulty across its length, while difficult to set, allowed for climbers of all abilities to safely attempt to lead the route.

6.1.4 Delimitations

- Data are representative and specific to the individual route profiles, the length of route and spacing of quickdraws used within the study.
- Findings of the current study are specific to the relative difficulty of the route to the best on-sight grade of the intermediate climbers
- The results are only representative of on-sight lead climbing indoors.

6.1.5 Assumptions

- All participants refrained from strenuous training 48 hours prior to testing and observed a period of complete rest for at least 12 hours before each testing session.
- All participants refrained from either inspecting or attempting the route prior to their testing session as requested.
- Self-reported climbing grades relied on participants accurately and honestly reporting their on-sight and red-point performance.
- The word of participants was taken that they had not consumed alcohol or caffeine prior to the session.

6.1.6 Limitations

Despite careful consideration of the methodologies employed and numerous pilot studies, there were still some limitations within *Study Two*:

- The study was difficult to perform because of the nature of the methodology and costs, limiting the sample size.

- The climbers' responses may have been affected by the study taking place in a public climbing wall.

6.2 Methods

This section provides details of the participants and an overview of the experimental design, procedures for the session, data and statistical analysis. Throughout these methods, references are made to the *General Methods* chapter, which should be referred to where applicable.

6.2.1 Participants

Sixty-one climbers volunteered to take part in the study. All climbers were actively involved in the sport, climbing at least once a week indoors. All climbers were proficient in the discipline of sport lead climbing. Participants were included based on their self-reported on-sight ability of between French 6a+ to 6c+ (IRCRA 12 to 16; YDS 5.10c to 5.11c; *see 4.2.1 Self-reported ability and experience*). The climbers were classified as intermediate to advanced (Draper et al., 2016). No inducement was offered to participants for taking part. Climbers who volunteered and met the recruitment criteria set out in Chapter 4 (*4.1.1 Participants*) were invited to participate. Descriptive data for experience, anthropometric and fitness characteristics, with respect to the 61 participants who met all requirements are presented in **Table 6.1**.

Table 6.1: *Participants anthropometric and climbing experience characteristics for combined and male and female participants (mean ± SD).*

	Combined (*n* = 61)	**Male** (*n* = 47)	**Female** (*n* = 14)
Anthropometrics			
Age (years)	33.4 ± 10.1	34.0 ± 10.6	31.6 ± 8.2
Height (m)	1.75 ± 0.07	1.77 ± 0.07	1.68 ± 0.05
Mass (kg)	70.0 ± 9.3	72.7 ± 8.2	61.1 ± 6.9
Experience			
Years Climbing	9.9 ± 9.3	10.5 ± 10.1	7.7 ± 5.9
Sessions a week	2.6 ± 1.1	2.6 ± 1.2	2.6 ± 1.1
Grade			
Indoor OS (IRCRA)	13.6 ± 1.7	13.8 ± 1.6	12.9 ± 1.8
Indoor RP (IRCRA)	15.7 ± 1.8	15.8 ± 1.7	15.2 ± 1.9

Note: m metres; kg kilogramme; OS on-sight; RP red-point; IRCRA international rock climbing research association

The participants were grouped based on their on-sight ability relative to the difficulty of the route (**Table 6.2**). The three groups were divided based on attempting a route at the climbers lead limit (CLL; *n* = 20; French 6a to 6a+; YDS 5.10b to 5.10c), above their on-sight grade (CLL^{above}; *n* = 17; French 6a to 6a+; YDS 5.10b to 5.10c) or below their on-sight grade (CLL^{below}; *n* = 24; French 6c to 6c+; YDS 5.11b to 5.11c).

Table 6.2: *Division of climbers across the three ability groups.*

Climber ability (French)	Description of climber ability	Abbreviation
6a & 6a+	Climb above lead limit	CLL^{above}
6b & 6b+	Climb at Lead limit	CLL
6c & 6c+	Climb below lead limit	CLL^{below}

6.2.2 Experimental design

All participants attended a single afternoon session at Awesome Walls climbing centre, Sheffield. Participants were asked to adhere to the pre-testing guidelines set out in *4.1.1 Participants*. Adherence to the guidelines was confirmed verbally before the commencement of the testing session. Anthropometrics were recorded in a quiet classroom (*4.1.2*); while the single route was set on the climbing wall at the same centre (*4.1.7 Route design*). The sessions were conducted in the afternoon to minimise the influence of circadian rhythm, particularly on salivary cortisol concentrations (*4.3.1*). Prior to the climb, heart rate (*4.3.2*), cortisol (*4.3.1*) and blood pressure reactivity (*4.3.3*) were assessed in response to pre-recorded task instructions. During the climbing phase of the session, participants were required to attempt a single on-sight ascent of a route set on an artificial climbing wall (*4.1.7*). The route was protected by a lead rope and competent belayer.

6.2.3 Climbing wall and route setting

A single route was set for the study. The route was graded French 6b (12 IRCRA; YDS 5.10c), which was confirmed by four expert climbers before the commencement of the study. As participants with self-reported ability ranging from f6a+ to f6c+ were asked to complete the route, the route was set so the bottom half was graded f6a and the top half f6b+, providing an overall grade of f6b. The easier first half of the route ensured all participants could reach at least the third quickdraw, reducing the chances of a ground fall. After the first quickdraw at 3.1 meters, the distance between the next nine quickdraws was 1.2 ± 0.1 meters (*4.1.7 Route design*). Participants were asked to refrain from watching preceding climber's ascents to limit the amount of information they had about the climb and the rate of success and failure.

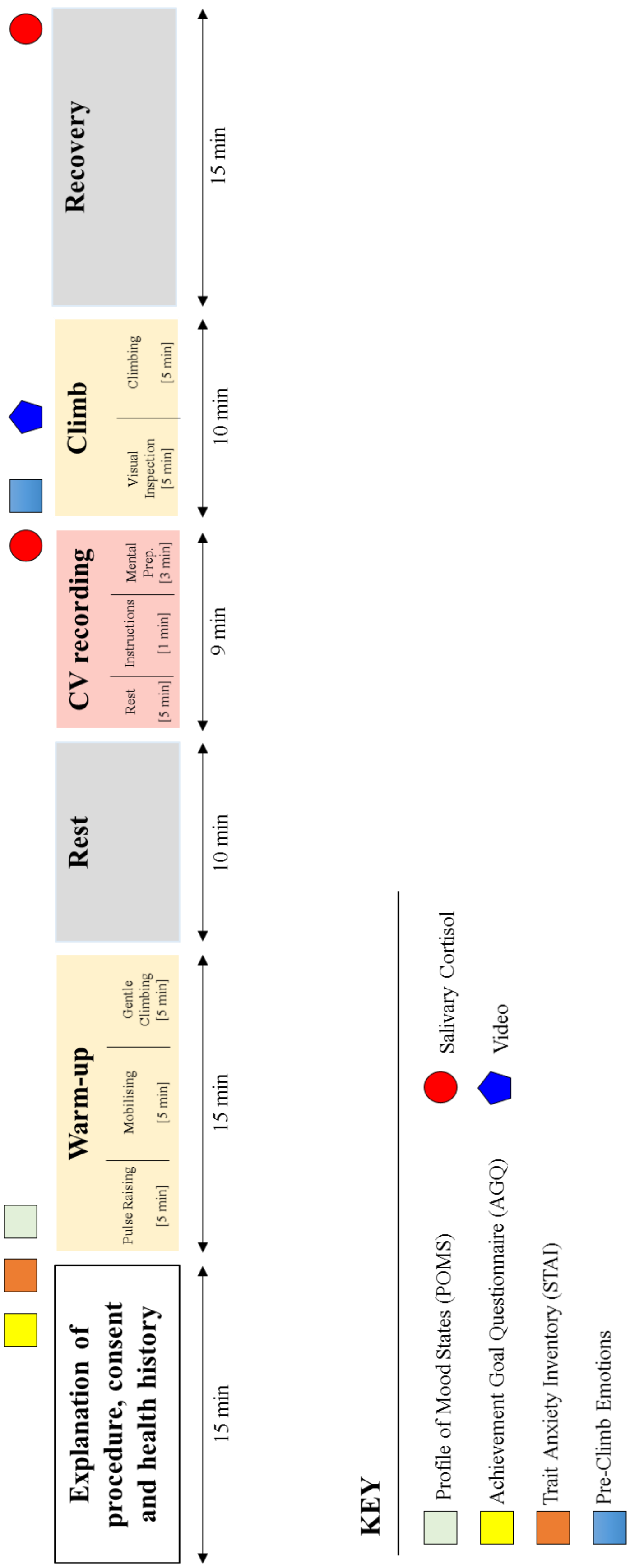


Figure 6.1: *Timeline for anthropometrics, baselines and climbing for each participant.*

6.2.4 Arrival and warm-up procedure

Figure 6.1 represents the procedures carried out over the single testing session. Following the explanation of the procedures, ascertaining health history and fitness to participate, and informed consent, participants completed the Profile of Mood States (POMS; *see 4.4.1*), Achievement Goal Questionnaire (AGQ; *4.4.3*) and the State-Trait Anxiety Inventory (STAI *4.4.2*). Participants completed a thorough warm-up, comprised of five minutes of pulse raising activity (walking, jogging skipping, etc.), five minutes of mobilising exercises and five minutes of gentle climbing (*see 4.1.2 Anthropometrics and warm-up*). Following the warm-up, participants were provided with 10 minutes of seated recovery time.

6.2.5 Task instructions procedure

Following the imposed 10 minutes of seated recovery, participants completed a nine-minute pre-climb data collection period, comprising of five minutes of rest, one minute of instructions and three minutes of mental preparation. During this time participants were equipped with a Polar H7 chest strap and V800 HRM (Polar, Finland) and, once seated, the Finapres Portapres Model-2 (Finapres Medical Systems B.V., Amsterdam, The Netherlands). Finger arterial pressure was recorded continuously using an appropriately sized Finapres finger cuff, applied to the mid-phalanx of the middle finger of the left hand (*4.3.3 Cardiovascular reactivity*). Participants were informed they would be required to sit still and quiet, upright, with their arm supported at the level of their heart and legs facings forwards, bent at a 90-degree angle. After five minutes of data collection, participants were presented with audio instructions concerning the upcoming climbing task, via a set of headphones (QC 25, Bose). Recordings of heart rate and blood pressure were made during this time.

The audiotaped instructions described the upcoming climb. The audio instructions lasted for one minute (*Appendix E Audio transcripts*), in which high task demands were promoted, typical of motivated performance situations. Participants were informed the task was designed to assess their performance *"The task that you are about to complete is designed to assess your on-sight lead climbing performance"*. With the novel *"on-sight"* nature of the climb aimed at promoting perceptions of uncertainty regarding performance. Participants were informed of the difficulty of the task *"You will be asked to lead a route graded French 6b, that has been set specifically for this study"*. The competence of the belayer was reinforced "*You will be belayed by an experienced, competent and capable belayer"*. As well as promoting task demands, the instructions reminded participants of the consequences of failure *"You will climb at your own pace until you either reach the top, or fall. Once you reach the top, or fall, you will be lowered* *back to the ground and your attempt at the route will be over"*. The final part of the task instructions asked participants to mentally prepare for the upcoming climbing task by thinking about their performance for three minutes. Following the presentation of the climbing task instructions, participants completed the combined inventory assessing self-efficacy, cognitive evaluation, perceived control, task importance, demand resource evaluation and achievement goals inventories (*4.4.5 Pre-climb*). Finally, this was followed by a salivary cortisol sample.

6.2.6 Procedure – climbing

At the end of the 9-minute pre-climb data collection period, participants were equipped with a climbing sit harness and fitted climbing shoes. If desired, the participants could use climbers' chalk to dry their hands, contained within a chalk-bag carried at the rear of the harness. Participants were then shown the route they were to complete. Following a visual inspection of the route, participants completed the Immediate Anxiety Measurement Scale (IAMS) in relation to the upcoming climbing task (*4.4.5 Pre-climb*). Finally, participants attempted the route, climbing until they either reached the top of the route or fell. Participants began climbing when ready, ascending at their own pace, protected from falling using a standard climbing harness, rope and an experienced belayer (*4.1.3 Protection of climbers*). During the climb, heart rate was recorded continuously. Saliva cortisol was sampled on returning to the ground after a 15-minute passive recovery period.

6.2.7 Data analysis

Baseline to pre-climb and pre-climb to post climb delta values were calculated for a number of dependent variables. The collection, processing and calculation of variables from individual measures are presented in *General Methods* chapter and should be referred to where appropriate.

6.2.8 Statistical analysis

All statistical analysis was conducted using SPSS (version 22; Chicago IL) and Microsoft Excel (Version 2015; Redmond WA) software. Outlier analysis was first conducted; univariate outliers were first identified based on being more than 3.3 standard deviations from the mean (Tabachnick et al., 2001). Following identification, as in Moore et al. (2012), outliers were winsorized by changing the deviant raw score to a value 1% larger or smaller than the next most extreme score, this was necessary for two participants cardiovascular data. Normal distribution and homogeneity of variance were then assessed through visual inspection of the frequency histogram, Shapiro-Wilk's tests and by examining variance around the mean with the use of box plots (if the maximum variance was less than three times the mean then equal variance was assumed). This is the normally accepted rule to determine whether the analysis of variance (ANOVA) test is reliable. Descriptive statistics were calculated for all variables; all values are reported as Mean ± SD.

A series of independent samples *t*-tests were used in determining differences between male and female participants climbing experience and anthropometrics. Because of significant differences for time spent sport climbing, this variable was considered as a covariate. For each independent variable, a series of analysis of covariance (ANCOVA) were conducted. For dependent variables found to be significantly affected by the covariate, results of the analysis of covariates were presented (including adjusted means and standard errors (SE) for the dependent variable). To control for increasing error rate due to multiple testing, conceptually linked independent variables were tested together using a multivariate analysis of variances (MANOVA, or MANCOVA). Analysis of variance (ANOVA, or ANCOVA) or two-way ANOVA tests were used for all other comparisons. The exception to this was pre-post task instruction heart rate, which was assessed using a paired samples *t*-test. Post-hoc least significant difference (LSD) tests were used to explore the source of the differences in the means between groups for each significant ANOVA, while controlling for the error rate. Pearson's product moment correlations were used to assess the relationship between the weighted challenge and threat index and performance with psychophysiological, performance, emotions and self-report characteristics.

For all analysis, the critical α-level was set at 0.05; corrections for multiple comparisons were made using Benjamini and Hochberg (1995) false-discovery rate (FDR) method, which has been supported for use in place of Bonferroni adjustments (Glickman et al., 2014). Unadjusted and adjusted *p* values were calculated and, where necessary, presented to provide an indication of the likelihood of type I and type II error rates; given it has been previously argued that reducing the possibility of type II error is preferable in exploratory research (Hoad & Monks, 2011; Perneger, 1998). Effects sizes were determined using η_p^2 for multiple comparisons and Cohen's *d* for comparisons with two groups.

6.3 Results

6.3.1 Participants climbing experience and anthropometrics

The experience and ability (mean ± SD) of the 61 participants (47 male, 14 female) are presented in (**Table 6.3**). A series of independent samples *t*-tests were used to investigate gender differences in participants climbing experience and ability. A significant difference was found for in the percentage of time spent sport climbing ($p = 0.008$), with females spending a significantly greater time sport climbing (mean difference = 24.2%, 95% confidence intervals = 6.5, 42.0), they also spent less time traditional climbing and bouldering, although neither differed significantly.

Table 6.3: *Participants' climbing experience and ability level (mean ± SD).*

	Combined (*n* = 61)	**Male** (*n* = 47)	**Female** (*n* = 14)	**IS *t*-test** $t_{(59)}$ =	p =	**ES (*d*)**
Experience						
Years Climbing	9.9 ± 9.3	10.5 ± 10.1	7.7 ± 5.9	0.998	0.322	0.13
Sessions a week	2.6 ± 1.1	2.6 ± 1.2	2.6 ± 1.1	0.101	0.920	0.01
Discipline						
% Sport	37.1 ± 30.6	31.6 ± 27.4	55.8 ± 34.5	**2.734**	**0.008**	**0.34**
% Traditional	29.7 ± 33.8	32.8 ± 32.9	19.3 ± 36.1	1.319	0.192	0.17
% Boulder	33.0 ± 28.8	35.4 ± 30.7	24.9 ± 20.3	1.203	0.234	0.15
In/out						
% Indoor	53.4 ± 32.2	52.6 ± 32.5	56.4 ± 32.3	0.392	0.697	0.05
% Outdoor	45.7 ± 32.0	46.4 ± 32.2	43.6 ± 32.3	0.286	0.776	0.04
Grade						
Indoor OS (IRCRA)	13.6 ± 1.7	13.8 ± 1.6	12.9 ± 1.8	1.800	0.077	0.23
Indoor RP (IRCRA)	15.7 ± 1.8	15.8 ± 1.7	15.2 ± 1.9	1.094	0.278	0.14

Note: OS on-sight; RP red-point; IRCRA international rock climbing research association; IS independent samples; ES effect size

Anthropometric characteristics (mean ± SD) are presented in **Table 6.4** for the 61 climbers. Gender differences were investigated with a series of independent samples *t*-tests between male and female participants. Significant differences in height ($p < 0.005$) and mass ($p < 0.005$) were found, female climbers were shorter in stature (MD = 0.09 m, CI_{95} = 0.05, 0.12) and lower mass (MD = 11.6 kg, CI_{95} = 6.8, 16.4). Such gender differences are typical of climbers (Watts, 2004) and were to be expected in such a sample.

Table 6.4: *Participants anthropometric characteristics (mean ± SD).*

	Combined (n = 61)	**Male** (n = 47)	**Female** (n = 14)	**IS *t*-test** $t_{(59)}$ =	***p*** =	**ES (*d*)**
Age (years)	33.4 ± 10.1	34.0 ± 10.6	31.6 ± 8.2	0.782	0.438	0.10
Height (m)	1.75 ± 0.07	1.77 ± 0.07	1.68 ± 0.05	**4.581**	**< 0.005**	**0.51**
Mass (kg)	70.0 ± 9.3	72.7 ± 8.2	61.1 ± 6.9	**4.795**	**< 0.005**	**0.54**

Note: m metres; kg kilogramme; IS independent samples; ES effect size

Trait anxiety (STAI), achievement goals (AGQ 2 x 2 framework) and mood state (POMS), are all presented in **Table 6.5** for combined, and male and female participants (mean ± SD). There were no significant gender differences in STAI, POMS total mood disturbance, or any of the sub-components of depression, vigour, confusion, tension, anger or fatigue, or any of the four dimensions of the AGQ, as assessed with a series of independent samples *t*-tests.

Table 6.5: *Response to trait anxiety, achievement goals and mood state questions for male and female participants (mean ± SD).*

	Combined (n = 61)	**Male** (n = 47)	**Female** (n = 14)	**IS *t*-test** $t_{(59)}$ =	***p*** =	**ES (*d*)**
STAI	39.4 ± 9.0	38.6 ± 8.0	42.1 ± 11.7	1.566	0.202	0.20
AGQ						
MAp	16.3 ± 3.6	16.2 ± 3.6	16.4 ± 3.7	0.030	0.912	0.00
MAv	13.3 ± 4.7	12.9 ± 4.6	14.7 ± 4.7	0.044	0.196	0.01
PAp	9.1 ± 4.7	9.4 ± 5.0	8.1 ± 3.7	2.915	0.360	0.35
PAv	8.2 ± 4.8	8.4 ± 5.0	7.6 ± 4.6	0.558	0.587	0.07
POMS						
Total Mood Disturbance	28.4 ± 13.2	28.7 ± 14.0	27.5 ± 10.2	0.292	0.771	0.39
Depression	9.7 ± 3.1	10.0 ± 3.4	8.9 ± 1.8	1.116	0.269	0.14
Vigour	16.7 ± 4.1	16.9 ± 4.1	16.4 ± 4.4	0.393	0.695	0.05
Confusion	7.6 ± 2.8	7.7 ± 3.0	7.4 ± 1.7	0.433	0.666	0.06
Tension	10.3 ± 3.2	10.1 ± 3.1	11.0 ± 3.7	0.952	0.345	0.12
Anger	7.9 ± 1.7	8.0 ± 1.8	7.4 ± 1.3	1.139	0.259	0.15
Fatigue	9.6 ± 3.8	9.7 ± 3.9	9.1 ± 3.6	0.514	0.609	0.07

Notes: STAI state-trait anxiety inventory; AGQ achievement goal questionnaire; MAp mastery approach; MAv mastery-avoidance; PAp performance approach; PAv performance avoidance; POMS profile of mood states; IS independent samples; ES effect size

6.3.2 Group differences in experience and ability

The experience and ability (mean ± SD) of the 61 participants are presented in **Table 6.6**. A series of ANOVAs (ANCOVA for percentage of indoor and outdoor) were used to investigate differences in participants climbing experience and ability, significant differences were found for years climbing (p = 0.001; η_p^2 = 0.201) and sessions a week (p < 0.005; η_p^2 = 0.253). Further follow up post-hoc LSD were significant and revealed CLL^{below} participants had climbed for longer, compared to both CLL^{above} (MD = 8.7 years, CI_{95} = 3.2, 14.0) and CLL (MD = 8.3 years, CI_{95} = 3.2, 13.4); and participated in the sport more regularly, compared to both CLL^{above} (MD = 1.0 sessions, CI_{95} = 0.4, 1.7) and CLL (MD = 1.2 sessions, CI_{95} = 0.6, 1.8).

Table 6.6: *Participants climbing experience and ability level with participant ability (mean ± SD).*

	CLL^{above} (*n* = 17)	**CLL** (*n* = 20)	**CLL^{below}** (*n* = 24)	**ANOVA** $F_{(2, 58)}$ =	*p* =	η_p^2	*FDR*
Experience							
Years Climbing	6.4 ± 9.4	6.7 ± 5.1	15.0 ± 9.9	**7.289**	**0.001**	**0.201**	**0.014**
Sessions a week	2.3 ± 1.1	2.1 ± 0.8	3.3 ± 1.0	**9.811**	**< 0.005**	**0.253**	**0.007**
Discipline							
% Sport	43.5 ± 39.8	37.6 ± 27.1	32.2 ± 26.1	0.675	0.513	0.023	
% Traditional	27.6 ± 39.9	35.4 ± 34.3	26.4 ± 29.3	0.423	0.657	0.014	
% Boulder	28.8 ± 30.6	27.1 ± 24.9	41.0 ± 29.9	1.558	0.219	0.051	
In/out							
**% Indoor*	64.7 ± 31.8	46.3 ± 35.4	51.5 ± 28.8				
Adjusted Mean (SE)	62.6 (7.5)	46.1 (6.8)	53.0 (6.3)	1.335	0.271	0.045	
**% Outdoor*	35.3 ± 31.8	51.3 ± 35.2	48.5 ± 28.8				
Adjusted Mean (SE)	37.2 (7.5)	51.4 (6.9)	47.1 (6.3)	1.004	0.373	0.034	

*Note: OS on-sight; RP red-point; IRCRA international rock climbing research association; FDR false-discovery rate; * Percentage sport climbing significant covariate.*

Anthropometric characteristics are presented in **Table 6.7**. Ability group differences were investigated with a series of one-way ANOVAs. No significant differences were found. It should be noted a greater proportion of the CLL^{above} participants were female, consequently, CLL^{above} were shorter and had a lower mass than CLL and CLL^{below}.

Table 6.7: *Participants anthropometric characteristics and ability (mean ± SD).*

	CLL^{above} (*n* = 17)	**CLL** (*n* = 20)	**CLL^{below}** (*n* = 24)	**ANOVA** $F_{(2, 58)}$ =	*p* =	η_p^2
Gender	8 ♀ 9♂	2♀ 18♂	4♀ 20♂			
Age (years)	32.8 ± 11.6	32.7 ± 9.3	34.5 ± 10.0	0.237	0.790	0.008
Height (m)	1.72 ± 0.09	1.75 ± 0.07	1.77 ± 0.06	2.052	0.138	0.066
Mass (kg)	66.6 ± 10.8	71.4 ± 8.7	71.3 ± 8.3	1.594	0.212	0.052

Note: m metres; kg kilogramme; ♀ female; ♂ male

There were no significant group difference for STAI or POMS, as assessed with a series of one-way ANOVAs (**Table 6.8**). Mastery approach goals were approaching significance (p = 0.007 [FDR = 0.004]; η_p^2 = 0.201), however, following correction for FDR group differences in MAp were not significant.

Table 6.8: *Response to trait anxiety, achievement goals and mood state with participant ability (mean ± SD).*

	CLL^{above} (n = 17)	CLL (n = 20)	CLL^{below} (n = 24)	ANOVA $F_{(2, 58)}$ =	p =	η_p^2	*FDR*
STAI	40.1 ± 12.3	37.5 ± 8.0	40.4 ± 6.9	0.667	0.517	0.022	
AGQ							
MAp	14.5 ± 3.7	15.8 ± 3.9	17.9 ± 2.6	5.361	0.007	0.156	0.004
MAv	13.1 ± 5.6	12.5 ± 4.3	14.1 ± 4.2	0.688	0.507	0.023	
PAp	8.1 ± 3.9	9.1 ± 5.4	9.9 ± 4.7	0.725	0.489	0.024	
PAv	8.4 ± 4.6	7.9 ± 5.4	8.4 ± 4.7	0.074	0.929	0.003	
POMS							
Total Mood Disturbance	31.4 ± 16.3	29.3 ± 12.8	25.6 ± 10.7	1.026	0.365	0.034	
Depression	9.9 ± 4.2	10.0 ± 3.0	9.4 ± 2.3	0.207	0.814	0.007	
Vigour	15.7 ± 4.8	16.8 ± 3.8	17.5 ± 3.7	1.020	0.367	0.034	
Confusion	7.9 ± 3.3	7.6 ± 2.7	7.5 ± 2.5	0.139	0.871	0.005	
Tension	11.2 ± 3.1	10.4 ± 3.3	9.5 ± 3.2	1.397	0.255	0.046	
Anger	7.7 ± 1.8	8.2 ± 1.9	7.8 ± 1.5	0.497	0.611	0.017	
Fatigue	10.1 ± 4.7	10.0 ± 4.0	8.9 ± 3.0	0.728	0.487	0.024	

Notes: STAI state-trait anxiety inventory; AGQ achievement goal questionnaire; MAp mastery approach; MAv mastery-avoidance; PAp performance approach; PAv performance avoidance; POMS profile of mood states; FDR false-discovery rate

6.3.3 Climbing Task Demands

Fourteen of CLL^{above} and seven of CLL did not complete the route. All participants in CLL^{below} were successful. Average and maximum heart rate data was recorded continuously throughout each of the climbs. Data for successful and unsuccessful participants in each of the three groups are presented in **Table 6.9**. Differences were assessed with three two-way ANOVAs for the main effects of 'group' and 'success', as well as the interaction effect 'group*success'. There was no statistically significant interaction for 'group*success' for climbing time (p = 0.364; η_p^2 = 0.015) and no significant effect was indicated for 'success' (p = 0.774; η_p^2 = 0.001). However, differences in the main effect of 'group' were significant (p = 0.034; η_p^2 = 0.113). Post-hoc LSD demonstrated significant differences between CLL^{below} and both CLL^{above} (MD = 40.0 sec, CI_{95} = 5.4, 74.6) and CLL (MD = 44.8 sec, CI_{95} = 16.4, 73.3). There were no significant or meaningful differences in heart rate. There was no statistically significant interaction for 'group*success' for average heart rate (p = 0.511; η_p^2 = 0.009), furthermore no significant main effect was indicated for 'success' (p = 0.554; η_p^2 = 0.007) or 'group' (p = 0.596; η_p^2 = 0.020). There was no statistically significant interaction for 'group*success' for peak heart rate (p = 0.887; η_p^2 < 0.0005) and no significant effect was indicated for 'group' (p = 0.789; η_p^2 = 0.009). However, differences in the main effect of 'success' were significant (p = 0.034; η_p^2 = 0.083). Post-hoc LSD demonstrated unsuccessful participants had significantly greater peak heart rate than those who were successful (MD = 18.6 b.min^{-1}, CI_{95} = 3.8, 33.4).

Table 6.9: *Group differences in success, climbing time and heart rate (mean ± SD).*

	CLL^{above}		**CLL**		**CLL^{below}**	
	F (*n* = 14)	S (*n* = 3)	F (*n* = 7)	S (*n* = 13)	F (*n* = 0)	S (*n* = 24)
Climb Time (Sec)	202.6 ± 68.9	213.9 ± 28.7	224.0 ± 43.3	202.2 ± 36.5		168.3 ± 33.8
Average Heart Rate (b.min^{-1})	157.1 ± 11.7	157.5 ± 20.8	158.8 ± 12.0	151.0 ± 12.1		148.2 ± 18.4
Peak Heart Rate (b.min^{-1})	174.4 ± 22.4	156.1 ± 20.3	181.8 ± 14.7	160.9 ± 31.3		161.6 ± 19.0

Notes: S successful ascent; F unsuccessful ascent; ANOVA analysis of variance; sec seconds; b.min^{-1} beats per minute; FDR false-discovery rate

In addition to the average and maximum heart rate data, **Figure 6.2** displays the average heart rate for each ability group immediately prior to the climb and at each quickdraw, to describe the changes in demand over the climb. Differences in heart rate on the route were greater for CLL^{above}, while CLL and CLL^{below} were much smaller.

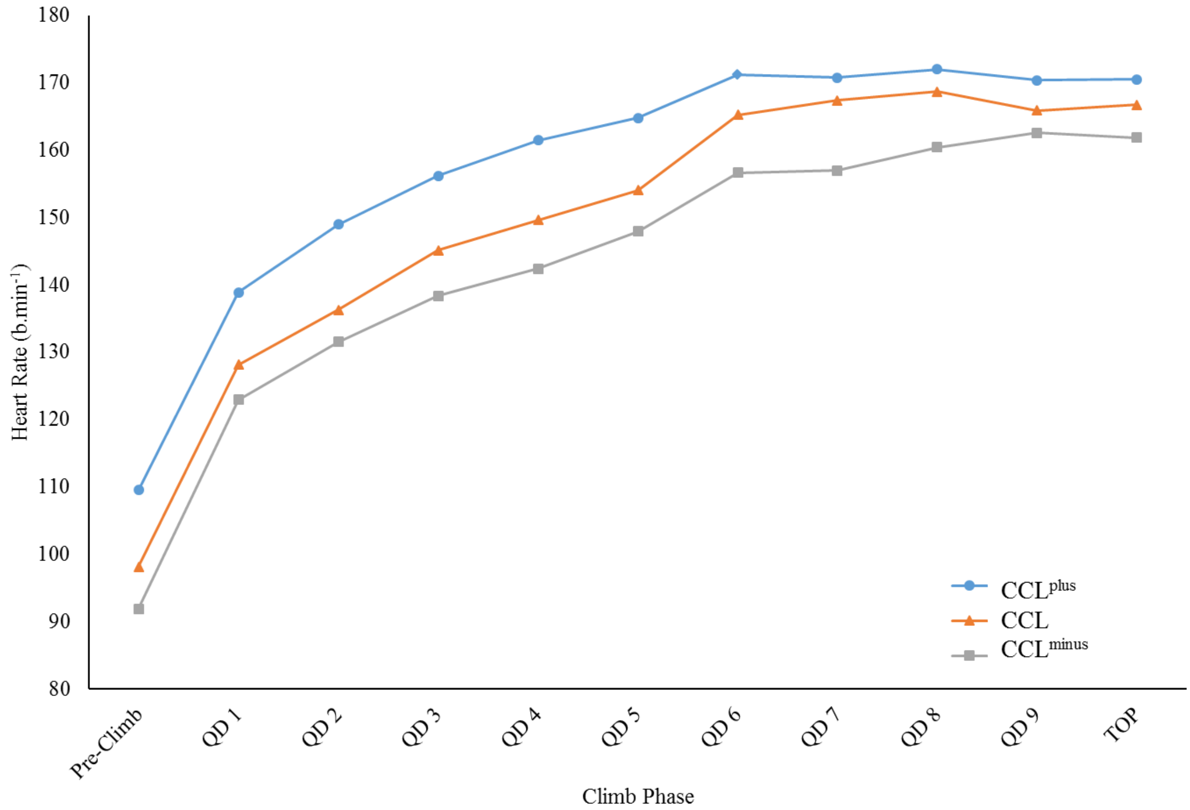


Figure 6.2: *Average heart rate (b.min^{-1}) for the CLL^{above}, CLL and CLL^{below} ability groups pre-climb and across the climb (QD Quickdraw).*

6.3.4 Climbing Performance

Climbing performance was assessed for each of the ability groups (**Table 6.10**). A one-way MANOVA determined group differences in performance. Two dependent variables were assessed, geometric entropy and total coaches' performance score. The difference between groups on the combined dependent variables was statistically significant (p = 0.006; η_p^2 = 0.357). Follow-up one-way ANOVAs showed significance ($p < 0.05$) for both dependent variables. Post-hoc LSD were significant and demonstrated geometric entropy was greater in CLL^{above} (less fluent movement) than both CLL (MD = 0.099, CI_{95} = 0.013, 0.186) and CLL^{below} (MD = 0.126, CI_{95} = 0.043, 0.210). In line with geometric entropy, total coaches score was greatest in CLL^{below}, with significant and meaningful differences between CLL^{above} and both CLL (MD = 9.3, CI_{95} = 3.6, 15.0) and CLL^{below} (MD = 18.5, CI_{95} = 13.0, 24.0), and between CLL and CLL^{below} (MD = 9.2, CI_{95} = 4.0, 14.5). Breakdown of the sub-components of coaches' score revealed significant differences in all five components; post-hoc LSD revealed significance between all measures and all groups.

Table 6.10: *Geometric entropy, coaches' score and movement analysis for the three ability groups (mean ± SD).*

	CLL^{above}	**CLL**	**CLL^{below}**	**MANOVA**	**ANOVA**			
	(n = 17)	(n = 20)	(n = 24)		$F_{(2, 58)}$ =	p =	η_p^2	*FDR*
Geometric Entropy	0.91 ± 0.15	0.81 ± 0.12	0.78 ± 0.11		**4.746**	**0.013**	**0.147**	**0.050**
Total Coaches' Score	40.1 ± 10.0	48.2 ± 8.2	57.4 ± 8.2		**23.085**	**< 0.005**	**0.443**	**0.005**
Base of Support	2.7 ± 0.6	3.3 ± 0.6	3.9 ± 0.7	**p = 0.006**	**19.946**	**< 0.005**	**0.408**	**0.010**
Transitioning	2.4 ± 0.7	2.9 ± 0.6	3.9 ± 0.6	**η_p^2 = 0.357**	**29.639**	**< 0.005**	**0.505**	**0.015**
Co-ordination	2.6 ± 0.8	3.2 ± 0.6	3.9 ± 0.7		**17.491**	**< 0.005**	**0.376**	**0.020**
Technique	2.0 ± 0.6	2.7 ± 0.6	3.5 ± 0.8		**24.005**	**< 0.005**	**0.453**	**0.025**
Tactics	3.0 ± 0.8	3.6 ± 0.7	4.4 ± 0.5		**21.765**	**< 0.005**	**0.429**	**0.030**

Notes: MANOVA multivariate analysis of variance; ANOVA analysis of variance; GI geometric entropy; FDR false-discovery rate

6.3.5 Task Instructions

Task engagement

Heart rate reactivity to the presented task instructions were calculated to assess task engagement (**Table 6.11**), an important prerequisite for the analysis of challenge and threat cardiovascular reactivity (Blascovich et al., 2011). Differences in heart rate were assessed with a two-way mixed ANOVA for the main effects of 'time' (pre- or post-instruction), 'group' (CLL^{above}, CLL, CLL^{below}), as well as the interaction effect 'time*group'. There was no statistically significant interaction for 'time*group' (p = 0.906; η_p^2 = 0.003), or for the main effect 'group' (p = 0.579; η_p^2 = 0.020). However, a significant effect existed for 'time' ($p < 0.005$; η_p^2 = 0.259). Post-hoc paired samples *t*-test showed heart rate to have increased significantly for all ability groups pre-post instructions. Additionally, participants indicated success on the route was important to them, with task importance scores of ≥ 4.3, a one-way ANOVA did not find a significant difference between ability groups (p = 0.867, η_p^2 = 0.005). Finally, the manipulation check indicated all participants engaged in task-relevant thoughts while considering the upcoming climbing task, supporting the heart rate and task engagement data in asserting all groups experienced a motivated performance situation.

Table 6.11: *Engagement with task instructions assessed with task importance and pre-post heart rate ($b.min^{-1}$) (mean ± SD).*

	CLL^{above} (n = 17)	**CLL** (n = 20)	**CLL^{below}** (n = 24)	***Two-way mixed***	**ANOVA** $F_{(2, 58)}$ =	p =	η_p^2
Heart Rate							
Pre-Instruction ($b.min^{-1}$)	83.6 ± 12.0	80.2 ± 12.8	79.2 ± 13.9	p = 0.906			
Post-Instruction ($b.min^{-1}$)	85.4 ± 12.8	82.4 ± 12.5	81.0 ± 14.5	η_p^2 = 0.003			
Task Importance							
How important is doing well?	4.5 ± 1.4	4.3 ± 1.5	4.5 ± 1.9		0.143	0.867	0.005

Notes: ANOVA analysis of variance; $b.min^{-1}$ beats per minute

Cardiovascular markers

Alterations in the cardiovascular markers of cardiac output and peripheral resistance were assessed continuously at rest prior to, during and post presentation of the task instructions (**Table 6.12**). Cardiovascular reactivity were assessed with a one-way MANOVA (cardiac output and total peripheral resistance reactivity). The difference between groups on the combined dependent variables was statistically significant ($p < 0.005$; η_p^2 = 0.617). Follow-up one-way ANOVAs did not demonstrate significance for the increase in cardiac output (p = 0.304 η_p^2 = 0.040), but were significant for the decrease in total peripheral resistance reactivity (p = 0.038, η_p^2 = 0.107). Post-hoc LSD revealed there were significant differences in the total peripheral resistance reactivity between CLL^{above} and CLL (MD = 60.9 $dyn.s.cm^5$, CI_{95} = 12.4, 109.4) and CLL^{below} (MD = 51.9 $dyn.s.cm^5$, CI_{95} = 1.5, 102.4). The combined challenge and threat index did not differ significantly (p = 0.072, η_p^2 = 0.087), although it was negative (towards threat) in CLL^{above}. Resting post instruction alterations in cortisol were measured post presentation of the instructions, while it was lower in CLL^{below}, a one-way ANOVA was not significant.

Table 6.12: *Cardiac output and total peripheral resistance cardiovascular markers pre-post task instructions (mean ± SD).*

	CLL^{above} (*n* = 17)	**CLL** (*n* = 20)	**CLL^{below}** (*n* = 24)	**MANOVA**	**ANOVA** $F_{(2, 58)}$ =	*p* =	η_p^2
Cardiac Output							
Pre-Instruction (L/min)	5.2 ± 0.8	5.3 ± 1.0	5.1 ± 1.3				
Post-Instruction (L/min)	5.5 ± 0.9	5.7 ± 1.1	5.4 ± 1.4				
Peripheral Resistance							
Pre-Instruction (dyn.s.cm^5)	1397 ± 287	1372 ± 296	1545 ± 404				
Post-Instruction (dyn.s.cm^5)	1404 ± 298	1327 ± 312	1481 ± 382				
Reactivity							
Cardiac Output (L/min)	0.25 ± 0.25	0.38 ± 0.29	0.34 ± 0.25	**$p < 0.005$**	1.215	0.304	0.040
Peripheral Resistance (dyn.s.cm^5)	7.3 ± 70.7	-44.6 ± 61.0	-53.6 ± 90.4	**$\eta_p^2 = 0.617$**	**3.466**	**0.038**	**0.107**
Challenge and Threat Index	-0.81 ± 1.53	0.35 ± 1.74	0.28 ± 1.73		2.755	0.072	0.087
Cortisol (nmol/L)	3.22 ± 3.33	2.52 ± 1.86	2.18 ± 1.63		0.997	0.376	0.034

Notes: ANOVA analysis of variance; nmol/L nanomoles per litre; CO cardiac output; dyn.s.cm^5 vascular resistance; FDR false-discovery rate

Self-report measures

A series of one-way ANOVAs (except for achievement goals, which were investigated using a one-way MANOVA) were used to assess differences in self-efficacy, cognitive evaluation, perceived control, demand resources and achievement goals (**Table 6.13**). Self-reported self-efficacy was significantly different between groups ($p < 0.005$, $\eta_p^2 = 0.367$). Post-hoc LSD indicated self-efficacy was significantly greater for both CLL (MD = 1.4, CI_{95} = 0.6, 2.2) and CLL^{below} (MD = 2.3, CI_{95} = 1.5, 3.1) when compared with CLL^{above}. Self-efficacy was also found to be significantly greater for CLL^{below} (MD = 0.9, CI_{95} = 0.1, 1.6) compared to CLL. Cognitive evaluation and perceived control did not differ significantly between groups ($p = 0.710$, $\eta_p^2 = 0.012$ and $p = 0.426$, $\eta_p^2 = 0.029$, respectively). Demand resource evaluation were statistically significant ($p < 0.005$, $\eta_p^2 = 0.418$). Post-hoc LSD showed significant and meaningful differences between CLL^{above} and both CLL (MD = 2.4, CI_{95} = 1.2, 3.6) and CLL^{below} (MD = 3.6, CI_{95} = 2.5, 4.8) as well as between CLL and CLL^{below} (MD = 1.2, CI_{95} = 0.2, 2.3). Achievement goals were comprised of four dependent variables. The difference between groups on the combined dependent variables was not statistically significant.

Table 6.13: *Self-report measures assessed post instructions for each of the three ability groups (mean ± SD). For cognitive evaluation, more +ve score indicates a challenge state, -ve more threatening; for demand resources, more +ve indicates coping resources outweighing demands.*

	CLL^above^	CLL	CLL^below^		ANOVA			
	(n = 17)	(n = 20)	(n = 24)	**MANOVA**	$F_{(2, 58)}$ =	p =	η_p^2	*FDR*
Self-Efficacy	3.3 ± 1.1	4.7 ± 1.4	5.6 ± 1.2		**6.847**	**< 0.005**	**0.367**	**0.013**
Cognitive Evaluation	1.5 ± 1.7	1.1 ± 1.2	1.2 ± 1.4		0.345	0.710	0.012	
Perceived Control	5.3 ± 1.6	5.9 ± 1.0	5.8 ± 1.5		0.866	0.426	0.029	
Demand Resource	-2.1 ± 1.5	0.4 ± 1.7	1.6 ± 2.0		**20.818**	**< 0.005**	**0.418**	**0.025**
Achievement Goals								
MAp	4.6 ± 1.7	5.1 ± 1.3	5.6 ± 1.2	p = 0.221 η_p^2 = 0.090				
MAv	3.5 ± 2.1	3.7 ± 1.5	3.5 ± 1.9					
PAp	2.1 ± 1.4	2.8 ± 1.8	2.5 ± 1.7					
PAv	2.3 ± 1.3	2.3 ± 1.6	2.3 ± 1.6					

Notes: MAp mastery approach; MAv mastery-avoidance; PAp performance approach; PAv performance avoidance; MANOVA multivariate analysis of variance; ANOVA analysis of variance; FDR false-discovery rate

6.3.6 Pre-climb

Emotions

Subjective assessment of the intensity and direction of somatic and cognitive anxiety and self-confidence, were assessed immediately prior to the climb with the IAMS (**Table 6.14**) and analysed with a series of one-way ANOVAs (self-confidence one-way ANCOVA). The results highlighted significant differences in somatic anxieties intensity and direction (p < 0.005, η_p^2 = 0.565; p < 0.005, η_p^2 = 0.325; respectively). Post-hoc LSD were significant and indicated meaningful differences occurred between CLL^{above} and both CLL (MD = 21.1, CI_{95} = 14.7, 27.4) and CLL^{below} (MD = 25.4, CI_{95} = 19.3, 31.5), while the direction was significant between CLL^{above} and both CLL (MD = 21.2, CI_{95} = 12.8, 29.6) and CLL^{below} (MD = 14.5, CI_{95} = 6.4, 22.5). The intensity of cognitive anxiety was significant (p = 0.005, η_p^2 = 0.169), but the direction was not. Post-hoc LSD were significant and indicated meaningful differences between CLL^{above} and both CLL (MD = 11.1, CI_{95} = 0.9, 21.3) and CLL^{below} (MD = 16.8, CI_{95} = 7.0, 26.6). Finally, self-confidence intensity and direction were both significant (p < 0.005, η_p^2 = 0.235 and p < 0.005, η_p^2 = 0.298, respectively). Post-hoc LSD were significant and revealed meaningful differences between CLL^{below} and both CLL^{above} (MD = 17.6, CI_{95} = 8.9, 26.3) and CLL (MD = 19.1, CI_{95} = 10.7, 27.5); and the direction between CLL^{above} and both CLL (MD = 17.6, CI_{95} = 8.9, 26.3) and CLL^{below} (MD = 19.1, CI_{95} = 10.7, 27.5).

Table 6.14: *Pre-climb emotional state, assessed immediately prior to climbing for the three ability groups (mean ± SD).*

	CLL^{above} (*n* = 17)	CLL (*n* = 20)	CLL^{below} (*n* = 24)	ANOVA $F_{(2, 58)}$ =	*p* =	η_p^2	*FDR*
Somatic Anxiety							
Intensity	40.1 ± 11.0	19.0 ± 9.5	14.7 ± 8.5	**37.715**	**< 0.005**	**0.565**	**0.008**
Direction	-8.5 ± 13.1	-1.7 ± 16.7	12.7 ± 9.7	**13.951**	**< 0.005**	**0.325**	**0.017**
Cognitive Anxiety							
Intensity	35.1 ± 15.9	24.0 ± 17.3	18.3 ± 13.4	**5.917**	**0.005**	**0.169**	**0.042**
Direction	-5.8 ± 14.1	-2.3 ± 16.9	4.0 ± 16.5	1.963	0.150	0.063	
Confidence							
**Intensity*	26.2 ± 13.7	39.2 ± 19.0	48.1 ± 13.7				
Adjusted Mean (SE)	27.1 (3.7)	39.2 (3.4)	47.4 (3.1)	**8.773**	**< 0.005**	**0.235**	**0.025**
Direction	-2.71 ± 14.05	14.9 ± 14.43	16.44 ± 11.05	**12.105**	**< 0.005**	**0.298**	**0.033**

Notes: ANOVA analysis of variance; FDR false-discovery rate; * % sport climbing significant covariate.

Anticipatory heart rate and delta cortisol concentrations were considered together to assess alterations in the psychophysiological component pre-climb. These were analysed using a one-way MANOVA, with the two dependent variables (**Table 6.15**). The difference between groups on the combined dependent variables was statistically significant (p = 0.037; η_p^2 = 0.089). Follow-up one-way ANOVAs demonstrated significance in pre-climb heart rate (p = 0.002, η_p^2 = 0.187), but not for the change in cortisol concentration (p = 0.816, η_p^2 = 0.007). Post-hoc LSD revealed there was a significant difference in average pre-climb heart rate between the CLL^{above} and CLL^{below} ability groups (MD = 20.9%, CI_{95} = 9.4, 32.3).

Table 6.15: *The psychological components of anticipatory heart rate and delta cortisol concentrations for the three ability groups (mean ± SD).*

	CLL^{above} (*n* = 17)	CLL (*n* = 20)	CLL^{below} (*n* = 24)	MANOVA	ANOVA $F_{(2, 58)}$ =	*p* =	η_p^2	*FDR*
Anticipatory Heart Rate (%)	36.3 ± 22.7	24.7 ± 18.3	15.4 ± 19.6	***p* = 0.037** η_p^2 **= 0.089**	**6.687**	**0.002**	**0.187**	**0.002**
Cortisol % Pre-Post	12.9 ± 35.6	15.0 ± 33.4	8.8 ± 31.1		0.204	0.816	0.007	

Notes: MANOVA multivariate analysis of variance; $b.min^{-1}$ beats per minute; FDR false-discovery rate

6.3.7 Correlations: Challenge and threat index and performance

The challenge and threat index allows the comparison of reactivity to be assessed with a single measure. Pearson's correlation were calculated (**Table 6.16**) and revealed several significant (p < 0.05) correlations. Greater challenge and threat index was associated with greater self-confidence interpretation (r = 0.266), perceived control (r = 0.312), performance approach (r = 0.308) and performance avoidance goals (r = 0.295). Greater coaches assessed performance was associated with a lower somatic anxiety (r = -0.560) and greater self-confidence intensity and direction (*r* = 0.405 and *r* = 0.460, respectively), greater self-efficacy (*r* = 0.507) and greater demand resources evaluation (*r* = 0.519).

Table 6.16: *Mean ± SD and correlation (r =) for performance, psychological variables, and the challenge and threat index.*

		Mean ± SD	Challenge and Threat Index	Coaches Assessment of Performance
Psychophysiological				
Heart Rate %		24.3 ± 19.6	-0.010	-0.131
Cortisol %		11.9 ± 32.5	-0.055	0.313
Performance				
Coaches' Score		49.2 ± 11.4	0.220	-
Geometric Entropy		0.82 ± 0.13	-0.122	-0.407**
Emotions				
Somatic Anxiety	*Intensity*	23.2 ± 14.3	-0.099	-0.560**
	Direction	2.1 ± 15.9	0.015	0.247
Cognitive Anxiety	*Intensity*	24.9 ± 16.7	0.018	-0.249
	Direction	-0.8 ± 16.2	0.041	0.011
Self-Confidence	*Intensity*	39.0 ± 17.8	0.218	0.481**
	Direction	10.5 ± 15.4	0.266*	0.460**
Self-Report				
Self-Efficacy		4.7 ± 1.5	0.156	0.507**
Cognitive Evaluation		1.2 ± 1.4	-0.035	-0.014
Perceived Control		5.7 ± 1.4	0.312*	0.229
Demand Resource		0.2 ± 2.3	0.197	0.519**
Achievement Goals	*MAp*	5.1 ± 1.4	0.172	0.230
	MAv	3.5 ± 1.8	0.205	0.030
	PAp	2.5 ± 1.6	0.308*	-0.122
	PAv	2.3 ± 1.5	0.295*	-0.195

*Notes: MAp mastery approach; MAv mastery-avoidance; PAp performance approach; PAv performance avoidance; *p < 0.05; **p* < 0.01

6.4 Discussion

The aim of *Study Two* was to examine differences in climber ability, relative to route difficulty, assessing participants' subjective psychological, objective physiological and behavioural responses. Specifically, the analysis focused on differences in participants' responses for those who were attempted a route set at their self-reported indoor on-sight grade (CLL), above their on-sight grade (CLL^{above}) or below their on-sight grade (CLL^{below}). To achieve this, 61 intermediate to advanced level climbers (French 6a to 6c+; 11 to 16 IRCRA; 5.10b to 5.11c YDS) attempted a single on sight ascent of a designated test route. The test route was graded 6b (13 IRCRA; 5.10d YDS) and was set so that the bottom half of the route was slightly easier than the top half. This was done to ensure participants were able to reach a safe distance from the ground before the likelihood of falling increased. Climbers listened to pre-recorded task instructions within 15 minutes of starting their ascent. Responses to the task were measured before and after receiving the task instructions, and pre, during and post climb.

The main findings of *Study Two*, investigating the differences based on route difficulty relative to the climber were: a) significant and meaningful improvements in the quality and fluidity of climbing performance with an increase in ability relative to the route; b) greater intensity of somatic anxiety and cognitive anxiety and lower self-confidence between CLL^{above} and both CLL and CLL^{below}; c) a significant difference in anticipatory heart rate, between CLL^{above} and CLL^{below}, but no significant or meaningful differences in salivary cortisol; d) cardiovascular reactivity indicative of a threat evaluation in CLL^{above} and challenge evaluation in CLL and CLL^{below}, although variation obscured any significance. The results of *Study Two* demonstrate a predictable difference in performance and success with relative route difficulty, supporting self-reported ability (Draper et al., 2016). Furthermore, the results show that an increase in the likelihood of a climber falling is evaluated as threatening, which in turn increases the psychophysiological and emotional response and is speculated to also be partially responsible for differences in performance. The results highlight the importance of the consideration of relative route difficulty in psychophysiology research; as well as the challenges faced by intermediate climbers attempting routes at and above their on-sight ability indoors.

To my knowledge, this is the first study to have explored climbers' responses to an on-sight ascent of a route, which asked participants of a range of abilities to attempt a single on-sight ascent of the same route indoors. While both Hardy and Whitehead (1984) and Hardy and Hutchinson (2007) have explored climbers responses to ascents of routes of different grades, they employed a repeated measures design outdoors and did not ask participants to attempt routes beyond their best on-sight ability. *Study Two* was also one the largest climbing studies completed to date. The complexity and time-consuming nature of the data collection and analysis typically preclude such large samples. Finally, as with *Study One*, it was also one of the first studies to use detailed performance measures while also exploring accompanying psychophysiological and emotional responses.

Route difficulty is one of the primary considerations for the indoor climber when selecting routes to attempt (Watts, 2004). Increased relative route difficulty results in greater physiological demands placed on the climber (Janot et al., 2000; Mermier et al., 1997; Watts & Drobish, 1998). Furthermore, an increase in the grade of the route also increases the likelihood the climber will be unable to complete it on their first attempt. A climber attempting a route they are unable to complete is faced with two choices; either they will fall, which is a potentially physically threatening situation, or should ask to be taken tight on the rope, potentially ego-threatening (Hurni, 2003). The potential for falling and an associated perceived concern of injury is often considered a potent stressor for climbers and one of the most difficult for them to overcome (Hurni, 2003; Macleod, 2010; Sagar, 2001). *Study One* demonstrated lead climbing to be a considerable stressor, with greater anxiety, reduced confidence and lower performance when compared with ascending the same route using a top-rope. Other factors considered, based on an alteration in the safety protocol the emotional response occurs because of the potential for and perceived consequences of a leader fall (Bisharat, 2009; Hörst, 2011). *Study Two* demonstrated that a factor such as route difficulty, which alters the likelihood of a climber falling, is also a significant stressor. These finding support those of Hardy and Hutchinson (2007) who concluded the threat of physical harm accompanying harder routes, especially when leading, is a major determinant of climbing performance anxiety.

The consideration of route difficulty also has methodological implications. While Hardy and Whitehead (1984) and Hardy and Hutchinson (2007) have both explicitly manipulated the grade of the route relative to climbers ability, other studies may have unintentionally introduced variability; for example, within the style of ascent studies discussed in *Chapter 3* and *Study One*, it is conceivable the difficulty of the route relative to the ability of participants was a covariate. Discussed studies have highlighted that route difficulty has implications for both the physiological demands (Janot et al., 2000; Mermier et al., 1997; Watts & Drobish, 1998) and the psychological response (Hardy & Hutchinson, 2007; Hardy & Whitehead, 1984). The following section will focus on the analysis of physiological, psychological and behavioural data.

6.4.1 Anthropometrics and demographics

The anthropometric and demographic characteristics of the climbers in *Study Two* are presented in **Table 6.3**, **Table 6.4** and **Table 6.5**. Recruited participants were considered healthy and normal and were not taking any medications that may have affected the measurements taken. Participant's on-sight ability ranged between 6a+ to 6c+ (IRCRA 12 to 16; YDS 5.10c to 5.11c; *see 4.2.1 Self-reported ability and experience*). The difficulty of the route was set so the bottom half was graded f6a and the top half f6b+, providing an overall grade of f6b (IRCRA 13; YDS 5.10d). As with *Study One*, participants' red-point grade, was an average of half a grade greater than their on-sight grade. There were no meaningful, or significant differences between male and female participants in terms of years climbing, time spent climbing indoors or out and on-sight and red-point grades (**Table 6.3**). However, there were differences in the time spent sport climbing, with female climbers spending a significant and meaningfully greater amount of their time in this discipline (56% vs. 32% for males). Because of the difference in the time spent sport climbing, it was considered as a covariate during analysis.

There were no differences in overall mood state, or its subcomponents, achievement goal disposition, or trait anxiety (**Table 6.5**). However, as with *Study One*, there were significant differences in the height and mass of the male and female climbers (**Table 6.4**). The female climbers were shorter in stature and had lower body mass than their male counterpart. Despite these differences, as with *Study One*, gender was not considered a covariate in the analysis. There is no conceptual relationship between height or body mass and the measures assessed, be it psychophysiological, psychological or behavioural; participants were recruited based on their self-reported on-sight lead climbing grade and, while it is possible, height and mass influence this, as participants were recruited based on this factor it is unlikely to have impacted on performance. Furthermore, recent studies have shown body fat percentage and mass may not be a prerequisite for a high level of climbing performance, being just one of several attributes (Macdonald & Callender, 2011).

The participants of *Study Two* were divided into three groups, based on their self-reported on-sight grade (Draper et al., 2011b; Draper et al., 2016). The anthropometric and demographic characteristics of the three ability groups are presented in **Table 6.6**, **Table 6.7** and **Table 6.8**. There were significant group differences in both the number of years climbing and sessions a week; CLL^{below} participants had climbed for 8.7 (CI_{95} = 3.2, 14.0) and 8.3 (CI_{95} = 3.2, 13.4) years longer than CLL^{above} and CLL, respectively. The CLL^{below} climbers participated more regularly, with 1 session more a week (CI_{95} = 0.4, 1.7) compared to CLL^{above} and 1.2 sessions per week more (CI_{95} = 0.6, 1.8) compared to CLL. There were no significant differences for each discipline, with climbers spending 32% to 44% of their time sport climbing and 45% to 52% climbing indoors. Draper et al. (2011d) found similar differences in years climbing and years leading between successful and unsuccessful climbers, with successful climbers having climbed and led for significantly longer.

Participants of CLL^{above} spent a greater proportion of their time sport climbing, this was likely to be due to the greater proportion of females in CLL^{above} (8 ♀ 9♂), compared to CLL

(2♀ 18♂) and CLL^{below} (4♀ 20♂). Despite the gender distribution, there were no significant or meaningful differences in age, height or mass (**Table 6.7**). Similarly, there were no significant differences in trait anxiety, or total mood disturbance or any of its subcomponents (**Table 6.8**), as reported following completion of consent, but before the presentation of the task instructions. Mastery approach goals, assessed via the achievement goals questionnaire, were approaching significance before correction for FDR, with CLL^{below} having greater mastery approach disposition than CLL^{above}, with a difference of 3.4 arbitrary units, (CI_{95} = 1.2, 5.5) and CLL of 2.2 arbitrary units, (CI_{95} = 0.1, 4.2). The values of mastery approach for CLL^{below} were in line with the climbers of *Study One*, although CLL and CLL^{above} were lower than values seen previously. The other components of the achievement goals were also in line with those of *Study One*, with a greater mastery disposition as opposed to performance. The achievement goal results describe a focus on performing a task as well as possible, or trying to surpass previous performance, while participants were less concerned about losing a contest or appearing incompetent in comparison with others (Duda, 2005).

6.4.2 Climbing task demands and performance

Participants attempted a single on-sight ascent, consequently, aside from grade, they were not provided with any information on the routes they were to attempt prior to starting to climb, but were informed of the colour of holds and which quickdraws they were to use. Because of the relative difficulty of the route, only a small proportion of CLL^{above} group were successful (reached the top of the route), with only 18% completing the route, compared to 65% and 100% of the CLL and CLL^{below} groups, respectively. It is possible the three climbers successful in the CLL^{above} group under-reported their climbing ability, as was found by Draper et al. (2011b). There were no anthropometric or demographic characteristics that set the three CLL^{above} successful climbers, one female and two males, apart from those who were unsuccessful. The distribution of success and failure of the participants across the three ability groups in the current study appear to further demonstrate the validity of self-reported climbing grades as suggested by Draper et al. (2011b), Draper et al. (2016) and Giles et al. (2017b).

Participants' heart rate were recorded continuously throughout the climb to provide an indication of the relative physiological load. Climbing time and heart rate data is presented in **Table 6.9** and **Figure 6.2**. There were significant differences in climbing time with a 40-second difference (CI_{95} = 5.4, 74.6) between CLL^{above} and CLL^{below}, and 44.8 sec between CLL and CLL^{below} (CI_{95} = 16.4, 73.3). However, there were no significant differences in average or peak heart rate on the route between groups, or an interaction between conditions, or success.

However, unsuccessful participants had significantly greater peak heart rate than those who were successful (MD = 18.6 $b.min^{-1}$, CI_{95} = 3.8, 33.4). The values observed in the current study are comparable with previous studies that have assessed responses to lead climbing (Aras & Akalan, 2011; Draper et al., 2008; Draper et al., 2010; Fryer et al., 2013). The results are also in line with those of Mermier et al. (1997), Watts and Drobish (1998) and Janot et al. (2000) with increased climbing difficulty bringing about greater heart rate, although, not always significantly. However, as with *Study One*, while the results of *Study Two* support the use of heart rate as an indication of physiological load, they do not support the use of average or maximum heart rate as an indication of the psychological challenge, as the results are obscured by other factors. Climbing time is likely to be an influential factor in heart rate observed, with lower heart rates observed when climbing time is greater, and *vice versa*.

Climbers performance was assessed using measures of geometric entropy and coaches' score (**Table 6.10**) and were found to differ significantly between ability groups. Further differences were apparent in all measures. Not only were the CLL^{above} participants less likely to be able to complete the route, but CLL^{above} also had greater entropy of their climbing trajectory (CLL^{above} 0.91 ± 0.15; CLL 0.81 ± 0.12; CLL^{below} 0.78 ± 0.11). The individual components of coaches' assessment of performance (base of support, transitioning, coordination, technique and tactics) were also significantly lower in CLL^{above} than both CLL and CLL^{below}. Greater geometric entropy indicated a less smooth displacement of the body's centre of mass, and is a characteristic of less skilled climbing behaviour (Cordier et al., 1993; Cordier et al., 1994). Greater geometric entropy has been demonstrated to also occur with increased levels of anxiety in *Study One* and previously in Pijpers et al. (2003). Similarly, the scores for the sub-components of performance for CLL^{above} were lower than those of even the run-out condition of *Study One*, while the scores of CLL^{below} were in line with those obtained in the top-rope condition of *Study One*. It is not possible to determine the exact cause of the deterioration in performance seen, this could be attributed to either the physical demands of the task and/or anxious disruption of performance (Nieuwenhuys & Oudejans, 2012). As the physical demands assessed with heart rate across all three groups were similar, it is possible the performance of the climbers of the present study were limited to a greater extent by technical performance, than physiological. It is speculated that this may be a characteristic of the formative nature of intermediate climbers' performance, and may not be true of more experienced climbers.

To summarise, participant's performance was significantly affected by attempting routes of differing relative difficulty. While there were no significant differences in the physical responses, there were meaningful differences in geometric entropy and coaches' performance assessment between groups. It is conceivable differences in climbing performance on the routes occurred because of physical climbing ability, but also because of a climber's ability to manage anxiety occurring because of the potential for falling. Not only may the chance of and potential for a fall be anxiety inducing, but the anxiety the climber experiences may also limit their ability to complete the route they are attempting (Hague & Hunter, 2011). To explore this, following the same methodology as *Study One*, objective physiological and subjective psychological measures were made in response to the task instructions, prior to the climber's attempt at the route itself and in response to the climb. Differences in these factors will be discussed in the following sections.

6.4.3 Cardiovascular reactivity to task instructions

Prior to the single on-sight attempt at the route, participants were provided with audiotaped task instructions, highlighting the demands of the climb, in particular, the graded difficulty of the route. Indoor lead climbing offers situations with salient task demands; perceived danger because of the possibility of taking a lead fall; uncertainty because the route is unknown and on-sight, and being presented with a task requiring an unknown amount of effort to complete. The TCTSA provides a theoretical framework for the objective quantification of participants' demand and resource evaluations of such factors (Seery, 2011). Through the assessment of participants' cardiovascular responses to task instructions, it is possible to gain an objective insight into the participant's evaluation of the task instructions (Jones et al., 2009). The cognitive evaluation theory (Lazarus, 1991) proposes two levels of evaluation; the primary appraisal establishes how important the situation is to an individual and whether it might endanger their well-being; the secondary cognitive evaluation process concerns the coping options available. If participants evaluated they had insufficient coping resources than threat cardiovascular reactivity patterns would be observed; while if they believed their resources match or exceed the demands of the task then challenge cardiovascular reactivity would be observed.

With respect to the current study, it is conceivable that attempting an on-sight ascent of a route with a difficulty level beyond, at, or below the ability of the participants would cause differences in appraisal of their coping resources relative to the task demands. An increase in the grade of a route, relative to the ability of the climber, creates a state in which the perceived demands of the climbing task, occurring because of perceived danger and uncertainty, may exceed the coping resources of the climber attempting the route (Lazarus, 1991). The cardiovascular data somewhat supports these predictions (**Table 6.12**). There were significant differences in cardiovascular reactivity for total peripheral resistance (CLL^{above} to CLL, MD = 61.6 $dyn.s.cm^5$, CI_{95} = -0.4, 123.6; CLL^{above} to CLL^{below}, MD = 78.1 $dyn.s.cm^5$, CI_{95} = 18.5, 137.7), but not cardiac output. The weighted challenge and threat index was approaching significance, with CLL^{above} participants possessing a negative index (-0.81 ± 1.53; threat reactivity), while both CLL and CLL^{below} reported a positive score (0.35 ± 1.74 and 0.28 ± 1.73, respectively; challenge reactivity). From the cardiovascular reactivity results presented above, CLL^{above} may be experiencing reactivity towards a threat state, with smaller-than-challenge increases in heart rate and cardiac output and no change or a small increase in total peripheral resistance. Conversely, both the CLL and CLL^{below} groups appear to exhibit cardiovascular reactivity indicative of a challenge state, with increased cardiac output and reduced total peripheral resistance (Jones et al., 2009).

The results of the present study appear to be in line with those hypothesised, and are further supported by the differences in the intensity of somatic anxiety, cognitive anxiety and self-confidence (*see 6.4.4 Pre-climb psychophysiology and emotion*), along with pre-climb anticipatory heart rate, and assessed performance. In addition, there were significant differences in participants' appraisal of the task demands and their coping resources. Meaningful differences in demand resource evaluation were found between CLL^{above} and both CLL (MD = 2.4, CI_{95} = 1.2, 3.6) and CLL^{below} (MD = 3.6, CI_{95} = 2.5, 4.8) as well as between CLL and CLL^{below} (MD = 1.2, CI_{95} = 0.2, 2.3), with the greatest differences seen between CLL^{above} and both CLL and CLL^{below}. The cardiovascular reactivity results suggest an imbalance between the CLL^{above} group's cognitive appraisal of the task demands and their coping resources, which act as a mediator between stressors and the individual's stress response (Lazarus, 1991). Further supporting this assertion, there was a significant positive correlation (r = 0.519) between coaches assessed performance and demand resources evaluation. It is likely that CLL^{above} participants perceived the task demands as exceeding their coping resources, as supported by self-report and reactivity data.

Challenge states may result in superior performance by promoting more favourable emotional responses and interpretation of emotions (Mendes et al., 2007; Moore et al., 2012; Moore et al., 2013; Turner et al., 2014). While it has not been possible to determine the contribution of performance occurring in this instance because of the technical difficulty of the route and the evaluation of the participants, the greater threat evaluation indicates that performance decrements in CLL^{above} may have, in part, occurred because of their appraisal of the difficulty of the route. A number of associated mechanisms have been explored in previous challenge and threat research. Differences in performance may occur because of more effective attention compared to a threat state (Blascovich et al., 2004; Jones et al., 2009; Skinner & Brewer, 2004). In particular greater quiet eye durations, which has been found to be important in gaze behaviour and attentional control in aiming tasks (Mann et al., 2007). Muscular tension is also possibly greater during a threat state than a challenge state (Blascovich et al., 2003; Moore et al., 2012; Moore et al., 2013). In a climbing context disruption of performance has been observed to occur through reduced degrees of freedom of the climbers movement (Pijpers et al., 2003), increased movement entropy and climbing time (Pijpers et al., 2003), increased explorative movements (Pijpers et al., 2005), and an increase in eye fixation duration (Nieuwenhuys et al., 2008). A combination of these factors may have contributed to disrupted climbing performance, demonstrated in the reduced fluency of movement and lower coaches assessed performance scores observed in this study.

Performance outcomes, and the climbers' resultant behaviour and emotional response to their state, are likely to be mediated by several factors, including perceived control (Jones, 1995), self-efficacy (Bandura, 1997) and achievement disposition (Duda, 2005), as described in the TCTSA (Jones et al., 2009). These factors are thought to come together, to determine participants coping ability. There was no significant or meaningful group differences in perceived control in the present study, and while perceived control was significantly correlated with the challenge and threat index ($r = 0.312$), it explained only ~10% of the variability. The control model of anxiety (Jones, 1995) promotes perceived control over coping and goal attainment as an important mediator of anxiety interpretation. Anxiety is interpreted as facilitative when expectations of coping and goal attainment are positive and debilitative when expectations of coping and goal attainment are negative. The current study does not appear to support this, with significant differences in anxiety and interpretation, despite a lack of differences in perceived control.

Perceptions of self-efficacy are likely to be important to climbers, particularly with respect to changes in route difficulty. Greater self-efficacy has been associated with participants being less likely to fear failure (Kontos, 2004). Similarly, Llewellyn et al. (2008) found greater self-efficacy were associated with climbers taking greater calculated risks, attempts of harder climbs and with climbers having greater feelings of confidence in their ability. An athlete's belief they have the skills necessary to execute the course of actions required to succeed is a key aspect of the resource appraisals and contributes significantly to climbers' perception they can cope with the tasks (Bandura, 1997). The results of the current study appear to support this with differences in participants' self-reported self-efficacy between all three ability groups (CLL^{above} to CLL, MD = 1.4, CI_{95} = 0.6, 2.2; CLL^{above} to CLL^{below}, MD = 2.3, CI_{95} = 1.5, 3.1; CLL to CLL^{below}, MD = 0.9, CI_{95} = 0.1, 1.6). Further supporting this assertion, there was a significant positive correlation between coaches' assessment of performance and self-efficacy (r = 0.507) across the three ability groups.

Finally, it was also hypothesised that an ascent of a route below a climber's on-sight ability (CLL^{below}) would be considered ego-threatening, thus resulting in threat reactivity, greater stress response, and reduced performance when compared with an ascent at a climber's on-sight ability level. Although it is possible, as speculated in *Study One* and by Hardy and Hutchinson (2007), participants may find top-roping a route towards their lead limit ego-threatening. It would, therefore, appear reasonable to expect a similar effect when asking climbers to attempt a route below their on-sight grade while being assessed; the hypothesis was not supported by the results of the present study. There were no significant differences in either the full achievement goal questionnaire, or the achievement disposition completed by the participants following the presentation of the task instructions. While the on-sight lead of a route below the participant's on-sight ability did not appear to be ego-threatening, anecdotally several the more experienced participants expressed disappointment at attempting a route they would consider too easy and they would not find challenging.

As hypothesised, in line with significant and meaningful differences in technical climbing performance, cognitive anxiety, somatic anxiety and self-confidence and anticipatory changes in heart rate, CLL^{above} were found to be experiencing cardiovascular reactivity indicative of a threat appraisal, compared to CLL and CLL^{below}. The CLL^{above} cardiovascular reactivity resulted in smaller-than-challenge increases in cardiac output and no change, or a small increase in peripheral resistance reactivity (Jones et al., 2009). Furthermore, the CLL^{above} participants' evaluation of the demands of the task, relative to their resources to cope with the challenges was also significant and meaningfully lower than those of both the CLL and CLL^{below}. It is possible, as speculated in *Study One*, that a more threatening state occurred in CLL^{above} because attempting a route beyond a climber's on-sight ability for an intermediate climber is a more novel task than leading a submaximal route. Further, it is reasonable to suggest that the threat state was responsible for some differences in performance, although it is not possible to directly attribute the changes to psychological factors or simply because of an increase in the difficulty of the route.

Unlike differences in the style of ascent of *Study One*, the relative difficulty of a route brought about demand-resource evaluations and cardiovascular reactivity in line with the predictions of BPS and TCTSA (Blascovich et al., 2004; Jones et al., 2009). Specifically, greater route difficulty, relative to the ability of a climber, resulted in demands outweighing resources and threat cardiovascular reactivity. Demand appraisals likely occurred in response to two factors, firstly uncertainty about the route to be completed as, while participants were aware of the difficulty of the route, they completed the route on-sight without prior practice; secondly, perceptions of danger due to the anticipation of the potential for a lead fall. While research testing the predictions of theories of challenge and threat have explored situations believed to elicit differences in perceptions of uncertainty and effort, no evidence has been presented for situations eliciting differences in perceptions of danger. Both changes in the style of ascent (*Study One*) and the relative difficulty of a route (*Study Two*) were both hypothesised to bring about danger demand appraisals, but both produced conflicting results. Further research is necessary to understand the antecedents of demand appraisals in climbing, particularly differences in stressors. However, unlike the style of ascent of Study One, relative route difficulty may prove to be a valid means of instigating danger evaluations in participants, further research would be necessary to confirm this.

6.4.4 Pre-climb psychophysiology and emotion

In line with previous climbing psychophysiology research, including *Study One*, alterations in salivary cortisol concentrations pre- to post-climb and anticipatory heart rate recorded one minute prior to climbing were assessed (Dickson, 2013; Draper et al., 2012; Draper et al., 2010; Fryer, 2013; Hodgson et al., 2009). Activation of the sympathetic-adreno-medullary (SAM) axis is associated with short-term physiological responses, such as increases in heart rate, while the hypothalamic-pituitary-adrenal (HPA) axis is a slower acting mechanism of which cortisol is the primary hormonal endpoint. Assessments of cortisol concentrations and anticipatory changes in heart rate allow for the determination of both short (heart rate) and longer-term (cortisol) responses to tasks, which occur to facilitate the mobilisation of physiological resources and to bring about responses to stressful stimuli. Participants also reported their subjective experiences of cognitive anxiety, somatic anxiety and self-confidence using the modified IAMS (Thomas et al., 2002).

Salivary cortisol concentrations were found to increase pre-post climb for all participants (CLL^{above} 13 ± 16%; CLL 15 ± 33%; CLL^{below} 9 ± 31%), however, the inter-individual differences and large standard deviations obscured any meaningful differences between groups. The findings of the present study are in line with the current understanding of alterations in cortisol concentration for the assessment of inter- and intra-participant differences in response to climbing stressors, such as the style of ascent (*3.1 The Safety Protocol*). To date, no meaningful differences have been found in examining cortisol concentrations in response to climbing tasks (Dickson, 2013; Dickson et al., 2012a; Draper et al., 2012; Fryer, 2013; Fryer et al., 2013), with the exception of the lower grade climbers of Dickson (2013). Considering the results of the present study, those of *Study One* and the analysed research presented in *3.1 The Safety Protocol*, it may be said that while cortisol concentrations increased in response to climbing tasks, these differences are unlikely to result solely because of physical effort (Hill et al., 2008; Jacks et al., 2002). As such, it is not possible to differentiate between styles of ascent (*Study One*), or between the ability group of participants (*Study Two*), with either plasma or salivary cortisol.

It is possible habituation to the climbing task played a significant role in the lack of difference in cortisol concentrations between groups in both *Studies One and Two*, and previous climbing psychophysiology research. Elevated concentrations of cortisol have been found when situational factors important to performance, or competition, have been manipulated (Fernandez-Fernandez et al., 2015; Filaire et al., 2001; Quested et al., 2011; Rohleder et al., 2007). However, cortisol reactivity has been found to be reduced with repeated exposures to stressors as a result of habituation (Kirschbaum et al., 1995). Consequently, it is conceivable that, because of the nature of the task the participants were asked to complete being typical of their normal recreational indoor climbing sessions, the participants were habituated to the tasks, blunting their response. An earlier pilot study supports this assertion; salivary cortisol was able to differentiate between non-climbers (59 ± 39% increase from rest) and an experienced group of climbers (18 ± 48% increase from rest) when attempting an indoor 20-meter wire ladder climb (Giles et al., 2017a). However, cortisol simply does not appear to be sensitive enough to differentiate between the responses of experienced climbers completing a task typical of their normal recreational sessions.

Anticipatory changes in heart rate, occurring one-minute prior to the commencement of the climbing task were elevated in all three ability groups (CLL^{above} 36 ± 23%; CLL 25 ± 18%; CLL^{below} 15 ± 20%). Furthermore, compared with those obtained at rest, they were able to differentiate between ability groups. Anticipatory heart rate data were elevated in the CLL^{above} group, compared to both CLL and CLL^{below}, with a significant difference found between CLL^{above} and CLL^{below} (MD = 21%, CI_{95} = 9, 32). However, in the present study, as with cortisol, there was still considerable variation. For example, the increases in the heart rate of CLL^{above} participants of the present study were less than even those of the top-rope of *Study One* (CLL^{above} 36 ± 23%; CLL 25 ± 18%; CLL^{below} 15 ± 20%). It is not clear why such differences occurred, although, it is possible to speculate this occurred because participants were only required to complete one climb, rather than the three of *Study One*.

Increases in heart rate immediately prior to attempting a route represent elevated sympathetic activation, caused by the climbers physiological and psychological readiness to complete the task (Malmo, 1957). Several explanations have been presented for anticipatory rises in heart rate: either as a beneficial response seen in experienced climbers, or a maladaptive or inappropriate response. The sympathetic response is suggested to occur to provide energy, re-distribution of blood, and, as seen in the results of the present studies, result in an increase in heart rate (Carlson, 2016). Heightened sympathetic activation in advanced and elite climbers may occur due to improved baroreceptor sensitivity (Sheel, 2004), which may, in turn, elevate heart rate pre-climb as part of an anticipatory response to exercise (Fryer, 2013). However, the findings of the present study contradict those of Fryer (2013) and do not lend support to greater increases in anticipatory heart rate enhancing physiologically and psychologically preparation in more experienced climbers. In fact, the heart rate results of the present study occurred in the opposite direction to those of Fryer (2013), with heart rate prior to climbing of 113 ± 17 $b.min^{-1}$ in CLL^{above}, 93 ± 25 $b.min^{-1}$ in CLL and 92 ± 19 $b.min^{-1}$ in CLL^{below}. The findings of the present study suggest an elevation in heart rate in anticipation of a climbing task is associated with greater anxiety and poorer climbing performance.

To date, Hardy and Whitehead (1984) are the only researchers to explore relative route difficulty and measure alterations in pre-climb heart rate. Hardy and Whitehead (1984) selected routes that were at a climbers' lead limit (LL), minus one grade (LL-1) and minus two grades (LL-2). Significant increases in integrated climbing heart rates were reported to result from baseline measures in both the LL-1 and LL groups. The results of the present study appear to support those of Hardy and Whitehead (1984) who found heart rate to have a moderately greater positive correlation with cognitive anxiety. This is also in line with the observations presented by Lacey (1967), heart rate increases when the participant attempts to "reject" the environment. However, further research is necessary to understand the nature of the alterations in heart rate, its role in preparation for tasks, and concomitant factors.

Self-reported cognitive anxiety, somatic anxiety, self-confidence's intensity and direction were assessed using the modified IAMS (Thomas et al., 2002), as with *Study One* this was collected immediately prior to participants' attempting the route. Analysis of the participants' responses revealed significant differences in the intensity of participants' somatic and cognitive anxiety and self-confidence (**Table 6.14**). In general, the greatest differences in the climbers' emotional experiences occurred between CLL^{above}, and both CLL and CLL^{below}. The significance of the findings for CLL^{above} likely occurred because of the climbers' perception of the demands of the task they were being asked to complete being beyond their on-sight climbing ability. Furthermore, unlike the intensity, CLL as with CLL^{above} participants also interpreted their somatic and cognitive anxiety as more debilitative than CLL^{below}. The results of each domain will be discussed separately below.

Somatic anxiety intensity was significantly greater for CLL^{above} than both CLL (MD = 21.1, CI_{95} = 14.7, 27.4) and CLL^{below} (MD = 25.4, CI_{95} = 19.3, 31.5), but not between CLL and CLL^{below}. As with the results of *Study One,* these findings support the idea of a threat of physical harm, or at least situations where there was an increased likelihood of a perceived threat of harm, being a major determinant of performance anxiety when leading (Morris et al., 1981). Participants interpretation of the somatic anxiety, as with the intensity, were also significant, however in contrast to the intensity, differences also occurred between both CLL^{above} (MD = 21.2, CI_{95} = 12.8, 29.6) and CLL (MD = 14.5, CI_{95} = 6.4, 22.5) groups compared to the CLL^{below}, in line with performance. Only CLL^{below} interpreted their lower levels of somatic anxiety as facilitative.

Not only were there significant group differences in somatic anxiety, but the total coaches' assessment of performance also showed a significant negative correlation (r = -0.560) (**Table 6.16**). Greater total coaches' performance score was associated with lower levels of somatic anxiety. However, such findings contrast with several studies that have reported greater somatic anxiety being associated with enhanced performance (Draper et al., 2011d; Hardy & Hutchinson, 2007; Sanchez et al., 2010). The successful climbers of Sanchez et al. (2010) reported higher pre-performance levels of somatic anxiety. Similar results were also found by Hardy and Hutchinson (2007), with greater somatic anxiety and belayers' rating of the climber's performance during a harder ascent; although, as previously stated Hardy and

Hutchinson (2007) research was conducted outside on traditional climbs with protection placed by the climber making it difficult to draw direct comparisons with the present study. Finally, Draper et al. (2011d) found successful climbers had greater somatic anxiety, compared to unsuccessful climbers. Differences between these studies and the present study may be attributed to climber ability. Draper et al. (2011d) found successful climbers were more experienced in terms of climbing and leading experience, which may have contributed to observed differences. Similarly, the climbers taking part in Sanchez et al. (2010) study were very experienced, being of a world cup level, with only very small variation in ability. It appears more experienced participants are able to interpret elevated levels of somatic anxiety as facilitative for performance (Woodman & Hardy, 2003). However, for the intermediate climbers of the present study, in particular, the CLL^{above} participants, somatic anxiety occurred alongside elevated cognitive anxiety and reduced performance.

Cognitive anxiety, as with somatic anxiety, differed significantly between CLL^{above} and both CLL (MD = 11.1, CI_{95} = 0.9, 21.3) and CLL^{below} (MD = 16.8, CI_{95} = 7.0, 26.6). Levels of cognitive anxiety were comparable with those of somatic anxiety (CLL^{above} 35.1 ± 15.9; CLL 24 ± 17.3; CLL^{below} 18.3 ± 13.4). While there were no significant differences in cognitive anxiety interpretation, both the CLL^{above} and CLL interpreted their cognitive anxiety as debilitative (-5.8 ± 14.1 and -2.3 ± 16.9, respectively), compared to CLL^{below} (4.0 ± 16.5). These results are similar to those of Hardy and Hutchinson (2007) who found both somatic anxiety and cognitive anxiety were significantly greater when participants were attempting an on-sight of a lead climb at their lead limit, compared to a lead of a route at two grades below. However, unlike Hardy and Hutchinson (2007), values were only significant in CLL^{above}, who were attempting a route beyond their on-sight ability, while CLL were not significantly different. This may have occurred because the difference in environment and discipline between studies given the participants in the study by Hardy and Hutchinson (2007) attempted an outdoor traditional route facilitating a greater objective danger, with the increased cognitive demands of placing gear (Bisharat, 2009). Climbing has been demonstrated to be a considerable cognitive task. In a dual-task study of climbing and word recall, Green and Helton (2011) demonstrated significant disruption of word recall and climbing performance, despite differences in the nature of both tasks. This is most likely due to the very high demands climbing places on the entire cognitive system. It is unsurprising then that elevated levels of cognitive anxiety in the present study were associated with reduced climbing performance.

Finally, self-confidence was relatively lower in CLL^{above} than both CLL^{below} (MD = 17.6, CI_{95} = 8.9, 26.3) and CLL (MD = 19.1, CI_{95} = 10.7, 27.5). Self-confidence direction was also significantly greater in CLL^{below} than CLL^{above} (MD = 17.6, CI_{95} = 8.9, 26.3) and CLL (MD = 19.1, CI_{95} = 10.7, 27.5). There was also a significant positive relationship with climbing performance for both the intensity (r = 0.481) and direction (r = 0.460) of self-confidence. Significantly lower self-confidence prior to lead climbs have been reported by several authors, when compared to top-rope, this finding was also present in *Study One* (Aras & Akalan, 2011; Dickson et al., 2012a; Fryer, 2013; Hodgson et al., 2009). Draper et al. (2011d) found significant differences in self-confidence between successful and unsuccessful climbers, more specifically the successful climbers of Draper et al. (2011d) had significantly greater self-confidence. Equally, Sanchez et al. (2010) found successful climbers had a small, but non-significantly greater self-confidence. Sanchez et al. (2010) demonstrated an individual may experience both positive and negative emotions in response to a stressor, but more successful athletes are able to maintain a more positive affective state, in line with findings in other sports (Jones, Swain, & Hardy, 1993; Lox, 1996). Such findings are also typical of more traditional sports settings, a meta-analysis of anxiety and self-confidence conducted by Woodman and Hardy (2003) found athletes achieved greater performances when being both anxious and self-confident. Increased relative self-confidence before a climb may improve route planning decisions and the choice of technique and tactics employed (Draper et al., 2011d); consequently, such differences are possibly responsible for the greater top-rope performance seen in *Study One*, and the performance of CLL and CLL^{below} in the present study and conversely the compromised performance of CLL^{above} participants (Draper et al., 2011d).

Given the equivocal results of previous studies investigating psychophysiology in relation to style of ascent (Draper et al., 2012; Fryer et al., 2013; Hardy & Hutchinson, 2007), the significance observed in *Study One*, particularly in the run-out condition, combined with the responses of CLL^{above} participants in the present study, it is possible to speculate about sources of anxiety within climbing. It may be that situations typical of participants' recreational sessions, such as a submaximal lead of a route, are not anxiety inducing and climbers are habituated to such situations. However, attempting routes with run-outs with greater consequences of a fall (*Study One*), or routes that are beyond the difficulty level of a climbers' on-sight ability (*Study Two*), elicit a greater response. The results of the non-climbers, compared to the experienced climbers of Giles et al. (2017a) also support this, with significant differences in self-reported anxiety, heart rate and salivary cortisol concentrations between groups in response to a ladder climb. It is suggested that these situations or conditions are anxiety-inducing, as they are unusual for the climbers attempting them and are atypical of their usual recreational sessions.

Situations that increase the likelihood of a climber being unsuccessful on a route, or perceiving they are going to be unsuccessful, appear to be anxiety inducing. It has been stated that failure is associated with either physical injury and a threat of physical harm (Backe et al., 2009), or a fear of falling may develop because of a fear of threat to self-efficacy brought about by a climber's perceived evaluation by others (Bandura, 1997). A fear of failure is associated with anticipation of shame in evaluative situations and a tendency to appraise situations as threatening (Conroy et al., 2002; Sagar & Lavallee, 2010). As, outside of competition, success in climbing is largely dictated by whether the climber reaches the top of a route, or not, climbing success is often described as self-esteem and self-confidence enhancing (Stiehl & Ramsey, 2005). With this in mind, attempting a route at or beyond the ability of the climber increases the likelihood of failure at the on-sight attempt. It is conceivable that failure will have a negative impact on esteem and confidence (Conroy et al., 2002; Sagar & Lavallee, 2010; Stiehl & Ramsey, 2005). From the results of *Study One and Two*, while it is possible to describe responses to the climbs investigated, they do not provide any explanation of *why* certain factors disrupt climbers' performance.

To summarise climbers' responses with respect to pre-climb psychophysiology and emotion, the ability for concentrations of salivary cortisol to differentiate between participants of the three ability groups were limited. While cortisol concentrations increased for all participants, in line with that observed in *Study One* and previous research to date (Dickson, 2013; Dickson et al., 2012a; Draper et al., 2012; Fryer, 2013; Fryer et al., 2013) the values obtained did not differentiate the psychophysiological responses of climbers based on relative difficulty and ability. Conversely, anticipatory changes in heart rate did increase from rest by a meaningful and significantly greater amount, but only between CLL^{above} and CLL^{below}. Clearer than the psychophysiological changes, were the significant and meaningful differences in cognitive, somatic anxiety and self-confidence between CLL^{above} and both CLL and CLL^{below}. Interestingly, while differences in the intensity of emotions were not significant between CLL and CLL^{below}, the interpretation was, supporting task differences in the positive affective state before climbing (Jones et al., 1993; Lox, 1996). Inter and intra-climber differences in the psychological and physiological responses to climbing tasks may occur because of situations unusual to the participant, including those resulting in physical harm, or ego-threatening; but not those typical of intermediate climber's recreational sessions.

The results suggest the difficulty of routes that intermediate climbers attempt during their recreational sessions are typically below their maximal on-sight ability. Furthermore, the findings support the assertion that performance is limited through a combination of both psychological and psychological factors. As with changes in the style of ascent of *Study One*, performance decrements were associated with greater levels of cognitive anxiety. For climbers and coaches two factors are apparent; firstly, there would be significant benefit to exploring sources of cognitive anxiety with intermediate climbers, in order to understand the antecedents of intermediate climbers performance; secondly, interventions addressing anxiety resulting from leading and leading beyond the on-sight ability of climbers should concentrate on reducing cognitive anxiety and improving self-confidence, in order to bring greater enjoyment and improvements in performance.

6.5 Perspectives

Ideally, a change in the difficulty of a route, relative to the ability of a climber should only increase the physical demands of completing the route. However, an increase in the difficulty of a route, relative to the ability of a climber, creates a situation where the likelihood of the climber falling increases. This is significant, as the potential for falling and an associated perceived concern of injury are considered stressors for climbers and a limiting factor for many (Hurni, 2003; Macleod, 2010; Sagar, 2001). Consequently, a significant aspect of the sport is the management of stress in order to maintain performance, and ultimately reach the top of the climb (Hörst, 2010). Prior to the present study, the only studies to have explored relative differences in route difficulty have investigated subjective experiences were conducted outdoors and did not assess climbing performance on routes beyond the on-sight ability of participants (Hardy & Hutchinson, 2007; Hardy & Whitehead, 1984). While the contributions of these previous studies are significant, *Study Two* is the first to assess differences in climber ability, relative to route difficulty, assessing participants' subjective psychological, objective physiological and behavioural responses.

As hypothesised the greater the difficulty of the route, relative to the ability of the climber, the less likely participants were of being successful. Climbers' performance was scored lower, and geometric entropy was greater in the CLL^{above} participants, furthermore, climbing heart rate was not significantly different between groups. Consequently, it was speculated that performance was limited to a greater extent by technical performance, than physiological factors; this may be a feature of intermediate climbers' performance, further research with other ability groups would be necessary to establish this. While differences in performance existed between all three ability groups, differences in subjective self-reported anxiety, anticipatory heart rate and challenge and threat state existed between the slightly lower ability CLL^{above} group and both the more competent CLL and CLL^{below} groups. The results of the current study demonstrated that an increase in the likelihood of a climber falling, or being unable to complete the route, are evaluated as threatening. This, in turn, resulted in an increased psychophysiological and emotional response, and is speculated to be partially responsible for differences in performance. The results highlight the importance of the consideration of relative route difficulty in psychophysiology research.

Given the largely equivocal results of previous style of ascent psychophysiology research (Dickson, 2013; Dickson et al., 2012a; Draper et al., 2012; Fryer, 2013; Fryer et al., 2013), the significance observed in *Study One*, particularly in the run-out condition, and the response of CLL^{above} participants in the present study, it is possible to speculate about the source of anxiety. It is possible that situations typical of participants' recreational sessions, such as a submaximal lead of a route, are not anxiety inducing and climbers are habituated to such situations. However, attempting routes with run-outs with greater consequences of a fall (*Study One*), or routes that are beyond a climbers' on-sight ability (*Study Two*), elicit a greater potential significant response. Failure is associated with either physical injury and a threat of physical harm (Backe et al., 2009), or a fear of falling may develop because of a fear of threat to self-efficacy because of climber's perceived evaluation by others (Bandura, 1997). However, it is unclear whether this is the case, and which is more salient to the climber. Common to both *Studies One and Two* were elevations in cognitive anxiety and reduced self-confidence when leading beyond the lead limit and leading compared to top-rope.

Unfortunately, the design of the present study meant that it was not possible to determine differences in performance occurring because of the technical difficulty of the route and the evaluation of the participants. There would be a significant benefit for future research exploring the effects of perceived route difficulty and antecedents of climbing performance. This would be true not only for climbing itself but challenge and threat research exploring antecedents of demand resource evaluations, in particular, evaluations occurring because of perceptions of danger. This could be achieved by providing a sample of climbers with task instructions relating to the relative difficulty of a single climb, just below their on-sight ability, as with the present study. However, instead of the three ability groups of the present study, recruit a homogenous group of climbers within one grade of each other, and employ deception regarding the grade of the route: instructing participants on the route being above, below or at the on-sight ability of the participations, without changing the grade. Not only would this provide an understanding of the psychophysiological and self-report characteristics as in the present study, but also differences in performance resulting purely because of psychological factors relating to the perceived difficulty of the route.

Research completed to date provides insight by way of objective psychophysiological and subject appraisals of tasks, identified by researchers and climbing authors as potential anxiety inducing, are associated with climbing performance. In particular, previous studies have demonstrated the multifaceted interactive nature of the sport, even within recreational climbers. *Studies One and Two* are amongst the first to explore the performance implications of stressors typical of the climbing environment, which has provided invaluable insight into changes in performance. However, the quantitative methods employed do not provide any explanation of *why* certain factors are salient to climbers, how they are managed, and potential stressors that have not yet been considered. Cognitive anxiety has been found to be elevated in both *Studies One and Two*, understanding the antecedents of such elevations in anxiety would be a benefit to both researchers and to climbers and coaches attempting to address such factors. There would be a significant benefit to exploring the characteristics and climbers' understanding of the situations they engage in, to better understand factors affecting performance. Further research is necessary to explore this; consequently, *Study Three* will explore potential sources of inter-individual variation in responses to challenges of indoor lead climbing in intermediate climbers.

7

Study Three

A qualitative investigation of psychological limiting factors in indoor lead climbing performance

7.1 Introduction

There is considerable anecdotal evidence within climbing coaching literature that indoor lead climbing is a potential psychological stressor (Hague & Hunter, 2011; Hörst, 2010; Hörst, 2008; Hurni, 2003; Macleod et al., 2007; Sagar, 2001). Not only is climbing potentially anxiety-inducing, the emotional experience may also have a significant impact on climbing performance (Nieuwenhuys et al., 2008; Pijpers et al., 2007; Pijpers et al., 2003). For recreational climbers taking part in the sport indoors, there are three primary decisions they may make about the challenges they face within their sessions. The first is the style of ascent, as investigated in *Study One*; the second is the difficulty of the climb they choose to attempt, as investigated in *Study Two*; and the third is the knowledge the climber has of the route. It is likely climbers' choices made during their sessions and the way they approach and respond to stressors are important determinants of performance (Dickson et al., 2012a; Draper et al., 2008; Draper et al., 2010; Fryer et al., 2013; Hardy & Hutchinson, 2007; Hodgson et al., 2009).

Climbing coaching authors have speculated as to the sources of fear and anxiety experienced by climbers when leading. Hörst (2008) suggested that *"it's not really falling that we fear but* *not knowing what the fall will be like"* (p. 40). Similarly, Hague and Hunter (2011) stated: *"fear in climbing is most often based on the possible consequences of a fall"* (p. 192) and Sagar (2001) "*Once you are in the air, you can't do anything until you hit the end of the rope. As I struggled to overcome my fear and tried taking falls on routes, I came to realize I really wasn't afraid of the fall. I was afraid of the anticipation of the fall"* (p. 114). Despite these contentions, little has been formally assessed. Previous research has largely been based on coaches' anecdote, climbing literature and the knowledge of the experimenters. The variation seen in previous research (see *Chapter 3 and Studies One and Two*) highlights the current lack of understanding of salient stressors in the climbing environment, the methods climbers use to manage their responses and how some climbers are able to maintain performance, while others are not.

An example of the variation is exemplified in the style of ascent research, discussed in *Section 3.1* and explored in *Study One*. Alterations in the style of ascent within indoor climbing has received considerable research attention (Dickson et al., 2012a; Draper et al., 2010; Fryer et al., 2013). The focus on the style of ascent is supported by anecdotal evidence from coaches, Macleod (2010) reports *"I've observed it [fear of falling] as the primary weakness in over 50% of climbers I meet for coaching sessions"* (p. 95), describing a fear of falling as one of the most *"insidious and unpleasant"* (p. 95) problems in climbing that coaches deal with. Developing on the methodologies of previous psychophysiology research, *Study One* investigated differences in the style of ascent. With a change in the style of ascent, meaningful differences were found in climbing performance with poorer less fluent movement and greater somatic and cognitive anxiety. However, while there have been significant developments in the assessment of responses to the challenges of climbing, including the use of psychophysiological techniques, there is still considerable variation present in the findings, including the results of *Studies One* and previous psychophysiology research discussed in *Chapter 3* (Dickson et al., 2012a; Draper et al., 2008; Draper et al., 2010; Fryer et al., 2013; Hardy & Hutchinson, 2007; Hodgson et al., 2009). While every effort has been made to control extraneous variables present in the environment, there was still variability present in the results. Consequently, it is likely there are other stressors within the climbing environment that are not fully understood or have not been considered.

In contrast to previous quantitative methods employed, including within *Studies One and Two* of this thesis, the use of interviews would allow for a more detailed and richer understanding of the antecedents and concomitant factors responsible for variation in climbers' performance to be gained. Factors yet to be explored may have been responsible for the inter- and intra-participant variability seen in *Studies One and Two* and previous climbing physiology and psychology research (*See Chapter 3* Literature Review: Part Two). The efficacy of interviews in such a context is well established (Brymer & Schweitzer, 2012; Hill & Shaw, 2013).

Hill and Shaw (2013) used semi-structured interviews to explore antecedents of choking in eight athletes who frequently choked under pressure while taking part in team sports. The interviews explored athletes' experience of a significant drop in performance occurring at important pressurised moments which were accompanied by high levels of anxiety. Hill and Shaw (2013) identified a number of perceived antecedents of choking common to choking literature, including important games and moments, high expectations, self-confidence, the presence of an audience and a lack of preparation. However, significantly, the interviews also revealed four antecedents which had not yet been explored in the literature: individual responsibility, making physical and mental mistakes, the actions of opponents and fatigue. Furthermore, the interviews provided support for choking being associated with high levels of anxiety; disruption of performance occurring to a greater degree because of distraction than self-focus and perceived control being a moderating variable. Such understanding gained through qualitative methods has implications for coaches developing athletes training and optimal performance climates. Further, it provides understanding which would not have been possible with a quantitative methodology.

In a similar style to Hill and Shaw (2013), Brymer and Schweitzer (2012) employed interviews to develop an understanding of fear and anxiety in extreme sport. The interviews conducted allowed the exploration of the experiences of participants who chose to take part in dangerous extreme sports. The interviews not only highlighted the experience of the participants, but also their complex relationship with fear. Fear was recognised as being something that was real, but also that was open to challenge. This led Brymer and Schweitzer (2012) to postulate that the meaning of experienced fear in extreme sports participants – it should be distinguished from the use of fear in common language: *"Fear is not a protagonist but represents a stage which can be recognized and transcended"* (p. 484). Interestingly, as with Hill and Shaw (2013), control was discussed by the extreme sports participants, however, unlike the team athletes this related to their ability to put aside the need to control all outcomes, which is not always possible, and through moving through those fears the participant is able to participate fully.

In both of the work of Hill and Shaw (2013) and Brymer and Schweitzer (2012), insight into the experience of the individual athletes was gained that would not have otherwise been possible with quantitative methodologies. With both the style of ascent of *Study One* and the relative route difficulty of *Study Two*, performance decrements were associated with greater levels of cognitive anxiety. There would be a significant benefit for climbers, coaches and researchers to exploring sources of cognitive anxiety with intermediate climbers, in the same way Hill and Shaw (2013) and Brymer and Schweitzer (2012) have with choking and the perceptions of extreme sports athletes.

7.1.1 Summary and aims

Taking into account the results of previous climbing psychophysiology research and the results of *Studies One and Two*, there remains a need to further explore sources of variation in climbers to determine the basis of a future investigations of psychophysiology within climbing; furthermore, such understanding will have implications for coaches and climbers, particularly those of an intermediate level progressing in the sport. The purpose of *Study Three* was to identify and discuss salient stressors and to determine potential sources of inter-individual variation in responses to the challenges of indoor lead climbing. Semi-structured interviews were conducted to explore the individual perceptions and experiences of intermediate recreational climbers'. Through discussion with climbers who regularly take part in indoor climbing, it was hoped it would be possible to determine potential sources of variation, the challenges faced by intermediate and advanced climbers and provide rich data and understanding for future climbing psychophysiology studies.

7.1.2 Objectives

O1: To determine salient stressors present in the indoor climbing environment as reported by intermediate and advanced level recreational climbers.

O2: To explain the ways in which participants respond and moderate their behaviour to manage stressors present in the recreational climbing environment.

O3: To describe participants techniques used to improve their performance and how important and effective they believed them to be.

7.1.3 Strengths of the study

- It is the only study of its type in climbing research. Perhaps due to the time-consuming nature of the research there has been a lesser focus on qualitative methods in climbing.

- The large sample considers the opinion and experiences of a large number of intermediate and advanced level recreational climbers.
- The study provides detailed and rich data to inform future research, while also providing context to existing research.

7.2 Methods

The interviews of *Study Three* were conducted as a continuation of *Study Two*. Climbers were recruited following participation in *Study Two* to take part in the interviews. All participants obliged. The interviews primary aim was to examine potential sources of inter-individual differences in on-sight lead climbing performance, from the perspective of intermediate and advanced lead climbers (Draper et al., 2016).

7.2.1 Participants

Sixty-one participants took part in semi-structured interviews, comprised of 14 females and 47 male climbers, who also participated in *Study Two*. As previously described, participants were included and grouped based on the self-reported on-sight ability of between French 6a+ to 6c+ (IRCRA 12 to 16; YDS 5.10c to 5.11c; *see 4.2.1 Self-reported ability and experience*). The climbers were classified as intermediate to advanced (Draper et al., 2016). The climbers had been participating in the sport for a number of years (males 10.5 ± 10.1 years; females 7.7 ± 5.9 years) and took part in the sport regularly (males 2.6 ± 1.2 sessions per week; females 2.6 ± 1.1 sessions per week). Ethical approval was received for the conducting the interviews (*see 4.1.4 Ethical approval*). Participants were reminded they may withdraw at any time and they did not have to answer any questions they did not wish.

7.2.2 Procedure

One-to-one semi-structured interviews were conducted to examine climbers' constructions of climbing performance and their antecedents in the context of indoor lead climbing, with specific reference to sources of fear and anxiety. Semi-structured interviews were chosen as their flexibility allows for the generation of rich and informative data, particularly suited to studies investigating new, underreported ideas (Robson & McCartan, 2016). The interviews aimed to ascertain why some climbers are unable to maintain performance on lead climbs as highlighted in *Study One* and the changes that occur with ability as highlighted in *Study Two*. The interviews were audio-recorded, ranged in duration from 20 to 35 min and were conducted face-to-face by a single trained interviewer. The interviews were conducted in the familiar environment of the climbing wall. For practicality, due to the testing schedule, interviews were conducted following the climbers' attempt at the route described in *Study Two*. Open-ended semi-structured format questions were used flexibly and were omitted, adapted or elaborated according to the demands of the individual interview. The interview schedule may be found in Appendix F. The interviewer adopted a *talk back* stance to the participant while trying to avoid directive or closed questions or interpretations (Shaffir & Stebbins, 1990). In this way, questions were used to promote a two-way dialogue with which to explore key themes.

7.2.3 Transcription

All the interviews were transcribed verbatim. To guarantee the quality of the transcription and eliminate any errors, the transcriptions were checked against the original interview recording. This facilitated any necessary amendments and corrections as well as allowing re-familiarisation with the data to assist with the data analysis process. All participant names were removed at this point to ensure participant confidentiality. Following transcription of interviews into Microsoft Word, data was stored and managed using specialist software for qualitative data (NVivo-10, QSR International).

7.2.4 Thematic analysis using a framework

The interview data were analysed following the principles of framework analysis (Ritchie, Lewis, Nicholls, & Ormston, 2013) and interpreted with thematic analysis (Braun, Clarke, & Terry, 2014). This method was used to assist the analysis of the qualitative data with a systematic staged-approach, from organising the data, summarising and interpreting; this allowed for a structured, systematic analysis, ensuring the process was explicit and repeatable, while still allowing for creative analysis of the data. Thematic analysis was used to identify, analyse and report the dominant themes within the data (Braun et al., 2014). Thematic analysis techniques minimally organises and describes the data set in detail. The thematic analysis may be differentiated from approaches such as grounded theory or discourse analysis, as it does not rely on pre-existing theoretical frameworks and is, therefore, a more accessible approach (Braun et al., 2014). It facilitates a rich thematic description of the whole data set and it is for this reason that it is a useful approach when exploring new or under-researched areas. The entire data set was coded using NVivo 10.

Ritchie et al. (2013) identify four key stages of the analysis process, which the interview analysis of the present study was based on:

1) Identification of initial themes and concepts: familiarisation with data within the aims and objectives of the study. The demographic of the sample was re-examined and the interview transcripts were reread to begin to identify key themes. From the identified key themes the start of a conceptual framework was developed. The framework was then sorted into a hierarchy, with broad sub-themes under main themes.

2) Labelling or tagging the data: the transcripts were indexed through the application of the previously conceived conceptual framework. Ritchie et al. (2013) differentiated this stage from coding, as the application of the index shows where the theme or concept mentioned or referred to, were contained in the data. The conceptual framework was refined throughout the process.

3) Sorting the data by theme or concept: data was sorted by the framework so similar content was collected together. The process was automated using NVivo.

4) Summarising or synthesising the data: The final stage summarised the data and ensured the participants' language was unchanged and key phrases retained, the interpretation was limited at this stage, all data was considered important, regardless of if its purpose or if its meaning was clear.

The process was not linear, the framework was refined at all stages, particularly if further key themes were identified. Following creation, the data was analysed following the principles of thematic analysis, as previously described (Braun et al., 2014).

7.2.5 Trustworthiness

Following the guidelines of Sparks (1998), as used in studies including Hill and Shaw (2013), the trustworthiness of the data was established through several methods. Firstly, the semi-structured interviews conducted were extensive, allowing participants to describe and explain their behaviour in detail. Furthermore, using probes to explore the meaning of behaviour each individual attached to their climbing experience, deeper understanding was also gained. Secondly, the interviews were transcribed verbatim and read several times to ensure familiarity. Thirdly, the themes were analysed independently and corroborated with other researchers. Finally, to ensure an accurate portrayal of the participants' personal experiences was represented by the interviews, the interviewer employed bracketing to reduce personal bias (Giorgi, 2012).

7.3 Findings

Following the principles of framework analysis, four main themes along with several sub-themes were identified. The main and sub-themes and the number reporting each are presented in **Table 7.1**.

Table 7.1: *Conceptual framework outlining the main themes and sub-themes from the climber interviews.*

Main Theme	Sub-Theme		Number reporting the theme
1. Internal Stressors	**Falling**		**49**
		The consequence of a leader fall	32
		Complacency and experience	3
	Route difficulty		**24**
	Route knowledge		**9**
	Height on route	Anxious low on the route	31
		Anxious high on the route	7
2. External Mediating Factors	**The belayer**	Attention	12
		Competency	32
		Technical factors	22
	Social factors		**19**
	Threats to self-efficacy	Demonstrate competence	14
		Evaluation by others	8
	Background	Previous experience	17
		Climbing discipline	9
	External stress		**15**
3. Control	**Pre-Climb Decisions**		**29**
	On-Route Decisions	Avoid falling and controlled fall	22
		Ability to protect climb	15
	Movement		**7**
4. Practice	**Structured practice**		**41**
	Unstructured practice		**17**

A discussion of the themes and sub-themes generated from the data will now be presented using this framework, including the identification of any relevant interrelationships.

7.3.1 *Theme One*: Internal Stressors

Recreational climbing may be defined by the self-selected pressure situations climbers choose to engage in during their sessions. Primarily these include the safety protocol, the difficulty of the route and the climbers' knowledge of the challenges and movement sequences a route contains. The decisions individual climbers make and their underlying reasons are important in understating differences in performance seen in previous research, for example, with changes in the safety protocol, as demonstrated in *Study One* and route difficulty as seen in *Study Two*.

Theme One was directly concerned with stressors described by the interviewees as originating internally and, importantly, largely without the influence of other climbers. The discussed factors were divided into the following sub-themes: 1) fall potential, falling and its consequences; 2) route knowledge; 3) route difficulty; and 4) how high or low the climber is on the route. Each will be discussed.

Fall potential, falling and its consequences

A fundamental component of participants' responses and decision making, discussed by 49 of the interviewees when asked about factors limiting their performance, related to falling. A further 32 of the interviewees also discussed associated concerns relating to injury due to falls. Falling and factors relating to situations where falls were likely were a significant source of anxiety. This was not restricted to the lower grade group, while 14 of the f6a/6a+ (French) grade reported such factors, nine of the f6b/6b+ and three of the f6c/6c+ climbers also reported they experienced negative emotional response towards falling:

> *I'm scared of falling . . . definitely that is the main thing that I feel holds me back. Yeah indoors and out is fear of falling.*
>
> (CG, Male, f6b/6b+)

> *My head, my brain. I am terrified of falling off.*
>
> (AW, Female, f6c/6c+)

The consequences of a leader fall

Falling when lead climbing indoors, while distinctly possible, does not present a significant risk to a competent climber. Despite this, 32 of the climbers discussed that anxiety and fear towards falling originated from a fear of physical harm:

> *I don't want to be injured, even moderately. I don't want a dislocated ankle or ruptured ligaments. They really are not acceptable to me.*
>
> (CH, Male, f6a/6a+)

I am fine going bold until I suddenly know that I am absolutely at my limit and I am not sure how this fall is going to be and then I'm terrified.

(CA, Male, f6b/6b+)

I'm too scared of falling. Because it is going to hurt and I don't particularly want to get hurt, not really.

(AC, Male, f6c/6c+)

Through practice and experience a small number of participants discussed the development of competencies related to management and control of risk:

If I was looking at a really bad fall, something that potentially hurts, I would have just said take or I would have used something else. I don't want to hurt myself, but at the same time in my own mind if I can say that it is safe I will take the risk, but it is about the judgement I would say.

(CN, Male, f6a/6a+)

Several interviewees acknowledged they were fearful of falling, but also identified that the extent of their feelings towards falling was at least somewhat irrational. This was especially true of the f6a/6a+ ability group climbers. Participants described a dissonance between the rational knowledge of knowing what will happen when they fall and their behaviour:

When you actually do it it's not that bad. I trust [my climbing partner] to be a competent belayer I trust him not to let me deck out, it just wouldn't happen. It is just one of those irrational silliness that you have.

(AK, Female, f6a/6a+)

I want to complete the route, but the main thing at least is that there is a primal instinct not to fall. Even when I have clipped the chains at the top. There is a little unwillingness, a little hump to get over to let go and I always have a check of the carabiner to make sure one last time.

(BQ, Male, f6a/6a+)

Indoors, it maybe that it is the anticipation of the *unknown* that comes with leading and falling that is feared, rather than the actual fall itself:

> *I am scared about falling . . . I am fine going bold until I suddenly know that I am absolutely at my limit and I am not sure how this fall is going to be and then I'm terrified.*
>
> (CA, Male, f6b/6b+)

> *I guess it is more fear of the unknowns than I am really going to hurt myself . . . for the most part, it is falling into the wall.*
>
> (AA, Male, f6b/6b+)

That was not to say that lead climbing is completely safe, the fearful response, while possibly disproportionate, is real and injuries can and do still occur:

> *I have fallen off and on a couple of occasions I have hurt myself. Not disastrously, I've not had any life changing injuries, but the potential for life changing injury limits my desire to take chances.*
>
> (CH, Male, f6a/6a+)

Injuries were more frequently reported by climbers who also chose to climb outdoors (22 injuries outdoors vs. seven indoors). The nature of climbing outdoors, in particular, traditional climbing, mean there are greater objective dangers. Several climbers reported serious injuries sustained outdoors, along with changes in their behaviour after injury – in particular being more cautious:

> *Well, I am pretty nervous about it and that is because I had a bad accident . . . I snapped my femur and broke my talus, I was in a really bad way and choppered off. So I remember the first time I went out . . . afterwards, I remember I was doing a bit of soloing and I was just on a V-diff I felt terrified the whole way up that feeling that I was about to fall like I fell before.*
>
> (BT, Male, f6c/6c+)

I fell on one route indoors and got injured and had to operate on my knee because of that and afterwards, things changed a bit . . . it was kind of hard . . . I cannot concentrate on the route.

(CC, Female, f6a/6a+)

Complacency and experience

Fear and anxiety are associated with disruption of performance (*Studies One and Two*), but the fearful response also serves a purpose. While not reported by many (three interviewees), an understanding of their own previous complacency while they were learning to lead climb was expressed:

I think that it is really limiting for people that are not prepared to fall off. But that said, from my background . . . falling definitely didn't come easy to me. I guess I was quite gung-ho on the trad when I first started, but a bit of caution crept in quite quickly just because of a lot of near misses [when] really going for it.

(BL, Male, f6c/6c+)

An interviewee who, while he was an experienced boulderer, was also an inexperienced lead climber described a similar effect. With a discipline such as lead climbing, there is an unavoidable technical element required to protect the climber in the event of a fall. In this case, the climber stepped their leg in front of their rope, a fall would have resulted in inverting, such situations are avoidable, but it takes experience to identify and manage them:

I might have been too comfortable with the climb. I know that I can climb this difficulty of route most of the time, I think I probably just got too confident in the movements forgetting that you have other things that you have to think about. Yeah I noticed that I had my foot on and I didn't really think about it, to be honest. I would give that to the fact that I haven't lead climbed in a little bit. So I hadn't had an amazing amount of practice.

(AC, Male, f6c/6c+)

Route difficulty

The difficulty of routes attempted by participants is one of the key variables decided on during their recreational day-to-day practice. Climbers are aware of the grade of climbs they are usually able to complete and choose hard or easier routes relative to this. Climbers may choose to attempt routes at or above their limit, *pushing* their climbing grade, however, 24 of the interviewees reported regularly choosing routes they knew they would be able to complete on their first attempt:

> *I choose the easier climbs that I know that I can finish.*
>
> (CS, Female, f6a/6a+)

> *I will usually have selected the route based on something that appeals. To be honest, it usually appeals because it appears to be the easier of the options at that grade perhaps. Different aesthetic. And I think that familiarity is a big deal as well. I think that if it is at a local crag that you have been to relatively recently and it is still feels tuned in or a climbing wall that you are particularly used to I feel easier to push out the boat a little bit.*
>
> (BN, Male, f6a/6a+)

Several participants, particularly those in the f6a/6a+ ability group, specifically reported not wishing to climb a route towards their limit while leading:

> *No, I don't normally push that much above my grade. Not leading anyway.*
>
> (CO, Male, f6a/6a+)

Choices concerning the difficulty of routes attempted were frequently related to falling. While a hard route towards a climber's limit was likely to result in a fall, the choice of easier routes ensures the climbers have the ability to deal with the challenges the route presents:

> *f6a+ on overhanging I will go for, f6b on overhanging I would expect to fall off, therefore I probably wouldn't bother with it. Because again I wouldn't do that sort of thing outdoors because if I thought I was going to fall off I would rather not.*
>
> (CH, Male, f6a/6a+)

> *I am terrified. I am a trad climber, I don't fall. Falling is a bad thing. Do I climb within my limits indoors? Yes, I do. I don't, I don't want to push beyond my limit very often and when I feel that I am pushing my limit, I will call my belayer and say watch*

us on this one. Or if I am on a route that is my limit I will say to him before I set off, keep a very tight eye on this I am likely to come off.

(CQ, Male, f6b/6b+)

Route knowledge

Knowledge of the route was identified as a significant source of anxiety by nine interviewees. Specifically, it is not always possible to know what the upcoming holds, movement patterns or clipping positions will be like on a route until the climber reached them. Route knowledge has implications for the physical and technical execution of movements, but was also related to climbers' emotional experience of a route:

When I know that it is a difficult route I am excited, but on the whole route I am nervous during on-sight. Because this is for me, I do not like on-sight. Because I do not like surprises during climbing, I need to know if the holds are good or not. And not try it. And it is absolutely horrible. I prefer red-point is the best style of climbing, definitely. When I climb on-sight easy routes but it is outside still I am nervous. But I think it is connected with on-sight.

(CP, Female, f6b/6b+)

When I am feeling comfortable, I feel confident that if I make another move, the next hold will be as good as or better and it will be fine to clip there.

(BR, Male, f6b/6b+)

Participants reported they were wary of the unknown challenges of an on-sight route as they are making progress:

Risk in the sense of when you are not sure if you are going to hold the next hold or something like that, that is risk for me not in the sense not safe. In the sense of not sure what is coming.

(CC, Female, f6a/6a+)

I wasn't sure of the next hold . . . I was quite wary of trusting something if it was going to be another slopey one . . . I didn't want to throw to it and then fall and be nearly at the next clip.

(BZ, Male, f6a/6a+)

Height on route

Lead climbing requires climbers to ascend to height; gaining height is an inherent part of the sport. However, height as a source of anxiety was also identified by seven of the interviewees, it also appeared to be inextricably linked to falling:

I am scared of heights, even though I know that it is safer I am still nervous. Because I don't like the height. If I am on a high point and I look down, the floor is a long way away, even if I am on a top rope. Height I don't like.

(AU, Female, f6a/6a+)

I do have a slight fear of heights, still even though I am a climber. It is kind of a thing that if you don't do it often, you don't want to do it. Before I used to do a lot of outdoor climbing and falls, so you kind of got used to the feeling of falling. Plus, also if it is a soft fall you don't even feel any bad anxiety or emotion. I think it is my own psychological in my head that is, err, it is just at that moment instincts kick in and I don't want to fall

(AF, Male, f6c/6c+)

Interviewees' response may be broadly, but not exclusively, divided into those discussing their perceptions of, and responses to, the lower portion of the route and the top of the route. A fall when clipping, with an inattentive belayer or poor clipping position low on a route can potentially result in the climber hitting the floor. Conversely, higher on the route a fall is unlikely to result in a ground fall.

Anxious low on the route

Participants discussed aspects of both being close to the ground and the increased likelihood of a slip resulting in a ground fall:

I think it does yeah, but having heard stories of people falling and hurting themselves from the third clip, like people say that two clips in you are golden, but for me, I would like to have three clips in and then I would feel a bit more confident.

(CI, Female, f6a/6a+)

As long as I am above the second or third clips, I know that Awesome Walls tend to have fairly low clips. So as long as I am above the third, then I know I am ok. I am quite aware and I am confident in my belayer that I won't be hitting the floor. Apart from that, I am pretty confident with falling and I don't mind taking a big fall indoors.

(BD, Male, f6a/6a+)

Anxious high on the route

An increase in the climber's height on the route, particularly when leading indoors, dramatically reduces the chance of a ground fall. However, a number of the f6a/6a+ ability participants reported feelings of anxiety when ascending to height:

I am scared of heights, even though I know that it is safer I am still nervous. Because I don't like the height. If I am on a height point and I look down, the floor is a long way away, even if I am on a top rope. Height I don't like.

(AU, Female, f6a/6a+)

Higher on the route they must place trust in the person belaying them:

If the move was lower down if it was set up lower down sort of bouldering thing, I would be more, I would just go for it because I know that I will only go down a few feet. I know that going down a few feet is what happens in leading, if not one or two but the fact that it is so high up and you are just trusting a person other than yourself, an external party cos in bouldering it is all your responsibility to land properly, but it is also lower down, so I think that it is the trust of the belayer being so high up. Because obviously first and second clip I would happily boulder anyway but then when it gets a little higher. I know as you get higher it gets safer to fall and longer reaction times, but yes I still get nervous on that kind of thing.

(CS, Female, f6a/6a+)

7.3.2 *Theme Two*: External mediating factors

Climbing is often seen as a *solo* independent sport; indeed, *Theme One* was concerned with stressors brought about by the decisions made by the climber. However, while the climber's own physical effort is responsible for their performance, interviewees also described a number of external factors. For example, the climber must have a belayer, interact with others during their sessions and may not always take part in the sport in an ideal mental state, brought about by the influence of other elements of day-to-day life. Such factors serve to moderate and mediate the behaviour of the climber and the factors previously discussed in *Theme One.* Several sub-themes were returned to by interviewees of all abilities relating to factors that either compounded or mediated their experiences, feelings and emotions. These were broadly divided into five sub-themes: (a) the belayer, (b) social factors, (c) threats to self-efficacy, (d) the climbers' background, (e) external stress and fatigue.

The belayer

Notable within interviewees' responses were the frequency that the climbing partner and belayer were discussed. In terms of protecting the climber when on the route, the belayer may be considered '*the other side of the equation'*: while the climber is responsible for clipping the rope to quickdraws intermittently on the route, the belayer is essential for their safety, paying out rope and, in the event of a fall, arresting them. Trust between the climber and the belayer was described by the interviewees as critical:

> *If I trust the person really well I will push a bit more. But if it is a stranger I would be very cautious. I would probably not try.*
>
> (AQ, Male, f6b/6b+)

> *I always feel like, climbing with a competent belayer and all of that I know that I am safe and everything is all quickdraws and bolts are all looked after.*
>
> (AE, Male, f6a/6a+)

Climbing may be unique amongst sports: confidence must be placed on a third party to protect the climber in the event of a fall. While many sports require competitors to work together as a team, there are rarely physical consequences or the potential for bodily harm with a breakdown in this relationship or a mistake on the part of one of the parties. In other climbing disciplines, such as bouldering, climbers are largely responsible for themselves. Confidence in the belayer protecting the climber while on the route was a notable factor for 31 of the interviewees:

> *You are just trusting a person other than yourself, an external party cos in bouldering it is all your responsibility to land properly, but it is also lowered down, so I think that it is the trust of the belayer being so high up.*
>
> (BZ, Male, f6a/6a+)

However, there were a small group of participants who reported their familiarity with the belayer was not a factor at all. Those few interviewees who indicated they were not concerned by who was belaying them, described how they would trust almost anyone:

> *If someone can hold a rope in a stitch plate, then they are not going to let me go . . . the chances of that resulting in you hitting the floor are fairly slim. I am not too worried about it indoors, outdoors I am much more picky about who belays.*
>
> (BQ, Male, f6a/6a+)

> *Yeah, I rock up at a wall I will chat someone and if they look to be a similar build I won't worry so much. I probably should.*
>
> (CO, Male, f6a/6a+)

If trust between the belayer and the climber does not exist or has not had time to develop several interviewees describe issues with the climber struggling to place trust into the person who is belaying. Conceivably, a lack of confidence in the belayer can have implications for the performance of the climber with climbers not trying or, simply being taken tight on the rope if they feel uncomfortable:

> *It is very important who is belaying me and on that actually that depends how I am climbing. If it is someone that I don't know I just say bloc [take] when it is too hard.*
>
> (CC, Female, f6a/6a+)

Further, concerning the belayer, several sub-themes were also highlighted, describing attributes participants looked for in belayers' or factors that affected the climber's performance. Specifically, the belayers' attentiveness, competence and technical factors relating to belaying.

Attention

It is the role of the belayer to anticipate the actions of the climber and to pay out rope when needed and take in excess slack, while also ensuring the rope does not travel through the device in the event of a fall. To ensure this is the case the belayer must be paying close attention to the actions and behaviour of the climber:

> *He has not dropped me, ever. But yeah - quite often I am pulling him up a route because he is not paying attention - comeon comeon or if I am seconding stuff outdoor I have got coils of rope around my feet - when you are ready!*
>
> (CQ, Male, f6b/6b+)

The attentiveness of the belayer may concern the climber, regardless of if they actually cause an issue:

> *That constant feeling that if they are not paying attention and they do that then the might let go. If you look down and they are not looking at you, which they might not always be I suppose. I guess they should, when belaying you are not always paying attention all of the time.*
>
> (BA, Male, f6b/6b+)

Competency

The competency of the belayer was discussed by several interviewees. As with any skill, a range of ability and experience may be found. A great deal of the skill of belaying is anticipating the actions of the climber on the route. The ability of climbers to effectively protect the climber while they are on the route can have a significant impact on the climbers' performance and the decisions they make:

> *I have a couple of friends that can belay safely. But their technique isn't what you would consider fantastic belaying technique. So when I am climbing with them, I feel that I have to instruct them on what to do. They can't really read my body language that well, enough to be able to react to situation, if I am climbing with a couple of the guys who do and I know for a fact that I don't have to look down and make sure that there is not too much slack out that makes the situation much easier. The guy that*

needs coaching on belaying I will either stick to the low grades or, be conscious that I need to tell them what to do. Hence I say when I am going to go, out of habit.

(AJ, Male, f6b/6b+)

My regular partner, I know that he is safe and he has got my back. My best interests at heart. He is not going to be reckless and not pay attention.

(CN, Male, f6a/6a+)

Conversely, an inexperienced or incompetent belayer can have a negative impact on the climber; such descriptions were particularly prevalent with the f6a/6a+ ability group, perhaps because of the f6a/6a+ ability participants typically climbed with others of the same ability:

They sometimes get confused with the rope systems. In my mind, it is not that complex, but they still seem to struggle with it. So I am always a bit uneasy.

(CN, Male, f6a/6a+)

As I said there were four people that I climb free of any thoughts, with the others I cannot concentrate on the route because I don't know how they are belaying me and so on.

(CC, Female, f6a/6a+)

Technical factors

The belay device the belayer uses can also affect confidence in the system and the emotional experience of the climber on the route. Many climbers reported feeling more confident if the climber uses an autolocking device and being aware of partners who did not use such devices:

I feel much more comfortable with a gri-gri or a locking device. It's another link in the chain.

(BA, Male, f6b/6b+)

Because I climb with the same people mostly different belayer doesn't normally cross my mind, although in that one of my friends only uses a standard belay plate rather than a gri-gri and that does cross my mind, so perhaps I wouldn't push it quite so far *out of the comfort zone, even if he has caught me a bunch of times in the past I just feel slightly more nervous.*

(AI, Male, f6b/6b+)

The second technical element to be discussed was the weight of the climber relative to the weight of the belayer. Due to the force involved in a fall, a large disparity between the weight of a climber and the weight of a belayer can cause issues, including the belayer being pulled from their feet. Concern was expressed by a small number of the more experienced climbers:

Generally speaking, I don't worry about falling off indoors. Unless it is a belayer that is very light.

(BL, Male, f6c/6c+)

Very rarely harder routes and that is mostly because of belayer problems. I don't have that many heavy climbing friends that I can feel confident with a belay from.

(AX, Male, f6c/6c+)

Similarly, a lighter interviewee also described a similar feeling when they were climbing with a heavier partner:

I think so, I think more because the people that I climb with are heavier than me, so it is normally me getting dragged along the floor when they fall off. And you almost get the feeling that you are out of control. Which I guess is what I am thinking of at that time.

(BA, Male, f6b/6b+)

Social Factors

Along with providing protection for the climber, the belayer and climbing partner(s) are an inherent part of the climbing experience, engaging, protecting and supporting the climber during their sessions. The motivational and emotional support of the climbing partner were referred to by a third of the interviewees as a source of motivation and confidence:

Yeah the people that I am climbing with is a big one. If I am climbing with someone who is sort of quite competent and is climbing at quite a high level, I am more likely *to climb to push myself, because I think it is just you get more motivated too. I think you sort of think ah I am going to try and push myself as well.*

(BS, Male, f6b/6b+)

It definitely depends on the mood of people that you are with, you can be with someone. If you are with someone, who is confident you are more likely to try something than if you are with someone who is really nervous on the ropes and the high things much more likely to shy away from things.

(AH, Female, f6a/6a+)

Conversely, the attitude of the climbing can also negatively influence the perceptions and behaviour of the climber, enhancing perceptions of stressors, such as those highlighted in *Theme One*:

I would say, my previous climbing partner had quite a fear of falling, he didn't like it all. So I think that was sort of, because I was sort of new to the sport, I think that was imparted onto me, whereas my climbing partners now people that I climb with are sort of happy to take absolutely massive whippers so that attitude has gone onto me a bit more.

(BS, Male, f6b/6b+)

Because she was scared when I was at the start, she was not sure about this, but I said it would be fine but before I just worked my head a bit, but I jumped on really quickly so she wouldn't have to think about it too much and then I got to the bit where it felt like I wasn't sure what goes on next cos I guess I normally only look at half the route and the doubt went into my mind and I fell and I decked from 7 or 8 meters. I was fine and didn't break anything, but it was - I started questioning things.

(CA, Male, f6b/6b+)

Threats to self-efficacy and confidence

Self-efficacy and confidence can play a significant role in how situations are approached, emotions experienced and consequently have an impact on performance. Three sub-themes were identified, the desire to demonstrate competence, to succeed and the evaluations of others.

Demonstrate competence

Several participants reported attempting a route which was at or of a lower grade than their self-reported on-sight ability, results in feeling they were under additional pressure to demonstrate their competency and their ability to complete the route:

> *You tell people that you can climb that grade so you expect to climb that grade and on the personal level you are trying to push yourself and do better especially since I know that I could climb harder than I am.*
>
> (BU, Male, f6b/6b+)

> *Yes, I feel obliged to demonstrate that I can. Which is almost mad in some respects, because every route is slightly different and grades are so subject yeah that is trying. Some climbs I am better at and some climbs that are vertical or slaby and overhangs. Although you know actually I like slopers as well so that is, a lot of people that I know don't.*
>
> (AT, Male, f6b/6b+)

Paradoxically, a number of the more experienced interviewees reported attempting a route of a grade they should be able to complete being more daunting than attempting a route well beyond their capabilities:

> *If I were to climb a f7a right now and I did fail and I did drop I would feel much happier to drop it and then to do it again. I think there is a little bit of pressure on this because you get one go only blow your on-sight and so it feels like it should be less pressure, but actually it might be more and me setting up for an on-sight climb, at my max.*
>
> (CD, Male, f6b/6b+)

Continuing the theme of demonstrating competence, many of the interviewees reported frustration and internal conflict in response to not being able to finish routes, which they perceived they should be able to complete:

> *You want to succeed, ultimately and if you know that you probably won't it takes the fun out of it because you like to do well . . . I don't like to turn up and persistently fail on something.*
>
> (CN, Male, f6a/6a+)

> *I am a little bit angry that I didn't push myself a little bit more because I think it was I know roughly what the sequence should be I could have gone for it and fallen off going for it rather than wimping out and saying no.*
>
> (BJ, Male, f6a/6a+)

A number of interviewees also described how success for them was not necessarily simply reaching the top of the route, but attempting to climb a route and feeling that had given it their best attempt. Climbing until they were unable to continue and then falling:

> *I would rather fall off and be happy about it, than not fall off but not be so sure about it.*
>
> (AH, Female, f6a/6a+)

> *It's more a personal thing and in terms of my motivation for climbing. I think kind of how I judge myself as being a good or bad climber. I guess I see myself as a climber that should be kind of pushing hard and not backing off for the wrong reasons. And usually why I get a bit upset with myself when I am climbing or get overly worked up it is not usually about falling and injuring myself, it is normally about failure. Not climbing as well as I think I should be climbing. Or, it is ok, all right to fall off as long as I have given it my best shot. But sometimes all these little things creep in and you don't perform very well.*
>
> (BL, Male, f6c/6c+)

Evaluation by others

Conspicuous by its limited prevalence in discussion with interviewees was the small numbers of participants' reports of a threat to esteem from falling or failing to reach the top of the route. One climber discussed *looking like an idiot* as a reason for the change in their behaviour, while another described doubts when other climbers were around:

I have been with a couple of other friends who are novices . . . I am a bit more conservative on how far I push myself when they are there. Not because I don't trust them, but I don't want to make a mistake and look like an idiot in front of them.

(AT, Male, f6b/6b+)

Sometimes all these little things creep in and you don't perform very well. Probably gets compounded when other people are around as well. Especially when they are other people that I probably look up to. It is rarely about thinking that I am going to hurt myself and more about social pressure and pressures that I put on myself. As in what it is to be a successful climber. Just cos it, I want to feel like I climb to the best of my ability and give myself every chance of getting to the top.

(BL, Male, f6c/6c+)

There were several interviewees who described not wanting to lead during their regular sessions. Climbers may choose not to lead and to top-rope a route instead, however, several interviewees described the unfounded negative perception of top-roping within the sport, this was reported especially by interviewees in the f6a/6a+ ability group:

There is a bit of top-rope shaming, sometimes in some places. Which I think top-roping has its time and place.

(AP, Female, f6a/6a+)

I don't really feel it too much, but there is a bit of pressure isn't there, there is the whole stigma behind it.

(AU, Female, f6a/6a+)

Several climbers, who themselves do not have issues with lead climbing, discussed feeling climbers are *kidding* themselves by top-roping routes, further implying they are cheating themselves by choosing the perceived easier option:

Top rope is a bit, it's fine if you are just starting out and it's fine you don't want to be clipping in and whatever. If you were to top-rope that you really are kidding yourself because half of the thing with hanging on to that is hanging on and knowing if you

> *should quit there or should you climb passed it . . . In my head that would knock it down a grade.*
>
> (CL, Male, f6b/6b+)

It appeared criticism of top-roping was both self-imposed and brought about through the evaluation of others in relation to expectations and perhaps consideration of climbing ethics, with only lead climbing being ‘true’ climbing. This may also affect the prospects of some participants’ long-term participation in the sport, restricting options for continued participation.

Climbers Background

The climber's background in the sport was discussed by interviewees, relating to previous experiences, how they were introduced to the sport and general trait fears and anxiety. While some of these were not directly related to the sport, they were still discussed as having an impact on participant’s enjoyment, emotional experience and performance.

Previous Experiences

A number of the more experienced (note, not necessarily higher ability) climbers discussed previous negative experiences, relating to injuries sustained while taking part in the sport and the impact on their climbing:

> *I have fallen off and on a couple of occasions I have hurt myself. Not disastrously, I’ve not had any life changing injuries, but the potential for life changing injury limits my desire to take chances. Although some of the people that I climb with consider me to be quite bold. But I am bold within my comfort zone, I am bold on runout slabs, because I am happy and comfortable with them. I am much less bold on thuggy overhanging trying to get around a roof type of routes. Familiar with and a type that I can be familiar with. It may be an on-sight lead but if it is an on-sight lead of a bold slab I am more likely to go for it. Even if there is a chance of a ground fall.*
>
> (CH, Male, f6a/6a+)

> *Quite a while. Initially I used to throw myself at anything and then I fell on Regent Street at Millstone and fell off from near the top and ended up near the floor. And that*

kind of put me off a bit. And that was two years after started climbing. So it took a while after that to get back into it.

(AM, Male, f6c/6c+)

Negative experiences concerning belayers were also discussed, in addition to attention and experience as presented previously. How the belayer arrests the climber in the event of a fall can dramatically effect the comfort of a leader fall. For example, a fall arrested by a heavy climber or someone who does not belay dynamically and moves with the fall, can be considerably different to a correctly belayed climber, despite both arresting the fall:

I have had a couple of bad falls and hurt my ankles through bad belayers' really. Just through my inexperience and my belayers' inexperience that we have made mistakes. He has pulled me tight instead of letting me run a little bit. It takes time as a belayer and if you are climbing with different people, then it takes a bit of time to get used to their weight and everything else. Had a few hard falls and I have got a bad ankle, there is actually a fracture in my ankle, so I am trying to get it sorted so I have always got that going on, so I guess there is a slight psychological thing.

(BC, Male, f6b/6b+)

Conversely, interviewees also highlighted positive experiences:

I think I can attribute that to my background in gymnastics and trampolining. I am used to being about 20 foot in the air and falling down. So I am used to that feeling of falling for a while and then hitting something. And essentially I trusted the person that I went climbing with first, I had known them for about five years. And I trust him and I know that he is good at stuff so I assumed he would be good at catching me. I find it quite good fun, It reminds me of good training times and things. Which can be a bit bad, because I remember at the beginning I remember I could, if I ran out of clips, I wouldn't be too afraid he would be absolutely bricking it. So, in the beginning, I was careless, now it is the case of, I don't mind climbing until I drop because I am confident in my belayer.

(CR, Male, f6b/6b+)

Climbing discipline background

The background of climbers and their preferred discipline was an important factor in their description and understanding of how they respond to stressors. Those climbers coming from a traditional background, particularly those who had been involved in the sport for a longer time, especially before indoor climbing walls were common, were more likely to describe a no-falls attitude:

> *Yeah yeah, coming from a trad climbing background I am not a great believer in the benefits of falling off.*
>
> (CH, Male, f6a/6a+)

One interviewee reported this was not only something common to older climbers, but was part of the mentality of British climbers:

> *I think it is a mentality in British climbing full stop. With the trad history that you just try to avoid climbing [falling] but on the continent falling is just a part of climbing and it naturally excepted and people do it all the time. I think people just afraid of climbing that kind of message just filters thought to everyone else that is around them as well. Yeah, I think it is basically British climbing.*
>
> (BL, Male, f6c/6c+)

Conversely, the same interviewee described younger climbers, coming through into the sport, who have been introduced to indoor sport climbing from a young age having a very different approach to the sport of lead climbing:

> *I think as young generations come through I think falling is becoming a lot more accepted you see kids getting onto squads where they have just been told fall off all the time as part of these squads, so I think that it is becoming more and more a natural thing to do. I still think the majority of recreational climbers are not used to the idea of falling off on the lead. A lot of people, anecdotally, have kind of these off-putting experiences, usually climbing with other novices where they have been dropped or something like that. Which again compounds the problem, does it. Because you know you were worried about that and now you are more worried cos something has*

happened to novices. Whereas I think if you come to a climbing squad you are getting the right introduction from the right people and that it is all right to fall off.

(BL, Male, f6c/6c+)

External stress

Considerable inter-individual variation has been found in previous climbing psychophysiology research including *Studies One and Two* of this thesis. Individual variation in climbers are not only situation specific but were also described as varying day to day, depending on a number of factors including fatigue, hunger, motivation and how their day was prior to arriving at the wall:

Sometimes it is fatigue, sometimes I don't get enough sleep really. And hunger as well. That can be a factor some days. Other days it is just that I have had a hard day before and I got pumped or I haven't warmed up well enough.

(AT, Male, f6b/6b+)

I seem to go through periods where I am doing really well when I can't explain why and periods where I am not doing really well and I cannot explain why either. So it really varies. I think that when I am really tired and I come here at the end of a day. But then I have had brilliant sessions here after a full day at work. And you know I can't blame it on anything specific.

(AP, Female, f6a/6a+)

Furthermore, the state participants arrive in at the climbing wall may influence both the type of routes the climber tries and how they feel they perform:

If I was on a top-rope, I could try anything at any moment. But it is more like the head game that starts getting harder. If more energy is being used for something.

(AY, Female, f6a/6a+)

> *In order to climb higher grades to be able to go for the next hold, you need to be in a mental state that you are not overwhelmed or tired or all the problems from the office are in your head.*
>
> (CC, Female, f6a/6a+)

Finally, for a small number of the interviewees, external stress and fatigue was expressed as one of the main limiting factors for their climbing performance during their normal recreational sessions:

> *I would say that the limiting factor is how I am feeling on the day because that will, that will influence what I get on and what I don't. So if I . . . get to the wall and I am as full of beans and want to get on something I will just like head for I think I probably can do, whatever is hardest based on what I have done previously. I might try and go up a grade or something and see what happens. But yeah if I get to the wall and just have a bit of a training session because I think ah it is better than nothing.*
>
> (BS, Male, f6b/6b+)

7.3.3 *Theme Three*: Control

Central to Themes One and Two were interviewees' discussion of salient stressors in the climbing environment brought about by both the decisions and influence of others. *Theme Three* discussed how climbers can influence and manage the internal and external stressors present in the climbing environment. Interviewees discussed strategies they used to maintain control over the stressors present and the choice they made when they were climbing. Avoidance behaviour was particularly prevalent. The factors discussed by participants were broadly divided into decisions made prior to leaving the ground, factors on the route and behavioural changes while climbing.

The prospect of a fall when climbing, can result in participants avoiding situations they perceive to be or may be anxiety inducing. A small number of the interviewees described avoiding elements of the sport they found unenjoyable:

> *If I stop enjoying it and I feel that I enjoy leading on a particular day, because why you know, why should put myself through something that is stressing me.*
>
> (AP, Female, f6a/6a+)

I don't like being stressed when I am climbing and being run out above some terrible gear is not my idea of fun so I don't. But even that said, I don't do sport climbing because I don't really like it.

(CN, Male, f6a/6a+)

Pre-Climb Decision Making

Interviewees discussed a number of decisions and choices made about the routes they typically attempt in their day-to-day recreational practice. Critically, the choices appear to influence the control climbers have on the routes they ascend, two sub-themes were highlighted, route difficulty and the style of ascent. For example, several participants discussed avoiding leading where possible, particularly on routes towards the top end of their ability. This was especially true of the f6a/6a+ grade climbers. The use of a top-rope all but removed the potential for the climber to fall:

Yes I think I have always been afraid. I would always top rope if I could, I would avoid leading.

(AQ, Male, f6b/6b+)

Indoors obviously, I can try much harder routes because I know that I am on a top-rope. It is being a bit feeble, I shouldn't try them on a top-rope, what is the worse that could happen?

(AK, Female, f6a/6a+)

As with the style of ascent, the same was also true of the difficulty of the routes climber's attempt. Increasing their chance of completing a route through reducing the difficulty:

I choose the easier climbs that I know that I can finish.

(CS, Female, f6a/6a+)

I don't normally push that much above my grade. Not leading anyway.

(CO, Male, f6a/6a+)

Interviewees also discussed choosing routes based on their angle and the types of holds. Route choice was described as being specific to the type of holds; for example, small positive crimps have a defined edge, in comparison to open handed sloping holds:

> *I am usually quite happy about falling off on something steep so I wouldn't climb something on a reasonably vertical wall because I was worried about falling.*
>
> (BR, Male, f6b/6b+)

> *I'm more comfortable on some types of holds than other . . . I tend to stay away from things that are sloppy. Naturally, on slopey holds, I don't feel as comfy, whereas on positive crimps I am more confident and feel like I have got hold of them. Same with the feet as well. Small but positive footholds.*
>
> (BL, Male, f6c/6c+)

This may be linked to the background of the climber. One f6b/6b+ climber discussed applying the same logic to choosing routes indoors as they do to their traditional climbs outdoors, despite the difference in the environment:

> *Do I climb within my limits indoors? Yes, I do. I don't, I don't want to push beyond my limit very often and when I feel that I am pushing my limit, I will call my belayer and say watch us on this one. Or if I am on a route that is my limit I will say to him before I set off, keep a very tight eye on this I am likely to come off.*
>
> (CQ, Male, f6b/6b+)

On-Route Decision Making

There are few factors the climber can influence once they have begun climbing route without detrimentally affecting their performance. This is particularly true indoors where the holds used generally prescribe a sequence to be followed and the climber does not have to make complex route reading decisions. The three sub-themes highlighted by participants were avoiding falling, taking controlled falls and changes in clipping positions. Such decisions described by the interviewees allow them to regain a sense of control, instead of climbing into uncontrolled situations on routes.

Avoid Falling and Controlled Falls

When attempting climbs indoors a climber will usually follow a single coloured set of holds, however, routes are rarely set in isolation, so if desired, participants can use holds on parallel routes to ensure they do not fall. A large number of the f6a/6a+ and f6b/6b+ ability climbers discussed times when this was not the case:

> *I have a choice of responses. One is to back down to the bolt below me and take a rest on the rope and take us tight. The other is to cheat, grab a hold that is not the right colour. Those are my two responses, rather than fall off*
>
> (CH, Male, f6a/6a+)

> *When I am at my edge quite often I will go for an easy hold on a different colour, which I know isn't the right thing to do. But I don't want to take the fall, an air of failure if I take the fall as oppose to when I control it, I am not sure. Or whether there is just a fear of having to let go.*
>
> (CD, Male, f6b/6b+)

The climber may also choose to take a lead fall from a point while they are still in control, rather than continuing to unknown holds, to a point where they are further above the quickdraw and can no longer continue:

> *I just sort of knew that I could do a controlled fall and knew what I was doing or sort of try my best and sort of come off uncontrollably. In which case, it was a big lob.*
>
> (AT, Male, f6b/6b+)

> *[if] there was a very small percentage chance of finishing the route and like I say I would rather take a controlled fall than an uncontrolled one.*
>
> (AT, Male, f6b/6b+)

A controlled fall provides an opportunity for the climber to opt out of the route, without having to continue to the point of physical failure:

If I am doing a route that I am not comfortable with sometimes I will opt out, I will opt to fall instead of making the next move to try and clip. So that is a mind game.

(AJ, Male, f6b/6b+)

Similarly, climbers have the option of the rope being taken tight if they are level or below the last quickdraw, they may then be lowered back to the ground or rest without having to fall:

If realise that I can't make the next move I will ask you to take indoors well I can just see it. I can see that I'm going to fall so I am going to ease that fall.

(AB, Male, f6a/6a+)

Ability to protect the climber

Unlike top-roping, when lead climbing the participant must consider the need to protect themselves at intermittent points on the route. The ability to clip quickdraws on a route is key for climbers' safe progress. It was highlighted by interviewees, as a significant component of their appraisal of the challenges of the sport. One aspect highlighted, was the possibility the climber may fall while clipping, such factors were discussed by 15 interviewees. A fall while clipping can result in a significantly larger fall:

If I am clipping and I am shaking that does throw me a bit. Just knowing that the fall will be that much longer.

(BG, Male, f6b/6b+)

Only when I am clipping the falling goes through my head. Just because that is when I have got the most rope out and when I might take a bigger fall factors . . . most of the time I don't really think about.

(BD, Male, f6a/6a+)

Typically, to clip the quickdraw the climber must assume a stable posture, remove one hand, pull through a *bite* of rope and attach it to a quickdraw. The physical difficulty of such positions largely depends on the difficulty of the route. This caused a small number of interviewees' issues, particularly when the difficulty of the route, relative to the ability of the participant increased:

When the moves get harder and I am finding it difficult and it is challenging and I am trying to make that clip and I am not comfortable I feel I am going to fall off making the clip, never mind doing the moves.

(BT, Male, f6c/6c+)

Conversely, the better the holds that the climber may clip from, the more secure the participant reported feeling when clipping. However, when a hold is open and slopey (rounded open hold, not positive), rather than positive and crimpy, then they reported being less confident and comfortable:

If the holds near the clip are good it feels fine, but if they're slopey and rubbish I worry about pinging off when I take my other hand off to clip.

(CL, Male, f6b/6b+)

As the climber makes progress, their position relative to the last quickdraw is constantly changing. While indoors, the spacing of quickdraws are relatively consistent there are times when they are below, protected from a rope above. There are also times when the climbers are above the quickdraw with the rope below, which will result in a longer fall. As the climber moves further above the quickdraw the potential distance the climber will fall increases:

If I'm below the bolt . . . I am happy to try things even if they are harder . . . if I'm too scared of the move and I'm too far above the bolt then I might . . . down climb and not do it.

(AY, Female, f6a/6a+)

I'm happy top-roping and I am happy leading when I am below the bolt. When I'm above it though. It's not great. I'm not happy again until I've clipped the next one.

(BZ, Male, f6a/6a+)

To compensate for a potentially greater fall from being above the quickdraw, the climber may choose to clip earlier. Generally, it is recommended climbers clip when the quickdraw is at around chest or waist height. However, clipping overhead can create short sections of the route where the climber effectively has a top-rope and if performed from a stable position from a good hold it can be a reasonable tactical decision:

> *There were one or two points on this where I clipped a bit earlier . . . I thought that the next hold . . . didn't look as good as the hold that I was on. I thought it might be easier to clip lower with the better hold.*

(BR, Male, f6b/6b+)

> *It is more from just a tactical perspective like I know that I am in a comfortable position here, where I can clip, but if I move I might not be able to. The next hold, if I was in a good position and if the clip was by my knees, then that would be fine, but I always think that better to think that if I can and If I can touch better to just get it in. Especially in the first half of the route, if it is something hard. Because you never know you can always just ping off. If you can, clip it.*

(BS, Male, f6b/6b+)

However, feelings of an inability, or potential inability, to clip safely may result in the climber attempting to compensate for changes in the clipping position:

> *I find that if there is a clip above me I am instantly calmer and able to progress or at least push it and fall off.*

(BA, Male, f6b/6b+)

While clipping quickdraws early may in some cases be considered a tactical decision, in others case it may be considered a maladaptive practice. The further below the quickdraw the climber chooses to attach the rope to the quickdraw from, the more rope the climber needs to pull through, increasing the potential fall while clipping, along with the energy and time that is required for the task:

> *I know that if I pull loads of rope out I know I have just made my fall bigger than if I climb up and clip there, because you have got that extra rope out. I do know that you have got a bigger fall*

(AA, Male, f6b/6b+)

> *Certainly, I notice if I am close to my edge that I will clip higher than I should. I know full well that the best position to clip from is right next to your harness, I mean obviously it is less effort to clip it shows a slight sign of confidence in your climbing*

to be able to clip when you are above the draw and just make it a much quicker clip, however, I think that it is quite natural to want to clip height when you are unsure of either the next move ahead or if you are struggling to be comfortable on the holds that you are on. Sometimes it is good to clip up, but most of the time I know that if I am clipping higher than my head, it's because I am uncertain of the moves ahead. But I still clip above my head because it feels like having that clip done will be safer I suppose you are on a bit of a top-rope.

(CD, Male, f6b/6b+)

Participants were more aware of the unknown challenges clipping high helped to mitigate, rather than the hazard clipping high presents:

I think that the safety and the fear aspect come from what if I drop the next move, oppose to dropping when I am clipping high, so maybe there is a bit of a fear that the next move the next move I am not sure how easy or hard it will be.

(CD, Male, f6b/6b+)

It is more from just a tactical perspective like I know that I am in a comfortable position here, where I can clip, but if I move I might not be able to. The next hold, if I was in a good position and if the clip was by my knees, then that would be fine, but I always think that better to think that if I can and If I can touch better to just get it in. Especially in the first half of the route, if it is something hard. Because you never know you can always just ping off. If you can, clip it.

(BS, Male, f6b/6b+)

Controlled Movement

The effects of climbing stressors on recreational climbing performance has seen limited investigation. However, interviewees were aware of how their performance was affected. For example, alterations in the fluency of movement were identified in participants' own performance. Interviewees describe how they reduce movement complexity and increase the feeling of control:

I will always push on, I won't let falling off stop me going upwards, but it doesn't help my climbing performance that I am still a bit tense climbing and worried about the fall.

(BL, Male, f6c/6c+)

I start getting into panic mode my body starts coming into the wall. I guess comfort of being close to something.

(AJ, Male, f6b/6b+)

The conscious control of movement may also be used to maintain performance if climbers are fearful. A number of the less experienced interviewees discussed such control of movement:

If I am getting a bit spooked about taking a fall if I am in a situation that could cause harm. I will take a lot more time to climb a lot more statically and try and control all of the movements. Which on an overhang can affect, as I mention I lack the endurance on some of the climbs I may be holding harder positions and wasting more energy.

(BD, Male, f6a/6a+)

If I am scared, I don't climb in a really fluent way. I really try and push back the idea that I might fall and I try and climb as well as I can with the maximum flow.

(AY, Female, f6a/6a+)

Climbers were also aware if there were committing moves, which on completion would not be reversible, they were climbing into situations where their perceived controlled decreased, forcing them to continue climbing until they could clip the next quickdraw or fall:

If it is a high rock over then I am a bit more, it is a bit more committing you have to get your foot. It is kind of the commitment of the move itself is more the fear than the placement, so if it was a really big move, I would be a little bit more anxious about making it.

(BD, Male, f6a/6a+)

Similarly, interviewees were aware of making progress on the route when they are unaware of the holds and movements required ahead. This applies in particular to climbers attempting routes at or beyond their on-sight climbing ability:

> *Having the confidence when you lead climbing to make tricky moves with the fact that you are going to fall off if you don't make it. And that still scares me*
>
> (BC, Male, f6b/6b+)

Climbers may choose to stop when they feel fatigued, rather than continuing to the point of failure:

> *When I get pumped, I tend to panic and give up quite easily, rather than. I tend to get scared and panicky and give up. Rather than pulling myself down and try and relax and rest a bit. I find it difficult to recover and rest and get rid of that pump.*
>
> (AS, Female, f6a/6a+)

Conversely, more experienced climbers reported having a *one more move* attitude. Trying to make more moves, regardless of whether they thought it was possible to complete the route, the sequence or if they were going to be able to clip the next quickdraw:

> *once you get passed that move, there is a chance that it will get easier and you will be able to finish it. And I have had that work for me a lot of times. And if you are not red point and going for the on-sight I find that one more move mentality very helpful, until you literally fall off because you don't have anything left*
>
> (AH, Female, f6a/6a+)

This was reported as something the interviewees had to work at and that did not come naturally:

> *What I wouldn't do is really pop up for moves but now I would see a hold that at the works I would happily launch myself at and in fact it could be exactly the same hold, exactly the same make and exactly the same shape and I see it on there and think that I am not going to do it, now I will do it. And if I come off I come off.*
>
> (CL, Male, f6b/6b+)

Interviewees were aware of how they gripped holds on the route, a number described over-gripping in relation to negative performance consequences of climbing while anxious or fearful, such over gripping can increase the rate of fatigue:

> *I felt like I was pulling really hard and hold things a lot harder than I needed to because I was anxious to keep going. And then I got tired and climbed into a corner I think and then came off.*
>
> (AH, Female, f6a/6a+)

> *I was quite anxious . . . I tried to pull on it instead of using my legs and that is where is started to get tired.*
>
> (BD, Male, f6a/6a+)

7.3.4 *Theme Four*: Practice

Interviewees described knowledge of structured methods for reducing fear of falling, including clip-drop techniques, which are extensively outlined in literature, along with unstructured practice.

Structured practice

Fall practice has been described in coaching literature extensively. Clip-drop techniques progressively expose climbers to falls. Generally, participants' reporting of their regular use was limited, although 41 interviewees discussed knowledge of such practices. The small number of interviewees who did describe their use highlighted its importance for them:

> *Falling indoors is probably the most important thing that I ever do . . . it helps me relax when I come to be in a 30-40 foot run-out on a trad route. It helps me with that, because once you are happy falling off here, then it feels like the same thing, you may not be really safe but it feels the same.*
>
> (CM, Male, f6c/6c+)

> *I think it is really important. I think a lot of problems that I have and a lot of problems that friends have I have seen as well.*
>
> (BG, Male, f6b/6b+)

Of the minority who partook in any form of fall practice, some were introduced to the techniques early in their climbers' career:

> *So my first introduction was . . . falling and practice it . . . to me this is completely normal and I have experience of catching this guy hundreds of times. So, if I can catch then, he can catch me.*
>
> (CR, Male, f6b/6b+)

Its effectiveness may be because it addresses the primary limitation in many climbers' performance:

> *Primarily with me it's that as soon as confidence goes a bit they will either just stop at the clip or ask to be taken in. But obviously, that doesn't help with progressing. I do see that in myself, but it does still get me. But when I do take falls I do feel like I am getting to a point where I am progressing. I defiantly think it is very important.*
>
> (BG, Male, f6b/6b+)

While effective for the climber, its effectiveness may be tied to the belayer and the development of trust that comes along with working with a belayer:

> *It depends on who is belaying as well. Like 100% it depends on who your belayer is.*
>
> (AW, Female, f6c/6c+)

However, they were rarely progressive, often being described as only consisting of regular planned falls:

> *I just climb up a route clip the chains and then just leave rope a little bit slack and so you have climbed the route clean and taken a little fall.*
>
> (BB, Male, f6b/6b+)

As with the previous section, describing control and route choice, a similar effect was present in clip-drop practice, steep terrain allows for falls to be taken with little risk of injury; but does not expose the climber to falls on more complex terrain:

Erm, yeah have done that old clip drop technique. And er the old edge climbing centre you could articulate the wall over. So you could take it over to about 60 degrees and we used to practice taking falls on that all the time. I am quite happy with falling, it is just on what terrain, it has to be on my terms I guess.

(CN, Male, f6a/6a+)

Unstructured Practice

For the f6c/6c+, 17 reported taking unstructured and unplanned falls, a characteristic that was not present in f6a/6a+ grade climbers. This was not necessarily associated with progressive fall practice. However, it would seem to be a logical progression, as it works on the same principle of positive reinforcement:

Just falling off and realising that you are not going to hurt yourself or whatever makes a big difference.

(BK, Male, f6c/6c+)

The idea of *one more move* was discussed as being central to this, with the climber continuing to make moves on route until failure or success:

I try really hard not to stop on a move knowing that I can't make the next move. I will always try and make the next move

(AL, Male, f6c/6c+)

I was climbing above clips and just having a look and having a word and saying I will make this move and if it sticks I will make the next move, if I fall off I am safe and I am not going to get hurt. And from that, I have found that I can make at least 6 more moves than I used to be able to. Positive reinforcement, it is a good thing if you fall. It is not a bad thing. It is not something to be scared about.

(BT, Male, f6c/6c+)

7.4 Discussion

The purpose of *Study Three* was to determine salient stressors within the sport of indoor lead climbing, their sources and potential antecedents. To achieve this, 61 semi-structured interviews were conducted. Through exploring the experiences of intermediate and advanced climbers who regularly practice indoor climbing the findings are able to describe in detail the challenges faced by climbers, providing rich insight for climbers, coaches and future research. To achieve this, the analysis explored a) the interviewee's perception of the sources of stressors and challenges present in the indoor recreational climbing environment; b) external mediating factors that influence how the interviewees respond and moderate their behaviour to manage stressors; and c) techniques interviewees use in their sessions to reduce fear and anxiety and improve their performance.

The main findings of *Study Three* were the identification of a multitude of stressors, which were broadly split into, a) those brought about by the decisions of the climber and b) factors external to the climber. The defining characteristics of lead climbing discussed were the potential for taking falls or more specifically the anticipation of falling. The negative emotional response towards falling appeared to occur because of a threat of physical harm and/ or a threat to the climber's esteem; evidence from the interviews and previous research suggests the threat of physical harm was the more salient of the two. The belayer and the background of the climber was described as a critical element in a climber's performance and important in determining participants’ responses to stressors. Interviewees frequently described avoidance behaviour in their attempts to manage stressors. While some decisions discussed by the interviewees may be considered discreet, such as the difficulty of route choice and taking controlled falls on routes, others were more overt, such as choices of the style of ascent, choosing to be taken tight on the rope before failure and changes in clipping positions. While the decisions made by the climbers allow them to engage with the sport on their own terms and exert a level of control, they are likely to have a significant impact on performance. Finally, to redress a fear of falling, fall practice techniques are frequently described in climbing coaching literature, while interviewees were aware of their potential, there were few who reported their regular use. The more advanced level climbers who were interviewed, did not report the use of clip-drop techniques any more regularly, however, they did describe a difference in their mentality toward climbing to failure, with a *one more move* attitude.

To my knowledge, this is the only study within the sport of climbing's growing body of literature that has qualitatively explored climber's perception towards indoor recreational lead climbing. The present study has made significant advances in our understanding of climbers' responses to lead climbing. The findings support those of *Study One* that lead climbing is a significant source of stress for some climbers; and the results of *Study Two,* that a route greater than a climbers' maximum on-sight grade was a significant and potent stressor. However, developing significantly on previous results, the interviewees discussed control and avoidance behaviour. Specifically, the interviewees identified how stressors in the climbing environment influenced their perception of control and coping resources and the decisions they make in order to manage the stressors, particularly avoidance behaviour. Alterations in perceptions of control are likely to have been responsible for significant increases in factors including self-reported anxiety, anticipatory heart rate and cardiovascular reactivity indicative of a threat state seen in previous studies, including *Studies One and Two*. Many possible extraneous variables were discussed that also serve to increase inter- and intra-individual variation and may be, at least in part, responsible for variation seen in previous research.

Understanding climbers' perception of stressors within the climbing environment and how climbers manage them are not only important for climbing psychophysiology research. As demonstrated by *Studies One and Two,* not only was anxiety an unpleasant feeling experienced by climbers, but it is also significantly detrimental to performance. While such understanding is not novel, it reinforces anecdotal evidence from coaches; for example, Hague and Hunter (2011) describes a fear of falling as performance-robbing and assert every climber should attempt to overcome it. The findings of the present study have implications for coaches working with intermediate climbers identifying sources of stress and areas for potential gains in performance. However, perhaps most importantly, understanding the challenge faced by climbers developing and progressing into lead climbing could have significant implications for long-term participation in the sport as anxiety has also been associated with discontinuation of sport participation (Gould et al., 1982; Scanlan et al., 2005) and less pleasure while participating (Scanlan et al., 2005; Smith & Smoll, 1991).

The following discussion is laid out to address the three objectives set out at the end of the introduction. The discussion aims to provide explanation and context for the findings of the interviews. Firstly, discussing the salient stressors present in the climbing environment as highlighted by intermediate and advanced recreational interviewees. Secondly, it explores potential external mediating factors. Thirdly, it discusses the ways in which participants respond and moderate their behaviour to manage stressors present. Fourthly, it provides an overview of how recreational climbers currently try and improve their performance and the techniques they employ. Finally, a preliminary model of anxiety in climbing is presented.

7.4.1 Stressors present in the indoor climbing environment

Recreational climbers make many decisions during their sessions to manipulate the difficulty and challenges they face. Many of the stressors present in the climbing environment are self-selected, including the safety protocol, route difficulty and climbers' knowledge of the challenges and movement sequences a route contains. Consequently, indoor climbing may be defined by the self-selected pressure situations climbers choose to engage in or alternatively avoid (*to be discussed in 7.4.3*). The decisions individual climbers make and their underlying reasoning are important in understanding differences in performance seen in previous research. For example, considerable variation has been found with psychological and physiological variables when assessing changes in the safety protocol, as demonstrated in *Study One* and route difficulty as seen in *Study Two*, along with the previous body of climbing psychophysiology research, discussed in *Chapter Three*.

Anecdotally, lead climbing is comprised of several potential stressors, which climbers must engage with to complete attempted routes. Climbing indoors, while containing less objective dangers than outdoor climbing, still presents a considerable number of stressors that may serve to disrupt the performance of climbers (Pijpers et al., 2003; Pijpers et al., 2005). Ideally, climbers attempting a lead climb indoors would be able to focus all their attention and effort on the physical task of climbing, regardless of the potential for falls or other consequences, in order to perform optimally (Sagar, 2001). However, the results of *Studies One and Two* demonstrate this was not the case. Stressors serve to disrupt the climbers' performance, likely through a combination of diverting attention away from relevant environmental cues and greater internal focus, reducing movement fluency and ultimately performance on the route (Nieuwenhuys & Oudejans, 2012). The inappropriate responses of climbers to said stressors are thought to be one the most significant factors in negative performance:

> *Fear is the root of many climbers' limitations. In the domain of traditional climbing or mountaineering, this is a relatively valid feeling. However, in sport climbing, the*

> *focus is not on the protection of the route, but rather, the physical movement and strength of the climber. (Sagar, 2001, p. 114).*

Theme One was concerned with stressors brought about by the decisions made by the climber within their typical recreational sessions. Interviewees described three key challenges of indoor lead climbing: route difficulty, height on the route and route knowledge. Firstly, route difficulty was discussed as one of the key variables decided on during recreational practice. Interviewees were acutely aware of the grade of climbs they were usually able to complete and the choices they were able to make about routes they attempted. Secondly, while gaining height is an inherent part of the sport and a key prerequisite of success, it was identified as a significant source of anxiety by several interviewees. Finally, climbers' knowledge of the route and the unknowns that an on-sight of a route contain were salient for several interviewees; specifically, they highlighted that not knowing what the upcoming holds, sequences of movements or clipping positions would be, had implications for the physical and technical execution of movements but also the climber's emotional experience. Interviewees reported they were wary of the unknown challenges of a difficult on-sight route, both when selecting routes and when climbing.

The degree of influence the climber has over the factors of difficulty, height and knowledge vary, based on the stressors characteristics. For example, for route height it is only possible to select between different wall heights in a climbing wall, which indoors are often limited; furthermore, paradoxically, taller walls may be safer as the chance of ground fall may be reduced. Route knowledge may be influenced by other climbers providing *beta* or information about the route to be attempted, but until the climber has attempted the route they will not have first-hand information of the sequences of movements required (*see Section 3.2* Route knowledge). Conversely, route difficulty is the most readily manipulated and selected, largely because of the grading of routes and climbers' knowledge of the grade they should normally be able to complete (Draper et al., 2016). Additionally, routes may also be selected based on characteristics such as route angle, types of holds and opportunities for rest, which are easily identifiable indoors (Boschker et al., 2002). These factors and the choices they afford climbers, readily provide opportunities for avoidance behaviour, which were discussed in *Theme Three* (*see 7.4.3* Climbers respond and moderate their behaviour to manage stressors).

While the interviewee's responses differed over the salient stressors, their responses were often underpinned by one factor: falling. Falling was reported as a significant source of stress for a considerable number of the interviewees. Furthermore, such responses were not restricted to those of f6a/6a+ ability, although a greater proportion of the f6a/6a+ ability interviewees reported such experiences. The actual feeling of falling was described as unpleasant by a small number of the interviewees, conversely, a much larger number described the anticipation of the fall and the potential consequences to be the salient factor. Interviewees were particularly aware of being out of control, in particular, the potential to fall and their unpredictable outcomes. Such findings support the assertions by authors of climbing literature (Hague & Hunter, 2011). For example, Sagar (2001) stated "*Once you are in the air, you can't do anything until you hit the end of the rope. As I struggled to overcome my fear and tried taking falls on routes, I came to realise I really wasn't afraid of the fall. I was afraid of the anticipation of the fall"* (p. 114), while Hörst (2008) specified *"it's not really falling that we fear but not knowing what the fall will be like"* (p. 40). As such, the following section is concerned with factors related to the underlying reasons behind the fear of falling, as discussed by the interviewees.

Interviewees' responses identified two potential reasons for a fear of falling occurring largely as speculated in *Studies One and Two*. Firstly, because of a concern of physical injury and secondly, for a limited number of interviewees, because of failures potential impact on self-efficacy. Despite some climbers' consternation over the potential for injury because of leader falls when climbing indoors, most accidents and injuries indoors result because of chronic overloading, not acute injuries (Backe et al., 2009). Regardless of the low incidences of acute injuries (Sagar, 2001), the potential for taking falls and an associated perceived concern of injury are often considered a considerable stressor for climbers, which was reflected in the responses of the interviewees (Macleod, 2010). However, because of the low injury rate an anxious or fearful response may in many cases be considered irrational or at least disproportionate to the potential consequences (Binney & McClure, 2005). Because of the potential for disproportionate and irrational response to falling it is unsurprising that coaches, such as Binney and McClure (2005), suggest skilful climbing performance lies in being able to manage and differentiate between rational and irrational fear and perceived and actual risk. Several interviewees discussed being aware of the dissonance between their rational knowledge of what will happen in the event of a fall and what they fear to happen. It has been stated with the development of expertise, particularly in traditional climbing, an emphasis is placed on cognitive skills required for risk management (Holland-Smith & Olivier, 2013). Within the sport, there is a strong emphasis on being in control and taking ownership of decisions (Holland-Smith & Olivier, 2013; Llewellyn et al., 2008). Both Robinson (1985) and West and

Allin (2010) found climbers defined themselves as rational risk managers, rather than reckless *adrenaline junkies*. Critically, the potentially negative emotional experience associated with leading should be thought of as a barrier to performance, rather than the reason participants engage in the sport.

The negative emotional experiences resulting because of a factor such as a fear of falling, even if irrational and towards a threat only imagined or anticipated by the climber, can have a real, significant, debilitative effect on performance. For example, previous research by Pijpers and colleagues demonstrated significant differences in performance with changes in traverse height, even when the protection of the climbers was kept constant (Nieuwenhuys et al., 2008; Pijpers et al., 2007; Pijpers et al., 2003). Along with greater reported anxiety and heart rate, performance and behaviour was also affected including alterations in climbing speed, increased number of explorative movements, decreased movement fluency and reduced perceived reach distance (Nieuwenhuys et al., 2008; Pijpers et al., 2007; Pijpers et al., 2003). Similar results were found in *Study One*, when performance was characterised by less accuracy of hand and foot placements, less fluid body movement, decreased coordination, less efficient movement selection and poor decision making. In *Study Two* it was also speculated that performance in the CLL^{above} group was compromised, however, it is not possible to determine the exact cause of the deterioration in performance seen; either because of the physical demands of the task or anxious disruption of performance (Nieuwenhuys & Oudejans, 2012). Given the interviewee's responses concerning their choice of routes and the number of participants expressing a wish not to attempt to lead climbs above their on-sight ability, differences in performance in *Study Two* are likely to have resulted because of a combination of uncertainty and perceived danger (Lazarus, 1991). This supports the findings of *Study Two*, suggesting on-sight lead climbing beyond the ability of participants is a suitable means of instigating demand appraisals because of the perceived danger and the anticipation of a fall.

An anxious or fearful response may develop from a significant event in the climbers' past. Several of the interviewees described injuries they had sustained while climbing indoors, while a greater number also described injuries sustained while lead climbing outdoors (both sport and traditional). A much greater number of the interviewees described sustaining injuries or situations where serious injuries were narrowly avoided while climbing outdoors, this result is predictable given the risk of injury while climbing outdoors is significantly greater than indoors (Schöffl & Kuepper, 2006). Consequently, it is unsurprising that several interviewees' related injuries sustained, contributed to factors affecting their lead performance. However, equally, a fear of falling is a non-associative phobia, that may develop without the individual experiencing any trauma (Menzies & Clarke, 1993b). Typically, the initial fearful response to falling will diminish over time due to habituation; however, poor habituates and individuals who do not get sufficient safe exposure may remain fearful (Clarke & Jackson, 1983). In support of occurring without trauma, a smaller number of interviewees who experienced fear of falling were unaware of a significant event in their past that may have triggered such a response.

Alternatively, a fear of falling may develop because of a fear of threat to self-esteem and the climber's perceived evaluation by others. Self-efficacy has the potential to play a significant role in how situations are approached, emotions are experienced and consequently how the climber performs (Bandura, 1997). These factors are particularly salient for recreational climbers, success may be dictated by whether the climber reached the top of a route or not; climbing success has been described as enhancing self-esteem and self-confidence (Stiehl & Ramsey, 2005). Fear of failure is associated with anticipation of shame in evaluative situations and a tendency to appraise situations as threatening (Conroy et al., 2002; Sagar & Lavallee, 2010). Consequently, it is conceivable failure or the potential for failure would have a negative impact on self-esteem. For example, in previous research Hardy and Hutchinson (2007), discussing the challenge of top-rope vs. lead climbing, stated: *"that it is not difficult to see how participants could perceive considerable ego threat in top-roping a climb at their leading limit in front of the experimenter"* (p. 158). Despite a potential threat to self-esteem, it was conspicuous by its limited prevalence. One interviewee discussed being self-conscious of their performance as a reason for the change in their behaviour, while another described being aware of their performance when climbing around other people whom they look up. These findings support those of *Studies One and Two* and participants response to the achievement goal questionnaire and pre-climb assessments of self-esteem. Such results may occur because of the way in which participants experience the sport: rarely do participants climb in isolation, even recreationally there is always at least the belayer watching. Such familiarity with climbing in front of others may have habituated the interviewees to negative evaluations in such situations. While there is little evidence of habitation to performing in front of an audience in sport research, it has been demonstrated extensively in other contexts, for example with social stress tests (Jönsson et al., 2010), conceivably the same is true of climbing.

Interviewee's indifference to the evaluation of others supports similar results in both *Studies One and Two* as reported using the AGQ, with greater internal mastery-approach goals than performance avoidance goals. For *Study One*, the achievement goal disposition of the participants occurred towards mastery, particularly, mastery-approach goals, while performance goals were consistently lower. Similarly, for *Study Two*, despite the differences in the ability of the participants relative to the difficulty of the route, there were no significant group differences in achievement goals, with mastery-approach goals being the greatest reported. In line with the results of *Studies One and Two,* interviewees reported frustration and internal conflict in response to not being able to finish routes they perceived they should be able to complete. Anecdotally, two of the CLL^{below} ability group participants from *Study Two,* described disappointment at the ease of the task they were being asked to complete when performing the post instruction manipulation check. Typically it would appear that climbers goals represent striving to approach absolute or intrapersonal competence, with a focus on performing a task as well as possible or surpassing a previous performance; interviewees were less concerned about appearing incompetent in comparison with others (Duda, 2005).

The feelings experienced by some participants, as described by the interviewees, may be disproportionate in terms of both their frequency and their magnitude and may occur in response to a threat that is either actual or potential (Steimer, 2002). However, the physiological and psychological responses and behavioural changes that occur are real (Sagar, 2001). The function of these responses facilitates coping with an adverse situation and fear or anxiety result in the expression of a range of adaptive or defensive behaviours, which are aimed at escaping from the source of danger or motivational conflict (Steimer, 2002). The positive element of disproportionate and potentially performance robbing interpretation of stressors are that they may serve to moderate climbers' behaviour, particularly early in climbers' participation in the sport when they have less experience of stressors. This is particularly important as there is a considerable inherent element of safety within the sport of climbing (Hörst, 2010).

A small number of participants described situations early on in their climbing careers, when they took risks they would not have otherwise have taken had they been aware of the potential consequence. Later re-evaluation in the interview with a greater appreciation of the dangers highlighted their own previous complacency. One example was a particularly capable climber who was predominantly a boulderer, with a small amount of lead climbing experience. With a discipline, such as lead climbing, there is an unavoidable technical element required to protect the climber in the event of a fall. In this particular case, the climber stepped their leg in front of their rope, a fall would have resulted in inverting and a greater chance of injury. Such situations are avoidable, but it takes the experience to identify and manage such situations

(Hurni, 2003). These findings support the idea that cognitive skills required for risk management, develop over time through the experience of the climbers (Holland-Smith & Olivier, 2013). Similar findings were reported by Llewellyn and Sanchez (2008) *"Rock climbers and instructors should be aware that inexperienced impulsive beginners may be motivated to take additional risks when leading, which considering their inexperience may make them prone to accidents"* (p. 424).

Another salient example of a potential performance robbing, but safe practice, highlighted by the interviewees were their responses relative to their position (height) on the route. Interviewees' responses were broadly, but not exclusively, divided into those discussing their perception of, and responses to, the lower portion of the route, where a fall if clipping or with an inattentive belayer, could result in the climber hitting the floor. Or, perceptions and responses when higher on the route, where a fall is significantly less likely to result in a ground fall (Hurni, 2003). More experienced interviewees discussed caution and anxiety towards falls low on the route, which may be considered an appropriate and adaptive response, protecting the climber. Conversely, an increase in the climber's height on the route, particularly when leading indoors, dramatically reduces the chance of a fall resulting in hitting the ground (Hurni, 2003). However, paradoxically, several interviewees particularly of f6a/6a+ ability also reported feelings of anxiety or fear higher on the route, despite the reduced consequences of a fall at that point. Such responses were not present in the more experienced climbers (f6c/6c+) as such confidence climbing to height would appear to be a factor that develops with experience and ability. It is only possible to speculate as to why more advanced climbers respond differently. It is conceivable they are habituated, through repeated exposures; alternatively, climbers who progress may be those who are not pre-disposed to anxiety concerning climbing to height, regardless of their experience.

To summarise while indoor climbing is objectively safer than climbing outdoors (Schöffl et al., 2010), there are still a considerable number of stressors present in the climbing environment. To date, there have not been any attempts to discuss the challenges of recreational climbing with participants themselves. The interviewees highlighted, in line with the anecdotal evidence presented previously by climbers and coaches, that falling is a significant factor for a large proportion of the interviewees; or at least anticipation of falls and their potential perceived consequences (Hague & Hunter, 2011; Hörst, 2010; Hörst, 2008; Hurni, 2003; Macleod et al., 2007; Sagar, 2001). It is believed fear and anxiety occur because of either (or both) a threat of physical harm or a threat to the climber's esteem, although, evidence from the interviews and previous research suggests the threat of physical harm is the more salient of the two. Three key characteristics were highlighted, along with the safety protocol, which altered the climbers' responses, namely route difficulty, height on the route and route knowledge. However, several factors, external to the specific challenges in the sport, were also discussed during the interviews. These are presented in the following section.

7.4.2 Mediating factors

Beyond the individual decisions discussed by the interviewees of the challenges faced within the sport, a number of important antecedents were also identified. While a climber's own physical effort is often seen as decisively important for performance, the climber does not take part in the sport in isolation. For example, the climber must have a belayer and interact with others during their sessions. Equally, the participant may not always be in an ideal physical or psychological state, with the influences of other elements such as their preferred climbing discipline, fatigue and day-to-day mood state highlighted by the interviewees as important considerations. It is such factors that *Theme Two* was concerned with and which will be discussed in the following section. Critically, the two themes are not exclusive; the factors discussed in *Theme Two* serve to moderate and mediate the behaviour of the climber and the factors previously discussed in *Theme One*.

Climbing may be unique amongst sports as confidence must be placed on a third party to protect the climber in the event of a fall (Hurni, 2003). It is the role of the belayer to anticipate the actions of the climber and pay out and take in excess slack, while also ensuring the rope does not travel through the device in the event of a fall (Hurni, 2003). The belayer is a critical element of the safety system; it is unsurprising the interviewees highlighted the relationship between the climber and the belayer as fundamentally important. While many sports require competitors to work together as a team, there are rarely physical consequences or the potential for bodily harm with a breakdown in this relationship or a mistake on the part of one of the parties. To my knowledge, the only similarity that may be drawn is with white-water kayaking, where paddlers providing safety cover for each other if a paddler is unable to successfully run a rapid (Ferrero, 2006). Significant within the responses of the interviewees was the potential for the belayer to both positively and negatively influence the climber's perceptions and responses to stressors, such as those highlighted in *Theme One* and discussed previously (*see section 7.4.1*).

Trust between the belayer and the climber was based on a number of characteristics including attention, competency, the belay device used and the weight differential. A great deal of the skill of belaying is anticipating the actions of the climber on the route (Sagar, 2001). Interviewees discussed the attentiveness of the belayer as a point of concern, regardless of whether it causes an issue for the climber. The fallibility of the belayer was also reflected in the prevalence of responses of the interviewees concerning the choice of belay device. While a traditional *stitch plate* achieves additional friction by introducing two tight bends into the rope, more recently assisted braking belay devices such as a Petzl Gri-Gri have become more common. Assisted braking devices do not mitigate the need for the attentive and experienced belayer but provide an extra link in the safety chain (Lewis & Cauthorn, 2000). Given the importance of safety offered by an assisted braking device, it is unsurprising several interviewees reported feeling more confident with belayers using such a device and wary of those who did not.

The perception of the belayer's ability to effectively protect the climber while they are on the route can have a significant impact on the climber's performance and the decisions they make. If a positive relationship between the climber and the belayer does not exist or has not had time to develop, several interviewees described conflict, with the climber struggling to place trust in the belayer. Such descriptions were particularly prevalent with f6a/6a+ ability interviewees, perhaps because they typically climb with others of similar ability, who also do not have as much experience belaying. The importance assigned by the interviewees support those of climbing coaches *"On most sport routes, there is little realistic fear of injury, unless you don't trust your belayer"* (Sagar, 2001, p. 114). As with the decisions made by the climber, conceivably a lack of confidence in the belayer can have knock-on effects for the performance, through a number of potential mechanisms, including the diversion of attention (Nieuwenhuys & Oudejans, 2012) and displaying avoidance behaviour. Conversely, there were a small number of interviewees who reported familiarity with who was belaying them not being a factor at all; this was not typical of participants' responses.

The role of the belayer has seen little research attention. It is hard to understate the importance of the belayer, both from a safety standpoint and their role in a climbers performance. Necessarily, research has concentrated on the climber. However, as we understand the role of the climber in more detail, particularly given the results of this thesis, the belayer should receive increased research attention. From the interviews, it is conceivable participants' responses in previous psychophysiology research may have been influenced through being belayed by an unfamiliar investigator (Aras & Akalan, 2011; Dickson et al., 2012a; Draper et al., 2011d; Draper et al., 2012; Draper et al., 2010; Fryer et al., 2013; Hardy & Hutchinson, 2007; Hodgson et al., 2009). Such factors have not been considered and are rarely included in the methodology of studies. One of the few to report the role of the belayer were Hardy and Hutchinson (2007), who further stated it was conceivable participants may find their performance being observed on a top-rope by an experimenter (who was belaying) to be ego-threatening. A similar effect is conceivable on all routes attempted by participants when belayed by someone unfamiliar to them, as is typical of previous climbing research. The role and importance of the climber-belayer relationship is a compelling avenue for future research.

Along with providing protection for the climber, the belayer and climbing partner(s) are an inherent part of the climbing experience, engaging, protecting and supporting the climber during their sessions. In line with descriptions of climbers motivation from Robinson (1985), the motivation of the interviewees’ climbing partners was found to be important. Motivation and emotional support of the climbing partner were referred to by around a third of the interviewees’ as a source of motivation and confidence and an important part of their session. For example, several interviewees described choosing harder routes if climbing with another climber of a higher ability, or someone they felt confident in. However, the climbing partner can also have a negative influence on the perception and behaviour of the climber, enhancing the climbers’ perceptions of stressors. For example, one interviewee described a climbing partner who frequently fumbled the ropes, was not very responsive and inattentive and that this affected his climbing performance.

The climber's experience and background within the sport are amongst the most important, yet infrequently considered factors when describing climbers. The interviewee's responses highlighted that their background and preferred discipline in the sport were essential in determining the attitudes and identification of the stressors present. This is particularly salient as there has been little consideration of the background of climbers in previous research, or the reporting of climbers’ background has been inconsistent. Indeed, discrepancies in reporting led Draper et al. (2016) to make recommendations for the description of climbers’ characteristics, including the number of years they have been taking part in the sport, their preferred climbing discipline, whether they were a competition climber; such characteristics come together to describe a climber and should be reported and considered as covariates if necessary (*see Studies One and Two*). Differences in the discipline and introduction to the sport may be an important factor in the description of the climber and how they identify and respond to stressors (Draper et al., 2016). For example, those climbers identified as coming from a traditional background, particularly the climbers who had been involved in the sport for a longer time, were more likely to describe a *no-falls* attitude. One interviewee reported such an attitude was not only something that exists in older climbers, but was part of the mentality of British climbers. Conversely, the same interviewee described younger climbers coming through into the sport who have been introduced to indoor sport climbing from a young age in teams and clubs, having a very different approach to the sport of lead climbing, without any reluctance to climb to failure.

As with the belayer and the climbers' background, factors involved in individual climbers' session-to-session variation have also received little attention. Typically, climbers and research participants report their climbing grade to provide an indication of their recent best performance. The validity of self-reported grades has been established (Draper et al., 2011b; Giles et al., 2017b), however, the interviewee's responses emphasise their reported grades are not necessarily representative of their performance on the day of testing. The state participants arrive at the climbing wall in may influence both the type of routes the climber tries and how they feel they perform, depending on many factors including fatigue, hunger, motivation and how their day was prior to arriving at the wall. Indeed, external stress and fatigue were expressed as one of the main limiting factors for climbing performance during their normal recreational sessions for a number of the interviewees. The state participants arrive in at the climbing wall was described as influencing both the type of routes the climber tries and how they feel they perform. Interestingly, elite level climbers report similar effects. Describing the recent challenges of red-point of Sabotage, an f8c+ sport route at Malham Cove, the British climber Neil Gresham recently described the effects of external stressors on his performance:

> *While chatting to Dave [MacLeod], I realised that I'd become far too obsessed with the minute details of training, tactics and nutrition but had lost sight of the bigger picture. Earlier in the year our house was flooded, we had our second child in temporary accommodation and I had also lost a major work contract. It probably wasn't the best time to be trying to climb the hardest route of my life, but when Dave suggested I accepted this rather than continuing to fight it, things just seemed to fall into place. After all, the reality is that stress has way more of an influence on our*

> *performance than the number of Aero-Cap laps we do or which protein shake we take. (Berry, 2016).*

In summary, the climber does not take part in the sport in isolation and while the decisions about the challenges and stressors comprising *Theme One* are important, they interact with and are mediated by other factors. These include climbers' relationship with the belayer, interactions with others during their sessions and the influences of other elements of day-to-day life. The multifaceted individual nature of recreational climbers' responses to stressors faced in their climbing sessions are likely to be at least partially responsible for variation seen in previous research. More significant are the responses and decisions made by climbers to manage the stressors, which will be disused in the following section.

7.4.3 Climbers respond and moderate their behaviour to manage stressors

A fundamentally important consideration of climbers' responses to stressors described by interviewees was the choices they may make within their sessions. While the findings of *Theme One and Two* support existing anecdotal evidence, the choices interviewees discussed in *Theme Three* made during their recreational sessions, to change, manage and exert control over the stressors faced, were novel. Interviewees discussed the strategies they used to maintain control particularly prevalent was avoidance behaviour. Climbers take part in the sport of their own volition, making choices that may increase or decrease the challenges of a climb: *"Rock climbers are clearly not a single-and-homogenous group. Climbers may adopt a dynamic behavioral strategy when choosing the difficulty of the climb to perform, and the style in which it will be ascended; for example, leading a difficult climb and then soloing an easier one."* (Llewellyn & Sanchez, 2008, p. 423). Some choices are discreet, such as route choice or route difficulty, while others are more overt and visible to others at the wall, such as the style of ascent or choosing to be taken tight on the rope before failure. These decisions are likely to affect performance either through behavioural changes when climbing, or decisions causing participants to select situations that do not allow them to perform optimally or reach their full potential. Consequently, the following section will discuss interviewees choices made while selecting routes to attempt, on the routes themselves and behavioural changes while climbing.

Descriptions of avoidance behaviour were prevalent within participants' responses, which is a typical response to feared activities or situations (Richard & Lauterbach, 2011). It is unsurprising choices over the difficulty of routes attempted were frequently related to falling in interviewees' responses. While a hard route towards a climber's limit is likely to result in a fall, the choice of easier routes ensures the climbers can deal with the challenges the route presents, ensuring their coping resources far outweigh the demands of the climb (Lazarus, 1991). Avoidance in the climbing environment is likely to perpetuate anxiety and avoids dealing with issues likely to affect performance. While an initial fearful response to falling will diminish over time due to habituation, poor habituates and individuals who do not get sufficient safe exposure may remain fearful (Clarke & Jackson, 1983).

The findings of the interviewees and avoidance behaviour support anecdotal evidence presented in previous research. Fryer (2013) reported it is common for intermediate climbers to ascend routes within the *comfort zone*, often choosing not to push their climbing grade. However, this may not be true for all ability groups, as anecdotally a couple of the more experienced climbers of *Study Two* expressed disappointment at the ease of the task they were being asked to complete. A *one more move* attitude was also discussed by the more advanced interviewees, describing continuing to the point of failure, rather than avoiding falls. As previously discussed, it is not clear whether the more advanced climbers are habituated or generally predisposed to respond effectively to the challenges.

The interviewees discussed two decisions made prior to leaving the ground, the first concerning the style of ascent and the second route difficulty. While the height of the route and route knowledge were also salient stressors, the climber has less opportunity to influence these factors during their session, it is unsurprising they did not receive the same attention from the interviewees. The use of a top-rope increases the amount of control the climber has over their protection on the route, all but removing the unknown fall factor from the climbing task (Hurni, 2003). Top-roping also reduces the physiological load placed on the climbers, particularly as there is no need to find stable isometric positions on the route to clip quickdraws (Fryer et al., 2012). However, the avoidance of lead climbing may have consequences for long-term participation in the sport, both because of the appraisal of others and the typical lack of provision (or more limited provision) for progression with top-roping indoors. As previously discussed, several interviewees expressed an unfounded negative evaluation of climbers who choose to top-rope.

Route difficulty, like the style of ascent, readily affords climbers the opportunity to moderate and mediate the challenges faced. It is likely choices about the style of ascent and route difficulty also interact, several interviewees, particularly those of f6a/6a+ ability reported not wishing to lead routes towards their limit. Rather, if climbing a harder route, they would top-rope it first, so they are familiar with the holds, movements and clipping positions. Once there are no unknown factors on the route, the climber would then attempt the route as a red-point lead (Hörst, 2011). Beyond simply the stated grade of the route interviewees described choices about the route itself; including factors relating to the types of holds, the angle of routes and the opportunities for clipping quickdraws. All of these factors contribute to pre-climb opportunities for avoiding or reducing the challenges of a climb.

Decisions made by climbers once on the route are more overt than those made prior to the attempt. As with the pre-climb decision-making process, several options were discussed by interviewees to increase the climbers' perception of control. While decisions made prior to leaving the ground have the potential to limit the choice of routes, the decisions described by interviewees while on the routes themselves have the potential to dramatically affect climbing performance. Interviewees highlighted three potential options. Firstly, being taken tight on the rope; secondly, opting out and moving onto an easier route; thirdly, taking a controlled fall. Such decisions were discussed by the f6a/6a+ ability interviewees and contrasted responses of more experienced interviewees, a large number who reported willingness to climb to failure. Being taken tight on the rope or choosing to move onto another route directly avoids the uncontrolled situations resulting in the climber taking a fall. While these two factors are overt displays of avoidance, a third option was discussed. The climber may choose to take a lead fall from a point while they are still in control, rather than continuing on unknown holds, to a point where they are further above the quickdraw, fatigued and an uncontrolled fall is likely. Furthermore, unlike the first two factors, the controlled fall also provides an opportunity for the climber to opt out of the route, without having to continue to the point of physical failure. Deciding to take a controlled fall potentially offers the climber the chance to *save face* with their climbing partner and peers, an outwards demonstration of confidence.

Less dramatic than the overt behaviour on the route were subtle decisions made over quickdraw clipping positions. Unlike top-roping, the participant must consider the need to protect themselves at intermittent points on the route when leading (Bisharat, 2009). The ability to clip quickdraws safely on a route is key for climbers' safe progress, requiring the climber to adopt a static isometric position, pull through a *bite* of rope and clip the quickdraw (Fryer et al., 2012; Hurni, 2003). Consequently, the clipping of quickdraws was highlighted by the interviewees to be a significant component of their appraisal of the challenges of indoor lead climbing. Importantly, the climber may choose to clip the quickdraw at any point they are within arm's reach of the point of protection. In terms of minimising fall potential, the optimal position to clip from is with the quickdraw level with the climber's waist, as there is little or no need to pull through the additional rope and the climber may clip hanging from a straight arm, if the holds allow. Conversely, clipping from below the quickdraw requires the adoption of a potentially more strenuous position, considerably more slack rope is introduced into the system and a fall will result in a larger distance travelled (Bisharat, 2009).

Clipping quickdraws early may in some cases be considered a tactical decision and in others a maladaptive practice. Due to differences in the holds available clipping high from a good hold, rather than level with the quickdraw from a poor hold, may be a reasonable tactical decision (Bisharat, 2009). Interviewees reported the better the hold they clip from, the more secure they reported feeling, understandably when a hold was open, rather than positive, they reported feeling less confident and comfortable. Clipping from below the quickdraw also creates the sense they have a top-rope, even if it is for a short time on the route. However, paradoxically, if the climber falls while clipping high, with the increased amount of rope in the system (compared to clipping when the quickdraw is level with the waist), the consequences of the fall may be worse (Hurni, 2003). Interviewees discussed being aware of the increased fall potential while clipping high, despite this, the apparently maladaptive behaviour serves to increase climbers' confidence on upcoming moves. Clipping early may also serve to disrupt performance, with participants clipping from strained positions, increasing muscular fatigue from over gripping, bent arms and the effort of pulling through excessive rope (Bisharat, 2009).

Given both *Studies One and Two* of this thesis highlighted significant alterations in the performance of participants, it is unsurprising the interviewees described alterations in their movement behaviour. Stressors encountered while climbing have the potential to have an adverse impact on movement behaviour (Draper et al., 2011d; Pijpers et al., 2003; Sanchez et al., 2010). Indeed, changes in movement performance were identified in *Studies One and Two* and previously by authors including Pijpers and Colleagues (Nieuwenhuys et al., 2008; Pijpers et al., 2003; Pijpers et al., 2005). An alteration in the fluency of movement was identified by the interviewees in their own performance. Interviewees describe how they revert to more basic movement strategies to reduce task complexity and increase the feeling of control. Such conscious control of movement is in line with reinvestment theory (Beilock & Carr, 2001). The consciously monitoring or controlling technique is thought to lead to the eventual breakdown of a skill. It is argued increases in anxiety and self-consciousness about the execution of successful performances cause an increase in the attention paid to skilled processes, their step-by-step control and consequently reduced performance (Nieuwenhuys & Oudejans, 2012). The conscious control of performance may be amongst the reasons why performance *Studies One and Two* were affected.

Interviewees also noted differences in how they grip the holds on the route when anxious. Participants reported over gripping in relation to the negative performance consequences of climbing while anxious or fearful, such over gripping may increase the rate of fatigue of the finger flexors. While there is no evidence in the literature concerning over gripping on routes, the optimal force for holding a given hold have been explored. Fuss and Niegl (2008) reported lower ability climbers apply a greater force than is necessary, which consequently leads to greater rate of fatigue of the finger flexors. The performance of the finger flexors has been identified as a significant determining factor in climbing performance (Fryer et al., 2016; Fryer et al., 2015b; Giles et al., 2017a). Conceivably, it may be speculated that over gripping was responsible for localised fatigue in the forearms and possibly differences in success rate of participants in *Studies One and Two*.

To summarise, the complex and multifaceted nature of the sport of climbing afford those taking part a range of opportunities for control over the challenges of the sport. While some of the decisions made by the interviewees highlighted may be considered discreet, such as the difficulty of route choice, taking controlled falls on routes and changes in the clipping position, others are more overt, such as the style of ascent or choosing to be taken tight on the rope before failure. The decisions made by the climbers allow them to engage with the sport on their own terms and exert a level of control over their climbing sessions. However, it is speculated that such decisions, while reducing the acute emotional experience, are detrimental to the long-term performance of the climber and their development. Finally, while the decisions discussed by the interviewees were conscious, it is likely many the decisions made by climbers in their sessions are made sub-consciously.

7.4.4 Understand if participants use techniques to improve their performance.

Methods for reducing associated fears of falling are frequently discussed in climbing literature. The primary method described are desensitisation through progressive exposure to leading and falling, so called clip-drop exercises (Hague & Hunter, 2011; Hörst, 2010; Hörst, 2008; Hurni, 2003; Sagar, 2001). The premise of such training is simple: through taking controlled falls over and over the climber grows to understand that falling is unlikely to result in injury (Hurni, 2003). When interviewees were asked if they participated in any exercises to reduce anxiety knowledge of clip-drop methods were described by many of the interviewees.

Through habituation, the reaction to the fear situation decreases, weakening previously learned associations between feared situations and facilitating positive experiences and trust in the belayer. The exposure to the feared activities or situations in a safe environment helps reduce fear and decrease avoidance (Richard & Lauterbach, 2011). Fall practice serves to mitigate several factors which were described by interviewees in Themes One and Two as being potentially anxiety-inducing, including unknowns about the consequences of falling, reducing anticipation, developing trust in the equipment and processes used to protect the climber and, most importantly, developing trust in the belayer.

The prevalence of coaching literature and anecdotal support from coaches on the effectiveness of fall practice is backed by the testament of the limited number of participants who used such techniques in their session. Of the interviewees who reported the use of clip-drop techniques within their sessions, they were limited, rarely progressive, of short duration and completed on steep overhanging ground. In contrast to the protocols set out by authors such as Hague and Hunter (2011), the clip-drop described by interviewees often only consisted of regular planned falls, rather than a progressive exercise. Their use was also inconsistent, with some interviewees describing their use only at the start of their lead climbing season. Interestingly, as with the previous section describing control and route choice, a similar effect was also described in clip-drop practice, with participants choosing steep overhanging routes that allowed for falls to be taken with little risk of hitting the wall. While falling on steep overhanging ground does provide a safe fall, it does not teach the climber about safe positions to adopt when falling on less steep ground. It may also encourage the climber to avoid attempting routes close to their limit on walls they are not comfortable or confident taking falls on, encouraging the avoidance behaviour.

The perceived effectiveness of exposure-based clip-drop therapies, at least as described, may be because they address the primary limitation in many climbers' performance: anticipation of the unknown consequences of a fall. While appearing effective for the climber, their effectiveness may also be tied to the belayer and the development of trust associated with working with the same person. The disparity between the proportion of the interviewees who understood the clip-drop techniques and the number who used them in their session provides some interesting questions, particularly, given a considerable number of interviewees who highlighted falling was a factor that affected their climbing performance. (1) Are clip-drop techniques effective and do participants discontinue their use because they are effective, even over a short duration? The number of participants reporting issues with falling, despite their use suggests otherwise. (2) What are the barriers preventing climbers incorporating clip-drop style tasks into every climbing sessions, as suggested by Macleod (2010)? (3) Finally, have more advanced level climbers progressed due to their use of clip-drop practice, in conjunction with technique and fitness or are they self-selected based on individuals who have fewer issues with leading and falling than other climbers?

In answer or development to the last question, for the more advanced interviewees a large number reported taking unstructured and unplanned falls, a characteristic not present in the f6a/6a+ interviewees. The unstructured falls were not necessarily associated with progressive fall practice either. However, it would seem to be a logical progression, as they work on the same principle of positive reinforcement. As previously discussed, the idea of *one more move* was central to this, with the climber continuing to make moves on routes until failure (or they are successful). From the participant's responses, it did not appear the advanced level climbers were any more likely to take part in structured fall practice, however, the majorities' description of their attitudes towards falling were different. They were more willing to climb to their limits and to climb into situations where falls were likely; while a single interviewee reported climbing to failure was something they had to work hard at, this was not typical.

To summarise, there is considerable literature on fall practice techniques, consequently, a large number of the interviewees were aware of its potential. However, despite its ubiquity and the number of interviewees with issues falling, which the technique claims to directly address, there were few interviewees who reported its regular use. The more advanced level climbers who were interviewed did not report the use of clip-drop techniques any more regularly, however, they did describe a difference in their attitude to climbing to failure. Many of the more advanced level interviewees described a *one more move* attitude, continuing to failure without regard for the potential consequences of a fall. It is not clear why, in general, the interviewees did not take part in fall practice more regularly, despite its apparent ability to address a limiting factor of so many climbers.

7.4.5 A preliminary model of anxiety in climbing

Research conducted to date examining the challenges of indoor climbing has largely been based either on anecdotal evidence presented by climbers, coaches and authors (Hague & Hunter, 2011; Hörst, 2010; Hörst, 2008; Hurni, 2003; Ilgner, 2003; Macleod, 2010; Sagar, 2001) or on researchers own knowledge and understanding of the sport. Such an approach has yielded mixed results over the past 10 years of research in this area. While significant methodological advances have been made, research has proved largely equivocal (Aras & Akalan, 2011; Draper et al., 2012; Draper et al., 2010; Fryer et al., 2013). Furthermore, while a number of studies have quantitatively explored the antecedents of success and failure in climbers, there has not been any comprehensive qualitative exploration of factors that may be salient (Draper et al., 2011d; Sanchez et al., 2010). The present study provides evidence of the many potential antecedents determining climbers' emotional response, which in turn govern how the climber manages the specific challenges of a climb. At the centre of this are the cognitive evaluation and decisions climbers make prior to and during climbs itself, which appear to be responsible for whether climbing performance is affected, or not.

Figure 7.1 is presented as a preliminary model of the relationships between the cognitive evaluation of recreational climbers, mediating factors that influence decisions and their potential consequences for performance. The model is based on the responses of the intermediate climbers of *Study Three* and is divided into four parts: (1) potentially salient factors; (2) cognitive evaluation and decisions made by the climbers; (3) how decisions limit potential; and (4) how decisions limit performance. These will briefly be discussed, along with consideration of a potential limitation of previous psychophysiology research.

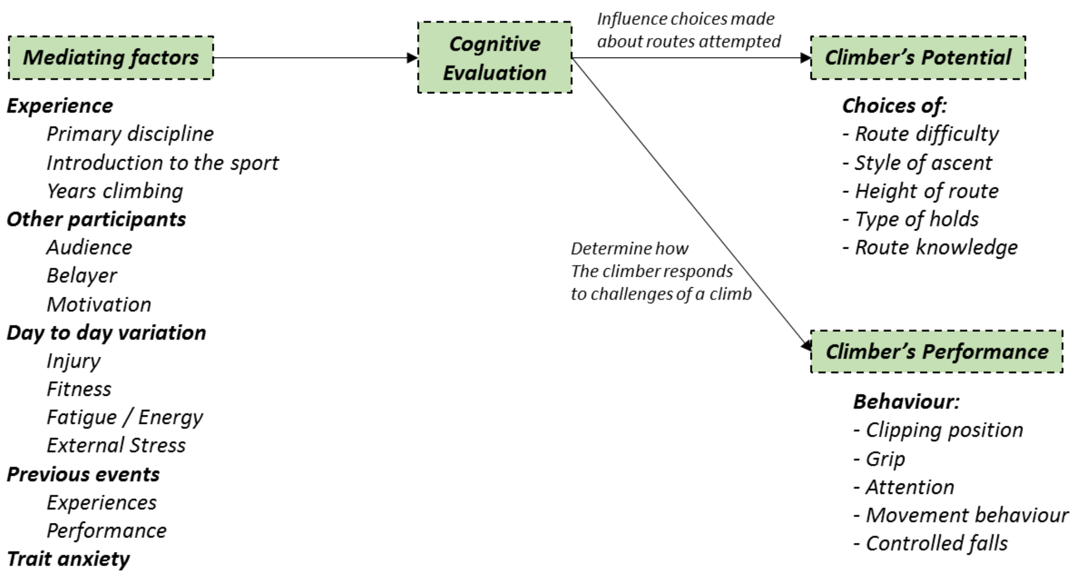


Figure 7.1: *A preliminary model of potential mechanisms for the limiting of potential and the disruption of performance.*

Central to the model is choice. Climbers take part in the sport of their own volition, making choices that may increase or decrease the physical, psychological and technical challenges present (Hörst, 2010; Watts et al., 2011). In turn, the choices made by the climber potentiate or limit opportunities for the climber to perform optimally. Additionally, climbers make decisions when on the routes themselves, which also facilitate or disrupt performance (Pijpers et al., 2003; Pijpers et al., 2005). Climbers' choices are likely to affect performance either through behavioural changes or decisions causing participants to select situations that do not allow them to perform. Ideally, the decisions made by climbers will facilitate maximum performance on all occasions, but even for the most experienced climbers this is unlikely to be the case; consider the examples of interviewees description of day-to-day variation or the experiences of the elite climber Neil Gresham discussed previously (Berry, 2016).

Individual's cognitive evaluation of a stressor and self-appraisal of available coping resources are believed to be critical in determining how the climber responds to challenges in the climbing environment (Lazarus & Folkman, 1984; Martens, 1977). However, the ability for the climber to choose the demands of the task they wish to complete reverses this relationship. Traditionally, in Lazarus' cognitive evaluation model, the primary appraisal establishes how important the situation is to the climber and whether it will endanger their wellbeing and the secondary cognitive evaluation process concerns the coping options available (Lazarus, 2006). Instead of the two levels of cognitive appraisal, the climber may choose the demands of the task, based on their perception of their coping resources. These are highlighted in the decisions made before the climber leaves the ground. Once on the route, however, it is conceivable that the evaluation process will take on a more traditional appearance, with the climber apprising the demands of the task they have taken on and their perception of coping resources, with further re-evaluation as the climber continues on the route (Lazarus, 2006).

Potentially, performance may be limited even before the climber leaves the ground, through decisions made, which may be either conscious or unconscious; these decisions include the style, difficulty, height and knowledge of routes to be ascended. Some choices are discreet, such as routes choice or difficulty, while others are more overt and visible to other climbers, such as the style of ascent. Decisions may cause participants to select situations that limit their performance or ability to reach their full potential. For example, while a climber may be physically capable of an on-sight lead of a route graded f7a, they may make one or more decisions that limit this. Including choosing to top-rope the route first removing the on-sight element, or choosing to lead an easier route they are likely to complete the first time.

Similarly, choices climbers make are likely to affect performance while on the route itself. From the responses of the participants and previous climbing research, there are two potential mechanisms for the disruption of performance. Firstly, through behavioural changes which directly affect the physical ability of the climber to complete the route, including the anxious disruption of attention (Nieuwenhuys & Oudejans, 2012), potentially over gripping and changes in movement behaviour (Pijpers et al., 2003; Pijpers et al., 2005). Secondly, as with the decisions made before the climber leaves the ground, the climber may make decisions to avoid the challenges of the route. For example, even if the climber does choose to attempt the on-sight lead of the f7a route, the climber may decide to opt out of the route through moving onto another easier coloured set of holds, asking to be taken tight or taking a controlled fall from a position they are comfortable with.

Fundamentally important are the factors that mediate the choices climbers make, including the climber's background, experience and past attempts at routes. These factors may be a facet of the climbers' personality or may be more situational dependent. The climber's experience and background within the sport is possibly one of the most important, yet infrequently considered aspects when describing the climber. The interviewee's responses highlighted their background in the sport were important in determining the attitudes and identification of the stressors present. However, equally important were session-to-session variation, including external stress, fatigue, injury and fitness. These more variable factors were expressed as the considerable limiters of performance during normal recreational sessions. Indeed, the state participants arrive at the climbing wall were described as influencing both the type of routes the climber tries and how they feel they perform. Others around the climber were also discussed as playing an important role, both in terms of the importance of trust in the belayer, the belief they can arrest the climber in the case of a fall and their motivational role, encouraging or discouraging the climber. Finally, previous experiences on routes and how the climber responded to a particular situation, such as discomfort when on-sighting a route or a previous bad fall influence future decisions made.

The model is a new look at recreation climbing and the way individual's decisions impact their performance. While a considerable amount of research has now been conducted on factors such as the style of ascent (Dickson et al., 2012a; Draper et al., 2011d; Fryer et al., 2013), there are a number of possible limitations given the ideas set out in the model. Namely, the study designs used to date do not allow for avoidance behaviour before climbers attempt routes to be displayed. This may place climbers in situations atypical of their normal recreational sessions, which they would normally avoid, for example leading towards their maximum ability. Unlike Lazarus (2006) cognitive evaluation model, during typical recreational session, as previously discussed, the climber has a choice over the demands of the task, relative to their coping resources. Conversely, the design of *Studies One and Two* presented task instructions, with participants appraising the demands of the task and their coping resources concurrently. It is likely this underpins the speculation in *Study Two* that situations typical of participants' recreational sessions, such as a submaximal lead of a route are not anxiety inducing and climbers are habituated to such situations. While, attempting routes with run-outs with greater consequences of a fall (*Study One*) or routes that are beyond the ability of a climbers' on-sight grade (*Study Two*), elicit a greater and potential significant response.

To summarise, **Figure 7.1** is presented as a preliminary model of the relationships between choices made by recreational climbers, factors that influence decisions and their consequences for limiting climbers' potential and performance. For the first time, it highlights that there are multiple routes to sub-optimal disrupted performance, not just while the climber is on the route itself. Climbers may also limit opportunities to perform optimally, even before they attempt a route. There are many mediating factors within the climber's recreational environment, both internal such as day-to-day fatigue and fitness and external including the belayer. Further research is necessary to explore the model in detail.

7.5 Conclusion

This is the first study within the sport of climbing's growing body of literature that has qualitatively explored a climber's perception towards indoor recreational lead climbing. The present study has made significant advances in our understanding of climbers' responses to on-lead climbing. The findings support the results of *Study One*, attempting a lead of a route for some climbers' is a significant source of stress and the results of *Study Two*, a route greater than a climbers' maximum on-sight grade may be a significant stressor. However, building from the results of *Studies One and Two*, the interviewees discussed control. Specifically, the interviewees identified how they respond to perceived stressors in the climbing environment and how they influence the decisions they make toward the route they attempt. Alterations in participants' perceptions of control are likely to have been responsible for increases in self-reported anxiety, anticipatory heart rate and cardiovascular reactivity indicative of a threat state seen in previous studies (*Studies One and Two*). A preliminary model is presented describing the relationships between choices made by recreational climbers, factors that influence decisions and their consequences for limiting potential and performance (**Figure 7.1**).

Understanding climbers' perception of stressors within the recreational climbing environment, why the individual responds to them and how climbers manage them are not only important for climbing psychophysiology research. *Studies One and Two* demonstrated not only is anxiety an unpleasant feeling, but it may also be detrimental to performance. Indeed, Hague and Hunter (2011) described a fear of falling as performance-robbing and asserted every climber should attempt to overcome it. Consequently, the findings of *Study Three* have implications for coaches working with intermediate climbers identifying sources of stress and areas for potential gains in performance. Perhaps more importantly, understanding the challenges faced for climbers developing and progressing in lead climbing could have significant implications for long-term participation in the sport as anxiety is also associated with discontinuation of sport participation (Gould et al., 1982; Scanlan et al., 2005) and less pleasure while participating (Scanlan et al., 2005; Smith & Smoll, 1991).

Despite the prevalence and potential consequence of fear and anxiety, there is only limited research exploring methods for techniques to reduce it (Boorman, 2008). Equally, despite interviewees' knowledge of clip-drop exercises and coaches' statements of their effectiveness, interviewees reporting the regular use of clip-drop exercises was limited. Fall practice serves to mitigate many of the factors described by participants of *Study Three* as being anxiety-inducing, including unknowns about the consequences of falling, reducing anticipation, developing trust in the equipment and processes used to protect the climber and, most importantly, development of trust with the climbing partner (*Study Three*). Consequently, *Study Four* set out to investigate the effectiveness of clip-drop and red-point climbing interventions on pre-climb psychological state and performance.

8

Study Four

The effectiveness of clip-drop and repeat practice interventions for improving pre-climb state and climbing performance

8.1 Introduction

The nature of leading, in particular the potential of a fall, can cause an increase in fear and anxiety, and can have a considerable impact on their behaviour and, consequently, affect climbing performance (Study One and Two; Dickson et al., 2012a; Draper et al., 2010; Fryer et al., 2013). Macleod (2010) speculated, based on his experience working as a coach, that around 50% of climbers are affected by such factors. The results of *Study One* suggest lead climbing is a significant stressor, leading to greater cognitive and somatic anxiety and reduced self-confidence, which are associated with significant reductions in climbing performance quality, seen through less fluent and more hesitant movements. Similarly, *Study Three* reported 49 of the intermediate and advanced climbers interviewed discussed factors relating to falling indoors, 32 expressed concern over the potential for physical injury and a notable number were aware of its affect on their performance. It is unsurprising then that coaches assert "*fear is a part of climbing for many. Its performance-robbing nature demands that every climber conquer it"* (Hague & Hunter, 2011, p. 196).

Indoors the consequences of a lead fall are rarely serious (Sagar, 2001), injury rates are relatively low, even compared to other sports such as football (Theron et al., 2013). Participation is more likely to result in chronic, rather than acute injuries (Backe et al., 2009). Consequently, the anticipation of the unknowns of a fall may be responsible for the demand evaluation seen previously; Hörst (2008) for example, speculates it is not the falling itself that is feared, but not knowing what the fall will be like *"This explains why your first fall on a route is the scariest, while subsequent falls are often much less stressful"* (p. 37). Binney and McClure (2005) suggest skilful climbing performance lies in being able to manage and differentiate between rational and irrational fear and perceived and actual risk. Responding appropriately to the demands of a stressor are particularly important, as inappropriate responses can have a significant detrimental effect on performance, including alterations in climbing speed, increased number of explorative movements, decreased movement fluency and reduced perceived reach distance (Nieuwenhuys et al., 2008; Pijpers et al., 2007; Pijpers et al., 2003). Further, and perhaps more importantly, anxiety may have consequences for long-term participation in the sport, as if not addressed, anxiety has been associated with less pleasure while participating (Scanlan et al., 2005; Smith & Smoll, 1991) and discontinuation of sport participation (Gould et al., 1982; Scanlan et al., 2005).

Climbing performance is commonly conceptualised as being comprised of physical, technical and psychological aspects (Hörst, 2008; Magiera et al., 2013). Critically, performance is thought to be underpinned by the psychological aspect, inattention to which can have a knock-on effect for both the technical and the physical components of performance (Hörst, 2008). The psychological aspect must be trained to the same degree as the physical and technical, although Hörst (2008) believes this is rarely true. *Studies One and Two* demonstrated that for both differences in the style of ascent and differences in the relative difficulty of routes there were negative performance implications for leading and attempting routes beyond the on-sight ability. Associated with the differences in performance were elevated levels of cognitive anxiety, reduced self-confidence and threat cognitive appraisal (*Study Two*). Consequently, there would be significant benefit to interventions that address salient antecedents of the investigated factors. These are likely to occur because (1) the climber perceives a fall may result in physical harm (danger of injury or humiliation) and/or (2) uncertainty over the sequence of movements required for the completion of a route on-sight.

Addressing the former, perceptions of a fall resulting in physical harm, the primary method of training suggested by coaches and in coaching literature is repeated exposure and desensitisation (Hague & Hunter, 2011; Hörst, 2010; Hörst, 2008; Hurni, 2003; Sagar, 2001). The premise of such training is simple: through taking controlled falls over and over, the climber grows to understand how to fall safely, to trust the belayer and understand the fall is not dangerous and they will unlikely to be hurt (Hurni, 2003). The climber is then able to focus on climbing, rather than the fall, directly addressing the *unknown* of the fall *"Beginners probably need some hands-on proof that falls can be safe"* (Hörst, 2008, p. 37). A fear of falling is a non-associative phobia, which may develop without the individual experiencing any trauma (Menzies & Clarke, 1993b). Typically, an initial fearful response will diminish over time due to habituation; however, poor habituates and individuals who do not get sufficient safe exposure may remain fearful (Clarke & Jackson, 1983). Fall practice protocols have been described extensively in coaching literature (Hague & Hunter, 2011; Hörst, 2010; Hörst, 2008; Hurni, 2003; Sagar, 2001). A safe environment in which to *expose* individuals to the situation they fear and avoid is created, the exposure helps reduce fear and decrease avoidance (Richard & Lauterbach, 2011; Wolitzky-Taylor, Horowitz, Powers, & Telch, 2008). Typically, the exposures are idiosyncratically developed. The climber begins with an initial exposure to the least feared situation, such as sitting on a tight climbing rope with a quickdraw clipped above the head, with subsequent exposures helping the climber progress through a hierarchy of situations that elicit greater anxiety (Richard & Lauterbach, 2011).

Conceivably, fall practice serves to mitigate many of the factors described by participants of *Study Three* as being anxiety-inducing, including unknowns about the consequences of falling, reducing anticipation, developing trust in the equipment and processes used to protect the climber and, most importantly, development of trust with the climbing partner (*Study Three*). Clip-drop is a progressive exposure therapy, helping the participant directly face the feared situation, this is particularly important given the prevalence of avoidance behaviour. Such avoidance was described by the interviewees of *Study Three*: the avoidance behaviour allowed the climber an element of control, however, while avoidance may reduce feelings of fear and anxiety in the short term, over the long term it may make the fear worse. Indeed, a specific phobia may be diagnosed when an individual experiences persistent and irrational fear of a situation and displays avoidance of such circumstances (Richard & Lauterbach, 2011). The desired end point is a climber who can ascend a route with no thought of falling or its consequences.

Evidence suggests exposure-based approaches are some of the most effective treatment methods for phobic fear and avoidance behaviour in a large number of phobias, including water

(Menzies & Clarke, 1993a) and heights (Baker, Cohen, & Saunders, 1973; Bourque & Ladouceur, 1980). A meta-analysis by Wolitzky-Taylor et al. (2008) demonstrated exposure therapy to be effective compared to a large number of alternative therapies in other contexts. Despite their ubiquity, there is little empirical evidence of the effectiveness of clip-drop interventions in a climbing setting. To date only Boorman (2008) have presented a very limited investigation of the efficacy of a simple clip-drop from the 7th quickdraw, finding a decrease in participants' cognitive state anxiety. However, the small sample of seven climbers, the lack of a control group and the measurement of only cognitive state anxiety, make drawing conclusions from Boorman (2008) research challenging. Further research is necessary to establish the effectiveness of fall practice. Given that a clip-drop intervention directly addresses one of the perceived antecedents of negative effects on climbing performance, perceptions of danger occurring because of the perceived consequences of a fall, a more favourable emotional state would be expected following a clip-drop intervention. Given the results of *Studies One and Two*, this would be expected to manifest as lower levels of cognitive anxiety, greater self-confidence, challenge cognitive evaluation and reduced cortisol and heart rate response, in a novel on-sight.

Clip-drop are not the only practice advocated for reducing fear and anxiety and improving performance on routes. An alternative may be the repeat practice, directly addressing the second salient factor: uncertainty over the sequence of movements required for the completion of a route on-sight. A climber's knowledge of a route they are completing and prior practice are fundamental aspects of the sport (*see section 3.2 Route Knowledge*). Climbers may increase their knowledge of a route either from information provided from another climber 'beta', or first-hand knowledge of a route through climbing. With practice, improvements in the fluency of movement have been demonstrated in both novice and expert climbers' (Cordier et al., 1994). Reductions in anxiety have also been shown. Draper et al. (2008) asked participants to complete an on-sight and a red-point ascent of a short ~10-meter route. It was found that, while there were small differences in climbing time, the combined knowledge and practice gained from the single ascent resulted in significant reductions in state anxiety, with both somatic and cognitive anxiety decreasing. Similarly, Hardy and Hutchinson (2007) asked climbers to lead and then subsequently top-rope two outdoor routes, the second red-point top-rope ascent resulted in reduced heart rate, ratings of perceived exertion and physical and mental effort. Although due to both a change in the style of ascent and route knowledge it was difficult to attribute changes found by Hardy and Hutchinson (2007) to one factor or another.

Neither Draper et al. (2008) or Hardy and Hutchinson (2007) speculate as to why anxiety may be reduced on a red-point ascent. However, as a key tenant of on-sight climbing is the uncertainty about the holds, sequences of movements and whether the climber is capable of executing them, a red-point ascent addresses many of these factors. Further, uncertainty of outcomes in tasks are also known to contribute to anxiety (Fisher & Zwart, 1982; Martens et al., 1990). In support of such an assertion, interviewees of *Study Three* discussed unknown factors on routes contributing to their anxiety; specifically, not knowing what the upcoming holds, sequences of movements or clipping positions would be like. Furthermore, this had implications for the physical and technical execution of movements, along with the climber's emotional experience. As a consequence, it would be expected that for repeat ascents of routes (but not an on-sight) participants would be able to maintain a more favourable emotional state, because of the reduction in uncertainty associated with the route, and be able to maintain performance. The more favourable emotional state would be expected to manifest as lower levels of cognitive anxiety, greater self-confidence and challenge cognitive evaluation. Compared to an ascent of a route without practice, psychophysiological markers of cortisol and anticipatory heart rate would be expected to be lower.

In summary, indoor lead climbing has the potential to have a significant impact on the emotional experience and climbing performance of participants, as demonstrated in *Studies One, Two and Three*. While there is a significant amount of coaching literature on the subject, there is little empirical evidence of the effectiveness of techniques. Conceivably, if it were the anticipation or avoidance of falls causing anxiety and changes in performance seen in *Study One* then structured practice of falls would be effective in reducing anxiety and improving performance. Similarly, if anxiety resulted because of unknowns on the route, then the route practice intervention will be effective at reducing anxiety and improving performance.

8.1.1 Summary and aims

The purpose *Study Four* was to investigate the effectiveness of clip-drop and red-point climbing interventions on pre-climb psychological state and performance. Two methods were employed, a clip-drop technique and repeated practice of a route. Both interventions were compared to a control group. Through the assessment of alterations in climbers' performance, the non-invasive assessment of cardiovascular reactivity and the psychophysiological response to the climbing tasks, it was hoped it would be possible to determine the effectiveness of such interventions on reducing anxiety and improving climbing performance. Therefore, the primary aims were: 1) to determine changes in psychophysiological and emotional factors pre- and post-intervention, with participants randomly assigned to either control, clip-drop or route practice interventions; and 2) to determine if any changes from part one were stable between situations, with an on-sight ascent of a further novel route.

8.1.2 Hypotheses

H1: In comparison to the control group, the practice intervention will result in reduced anxiety and improved performance for the red-point ascent, but not the second on-sight.

H2: In comparison to the control group the clip-drop will result in reduced anxiety and improved performance for the red-point ascent, and to a greater extent on the second novel on-sight.

8.1.3 Strengths of the study

- The current study the largest study to assess the effectiveness of interventions for reducing anxiety in climbing.
- It is the only such study to use a control group.
- The routes were set by a highly-experienced route setter, who has set at a world-cup level, to ensure the routes allowed all style of ascent to be completed on-sight while providing the same opportunities for rest, clipping and style of climbing.

8.1.4 Delimitations

- Data are representative and specific to the individual route profiles, the length of route and spacing of quickdraws used within the study.
- Findings of the current study are specific to the relative difficulty of the route to the best on-sight grade of the intermediate climbers
- The results are only representative of on-sight lead climbing indoors.

8.1.5 Assumptions

- All participants refrained from strenuous training 48 hours prior to testing and observed a period of complete rest for at least 12 hours before each testing session.
- All participants refrained from either inspecting or attempting the route prior to their testing session as requested.
- Self-reported climbing grades relied on participants accurately and honestly reporting their on-sight and red-point performance (Draper et al., 2011b).
- The word of participants was taken that they had not consumed alcohol or caffeine prior to the session.

8.1.6 Limitations

Despite careful consideration of the methodologies employed and numerous pilot studies, there were still some limitations within *Study Four*.

- The study was difficult to perform because of the nature of the methodology and costs, limiting the sample size.
- Because the climbs took place in a public climbing wall, it may have affected climbers' responses.
- Participants who perform poorly on a task may be more likely to evaluate the task as threatening in subsequent ascents.

8.2 Methods

This section provides details of the participants and an overview of the experimental design, procedures for the session, data and statistical analysis. Throughout these methods, references are made to the *General Methods* chapter, which should be referred to where applicable.

8.2.1 Participants

Thirty rock climbers (6 Female and 24 Male) completed the study. The climbers were classified as intermediate (Draper et al., 2016) with self-reported on-sight ability ranging from French 6a+ to 6b (12 to 13 IRCRA; YDS 5.10c to 5.10d) and red-point ability ranging from French 6b to 6c (13 and 15 IRCRA; YDS 5.10d to 5.11b; *see 4.2.1 Self-reported ability and experience*). No inducement was offered to participants for taking part. Participants volunteered and met the recruitment requirements set out in Chapter 4 (*4.1.1 Participants*). Participants were matched for age, sex and experience and were randomly assigned to either a *control*, *practice* or *clip-drop* interventional group. Descriptive data for anthropometric and climbing ability data for participants who met all testing requirements are presented in **Table 8.1**.

Table 8.1: *Participants anthropometric and climbing experience characteristics for combined and male and females (mean ± SD).*

	Combined (*n* = 30)	**Male** (*n* = 24)	**Female** (*n* = 6)
Anthropometrics			
Age (years)	29.7 ± 6.9	29.5 ± 7.5	30.6 ± 4.3
Height (m)	1.75 ± 0.07	1.77 ± 0.04	1.64 ± 0.06*
Mass (kg)	71.5 ± 9.1	74.8 ± 6.6	58.3 ± 4.1*
Experience			
Years Climbing	6.5 ± 5.1	6.4 ± 5.5	7.1 ± 3.0
Sessions a week	2.3 ± 1.2	2.3 ± 1.3	2.3 ± 1.0
Grade			
Indoor OS (IRCRA)	13.1 ± 0.7	13.1 ± 0.7	13.0 ± 0.9
Indoor RP (IRCRA)	13.9 ± 0.8	14.0 ± 0.7	13.7 ± 1.0

Note: m metres; kg kilogramme; OS on-sight; RP red-point; IRCRA international rock climbing research association
** significant difference between genders*

8.2.2 Experimental design

All participants attend two afternoon sessions; at least 24 hours and no more than 48 hours separated the sessions. Participants were asked to adhere to the pre-testing guidelines set out in *4.1.1 Participants*. Adherence to the guidelines was confirmed verbally before the commencement of each of the testing sessions. Both sessions took place at Awesome Walls climbing centre, Sheffield and were conducted at the same time of day ± 20 minutes, to minimise the influence of circadian rhythm, particularly on salivary cortisol concentrations (*4.3.1*). For session one, participants attempted to ascend a novel route and completed the first part of the intervention, of either *control*, *practice* or *clip-drop*. The second session, participants completed the second part of the intervention, followed by a re-assessment (red-point) on the same route as the first session. Finally, participants completed an ascent of a second novel route, similar in difficulty and style. Prior to each climb heart rate (*4.3.2*), cortisol (*4.3.1*) and blood pressure (*4.3.3*) reactivity were assessed in response to pre-recorded task instructions.

8.2.3 Climbing wall and route setting

Two routes were set for the purpose of the study, the routes were of a consistent grade across their length and a consistent style and grade with each other. Considerations were made of the type of holds, the style of the climbing and the difficulty. The routes were set at one grade below the climber's on-sight limit, to ensure the route was within the ability of all participants (*4.1.7 Route design*). The two routes were graded French 6a+ (IRCRA 12; YDS 5.10c), which was confirmed by four expert climbers before the commencement of the study. After the first quickdraw at 3.05 meters, the distance between the next nine quickdraws was 1.21 ± 0.13

meters. Where possible, participants were asked to refrain from watching preceding participants, to limit the amount of information about the climb and the success or failure of previous participants.

8.2.4 Procedure: Resting measurements

Figure 8.1 represents the procedures carried out over the two testing sessions. Following an explanation of the procedures, ascertaining heath history and fitness to participate and informed consent participants completed the Profile of Mood States (POMS; *see 4.4.1*), Achievement Goal Questionnaire (AGQ; *4.4.3*) and the State-Trait Anxiety Inventory (STAI; *4.4.2*). Prior to each of the sessions, participants completed a thorough warm-up, comprised of five minutes of pulse raising activity (walking, jogging skipping), five minutes of mobilising exercises and five minutes of gentle climbing (*see 4.1.2 Anthropometrics and warm-up*). Following the warm-up, participants were provided with 10 minutes of seated recovery time. Prior to each of the ascents, participants completed resting cardiovascular assessment, during which time they were provided with the task instructions.

Resting Cardiovascular Assessment

Following the rest period, prior to each of the climbs, participants completed a nine-minute cardiovascular data recording, comprising of five minutes of rest, one minute of instruction and three minutes of mental preparation. Participants were equipped with a Polar H7 chest strap and V800 HRM (Polar, Finland) and once seated, the Finapres Portapres Model-2 (Finapres Medical Systems B.V., Amsterdam, The Netherlands). Finger arterial pressure was recorded continuously using an appropriately sized Finapres finger cuff, applied to the mid-phalanx of the middle finger of the left hand (*4.3.3 Cardiovascular reactivity*). Participants were informed they would be required to sit still and quiet, upright, with their arm supported at the level of their heart and legs facings forwards, bent at a 90-degree angle. After five minutes of data collection, participants were presented with audio instructions concerning the upcoming climbing task, via a set of headphones (QC 25, Bose). The audiotaped instructions described the upcoming climb. Resting recordings of heart rate and blood pressure were made during this time.

The audiotaped instructions were similar to those used within *Study One's* lead climb condition. The audio instructions lasted for one minute (*Appendix E Audio transcripts*), in which high task demands were promoted for the conditions, typical of motivated performance situations. Participants were informed the task was difficult *"The climb is designed to be close*

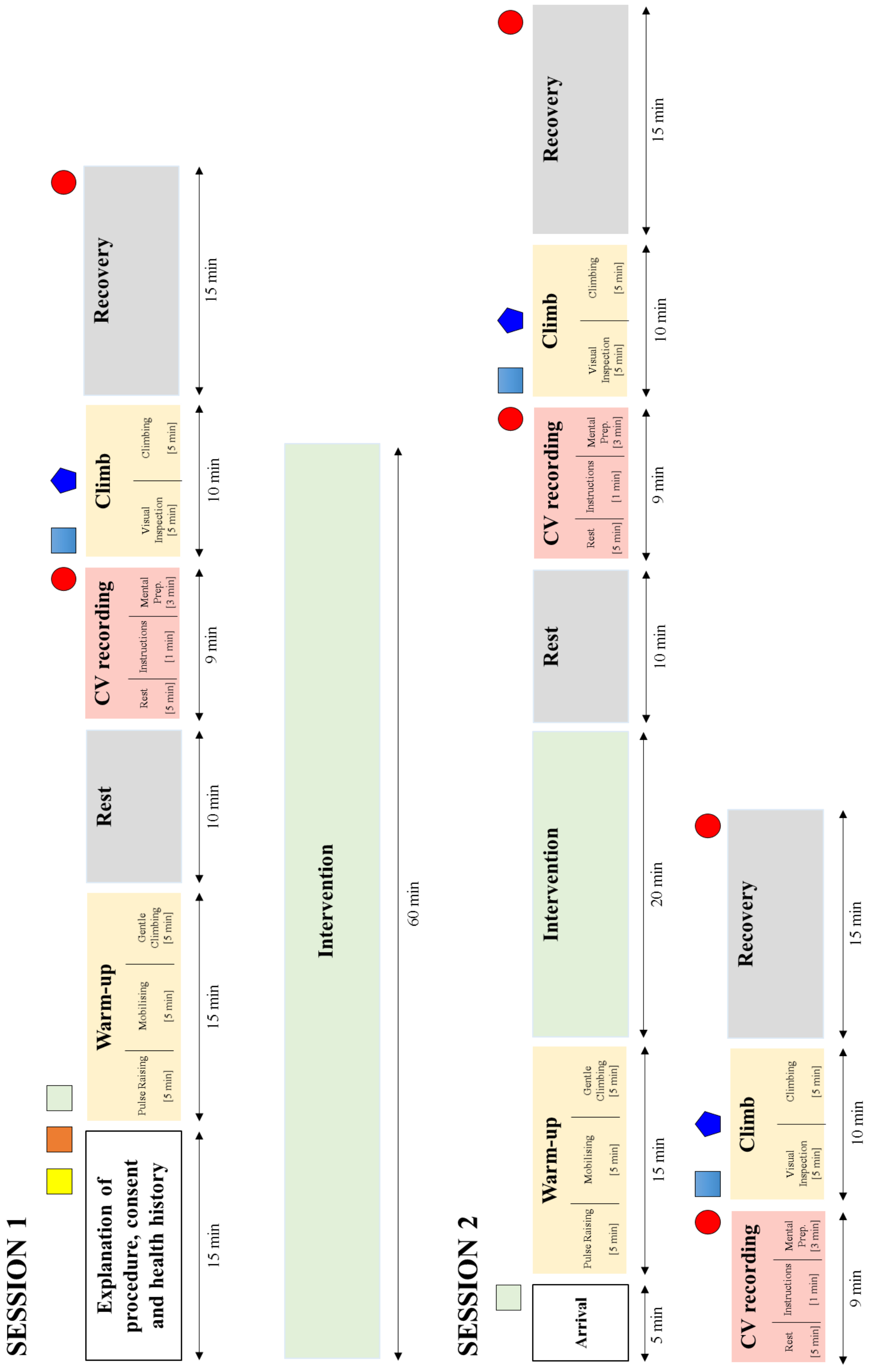


Figure 8.1: *Timeline for anthropometrics, resting and climbing measurements.*

to your on-sight lead grade" (thus requiring physical and mental effort). The novel *"on-sight"* nature of the first and third climbs were highlighted, aimed at promoting perceptions of uncertainty regarding performance, while the second *"red-point"* highlighted climbers' familiarity. As well as promoting task demands, the instructions contained the physical and emotional danger manipulation, in the form of drawing climbers attention to the need to lead the climb, in line with the theory of resource appraisals put forth in the TCTSA (Jones et al., 2009). Regarding the style of ascent, the instructions stated *"You are required to lead climb the route, clipping every quickdraw"*. Attention was drawn to the assessment of performance *"The task that you are about to complete is designed to assess your lead climbing performance"*. The final part of the task instructions asked participants to mentally prepare for the upcoming climbing task by thinking about their performance for three minutes. This was followed by a pre-climb salivary cortisol sample. Following the presentation of the climbing task instructions, participants completed combined self-efficacy, cognitive evaluation, perceived control, task importance, demand resource evaluation and achievement goals inventories (*4.4.5 Pre-climb*).

8.2.5 Procedure: Climbing assessment

Participants performance was assessed on three routes, an initial on-sight, which the participants had no prior knowledge of; a repeat red-point ascent of the first route; and an on-sight of a further novel route. On each occasion, after the cardiovascular data collection, the climbers moved out onto the climbing centre main floor and were shown the route they were to ascend. Following visual inspection of the route, climbers completed the Immediate Anxiety Measurement Scale (IAMS) in relation to the upcoming climbing task (*4.4.5 Pre-climb*). Finally, participants attempted the assigned route, climbing until they either reached the top of the route, or fell. Participants began climbing when ready, ascending at their own pace, protected from falling using a standard climbing harness, rope and an experienced belayer (*4.1.3 Protection of climbers*). During the climb, heart rate was recorded continuously and the performance was video recorded (*4.2.2 Video recording of climbs*). Saliva cortisol was sampled on returning to the ground after a 15-minute passive recovery period.

8.2.6 Procedure: Interventions

Following completion of the initial on-sight of the route, participants were matched for age, sex and experience and were randomly assigned to either a *control practice* or *clip-drop* interventional group. Participants completed a one-hour intervention. The effectiveness of two different interventions were assessed, addressing two factors: route knowledge and familiarity with falling. A further control group were also included. As close as possible, the three interventions aimed to incorporate a similar amount of climbing. Procedures were as follows:

Practice. The route knowledge condition allowed climbers the opportunity to become familiar with the sequence of moves required to complete the first route completed during session one. Participants initially led the route, if the climber wished to repeat a section having lead past it, on a top-rope, then they could stop and repeat a sequence. Climbers ascended the route three times during session one, and once again during session two, practising sections they wished. Each ascent was separated by 10 minutes of rest.

Clip-Drop. The clip-drop intervention progressively introduced participants to falling, with the aim of habituating the climber to the feeling of falling and its consequences. The length of falls were gradually increased over the course of the ascent of a route, in line with fall practice described by Hague and Hunter (2011). To begin, participants led to the third quickdraw, which they clipped and weighed the rope, the belayer and the climber then communicated to ensure the climber was happy with the process and happy to continue. From the 4^{th} quickdraw, participants climbed up, clipped and fell, gradually increasing the height of the quickdraw, and thus slack in the system, and the length of the fall at each subsequent quickdraw. Participants were instructed to aim for falling with the rope level with their knees, or feet, by the top of the climb. However, the fall size was left to the climber to determine. The process was repeated three times during session one and once again at the start of session two.

Control. The control group completed three lead ascents of novel routes during session one and one route following the warm-up in session two, no instruction was provided. The routes were of similar style, length, angle and difficulty to the two primary routes used within the session. However, the routes were not assessed.

8.2.7 Statistical analysis

All statistical analysis was conducted using SPSS (version 22; Chicago IL) and Microsoft Excel (Version 2015; Redmond WA) software. Outlier analysis was first conducted; univariate outliers were first identified based on being more than 3.3 standard deviations from the mean (Tabachnick et al., 2001). Following identification, as in Moore et al. (2012), outliers were identified and winsorized by changing the deviant raw score to a value 1% larger or smaller than the next most extreme score, this was necessary for three participants cardiovascular data. Normal distribution and homogeneity of variance were then assessed through visual inspection of the frequency histogram, Shapiro-Wilk's tests and by examining variance around the mean with the use of box plots (if the maximum variance was less than three times the mean then equal variance was assumed). This is the normally accepted rule to determine whether the analysis of variance (ANOVA) test is reliable. Descriptive statistics were calculated for all variables; all values are reported as Mean ± SD.

A series of independent samples *t*-tests were used in determining differences between male and female participants and a series of one-way ANOVAs between intervention groups for climbing experience, anthropometrics and climbers state. Two-way mixed analysis of variance (ANOVA) were used to investigate the main effects of 'intervention' (control, clip-drop, repeat practice), 'ascent' (initial on-sight, red-point, novel on-sight), as well as the interaction effect 'intervention*ascent'. If an interaction was present follow-ups were performed with simple main effects, using a series of FDR corrected independent samples ANOVA between groups and repeated measures ANOVA between ascents for each ascent. Else if no interaction was present significant differences were further investigated using one-way ANOVA. Post-hoc least significant difference (LSD) tests were used to explore the source of the differences in the means between conditions for each significant ANOVA.

For all analysis, the critical α-level was set at 0.05; corrections for multiple comparisons were made using Benjamini and Hochberg (1995) false-discovery rate (FDR) method, which has been supported for use in place of Bonferroni adjustments (Glickman et al., 2014). Unadjusted and adjusted *p* values were calculated and, where necessary, presented to provide an indication of the likelihood of type I and type II error rates; given it has been previously argued that reducing the possibility of type II error is preferable in exploratory research (Hoad & Monks, 2011; Perneger, 1998). Effects sizes were determined using η_p^2 for multiple comparisons.

8.3 Results

Participants were randomly allocated to either, control group (n = 10), practice intervention (n = 10) or clip-drop (n = 10). All participants attempted three ascents, the first a pre-intervention assessment, the second a red-point ascent and the third assessment an on-sight of a novel route.

8.3.1 Participants climbing experience and anthropometrics

The anthropometric characteristics, experience and ability (mean ± SD) of the 30 participants (24 male, 6 female) are presented in (**Table 8.1**). Gender differences were investigated with a series of independent samples *t*-tests. Significant differences in height ($p < 0.005$) and mass ($p < 0.005$) were found, with female climbers shorter (MD = 0.13 m, CI_{95} = 0.09, 0.18) and with lower mass (MD = 16.5 kg, CI_{95} = 10.6, 22.3).

Intervention Group Differences

Anthropometric characteristics, experience and ability (mean ± SD) are presented in **Table 8.2** for the climbers in each intervention. A series of one-way ANOVAs were used to explore differences in the participants climbing anthropometrics, experience and ability; there were no significant differences.

Table 8.2: *Participants anthropometric characteristics for participants assigned to the control, practice and clip-drop interventions (mean ± SD).*

	Control (*n* = 10)	**Practice** (*n* = 10)	**Clip-Drop** (*n* = 10)	**One-way ANOVA**		
				$F_{(2,27)}$ =	p =	η_p^2
Anthropometrics						
Gender	2 ♀ 8♂	2 ♀ 8♂	2 ♀ 8♂			
Age (years)	28.7 ± 7.7	31.1 ± 7.0	29.3 ± 6.5	0.311	0.735	0.023
Height (m)	1.73 ± 0.06	1.76 ± 0.06	1.75 ± 0.09	0.543	0.593	0.038
Mass (kg)	70.2 ± 11.4	74.0 ± 7.8	70.2 ± 8.0	0.559	0.578	0.040
Experience						
Years Climbing	6.4 ± 6.5	6.7 ± 4.5	6.6 ± 4.6	0.006	0.994	0.000
Sessions a week	2.5 ± 1.2	2.4 ± 1.6	2.1 ± 0.7	0.344	0.712	0.025
Discipline						
% Sport	40.0 ± 29.1	40.3 ± 27.4	39.5 ± 41.9	0.001	0.999	0.000
% Trad	18.0 ± 21.0	11.3 ± 15.0	16.5 ± 31.8	0.221	0.803	0.016
% Boulder	42.0 ± 29.7	46.4 ± 33.9	44.0 ± 40.2	0.040	0.961	0.003
In/out						
% Indoor	71.4 ± 34.7	81.6 ± 21.3	79.0 ± 24.7	0.372	0.693	0.027
% Outdoor	28.6 ± 34.7	18.4 ± 21.3	21.0 ± 24.7	0.372	0.693	0.027
Grade						
Indoor OS (IRCRA)	13.0 ± 0.8	13.0 ± 0.8	13.3 ± 0.5	0.574	0.570	0.041
Indoor RP (IRCRA)	13.9 ± 1.0	13.9 ± 0.6	13.9 ± 0.7	0.000	1.000	0.000

Note: m metres; kg kilogramme; ANOVA analysis of variance; IRCRA international rock climbing research association

Trait anxiety was assessed with the STAI, achievement goals with the AGQ (2x2 framework) and mood state with POMS, all are presented in **Table 8.3** for control, practice and clip-drop groups (mean ± SD). There were no significant group differences in trait anxiety (STAI), mood (POMS) or any of the four dimensions of achievement goals (AGQ), as assessed with a one series of one-way ANOVAs.

Table 8.3: *Response to trait anxiety, achievement goals and mood state questions for participants assigned to the control, practice and clip-drop interventions (mean ± SD).*

	Control (n = 10)	**Practice** (n = 10)	**Clip-Drop** (n = 10)	**One-way ANOVA** $F_{(2,27)}$ =	p =	η_p^2
STAI	42.6 ± 12.2	40.7 ± 6.9	36.2 ± 8.9	1.182	0.322	0.080
AGQ						
MAp	18.0 ± 3.2	17.0 ± 2.9	17.5 ± 1.5	0.362	0.700	0.026
MAv	16.2 ± 5.3	13.2 ± 4.0	15.4 ± 2.2	1.476	0.247	0.099
PAp	11.8 ± 5.2	9.9 ± 5.6	12.0 ± 5.4	0.457	0.638	0.033
PAv	11.3 ± 4.9	8.6 ± 5.0	10.2 ± 5.2	0.717	0.497	0.050
POMS						
Total mood disturbance	27.6 ± 12.5	24.7 ± 11.7	20.6 ± 6.8	1.095	0.349	0.075
Depression	9.3 ± 1.8	9.0 ± 1.6	8.4 ± 0.7	0.969	0.392	0.067
Vigour	17.1 ± 4.4	16.5 ± 4.4	18.4 ± 2.7	0.616	0.548	0.044
Confusion	7.3 ± 2.2	7.4 ± 2.0	6.4 ± 1.2	0.901	0.418	0.063
Tension	10.9 ± 4.3	9.5 ± 2.7	8.9 ± 2.2	1.037	0.368	0.071
Anger	7.9 ± 1.5	7.5 ± 0.8	7.6 ± 1.1	0.310	0.736	0.022
Fatigue	9.3 ± 3.4	7.8 ± 2.6	7.7 ± 2.8	0.928	0.408	0.064

Notes: ANOVA analysis of variance; STAI state-trait anxiety inventory; AGQ achievement goal questionnaire; MAp mastery approach; MAv mastery-avoidance; PAp performance approach; PAv performance avoidance; POMS profile of mood states

8.3.2 Climbing task demands

The routes used for assessment, were set to be within one grade of the on-sight ability of all participants who took part. Despite this, several participants were not successful on the route (**Table 8.4**). A greater number of climbers fell in the control group on the third on-sight climb, compared to practice and clip-drop interventions, there were only small differences for the initial on-sight and red-point ascents.

Table 8.4: *Success and failure on the climbs for initial on-sight, red-point and novel on-sight for the control, practice and clip-drop groups.*

Success | Failure	**Control** (n = 10)	**Practice** (n = 10)	**Clip-Drop** (n = 10)
Initial On-Sight	8 S | 2 F	8 S | 2 F	8 S | 2 F
Red-Point	7 S | 3 F	10 S | 0 F	9 S | 1 F
Novel On-Sight	6 S | 4 F	8 S | 2 F	9 S | 1 F

Notes: S successful; F unsuccessful

Physical demands

Table 8.5 presents climbing time and average and maximum heart rate data, recorded continuously throughout each of the climbs. Differences were assessed with three two-way mixed ANOVAs for the main effects of 'intervention' (control, clip-drop, repeat practice), 'ascent' (initial on-sight, red-point, novel on-sight) for each of climbing time and average and maximum heart rate, as well as the interaction effect 'intervention*ascent'. There was no statistically significant interaction for 'intervention*ascent' for climbing time (p = 0.238; η_p^2 = 0.099), or for the main effect 'intervention' (p = 0.520; η_p^2 = 0.049). However, a significant effect existed for 'ascent' for climbing time ($p < 0.005$; η_p^2 = 0.259). Post-hoc LSD were significant and demonstrated meaningful faster ascents in the red-point than both the initial on-sight (MD = 15.8 sec, CI_{95} = 6.2, 25.4) and the novel on-sight (MD = 17.0 sec, CI_{95} = 10.7, 23.3). There was no statistically significant interaction for 'intervention*ascent' for average heart rate (p = 0.139; η_p^2 = 0.156), for the main effect 'intervention' (p = 0.487; η_p^2 = 0.069), or the main effect 'ascent' (p = 0.850; η_p^2 = 0.008). Similarly, there was no statistically significant interaction for 'intervention*ascent' for maximum heart rate (p = 0.851; η_p^2 = 0.031), for the main effect 'intervention' (p = 0.226; η_p^2 = 0.132), or the main effect 'ascent' (p = 0.529; η_p^2 = 0.030).

Table 8.5: *Climbing time and average and maximum heart rate for the initial on-sight, red-point and final novel on-sight ascents for the control, practice and clip-drop groups (mean ± SD).*

		Initial On-sight	Red-Point	Novel On-sight
Climb Time (sec)	*Control*	140.2 ± 16.8	130.8 ± 26.9	141.4 ± 40.2
	Practice	129.7 ± 31.8	112.0 ± 17.2	140.3 ± 26.3
	Clip-Drop	137.6 ± 19.3	115.9 ± 21.0	128.0 ± 16.6
	TOTAL	**135.2 ± 23.3***	**119.2 ± 22.6**	**136.4 ± 28.4***
Avg Heart Rate ($b.min^{-1}$)	*Control*	143.7 ± 28.3	157.3 ± 19.4	155.4 ± 20.3
	Practice	145.1 ± 25.6	135.7 ± 17.1	146.8 ± 17.0
	Clip-Drop	154.7 ± 19.0	148.7 ± 15.0	146.6 ± 11.1
	TOTAL	**147.8 ± 26.2**	**147.2 ± 17.2**	**149.6 ± 17.8**
Max Heart Rate ($b.min^{-1}$)	*Control*	159.3 ± 29.2	164.2 ± 28.9	176.5 ± 18.6
	Practice	157.4 ± 26.1	152.3 ± 29.5	170.7 ± 10.4
	Clip-Drop	169.3 ± 26.6	170.3 ± 16.4	169.2 ± 14.1
	TOTAL	**162.0 ± 27.3**	**162.3 ± 27.4**	**172.1 ± 15.9**

Notes: Sec seconds; $b.min^{-1}$ beats per minute
**Shows the group is significantly different ($p < 0.05$) from the red-point ascent*

8.3.3 Climbing performance

Climbing performance was assessed using geometric entropy and coaches' performance scores (**Table 8.6**). Differences were assessed with two two-way mixed ANOVAs for the main effects of 'intervention' and 'ascent' for both geometric entropy and coaches score, as well as the interaction effect 'intervention*ascent'. There was no statistically significant interaction for 'intervention*ascent' for geometric entropy (p = 0.291; η_p^2 = 0.100) and no significant effect was indicated for 'intervention' (p = 0.698; η_p^2 = 0.031). However, group differences in 'ascent' for geometric entropy were significant (p = 0.013; η_p^2 = 0.171). Post-hoc LSD were significant and demonstrated meaningful lower geometric entropy for both the red-point (MD = 0.82, CI_{95} = 0.01, 0.15) and the novel on-sight (MD = 0.72, CI_{95} = 0.01, 0.14), compared to the initial on-sight. There was no statistically significant interaction for 'intervention*ascent' for total coaches' performance (p = 0.427; η_p^2 = 0.070), or for the main effect 'intervention' (p = 0.225; η_p^2 = 0.180). However, as with geometric entropy, a significant effect existed for 'ascent' for total score (p = 0.001; η_p^2 = 0.235). Post-hoc LSD were significant and demonstrated meaningful greater total coaches score in the red-point than both the initial on-sight (MD = 5.4, CI_{95} = 1.7, 9.4) and the novel on-sight (MD = 2.9, CI_{95} = 0.2, 5.7).

Table 8.6: *Geometric entropy and coaches' score for the initial on-sight, red-point and final novel on-sight ascents for the control, practice and clip-drop groups (mean ± SD).*

		Initial On-sight	Red-Point	Novel On-sight
Geometric Entropy	*Control*	0.82 ± 0.18	0.75 ± 0.11	0.69 ± 0.14
	Practice	0.81 ± 0.12	0.73 ± 0.06	0.74 ± 0.11
	Clip-drop	0.76 ± 0.15	0.66 ± 0.12	0.75 ± 0.14
	TOTAL	**0.80 ± 0.15**	**0.71 ± 0.10****	**0.73 ± 0.13****
Coaches' Score	*Control*	48.4 ± 5.0	52.4 ± 6.3	49.6 ± 6.6
	Practice	48.7 ± 6.3	57.5 ± 4.4	51.0 ± 5.4
	Clip-drop	52.3 ± 4.3	55.8 ± 6.4	54.6 ± 3.7
	TOTAL	**49.9 ± 5.4***	**55.3 ± 5.9**	**51.8 ± 5.6***

**Shows the group is significantly different (p < 0.05) from the red-point ascent*
*** Shows the group is significantly different (p < 0.05) from the initial on-sight ascent*

The breakdown for each of the factors of the coaches' score was also calculated, to describe differences in performance within the factors (**Table 8.7**). Differences were assessed with a series of two-way mixed ANOVAs for the main effects of 'intervention', 'ascent' for base of support, transitioning, coordination, technique and tactics, as well as the interaction effect 'intervention*ascent'.

Base of support, there was a significant interaction for 'intervention*ascent' (p = 0.005; η_p^2 = 0.242). Follow-ups to investigate the interaction were performed with simple main effects, using a series of FDR corrected independent samples ANOVA between groups and repeated measures ANOVA between ascents, for each ascent. Independent samples ANOVA reported no significant intervention group difference for the initial on-sight (p = 0.159, η_p^2 = 0.127), repeat red-point (p = 0.074, η_p^2 = 0.181), or second novel on-sight (p = 0.357, η_p^2 = 0.076). However, repeated measure ANOVA demonstrated significant and meaningful (post-hoc LSD) differences between ascents for control between on-sight ascents (p = 0.018, η_p^2 = 0.396; MD = 0.40, CI_{95} = 0.14, 0.66); practice between on-sight and red-point ascents (p = 0.006, η_p^2 = 0.432; MD = 0.27, CI_{95} = 0.04, 0.50) and clip-drop between on-sight and red-point ascents (p = 0.025, η_p^2 = 0.335; MD = 0.42, CI_{95} = 0.12, 0.72).

Transitioning, there was no statistically significant interaction for 'intervention*ascent' (p = 0.126; η_p^2 = 0.099), or for the main effect 'intervention' (p = 0.461; η_p^2 = 0.058). However, a significant effect existed for 'ascent' for transitioning score (p < 0.005; η_p^2 = 0.277). Post-hoc LSD were significant and demonstrated the score was greater in the red-point than the initial on-sight (MD = 0.3, CI_{95} = 0.2, 0.5) and the novel on-sight (MD = 0.4, CI_{95} = 0.2, 0.6).

Coordination, there was no statistically significant interaction for 'intervention*ascent' (p = 0.411; η_p^2 = 0.072), or for the main effect 'intervention' (p = 0.461; η_p^2 = 0.058). However, a significant effect existed for 'ascent' for coordination score (p < 0.005; η_p^2 = 0.277). Post-hoc LSD were significant and demonstrated meaningful greater coordination score in the red-point than both the initial on-sight (MD = 0.5, CI_{95} = 0.3, 0.6) and the novel on-sight (MD = 0.3, CI_{95} = 0.1, 0.5).

Technique, there was no statistically significant interaction for 'intervention*ascent' (p = 0.795; η_p^2 = 0.031), or the main effect 'intervention' (p = 0.687; η_p^2 = 0.029). However, a significant effect existed for 'ascent' for technique score (p < 0.005; η_p^2 = 0.268). Post-hoc LSD were significant and demonstrated meaningful greater technique score in the red-point than the initial on-sight (MD = 0.5, CI_{95} = 0.2, 0.7) and the novel on-sight (MD = 0.3, CI_{95} = 0.1, 0.5).

Tactics, there was no statistically significant interaction for 'intervention*ascent' (p = 0.187; η_p^2 = 0.110), for the main effect 'intervention' (p = 0.932; η_p^2 = 0.005), or the main effect 'ascent' (p = 0.060; η_p^2 = 0.103).

Table 8.7: *Breakdown of coaches' score for the initial on-sight, red-point and final novel on-sight ascents for the control, practice and clip-drop groups (mean ± SD).*

		Initial On-sight	Red-Point	Novel On-sight
Base of Support	*Control*	3.0 ± 0.5	3.3 ± 0.7	3.4 ± 0.5**
	Practice	3.5 ± 0.5*	3.8 ± 0.4	3.3 ± 0.6
	Clip-drop	3.3 ± 0.5*	3.7 ± 0.4	3.6 ± 0.4
	TOTAL	**3.3 ± 0.5**	**3.6 ± 0.5**	**3.4 ± 0.5**
Transitioning	*Control*	3.6 ± 0.5	3.7 ± 0.5	3.4 ± 0.5
	Practice	3.6 ± 0.4	4.1 ± 0.4	3.5 ± 0.3
	Clip-drop	3.5 ± 0.3	3.9 ± 0.4	3.7 ± 0.3
	TOTAL	**3.6 ± 0.4***	**3.9 ± 0.4**	**3.5 ± 0.4***
Co-ordination	*Control*	3.1 ± 0.5	3.6 ± 0.5	3.2 ± 0.6
	Practice	3.2 ± 0.4	3.7 ± 0.4	3.3 ± 0.4
	Clip-drop	3.2 ± 0.6	3.6 ± 0.4	3.5 ± 0.6
	TOTAL	**3.1 ± 0.5***	**3.6 ± 0.4**	**3.3 ± 0.5***
Technique	*Control*	2.9 ± 0.6	3.2 ± 0.5	3.0 ± 0.6
	Practice	3.0 ± 0.5	3.5 ± 0.6	3.1 ± 0.5
	Clip-drop	2.9 ± 0.5	3.4 ± 0.5	3.2 ± 0.4
	TOTAL	**2.9 ± 0.5***	**3.4 ± 0.6**	**3.1 ± 0.5***
Tactics	*Control*	4.0 ± 0.4	4.1 ± 0.6	3.9 ± 0.7
	Practice	3.9 ± 0.5	4.1 ± 0.6	3.8 ± 0.6
	Clip-drop	3.7 ± 0.6	4.0 ± 0.6	4.1 ± 0.2
	TOTAL	**3.8 ± 0.5**	**4.1 ± 0.6**	**3.9 ± 0.5**

**Shows the group is significantly different ($p < 0.05$) from the red-point ascent*
*** Shows the group is significantly different ($p < 0.05$) from the initial on-sight ascent*

8.3.4 Task instructions

Task engagement

Heart rate reactivity to the presented task instructions was assessed for task engagement (**Table 8.8**), an important prerequisite for the analysis of challenge and threat cardiovascular reactivity (Blascovich et al., 2011). Differences were assessed with two two-way mixed ANOVAs for the main effects of 'intervention' and 'ascent' for heart rate and task importance, as well as the interaction effect 'intervention*ascent'. There was no statistically significant interaction for 'intervention*ascent' for heart rate (p = 0.718; η_p^2 = 0.046), for the main effect 'intervention' (p = 0.088; η_p^2 = 0.199), or the main effect 'ascent' (p = 0.116; η_p^2 = 0.093). Although, heart rate increased pre-post instruction for all groups and for each climb. There was no statistically significant interaction for 'intervention*ascent' for task importance (p = 0.392;

η_p^2 = 0.072), for the main effect 'intervention' (p = 0.793; η_p^2 = 0.017), or the main effect 'ascent' (p = 0.428; η_p^2 = 0.031). However, participants indicated success on the route was important to them with task importance scores of > 4.5. Finally, the manipulation check indicated all participants engaged in task-relevant thoughts while considering the upcoming climbing task, supporting the heart rate and task engagement data, in asserting they represented a motivated performance situation.

Table 8.8: *Engagement to task instruction assessed with task importance and pre-post heart rate (b.min^{-1}) (mean ± SD).*

		Initial On-sight	Red-Point	Novel On-sight
HR Reactivity (b.min^{-1})	*Control*	3.1 ± 5.4	1.2 ± 4.6	1.3 ± 2.7
	Practice	5.1 ± 2.6	4.6 ± 4.2	4.3 ± 5.1
	Clip-Drop	6.7 ± 5.0	3.4 ± 4.1	5.9 ± 6.5
	TOTAL	**5.3 ± 4.6**	**3.1 ± 4.6**	**3.5 ± 5.4**
Task Importance	*Control*	4.5 ± 1.8	4.8 ± 1.5	4.7 ± 1.6
	Practice	5.2 ± 1.7	4.8 ± 2.3	4.9 ± 1.9
	Clip-Drop	5.5 ± 1.9	4.7 ± 1.8	5.3 ± 1.7
	TOTAL	**5.1 ± 1.8**	**4.8 ± 1.8**	**5.0 ± 1.7**

Notes: b.min^{-1} beats per minute

Cardiovascular markers

Cardiovascular reactivity was assessed through changes in cardiac output and total peripheral resistance before and after the task instructions for each of the climbs, along with challenge and threat index and post-instruction cortisol (**Table 8.9**). Differences were assessed with a series of two-way mixed ANOVAs for the main effects of 'intervention', 'ascent' for cardiac output reactivity, peripheral resistance reactivity, challenge and threat index and cortisol concentration, as well as the interaction effect 'intervention*ascent'.

Cardiac output reactivity, there was no statistically significant interaction for 'intervention*ascent' (p = 0.759; η_p^2 = 0.041), or for the main effect 'intervention' (p = 0.346; η_p^2 = 0.092). However, a significant effect existed for 'ascent' for cardiac output reactivity (p = 0.031; η_p^2 = 0.146). Post-hoc LSD were significant and demonstrated meaningful greater cardiac output reactivity in the red-point than the initial on-sight (MD = 0.4 L/min, CI_{95} = 0.2, 0.8) and between the initial on-sight and the novel on-sight (MD = 0.4 L/min, CI_{95} = 0.1, 0.8).

Peripheral resistance reactivity, there was no statistically significant interaction for 'intervention*ascent' (p = 0.209; η_p^2 = 0.122), or for the main effect 'intervention' (p = 0.610; η_p^2 = 0.044). However, a significant effect existed for 'ascent' for peripheral resistance reactivity (p = 0.036; η_p^2 = 0.140). Post-hoc LSD were significant and demonstrated meaningful greater peripheral resistance reactivity in the red-point than the initial on-sight (MD = 76 dyn.s.cm^5, CI_{95} = 15, 137).

Challenge and threat index, there was no statistically significant interaction for 'intervention*ascent' (p = 0.436; η_p^2 = 0.081), for the main effect 'intervention' (p = 0.535; η_p^2 = 0.055), or the main effect 'ascent' (p = 0.983; η_p^2 = 0.001).

Cortisol concentration, there was no statistically significant interaction for 'intervention*ascent' (p = 0.446; η_p^2 = 0.065), for the main effect 'intervention' (p = 0.953; η_p^2 = 0.004), or the main effect 'ascent' (p = 0.103; η_p^2 = 0.081).

Table 8.9: *Cardiac output, total peripheral resistance and cortisol for the initial on-sight, red-point and final novel on-sight ascents for the control, practice and clip-drop groups (mean ± SD).*

		Initial On-sight	Red-Point	Novel On-sight
Cardiac Output Reactivity (L/min)	*Control*	0.78 ± 0.42	0.41 ± 0.59	0.15 ± 0.35
	Practice	0.87 ± 0.79	0.53 ± 0.69	0.74 ± 0.78
	Clip-Drop	1.15 ± 0.40	0.65 ± 0.95	0.68 ± 0.92
	TOTAL	**0.95 ± 0.57**	**0.54 ± 0.74****	**0.55 ± 0.76****
Peripheral Resistance Reactivity (dyn.s.cm^5)	*Control*	-96.3 ± 52.0	-46.2 ± 116.8	16.4 ± 50.6
	Practice	-74.2 ± 99.7	-15.5 ± 116.3	-94.1 ± 111.3
	Clip-Drop	-136.2 ± 79.4	-16.8 ± 125.0	-83.4 ± 166.1
	TOTAL	**-102.7 ± 82.6***	**-24.6 ± 115.4**	**-59.3 ± 127.7**
Challenge and Threat Index	*Control*	-0.19 ± 0.61	-0.36 ± 0.61	0.06 ± 0.35
	Practice	0.23 ± 0.73	0.08 ± 0.52	-0.09 ± 0.38
	Clip-Drop	-0.05 ± 1.30	0.25 ± 0.67	-0.08 ± 0.35
	TOTAL	**0.01 ± 0.93**	**0.02 ± 0.63**	**-0.04 ± 0.35**
Cortisol (nmol/L)	*Control*	3.10 ± 2.89	6.68 ± 8.08	5.86 ± 6.72
	Practice	5.68 ± 5.38	5.42 ± 3.59	5.44 ± 7.13
	Clip-Drop	4.76 ± 7.11	7.54 ± 7.21	5.58 ± 4.99
	TOTAL	**4.52 ± 5.33**	**6.55 ± 6.42**	**5.63 ± 6.13**

Notes: ANOVA analysis of variance; nmol/L nanomoles per litre; CO cardiac output; dyn.s.cm^5 vascular resistance
**Shows the group is significantly different (p < 0.05) from the red-point ascent*
*** Shows the group is significantly different (p < 0.05) from the initial on-sight ascent*

Self-report measures

Self-reported self-efficacy, cognitive evaluation and demand resources were assessed following the presentation of the task-instructions (**Table 8.10**). Differences were assessed with a series of two-way mixed ANOVAs for the main effects of 'intervention', 'ascent' for self-efficacy, cognitive evaluation, perceived control and demand resources, as well as the interaction effect 'intervention*ascent'.

Self-efficacy, there was no statistically significant interaction for ‘intervention*ascent’ (p = 0.153; η_p^2 = 0.115). However, a significant effect existed for ‘intervention’ for self-efficacy (p = 0.009; η_p^2 = 0.295) and for the main effect ‘ascent’ (p = 0.001; η_p^2 = 0.217). Post-hoc LSD were significant and demonstrated meaningful greater self-efficacy in the red-point than both the initial on-sight (MD = 0.8, CI_{95} = 0.3, 1.3) and the novel on-sight (MD = 0.5, CI_{95} = 0.1, 0.9).

Cognitive evaluation, there was no statistically significant interaction for ‘intervention*ascent’ (p = 0.829; η_p^2 = 0.027), for the main effect ‘intervention’ (p = 0.516; η_p^2 = 0.048), or the main effect ‘ascent’ (p = 0.486; η_p^2 = 0.026).

Perceived control, there was no statistically significant interaction for ‘intervention*ascent’ (p = 0.113; η_p^2 = 0.120), for the main effect ‘ascent’ (p = 0.208; η_p^2 = 0.056) or for ‘intervention’ (p = 0.200; η_p^2 = 0.051).

Demand resources, there was no statistically significant interaction for ‘intervention*ascent’ (p = 0.608; η_p^2 = 0.048), or for the main effect ‘intervention’ (p = 0.691; η_p^2 = 0.027). However, a significant effect existed for ‘ascent’ for demand resources (p = 0.001; η_p^2 = 0.237). Post-hoc LSD were significant and demonstrated meaningful greater demand resources in the red-point than the initial on-sight (MD = 1.7, CI_{95} = 0.8, 2.5).

Table 8.10: *Self-report measures assessed post instructions for the initial on-sight, red-point and final novel on-sight ascents for the control, practice and clip-drop groups (mean ± SD). For cognitive evaluation, a more +ve score indicates challenge state, -ve more threatening; for demand resources, more +ve indicates coping resources outweigh demands.*

		Initial On-sight	Red-Point	Novel On-sight
Self-Efficacy	*Control*	4.0 ± 1.1	4.1 ± 1.3	4.0 ± 1.1
	Practice	4.5 ± 0.8	6.1 ± 1.0	5.2 ± 1.2
	Clip-Drop	4.9 ± 1.1	5.7 ± 1.6	5.2 ± 1.2
	TOTAL	**4.4 ± 1.0***	**5.3 ± 1.5**	**4.8 ± 1.2***
Cognitive Evaluation	*Control*	0.7 ± 1.1	0.3 ± 0.8	0.9 ± 0.6
	Practice	0.4 ± 1.1	0.0 ± 1.1	0.5 ± 0.7
	Clip-Drop	0.9 ± 1.4	0.7 ± 1.6	0.5 ± 2.3
	TOTAL	**0.7 ± 1.2**	**0.3 ± 1.2**	**0.6 ± 1.4**
Perceived Control	*Control*	6.4 ± 1.2	5.4 ± 1.5	6.5 ± 1.3
	Practice	6.6 ± 0.5	5.6 ± 2.0	6.4 ± 0.8
	Clip-Drop	6.5 ± 0.8	6.7 ± 0.5	6.8 ± 0.4
	TOTAL	**6.5 ± 1.0**	**5.9 ± 1.5**	**6.6 ± 1.0**
Demand Resources	*Control*	0.2 ± 1.5	1.0 ± 2.5	0.6 ± 2.2
	Practice	-0.2 ± 1.6	2.2 ± 3.0	0.7 ± 2.3
	Clip-Drop	-0.6 ± 1.0	1.2 ± 2.7	0.1 ± 1.7
	TOTAL	**-0.2 ± 1.4***	**1.5 ± 2.7**	**0.5 ± 2.0**

**Shows the group is significantly different (p < 0.05) from the red-point ascent*

8.3.5 Climbing Tasks

Emotions

Subjective assessment of the intensity and direction of somatic and cognitive anxiety and self-confidence, were assessed immediately prior to the climbs (**Table 8.11**). Differences were assessed with a series of two-way mixed ANOVAs for the main effects of ‘intervention’, ‘ascent’ for the intensity and direction of somatic and cognitive anxiety and self-confidence, as well as the interaction effect ‘intervention*ascent’.

Table 8.11: *Pre-climb emotional state for the initial on-sight, red-point and final novel on-sight ascents for the control, practice and clip-drop groups (mean ± SD).*

		Initial On-sight	Red-Point	Novel On-sight
Somatic Anxiety	*Control*	34.2 ±16.8*	32.7 ± 16.6	40.4 ± 10.8**; *
Intensity	*Practice*	36.8 ±14.0*	32.3 ± 17.0	31.8 ± 13.5**; *
	Clip-Drop	35.0 ±14.2*	32.4 ± 14.1	24.9 ± 11.5**; †
	TOTAL	**35.3 ±14.6**	**32.5 ± 15.4**	**32.4 ± 13.2**
Direction	*Control*	-3.7 ±11.7*	-2.7 ± 12.0	-10.5 ± 11.8**; *
	Practice	3.1 ±17.8*	11.1 ± 18.3	8.8 ± 18.4**; *; †
	Clip-Drop	-0.3 ±19.3*	3.5 ± 19.7	2.4 ± 19.0**; *
	TOTAL	**-0.3 ±16.3**	**4.0 ± 17.4**	**0.2 ± 18.3**
Cognitive Anxiety	*Control*	31.3 ±16.4	24.8 ± 19.4	26.2 ± 22.8
Intensity	*Practice*	34.1 ±17.0	22.7 ± 21.2	17.1 ± 16.0
	Clip-Drop	28.8 ±15.0	6.9 ± 3.6	10.0 ± 8.0
	TOTAL	**31.4 ±15.7**	**18.1 ± 18.1****	**17.8 ± 17.5****
Direction	*Control*	-9.7 ±11.2	1.3 ± 17.4	-2.2 ± 12.0
	Practice	-3.7 ±17.8	-1.3 ± 22.0	-2.9 ± 18.6
	Clip-Drop	-5.9 ±20.8	8.8 ± 21.4	1.0 ± 22.5
	TOTAL	**-6.5 ±16.4**	**2.9 ± 20.0****	**-1.4 ± 17.5****
Self-Confidence	*Control*	28.9 ±14.0	28.1 ± 17.3	25.7 ± 11.9
Intensity	*Practice*	34.1 ±8.5*	49.1 ± 14.5†	39.5 ± 14.5†
	Clip-Drop	32.1 ±16.5*	48.3 ± 11.0†	41.5 ± 10.3**; †
	TOTAL	**31.7 ±13.1**	**41.8 ± 17.1**	**35.6 ± 13.9**
Direction	*Control*	8.1 ±15.6	2.0± 18.8	1.6± 11.8
	Practice	18.4 ±8.0	22.1± 11.7	20.1± 13.8†
	Clip-Drop	14.4 ±18.5	17.0± 19.4	20.7± 12.3†
	TOTAL	**13.5 ±14.9**	**13.3 ± 18.7**	**13.7 ± 15.2**

† Shows group is significantly different (p < 0.05) from the control group
** Shows the group is significantly different (p < 0.05) from the red-point ascent*
*** Shows the group is significantly different (p < 0.05) from the initial on-sight ascent*

Somatic anxiety intensity, there was a significant interaction for ‘intervention*ascent’ ($p < 0.005$; $\eta_p^2 = 0.535$). Follow-ups to investigate the interaction were performed with simple main effects, with independent samples ANOVA between groups and repeated measures ANOVA between ascents, for each ascent. Post-hoc LSD were used for further comparisons. Independent samples ANOVA reported no significant intervention group difference for the initial on-sight (p = 0.925, η_p^2 = 0.006), or the red-point ascent (p = 0.998, η_p^2= 0.000). However, there were significant group differences in the novel on-sight (p = 0.026, η_p^2 = 0.237). Further post-hoc LSD reported significant difference only between the control and clip-drop groups for the novel on-sight (MD = 15.5, CI_{95} = 4.5, 26.5). Secondly, a series of FDR corrected repeated measures ANOVAs showed that across the three climbs there was a significant change in the control groups somatic anxiety (p = 0.003, η_p^2 = 0.480) as well as the clip-drop (p < 0.005, η_p^2 = 0.851) and practice groups (p = 0.023, η_p^2 = 0.341). Post-hoc LSD demonstrated that somatic anxiety decreased significantly from the on-sight to the red-point ascent for all three groups (Control MD = 1.5, CI_{95} = 0.89, 2.1; Clip-drop MD = 2.6, CI_{95} = 1.7, 3.5; Practice MD = 4.5, CI_{95} = 1.6, 7.3). However, for the second novel on-sight while there was a significant increase for the control group compared to the initial on-sight (MD = 6.2, CI_{95} = 0.58, 11.8), there was a small decrease in the repeat practice intervention (MD = 5.0, CI_{95} = 1.1, 8.9) and a large decrease for the clip-drop intervention (MD = 10.1, CI_{95} = 7.3, 12.9).

Somatic anxiety direction, there was a significant interaction for ‘intervention*ascent’ (p < 0.005; η_p^2 = 0.726). Follow-ups to investigate the interaction were performed with simple main effects, with independent samples ANOVA between groups and repeated measures ANOVA between ascents, for each ascent. Post-hoc LSD were used for further comparisons. Independent samples ANOVA reported no significant intervention group difference for the initial on-sight (p = 0.661, η_p^2 = 0.030), or the red-point ascent (p = 0.211, η_p^2 = 0.109). There were significant group differences in the novel on-sight for the interpretation of somatic anxiety (p = 0.050, η_p^2 = 0.199). Further post-hoc LSD reported significant difference only between the control and practice groups (MD = 19.3, CI_{95} = 3.7, 34.9). Secondly, a series of FDR corrected repeated measures ANOVAs showed significant differences in all three groups across all three ascents (Control p < 0.005, η_p^2 = 0.933; Clip-drop p < 0.005, η_p^2 = 0.620; Practice p < 0.005, η_p^2 = 0.776). Post-hoc LSD illustrated a small significant increase in how the control group interpreted their somatic anxiety for the red-point ascent (MD = 1.0, CI_{95} = 0.42, 1.58) and larger increases in the clip-drop (MD = 3.8, CI_{95} = 1.9, 5.7) and practice groups (MD = 8.0, CI_{95} = 5.3, 10.6). Only the control group interpretation decreased to below the initial on-sight interpretation prior to the second on-sight (MD = 6.8, CI_{95} = 5.34, 8.26), both the clip-drop (MD = 2.7, CI_{95} = 0.7, 4.7) and practice interventions (MD = 5.7, CI_{95} = 2.6, 8.8) were less positive than the red-point, but were still more positive than the initial on-sight.

Cognitive anxiety intensity, there was no statistically significant interaction for ‘intervention*ascent’ (p = 0.290; η_p^2 = 0.087), or for the main effect ‘intervention’ (p = 0.088;

η_p^2 = 0.165). However, a significant effect existed for 'ascent' for cognitive anxiety intensity (p < 0.005; η_p^2 = 0.271). Post-hoc LSD were significant and demonstrated meaningful greater cognitive anxiety intensity in the initial on-sight than the red-point ascent (MD = 13.3, CI_{95} = 6.6, 19.9) and novel on-sight (MD = 13.6, CI_{95} = 5.4, 21.8).

Cognitive anxiety direction, there was no statistically significant interaction for 'intervention*ascent' (p = 0.605; η_p^2 = 0.052), or for the main effect 'intervention' (p = 0.782; η_p^2 = 0.019). However, a significant effect existed for 'ascent' for cognitive anxiety direction (p = 0.019; η_p^2 = 0.147). Post-hoc LSD were significant and demonstrated meaningful more positive cognitive anxiety direction in the red-point ascent than the initial on-sight (MD = 9.3, CI_{95} = 1.5, 17.1) and the novel on-sight compared to the initial on-sight (MD = 5.1, CI_{95} = 0.1, 10.0).

Self-confidence intensity, there was a significant interaction for 'intervention*ascent' (p = 0.035; η_p^2 = 0.171). Follow-ups to investigate the interaction were performed with simple main effects, with independent samples ANOVA between groups and repeated measures ANOVA between ascents for each ascent. Post-hoc LSD were used for further comparisons. Independent samples ANOVA reported no significant intervention group difference for the initial on-sight (p = 0.686, η_p^2 = 0.027). In comparison, there were significant group differences for both the repeat red-point (p = 0.004, η_p^2 = 0332) and follow-up novel on-sight (p = 0.016, η_p^2 = 0.264). Post-hoc LSD demonstrated that the differences for the red-point ascent were significant for both the practice (MD = 21.0, CI_{95} = 7.7, 34.3) and clip-drop groups (MD = 20.2, CI_{95} = 6.9, 33.5), but not between practice and clip-drop. The same was true for the final novel on-sight (Practice MD = 13.8, CI_{95} = 2.5, 25.1; clip-drop MD = 15.8, CI_{95} = 4.4, 27.1). A FDR corrected repeated measures ANOVA showed that across the three climbs there was a small, non-significant decrease in self-confidence for the control group (p = 0.701, η_p^2= 0.039). Conversely, for both the clip drop (p = 0.018, η_p^2 = 0.361) and practice groups (p = 0.001, η_p^2 = 0.549) there was a large increase in confidence between the initial on-sight and the red-point ascent (Clip-drop MD = 16.2, CI_{95} = 3.7, 28.7; Practice MD = 15.0, CI_{95} = 7.8, 22.2). While both clip-drop and practice intervention groups self-confidence decrease on the second on-sight it did not reach initial on-sight levels, the decrease was only significant for the practice group (MD = 9.6, CI_{95} = 2.0, 17.2).

Self-confidence direction, there was no significant interaction for 'intervention*ascent' (p = 0.329; η_p^2 = 0.087) and no significant effect for 'ascent' (p = 0.983; η_p^2 = 0.001). However, there was a significant effect for ‘intervention’ for self-confidence direction (p = 0.017; η_p^2 = 0.277). Three FDR corrected one-way ANOVAs demonstrated significant difference in self-confidence direction existed only in the novel on-sight (p = *0.004;* η_p^2 = 0.363), with further post-hoc LSD were significant and showed significance from the control group in both the repeat practice (MD = 18.5, CI_{95} = 6.6, 30.5) and clip-drop interventions (MD = 19.1, CI_{95} = 7.1, 31.0).

Psychophysiological Markers

Alterations in the psychological components of anticipatory heart rate and delta cortisol concentrations were assessed with two-way mixed ANOVA (**Table 8.12**), for the main effects of ‘intervention’, ‘ascent’ for anticipatory heart rate and cortisol, as well as the interaction effect ‘intervention*ascent’. There was no statistically significant interaction for ‘intervention*ascent’ for anticipatory heart rate (p = 0.224; η_p^2 = 0.114), for the main effect ‘intervention’ (p = 0.506; η_p^2 = 0.058), or the main effect ‘ascent’ (p = 0.606; η_p^2 = 0.022). Similarly, there was no statistically significant interaction for ‘intervention*ascent’ for cortisol pre-post climb (p = 0.669; η_p^2 = 0.045), for the main effect ‘intervention’ (p = 0.370; η_p^2 = 0.076), or the main effect ‘ascent’ (p = 0.232; η_p^2 = 0.057).

Table 8.12: *The psychological components of anticipatory heart rate (% increase from rest) and delta cortisol concentrations for the initial on-sight, red-point and final novel on-sight ascents for the control, practice and clip-drop groups (mean ± SD).*

		Initial On-sight	Red-Point	Novel On-sight
Anticipatory Heart Rate (%)	*Control*	39.8 ± 17.4	63.3 ± 21.6	55.4 ± 17.1
	Practice	46.3 ± 16.0	38.0 ± 26.5	37.4 ± 36.1
	Clip-Drop	45.4 ± 26.1	43.2 ± 18.0	36.5 ± 26.5
	TOTAL	**44.0 ± 19.8**	**47.6 ± 24.0**	**42.6 ± 28.3**
Cortisol Pre-Post (nmol/L)	*Control*	0.81 ± 0.81	1.41 ± 3.61	0.85 ± 1.18
	Practice	1.13 ± 3.09	-0.18 ± 3.07	-0.52 ± 1.62
	Clip-Drop	1.29 ± 3.03	-0.39 ± 1.92	-0.99 ± 5.11
	TOTAL	**1.07 ± 2.41**	**0.32 ± 2.99**	**-0.18 ± 3.10**

Notes: nmol/L nanomoles per litre;

8.4 Discussion

The aim of *Study Four* was to investigate the effectiveness of clip-drop and practice interventions on pre-climb psychological state and climbing performance. To achieve this, 30 intermediate participants were matched and randomly assigned to either a practice intervention, comprised of structured practice of the assessment route; a clip-drop intervention, with a progressive fall exercise; or a control group, with repeated ascents of a novel route. Participants performances were assessed on three routes, firstly an initial on-sight lead climb; secondly, a red-point ascent of the first route following the intervention; thirdly, a novel on-sight, to determine the effectiveness of the intervention on a route without practice. Participants were protected with a lead rope and an experienced belayer for all ascents. The routes were within one grade of the climbers' maximum self-reported indoor on-sight ability, ensuring the climbing was difficult for all participants and falling from the route was a distinct possibility. As with *Studies One and Two,* for each of the assessed climbs the participants were informed of the task via pre-recorded instructions, presented to the climbers within 15 minutes of the start of their ascent. Prior to presentation of the instructions, the climbers were unaware of the route they were to complete. Responses to the task were measured before and after receiving the task instructions and pre, during and post climb for each of the ascents. The analysis explored relative differences in psychological, physiological and behavioural factors between the interventions and over the three ascents.

Methods for reducing associative fears of falling are frequently discussed in climbing literature. One of the primary methods described is desensitisation through progressive exposure to leading and falling (Hague & Hunter, 2011; Hörst, 2010; Hörst, 2008; Hurni, 2003; Sagar, 2001). The premise of such training is simple: through taking controlled falls over and over the climber grows to understand how to fall safely, to trust the belayer, understand the fall is not dangerous and they are unlikely to be hurt (Hurni, 2003). *Study Three* highlighted that while clip-drop techniques are well understood, they are infrequently used. Conversely, repeated practice techniques are frequently used by climbers to achieve ascents of maximum difficulty. Through rehearsal of movements, clipping positions and rests, climbers are able to maximise their chances of completing a route (Hague & Hunter, 2011). Because of the extensive practice, a red-point (repeat ascent) of the same route reduces uncertainty and should not require the same commitment of energy or time, to work out the sequence of movements needed (Draper et al., 2008; Hardy & Hutchinson, 2007). Given the results of *Studies One and Two,* in comparison to the control group, the practice intervention should result in reduced anxiety, cognitive appraisal in line with a challenge state and improved performance for the red-point ascent, but not the novel on-sight; while the clip-drop should result in reduced anxiety, cognitive appraisal in line with a challenge state and improved performance for the novel on-sight, but not to the same extent for the red-point ascent.

The main findings of *Study Four*, were notable differences in the success rate of participants in the intervention groups, compared to control. Further, the clip drop-interventions group's somatic anxiety was significantly lower for the novel on-sight, compared to the control group; while the practice intervention participants interpreted their somatic anxiety as significantly more positive in the novel on-sight. There was no statistical difference in cognitive anxiety, although the clip-drop intervention's cognitive anxiety decreased compared to the control and practice groups. Self-confidence increased and was significant and meaningfully greater for the practice and clip-drop interventions for both the red-point and novel on-sight ascents compared to the control, although there were no meaningful difference between interventions. Furthermore, when combined means for each of the ascents were considered, there were significant differences in performance between the red-point ascent and the initial on-sight ascent. These differences occurred alongside greater self-efficacy, significantly lower cognitive and somatic anxiety and greater demand-resource evaluation. It is speculated such differences were observed as the largest changes with practice occur on the first red-point ascent of a route, based on the knowledge gained from the initial ascent, with subsequent ascents only resulting in smaller differences.

Despite their ubiquity in coaching literature, there is little empirical evidence of the effectiveness of clip-drop interventions. The present study was only the second to explore the effectiveness of clip-drop and practice interventions for reducing anxiety in climbing; furthermore, it was the first to have used a control group. Boorman (2008) presented a limited investigation of the efficacy of a simple clip-drop from the 7th quickdraw, demonstrating a decrease in participants' cognitive state anxiety. However, the small sample size of seven climbers, the lack of a control group and the measurement of only cognitive state anxiety, make drawing conclusions from Boorman (2008) research challenging. The findings of the present study suggest the results of Boorman (2008) occurred because of repeated attempts and may have occurred regardless of the intervention. Similarly, only Draper et al. (2008) have made a direct comparison between an on-sight and a subsequent red-point lead of the same route. As with the findings of the present study, the combined knowledge and practice gained through a repeat ascent of a short ~10-meter route resulted in a small, but significant, reduction in ascent time and a reduction in state anxiety, with both somatic and cognitive anxiety decreasing significantly. The following sections will discuss the findings of *Study Four* in detail, considering the findings of previous research and their implications for climbers, coaches and future research.

8.4.1 Anthropometric and demographic data

Intermediate climbers were recruited for participation based on the findings of *Studies One and Three*. Both previous studies highlighted that, for climbers of an intermediate ability, lead climbing was likely to represent a considerable stressor. *Study Three* also reported that while climbers were aware of the potential of clip-drop exercises, they were unlikely to regular partake in such practice. There were no participants who reported the use of clip-drop interventions regularly in their recreational sessions. Considering previous climbing psychophysiology research, the participants were similar to the intermediate climbers of Dickson (2013) and Draper et al. (2012) in terms of height, mass, years climbing, and on-sight and red-point climbing ability. Participants were more experienced in terms of years climbing and ability than those of Draper et al. (2011d). Participant's on-sight ability ranged between French 6a+ to 6b (12 to 13 IRCRA; YDS 5.10c to 5.10d), and red-point between French 6b to 6c (13 and 15 IRCRA; YDS 5.10d to 5.11b). The difficulty of the routes was set at French 6a+ (12 IRCRA; YDS 5.10c). Participants' red-point grade was an average of half a grade greater than their on-sight, this was lower than would be expected of climbers and likely occurred due to the intermediate ability of the participants.

Recruited participants were considered healthy and normal and were not taking any medications that may have affected measurements made. There were no meaningful, or significant differences between male and female participants in terms of years climbing, the percentage of time in each discipline, time spent indoors or out and on-sight and red-point grade; there were also no significant differences between the intervention or control groups (**Table 8.2**). However, there were significant differences in the height and mass of male and female climbers. The female climbers were shorter in stature and had lower body mass than their male counterparts. As with *Studies One and Two,* gender was not considered a covariate, for the same reasons as previously stated – primarily the lack of conceptual relationships, participants were recruited based on grade and the repeated measures study design. Furthermore, once the participants had been randomly assigned to the interventions, there were no significant differences. Finally, there were no differences in total mood disturbance, or its sub-components, achievement goal disposition, or trait anxiety with gender or intervention (**Table 8.3**).

8.4.2 Demands of the climbing tasks and interventions

The initial pre-intervention ascents were completed on-sight, participants were not provided with any information of the routes they were to attempt, other than the colour of holds and which quickdraws they were to use. The red-point ascent of the first route in the second session, however, was completed with the knowledge gained from the first initial ascent. Importantly, the knowledge a climber possesses and the amount of practice a climber has had before leaving the ground can have a significant impact on performance (Cordier et al., 1994; Draper et al., 2008; Hardy & Hutchinson, 2007). Consequently, the third novel on-sight route was included to assess climbers' on-sight performance and determine the effectiveness of the interventions on a new unfamiliar route.

The two routes were set so the requirements for each, regardless of the style of ascent, were similar. To provide an indication of the physiological load, participants' heart rate was recorded continuously throughout each of the climbs (**Table 8.5**). There were no significant differences in average or maximum heart rate between interventions or between ascents. The heart rate results support that the physiological task demands are likely to have been similar for each ascent. It is possible to speculate that the lack of significant difference in heart rate occurred because of the self-paced nature of the climb as, unlike heart rate, there were significant difference in climbing time between the ascents, but not between the interventions. Climbing time decreased significantly with faster ascents in the red-point than both the initial on-sight (MD = 15.8 sec, CI_{95} = 6.2, 25.4) and the novel on-sight (MD = 17.0 sec, CI_{95} = 10.7, 23.3).

Reduced climbing time with practice of a route were also found by Draper et al. (2008) and, like the present study, were not accompanied by any significant difference in mean heart rate. Differences in climbing time between the two ascents, in the present study and those of Draper et al. (2008), may be attributed to the need for route planning during the first ascent and climbers' familiarity with the route during the second. For the same reason, the much smaller decrease in climbing time for the final novel on-sight with the repeat practice intervention occurred as the route was unknown to the participants. In contrast, Hardy and Hutchinson (2007) found when climbers were asked to lead, and then subsequently top-rope two outdoor routes, the second red-point ascent resulted in reduced heart rate, ratings of perceived exertion and physical and mental effort. However, Hardy and Hutchinson (2007) research was conducted outdoors and there were changes in both the style of ascent and route knowledge, it is difficult to attribute changes to a single factor.

The intensity of the interventions were not assessed or recorded. However, the interventions were designed to provide a similar physiological load for all participants. The participants completing the clip-drop intervention were required to climb intermittently between falls, they were provided with as much rest as necessary and climbed on a submaximal route graded at f6a (IRCRA 11; YDS 5.10b). The participants taking part in the repeat practice and control interventions, completed a set number of ascents of a route, the load of which was approximated by four expert climbers to be the same as the clip-drop intervention; as with the clip-drop, adequate rest was provided between each attempt.

While the demands of the climbing tasks were comparable, there were notable differences in the success and failure of the participants (**Table 8.4**). For the initial on-sight ascents of the route eight participants, of ten, were successful for each of the groups. For the red-point ascent, there was an increase in the success of both the practice and clip-drop interventions, despite the clip-drop group having only ascended the climb once. The same was true of the final novel on-sight, with only six of the control group completing the climb, compared to eight of the practice and nine for the clip-drop intervention. While the difference in success and failure are promising, they should be treated with caution because of the lack of significance between interventions in any of the assessed measures of performance, with the exception of the base of support.

Climbing performance, as with *Studies One and Two*, was assessed through quantitative and qualitative methods. The use of thorough assessment of climbing performance allowed for the comparison of changes over the three climbs and between the three interventions (**Table 8.6**). There was no interaction or differences between the intervention groups for either geometric entropy or coaches assessed performance, with the exception of the base of support. There were, however, differences in geometric entropy between ascents. Geometric entropy was significantly lower (smoother displacement of mass) for both the red-point (MD = 0.82, CI_{95} = 0.01, 0.15) and novel on-sight (MD = 0.72, CI_{95} = 0.01, 0.14), compared to the initial on-sight. It is unclear why, despite the novel on-sight nature of the third route, that geometric entropy remained lower. Like geometric entropy, total coaches' performance score was significantly greater in the repeated red-point ascent, however, unlike geometric entropy the greatest performance was seen in the red-point ascent, while climbers were scored lower in both on-sight ascents (initial on-sight, MD = 5.4, CI_{95} = 1.7, 9.4; novel on-sight, MD = 2.9, CI_{95} = 0.2, 5.7).

The further breakdown of the coaches' scores indicated significant differences between on-sight and red-point ascents for transitioning, coordination and technique, while the base of support score was significant from the initial on-sight for the clip-drop and practice intervention groups (**Table 8.7**). Significant differences in geometric entropy with a red-point ascent are comparable with previous results seen with repeat practice. Cordier et al. (1994) reported greater fluency of a climber's trajectory, following ten successive ascents of a route. In contrast, Hardy and Hutchinson (2007) found climbers performance to decrease with a repeat top-rope ascent of a previously led route; however, the difference was attributed to the change in style of ascent and greater performance when leading the traditional route.

The intervention groups' lack of significance in performance is likely to have occurred because of the nature of the studies design, specifically the inclusion of a control group, who also had knowledge of the initial route. Indeed, the repeat practice intervention resulted in a 0.08 (0.81 ± 0.12 to 0.73 ± 0.06) decrease in geometric entropy, while the control group decreased by 0.07 (0.82 ± 0.18 to 0.75 ± 0.11). Similar effects were observed for coaches' performance score, and its sub-components; while total coaches score increased by 8.7 points (initial on-sight 48.7 ± 6.3; red-point 57.5 ± 4.4) for the repeat practice group, it also increased by 4 points for the control group (initial on-sight 48.4 ± 5.0; red-point 52.4 ± 6.3). It is possible to speculate the greatest improvements with practice occurred with the first red-point ascent of a route, with smaller more subtle changes occurring after that. In the present study, all participants had at least one ascent of the route (the initial on-sight), before the red-point ascent including the control group. Indeed, on examination of Cordier et al. (1994) results, the greatest difference in climbers trajectory were seen on the second attempt at the route, while subsequent ascents resulted in an increased fluency, they were not as great as the first (*see Section 3.2 Route knowledge and* **Figure 3.9**).

Differences in performance may be subtler than observable with the measures used in the present study. The effectiveness of the clip-drop intervention relies on exposure to falling, which are thought to be among the most effective treatment methods for phobic fear and avoidance behaviour (Baker et al., 1973; Bourque & Ladouceur, 1980). Through habituation, the reaction to the feared situation decreases, weakening previously learned associations and facilitating positive experiences and trust in the belayer. Critically, the exposure to the feared activities or situations in a safe environment helps decrease avoidance behaviour (Richard & Lauterbach, 2011). While the experimental setup of the present study facilitates the assessment of changes in performance on the routes themselves, it was not possible to assess decisions made prior to their ascent. Consequently, it may be the interventions addressed avoidance behaviour, but as the climbers of the present study were asked to complete a specific route, there was no opportunity for the participants to display such behaviour. Equally, the length of the intervention, over two sessions, may have been too short. Coaches, such as Macleod (2010) and Ilgner (2003) do not describe clip-drop style interventions as short-term fixes, but as integral parts of every session. Further research would be necessary to establish changes in off route behaviour and the effectiveness of longer-term interventions.

Differences that occurred between ascents, particularly the initial on-sight and red-point ascents, highlight the importance of practice. Previously several authors have speculated the lack of difference in responses seen within style of ascent research may be due to the novel, on-sight, nature of the climbs (Dickson, 2013; Hardy & Hutchinson, 2007). The stress of completing climbs on-sight may be of greater importance and obscure the influence of ascent style on the psychophysiological response of the participants (Dickson, 2013). For example, Hardy and Hutchinson (2007) reported, when attempting an unknown route, climbers described similar levels of anxiety before their ascent, regardless of the safety protocol. On-sight climbs, for example those of *Study One*, may create a degree of uncertainty for the participants in all conditions, despite the differences in the style of ascent.

To summarise the physiological and performance differences observed, there were no significant differences between the intervention and control groups, although the participants of the intervention groups were more successful. There were, however, significant differences between the ascents. When considered together, there were differences in climbing time, geometric entropy, coaches' performance scores and its sub-components (aside from tactics and base of support) between the on-sight and the red-point. These findings highlight improvements in performance with practice, even with only a single ascent of a route. The results also suggest several possible methodological challenges, and potential reasons why significant or more significant differences between groups were not observed. Firstly, because of the inclusion of a control group and their knowledge of the initial route, the studies design necessitated the inclusion of a second novel ascent. Secondly, the control task completed by the control group participants may have emphasised a 'Hawthorne Effect' in these participants, accentuating bias occurring as a result of their inclusion in the study (discussed further in the following section). Finally, differences in performance may be subtler than observable with the measures used in the present study. It may be the interventions address avoidance behaviour, but as the climbers of the present study were asked to complete a specific route, there was no opportunity for the participants to display such behaviour.

8.4.3 Physiological and psychological measures of climbers' state

To determine differences in climbers' state with the three interventions, a series of physiological and psychological measures were employed. In line with previous style of ascent research, including *Studies One and Two*, participants' cardiovascular responses to the task instructions were assessed, along with self-reported state anxiety, alterations in participants heart rate prior to climbing and pre-post climb cortisol (Dickson, 2013; Draper et al., 2012; Draper et al., 2010; Fryer, 2013; Hodgson et al., 2009). Through the assessment of cardiovascular responses to task instructions, it was possible to gain an objective insight into the participant's demand and resource evaluation (Jones et al., 2009). Alterations in cortisol and heart rate allow for the assessment of both short (heart rate) and longer (cortisol) responses to the climbing task, occurring to facilitate the mobilisation of physiological resources to respond appropriately to a stressful stimulus.

Prior to each attempt of a route, participants were provided with standardised audiotaped task instructions (Moore et al., 2014; Moore et al., 2013; Turner et al., 2013). The instructions highlighted the demands of the climb and the graded difficulty of the route they were to attempt, while continuous cardiovascular measurements were made. As with *Studies One and Two* the analysis of cardiovascular reactivity data was based on the corollary of the findings of previous challenge and threat research (Blascovich et al., 2004; Moore et al., 2012; Turner et al., 2013; Turner et al., 2012); specifically, the assumption that in response to the presentation of task instructions, if participants evaluated they had insufficient coping resources then threat cardiovascular reactivity patterns would be observed, while if they believed their resources match or exceed the demands of the task then challenge cardiovascular reactivity would be observed. It was hypothesised the practice intervention would result in a reduction in the uncertainty of the demands of the task and the amount of effort required, due to the participant's familiarity with the task they were being asked to complete. Conversely, the clip-drop intervention would result in a reduction in perceptions of danger, because of the greater familiarity with falling and reduced uncertainty of the risk (Hague & Hunter, 2011).

The hypothesised differences between interventions and ascents were not supported by the cardiovascular reactivity results. The results suggest, while the tasks represented a motivated performance situation, neither the clip-drop or the repeat practice interventions resulted in significant differences in cardiac output, total peripheral resistance reactivity, challenge and threat index or salivary cortisol from the control group. There were a number of non-significant differences, however, the large standard deviations suggest considerable inter-participant variation. Cardiac output and peripheral resistance reactivity were significantly lower in the red-point ascent than the initial on-sight and cardiac output was also significantly lower in the novel on-sight than the initial on-sight. While these differences were significant, the variation and small relative differences do not suggest meaningful differences in cardiovascular reactivity with the ascents. The lack of differences in challenge and threat index and resting salivary cortisol supports this assertion. It is possible the lack of significance and variability occurred because of the repeated measures design and successive evaluations of the task (Kelsey et al., 1999). Participants previous performance may have influenced successive evaluations of the task (Moore et al., 2013).

Self-reported cognitive evaluation and perceived control, thought to be significant factors in participants demand and coping resource appraisal, also did not differ significantly between interventions (Jones et al., 2009; Skinner & Brewer, 2004). However, self-efficacy was greater in the red-point than both the initial on-sight (MD = 0.8, CI_{95} = 0.3, 1.3) and the novel on-sight (MD = 0.5, CI_{95} = 0.1, 0.9); similarly, the demand resource evaluation score was significantly greater in the red-point than the initial on-sight (MD = 1.7, CI_{95} = 0.8, 2.5). Both increased in response to the familiar red-point ascent, regardless of the group. Higher levels of self-efficacy have been associated with participants being less likely to fear failure (Kontos, 2004). Similarly, in a climbing context, Llewellyn et al. (2008) found greater self-efficacy were associated with participants taking greater calculated risks, attempting harder climbs and climbers having greater feelings of confidence in their ability. It is speculated that greater coping resources relative to the demands of the task, increased self-efficacy together with lower anxiety and greater confidence were responsible for the improvements in performance previously discussed.

Salivary cortisol was sampled pre- and 15 minutes' post-climb. As with *Studies One and Two*, there were no significant differences found with concentrations of salivary cortisol (**Table 8.12**). The lack of significance was unsurprising given the large standard deviations. Like cortisol concentrations, anticipatory pre-climb heart rate suffered from large amounts of variation, obscuring any significance. It is conceivable, because of the nature of the on-sight and red-point assessment task being typical of their normal recreational indoor climbing sessions, the lack of significance occurred because of habituation to the task and blunting the physiological response (Kirschbaum et al., 1995). As with *Studies One and Two,* salivary cortisol cannot be recommended for the comparison of populations of similar ability (Giles et al., 2017a).

In addition to the psychophysiological measures, state anxiety was assessed with the IAMS (Thomas et al., 2002). *Studies One and Two* demonstrated the IAMS ability to differentiate between climbers' responses to changes in the style of ascent (*Study One*) and the relative difficulty of routes (*Study Two*). The intensity and direction of somatic anxiety, cognitive anxiety and self-confidence were assessed immediately prior to each of the climbers' attempts of the routes. It was hypothesised, based on the previous significance, in particular of cognitive anxiety, with stressors in *Studies One and Two* that the clip-drop intervention would bring about a reduction in cognitive anxiety and an increase in confidence in the repeat ascent and novel on-sight, while the repeat practice intervention would only occur in the red-point ascent. As with measures of success and failure, there were a number of significant differences between the interventions, as well as significant differences between ascents.

A number of group differences in anxiety and confidence were found (**Table 8.11**). Significant and meaningful differences in somatic anxiety were found between the control and clip-drop groups for the novel on-sight (MD = 15.5, CI_{95} = 4.5, 26.5). While there were no significant differences in the intensity for the repeat practice group, there were significant difference between the control and practice groups more positive interpretation of their somatic anxiety (MD = 19.3, CI_{95} = 3.7, 34.9). There were no significant group differences in cognitive anxiety, although the clip-drop intervention group were considerably lower and more positive than both the control group and the repeat practice groups. Self-confidence increased and was significant and meaningfully greater for the practice and clip-drop groups for both the red-point (MD = 21.0, CI_{95} = 7.7, 34.3 and MD = 20.2, CI_{95} = 6.9, 33.5, respectively) and novel on-sight ascents (compared to the control group: practice MD = 13.8, CI_{95} = 2.5, 25.1; clip-drop MD = 15.8, CI_{95} = 4.4, 27.1), although there were no meaningful difference between the interventions.

Considering differences that occurred between ascents, there was a significant and meaningful reduction in somatic anxiety between the initial on-sight and the red-point ascent for all three groups. Furthermore, while for the second novel on-sight there was a significant increase for the control group compared to the initial on-sight (MD = 6.2, CI_{95} = 0.58, 11.8), there was a small decrease in the repeat practice intervention (MD = 5.0, CI_{95} = 1.1, 8.9) and a larger decrease for the clip-drop intervention (MD = 10.1, CI_{95} = 7.3, 12.9). The same was also true for the interpretation of somatic anxiety, with more positive interpretation for all three groups between the red-point and novel on-sight. Like the intensity, while there were only small changes in the clip-drop and repeat practice for somatic anxiety interpretation, the control group interpreted their anxiety as significantly less positive. Similarly, there were also significant differences in both the intensity (red-point, MD = 13.3, CI_{95} = 6.6, 19.9 and novel on-sight, MD = 13.6, CI_{95} = 5.4, 21.8) and direction of cognitive anxiety (initial on-sight MD = 9.3, CI_{95} = 1.5, 17.1 and the novel on-sight compared to the initial on-sight MD = 5.1, CI_{95} = 0.1, 10.0), between ascents, but not interventions.

Perceived anxiety may be responsible for differences in performance and consequently success and failure, through its influence on attention, decision making and movement behaviour (Nieuwenhuys & Oudejans, 2012). While elevated, somatic anxiety has been found to be associated with performance in climbers in a number of studies including Sanchez et al. (2010) and Hardy and Hutchinson (2007), this does not appear to be the case for climbers of the present study. For the intermediate climbers of both *Studies One and Two,* greater anxiety occurred alongside significantly lower coaches' performance scores and geometric entropy. Consequently, a reduction in anxiety for intermediate climbers would appear to be of benefit to performance. It may be that experience is responsible for the difference, as the climbers of both Sanchez et al. (2010) and Hardy and Hutchinson (2007) were more experienced than those of the present study. Experienced climbers may be able to deliberately use relatively high anxiety to their advantage and expert performers often perceive anxiety as facilitative (Jones, 1995). Further, greater self-confidence before a climb may have improved route planning decisions and the choice of technique and tactics employed. Self-confidence has been termed a moderating variable with athletes achieving fine performances when being both anxious and self-confident (Hardy et al., 2004; Woodman & Hardy, 2003). The differences in self-confidence and anxiety together are possibly responsible for improved performance and the success of the intervention groups in the present study (Draper et al., 2011d).

The results only partially support the findings of Boorman (2008), who reported reduced anxiety for participants who took part in a clip-drop intervention. In contrast to the hypothesised difference, there were no significant difference in cognitive anxiety, although the clip-drop groups' somatic anxiety was lower than the control and repeat practice groups. There were also significant and meaningful reductions in somatic anxiety in the repeat practice groups. Furthermore, while participants in the intervention groups were more successful and interpreted their self-confidence as more positive, it was not possible to differentiate between the two interventions. The lack of reduction in cognitive anxiety occurred despite evidence suggesting exposure-based approaches are some of the most effective treatment methods for phobic fear and avoidance behaviour (Baker et al., 1973; Bourque & Ladouceur, 1980; Wolitzky-Taylor et al., 2008). It is possible this was due to the length of the intervention, however, further research is necessary to establish this. As with the significant difference observed in performance, particularly coaches' score and its sub-components, the red-point ascent of a route resulted in reduced anxiety, improved confidence, greater self-efficacy and demand resource evaluation, regardless of the intervention group. Differences occurring on the red-point ascent of a route support those of earlier studies by Draper et al. (2008) and Hardy and Hutchinson (2007). Particularly the findings of Draper et al. (2008), who stated that prior route knowledge affects both the physical and emotional responses to the stress of climbing.

The lack of difference between the interventional and the control groups may have occurred because of the nature of the control group. Specifically, while both intervention groups received coached interventions, the control group also climbed during this period. The climbs completed by the control group, while intended to ensure the participants were in a similar state of fatigue for their reassessment on the route, may have acted as an intervention in itself. The routes attempted by the control group during this period were sub-maximal, unconnected to the routes attempted during the assessed periods and did not result in participants failing to complete the routes or fall. As a consequence it is conceivable, because of the routes completed emphasised a Hawthorn like effect, that biases and lack of significance occurred in the interventions (McCarney et al., 2007). It is not possible to determine if such bias occurred in the present study because of the control task the control group were asked to complete. However, all participants were cognisant of being part of a research study, even if they were not aware of the nature of the other interventions. Future interventional climbing research should consider of the impact of such bias on control group responses.

8.5 Perspectives

The results of *Studies One, Two and Three* of this thesis support coaches' assertions that lead climbing is potentially anxiety-inducing, as well as demonstrating the detrimental effect of anxiety on performance, with less fluent movement, lower coaches' performance score and changes in movement behaviour. Furthermore, *Study Three* highlighted, while climbers are aware of techniques for the reduction of anxiety, they are infrequently used. Instead, to avoid negative experiences *Study Three's* interviewees described modifying their climbing behaviour. Particularly prevalent were discussions of avoidance behaviour, for example with climbers choosing to top-rope easier routes. In order to address a fear of falling, climbing coaches frequently discuss clip-drop exposure based exercise (Hague & Hunter, 2011; Hörst, 2010; Hörst, 2008; Hurni, 2003; Sagar, 2001). While participants of *Study Three* were knowledgeable of such methods, they were infrequently used. Conversely, repeat practice is more frequently used by climbers attempting routes at the top of their ability.

The findings provide limited support for the hypotheses. Neither the clip-drop nor the repeat practice interventions resulted in significantly reduced cognitive anxiety or improved performance. There were small differences in the success rate of participants in the intervention groups, the intensity of somatic anxiety in the novel on-sight was significantly lower in the clip-drop and interpreted as more positive by the repeat practice and both interventions interpreted their level of self-confidence as significantly more positive, compared to the control. However, with the exception of somatic anxiety it was not possible to differentiate between the two interventions. Conversely, when combined means for each of the ascents were considered, there were notable significant differences in performance observed in the red-point ascent compared to the initial on-sight and in many cases the novel on-sight. These differences occurred alongside greater self-efficacy, self-confidence, lower cognitive and somatic anxiety and greater demand-resource evaluation. It is speculated such differences were observed because of the largest changes with practice occurring on the first red-point ascent of a route, based on the knowledge gained from the initial ascent, with subsequent ascents only resulting in smaller differences.

Several salient factors and considerations for future research were highlighted in completing this study. The present study has investigated acute change occurring in response to a short-term intervention, however, Macleod (2010) suggests that interventions, such as the clip-drop used in the present study, are not short-term fixes. For such interventions to be truly effective for the management of fear associated with falling, they should be integrated into every session, becoming as integral to the climbers' routine as the warm-up (Ilgner, 2003; Macleod, 2010). If the sample of climbers interviewed in *Study Three* are representative of intermediate climbers as a whole, such an approach is rarely used. A further consideration is of the individual climbers' response; in the present study participants were randomly assigned to a control group, precluding the investigation of differences in individual responses. Perhaps more importantly, the design prohibited the creation of bespoke individual interventions, focusing on factors salient to the individual. An example of the individual-focused approach is the mental training advanced by Ilgner (2003) in his book, *'The Rock Warriors Way'*. Future research consider the long-term application of techniques for the reduction of fear and anxiety and the importance of individual factors and the barriers to climbers integrating practice into every session.

9

General Conclusions

Climbing is a complex multi-faceted sport, enjoyed recreationally and competitively both indoors and out. Climbing performance is comprised of a combination of physical, psychological, technical and tactical elements; however, unlike many sports, it is believed to require a near equal contribution of each (Hörst, 2010). While the psychological element has been acknowledged and described, until the last ten years it had not received detailed research attention. More recently, a growing body of research has developed exploring the psychological challenges of the sport (Draper et al., 2010; Hardy & Hutchinson, 2007; Hodgson et al., 2009). Of significance has been the application of psychophysiological methodologies, providing a means of objectively quantifying the responses of climbers to a range of potential stressors (Dickson et al., 2012a; Draper et al., 2012; Fryer et al., 2013).

The advances made in recent years, particularly by Draper, Dickson, Fryer and colleagues, refining methodologies and applying psychophysiological techniques in the climbing environment, have been considerable (Dickson, 2013; Dickson et al., 2012a; Draper et al., 2012; Fryer, 2013; Fryer et al., 2013). Despite this, the results have largely been inconclusive (*see Chapter 3*). The lack of elucidation has occurred despite the assertion of climbers and coaches of the detrimental effects of the stressors present (Hague & Hunter, 2011; Hörst, 2010; Hörst, 2008; Hurni, 2003; Sagar, 2001). Developing on previous findings, and considering the significant understanding gained from climbing research to date, this thesis continued to explore the stressors present in the climbing environment. *Studies One and Two* of this thesis explored the subjective psychological, objective psychophysiological and behavioural responses to changes in the style of ascent (*Study One*) and route difficulty (*Study Two*). While of importance, the findings of *Studies One and Two* were unable to explain what underpins participants' responses. To answer this question, *Study Three* qualitatively investigated participants' experiences within indoor sport climbing; in order to further understand salient stressors, their effect on performance and how climbers manage them. Finally, addressing the limited research examining techniques for reducing anxiety, *Study Four* explored the effectiveness of repeat practice and clip-drop techniques, as suggested anecdotally by climbing coaches, for improving performance and reducing anxiety, along with exploring their effect on psychophysiological measures. The results of each of these will briefly be discussed.

The purpose of *Study One* was to investigate the responses of climbers to routes with differences in the means of protecting them from falling (style of ascent). To achieve this, 32 intermediate climbers were asked to on-sight three routes, which differed only in the safety protocol: protected by a top-rope, lead rope or lead with a run-out. The results of *Study One* suggested lead climbing was a significant stressor for intermediate climbers. When compared to the top-rope ascent, lead climbing performance quality was reduced, with less fluent, hesitant movement and increased cognitive anxiety, somatic anxiety and reduced self-confidence. However, cardiovascular reactivity to the task instructions was in line with challenge reactivity for all ascents, despite and in contrast to the emotional and performance differences seen. Like previous climbing psychophysiology research, there were no meaningful or significant differences in salivary cortisol or pre-climb heart rate from baseline. These findings indicated on-sight lead climb was a significant stressor, with significant performance implications; this was despite leading being a typical part of the recreational climber's practice.

Continuing from *Study One*, *Study Two* explored the importance of climber ability and route difficulty on a single on-sight lead of a route. Specifically, 61 climbers of a range of abilities (intermediate to advanced) were asked to complete an on-sight lead ascent of a single route; this resulted in three groups of climbers attempting a route above (CLL^{above}), at (CLL) or below (CLL^{below}) their maximum on-sight ability. There were significant and meaningful increases in the quality and fluidity of climbing performance with an increase in ability relative to the difficulty of the route. Ideally, when climbers attempt a route beyond their on-sight ability they would be limited only by their physiological capabilities, this was not the case. The CLL^{above} group experienced greater intensity of somatic anxiety and cognitive anxiety and lower self-confidence compared to both CLL and CLL^{below} participants; along with significantly elevated anticipatory heart rate but no significant or meaningful differences in salivary cortisol. Finally, cardiovascular reactivity indicative of a threat evaluation in CLL^{above} and challenge evaluation in CLL and CLL^{below} were found, although variation obscured significance. Unfortunately, it was not possible to differentiate between differences in performance occurring because of the technical difficulty of the route or the cognitive evaluation of the participants. The findings demonstrate the impact of task difficulty on a climbers' ability to manage and respond effectively to evocative stimuli. However, as with *Study One*, it was not possible to identify what processes and decisions underlie participants' anxious responses to leading a route beyond their on-sight ability.

To elucidate the underlying factors involved in the perception and response to stressors, *Study Three* qualitatively explored the individual discourse of climbers. Specifically, semi-structured interviews were conducted with 61 intermediate and advanced climbers, exploring the challenges of indoor lead climbing and how climbers manage salient stressors. The main findings of *Study Three* were the identification of a multitude of stressors present within the climbing environment, which were broadly split into those brought about by the decisions of the climber and factors considered to mediate those decisions. The defining characteristics of lead climbing discussed were the potential for taking falls and the anticipation of falling. The negative emotional response towards falling predominantly occurred because of a threat of physical harm, while threats to the climber's esteem were less salient. The belayer was identified as a critical element in the climber's performance, along with the background of the climber and their day-to-day state, in determining participants' responses and decisions.

The interviews highlighted that climbers take part in the sport of their own volition, making choices that may increase or decrease the physical, psychological and technical challenges present. In turn, the choices made by the climber potentiate or limit opportunities for the climber to perform optimally. Significantly, descriptions of avoidance behaviour were prevalent in interviewees' responses when discussing their ability to manage stressors. While many of the decisions made by the interviewees were considered discreet, such as the choice of route difficulty, taking controlled falls on routes and changes in the clipping position, others were more overt, such as choices of the style of ascent or being taken tight on the rope before failure. Common to all the decisions described by the interviewees were that they allow them to engage with the sport on their own terms and exert a level of control over the stressors present in their climbing sessions. However, the decisions made to increase control often appeared to be at the expense of performance.

Summarising the interviews findings, a preliminary model was presented to describe the relationships between choices made by recreational climbers, mediating factors and their consequences for limiting potential and performance (**Figure 7.1**). Central to the model, and in contrast to the two levels of cognitive appraisal of Lazarus (2006), it proposed that a climber may choose the demands of the task based on their perception of their coping resources. It is this perception of their resources that will determine if the climber performs to their potential. Finally, a large number of interviewees were aware of methods, in particular clip-drop techniques, to reduce fear-of-falling anxiety. Despite this, there were few interviewees who reported their regular use. Equally, more advanced level climbers did not report the use of clip-drop techniques anymore regularly than their lower ability counterparts, although, they did describe a '*one more move'* attitude, continuing to the point of failure regardless of the fall.

Addressing the limited research exploring methods for reducing anxiety when leading, identified in *Study Three*, *Study Four* investigated the effectiveness of clip-drop and route practice in a randomised controlled study. Thirty intermediate climbers were randomly assigned to a practice or clip-drop intervention or a control group. Both clip-drop and repeat practice participants were more successful, compared to the control group. Alongside differences in the success rate, the intervention groups were less anxious and more confident for both the red-point and novel on-sight ascents compared to the control, although there were no meaningful difference between interventions. The findings provide limited support for the effectiveness of clip-drop and repeat practice interventions for reducing anxiety and improving performance. However, when means values for each ascent across all three groups were considered, there were significant improvements in performance with the red-point ascent of a route. Performance differences are likely to have resulted because of reduced anxiety, improved confidence and coping resources out-weighing the demands of the task of the repeat ascent. Consequently, the findings also highlight the importance of route knowledge. It was speculated such effects were observed because of the largest differences occurring in the first repeat ascent of a route, with subsequent ascents only resulting in smaller differences.

9.1 Findings summary

The stressors present in the recreational climbing environment are the consequence of a number of factors, but significantly are defined by the decisions intermediate climbers make during their sessions. In making these decisions climbers choose a level of challenge, including the style of ascent as investigated in *Study One*, route difficulty as explored in *Study Two* and route knowledge as found in *Study Four*. These factors are salient and have significant implications for climbers' emotional experience and climbing performance. Furthermore, the qualitative investigation with intermediate climbers (*Study Three*) highlighted that the manipulation of these stressors principally relates to reducing a fear of falling, specifically a risk of physical harm. Each climber's unique response to these stressors are likely to impact climbers by differing amounts, based on a number of factors including their background, mood during a given session, the belayer and relationships with their climbing partners. Finally, climbers' responses are likely to be determined by a combination of their anxiety, confidence and demand-resource evaluation, based on the findings of the experimental studies of this thesis (*Studies One, Two and Four*).

The interviewees of *Study Three* explained how their decisions, regarding the challenges they choose to engage with, have implications for both the routes they ascend and their performance. Climber's indicated that their decisions are influenced by a number of key factors including their background, experience and past attempts at routes, as well as factors that vary session to session, such as external stress, fatigue, injury and fitness. These decisions may be either be unconscious or conscious. Climber's also indicated that the interaction and relationship with their belayer and others present are also likely to be important. Furthermore, performance may be affected at two time points: firstly, pre climb, through the decisions taken prior to leaving the ground, such as route knowledge, difficulty, style of ascent and the types of routes; secondly, en-route, through alterations in attention, avoidance behaviour and muscular tension may affect performance while climbing a route.

The potential effects of stress and anxiety on performance are considerable. Stressors can have a significantly debilitative effect on almost all aspects of climbers' performance. *Study One* found decreases in performance quality were characterised by reduced accuracy of hand and foot placement, less fluid body movement, decreased coordination, less efficient movement selection and impaired decision making. In *Study Two* performance in the CLL^{above} group was affected in the same way as described for *Study One*; however, it was not possible to determine the exact cause of the deterioration in performance seen, with differences occurring because of either the physical demands of the task and/or cognitive evaluation and anxiety. Techniques for reducing fear and anxiety when leading are frequently discussed in coaching literature. While intermediate climbers are aware of techniques for exposing and habituating themselves to falling, they were described by the interviewees of *Study Three* as infrequently being used. Despite evidence of differences in performance occurring, the route practice and clip-drop interventions of *Study Four* were unable to produce meaningful improvements in coaches assessed performance. However, there were improvements in both the intervention group participant's success, somatic anxiety and interpretation of self-confidence in comparison to the control group; although, it was not possible to differentiate between the two interventions. It was speculated that the interventions may have implications for the challenges climbers choose to engage with within their sessions (e.g. style of ascent [*Study One*] or route difficulty [*Study Two*]), however, the design of *Study Four* did not allow for climbers to display such behaviour.

Developing on existing climbing psychophysiology research, cardiovascular and self-report measures quantifying participants' cognitive evaluation of task demands and their coping resource were employed in *Studies One, Two and Four*. Based on previous challenge and threat research, it was hypothesised that if participants evaluated they had insufficient coping resources then threat cardiovascular reactivity patterns would be observed, while if they believed their resources matched or exceeded the demands then challenge cardiovascular reactivity would result. This was true of *Study Two,* where differences in the relative difficulty of a route brought about demand-resource evaluations and cardiovascular reactivity in line with the predictions of biopsychosocial (BPS) model of challenge and threat, and theory of challenge and threat states in athletes (TCTSA). Demand appraisals in *Study Two* likely occurred in response to uncertainty regarding the route to be completed and perceptions of danger due to the anticipation of a potential of lead fall. Conversely, in *Study One*, despite significant and meaningful differences in climbing performance and emotional response, there were only small differences in cardiovascular reactivity with changes in the style of ascent. It is possible this occurred due to habituation to the tasks, as leading is a typical part of the intermediate climbers' recreational session; the top-rope condition being the more unusual and possibly more ego-threatening of the conditions. Future challenge and threat research wishing to explore demand evaluations occurring because of perceptions of danger may wish to explore the use of changes in the relative difficulty of a climb. There would also be benefit to further research to understand the antecedents of demand appraisals in climbing, particularly variation in responses occurring because of stressors present in the climbing environment.

The studies of this thesis make a number of new findings, building on previous research. The detailed assessment of performance provides insight into the effects of stressors on climbing performance; largely these have not been considered, particularly in indoor lead climbing. Firstly, the performance measures provide insight for researchers, but also provide coaches with an overview of the mechanisms of how anxiety can disrupt performance. Secondly, salivary cortisol appears to be ineffective at quantifying psychophysiological responses in experienced climbers in response to climbing tasks. While it appears to be useful when comparing groups with large differences in experience, such as the non-climbers and climbers of the pilot study, it unable to differentiate experienced climbers responses (Giles et al., 2017a). Consideration should be given to the importance of avoidance behaviour in future research designs (*Study Three*). Finally, based on the findings of *Study Four,* future interventions designed to reduce anxiety and improve performance should be idiosyncratically developed and longer lasting.

When considering these findings, the following delimitations should be acknowledged: the data are representative and specific to the individual route profiles, the length of route and spacing of quickdraws used within the thesis; the findings of the current study are specific to the relative difficulty of the route to the best on-sight grade of the intermediate and advanced climbers who participated; and finally, the results are the only representative of on-sight lead climbing indoors.

9.2 Implications and future research directions

Together, the studies that make up this thesis represent one of the most complete assessments of the psychophysiological challenges intermediate-advanced level indoor climbers face. Developing on the significant and pioneering body of climbing research that has gone before, the qualitative examination of this issue highlighted the significance of climbers' decisions about the stressors faced and the way in which they are managed. Finally, the thesis provided a first look at techniques purported to reduce anxiety and improve performance. The findings of this thesis are of importance to both climbers and coaches and have methodological and theoretical implications. These will briefly be discussed here along with future research directions which have emerged while completing this thesis.

9.2.1 Climbers and coaches

The findings of this thesis are most relevant to intermediate climbers, or those working with climbers of this ability level. Particularly pertinent is the understanding gained regarding the individual nature of responses to the potential stressors present in the indoor recreational climbing environment. From the interviews of *Study Three*, it was apparent that many factors interact to dictate how the climber will respond in a given session. The factors described were both long term, such as the climber's background in the sport, previous experiences, fitness and injury; and short-term, such as the climbers state on arrival to a session, previous experiences on routes, the belayer and climbing partner. Together these factors influence the choices made by the climber and their resultant behaviour, ultimately dictating how the climber performs, their enjoyment and how they progress in the sport.

It is important to consider the choices available to climbers. Previous psychophysiology research, and the findings of the studies in this thesis, highlight that climbing-specific stressors can have an impact on both the emotional experience and performance of participants (Dickson et al., 2012a; Draper et al., 2012; Fryer et al., 2013). Respondents in *Study Three* discussed opportunities for choice within climbers' sessions, to both engage with, moderate and avoid stressors. For example, climbers may choose to lead a route, on-sight, at their limit, pushing themselves to finish the ascent or fall trying. Alternatively, the climber may moderate the challenge by reducing the difficulty, top-roping the route first, choosing a route with certain angles or types of holds or asking for information on the holds and sequences. Furthermore, the climber may make choices while on the route itself, stopping before they fall, moving onto a different route or take a controlled fall. The choices made by the climber are likely to be both conscious and unconscious and based on factors pertinent to the individual. Avoidance behaviour is potentially climbers' primary method of managing the stressors and, in conjunction with any changes occurring in attention and movement behaviour, a significantly limiting factor for performance. This behaviour may not be immediately obvious to the climber or their coach; indeed, the climber may be unaware they are even doing it.

Despite the differences in performance observed in *Studies One and Two* and the acknowledgement of falling being a significant factor in the interviewees of *Study Three*, there was limited discussion of the use of methods for the reduction of fear and anxiety. Given its implications for performance, continued participation and enjoyment, a fear of falling should be addressed. Consequently, *Study Four* explored the efficacy of repeat practice and clip-drop interventions. While *Study Four* demonstrated an increase in the success rate, reduced anxiety and improved interpretation of self-confidence with the clip-drop and repeat practice interventions, further research is still necessary, particularly addressing the potential for avoidance behaviour. Given the results of *Study Four*, methods likely need to be idiosyncratically developed, progressive and long lasting. An example of a progressive intervention may be found in *Appendix G*. The example intervention first ensures participants are familiar with the basic skills of leading; it then works through a progressive fall exercise, similar to the exercise described by Hague and Hunter (2011); it progresses to unstructured fall practice and then finally falling while climbing at the lead limit. The key to this process is likely to be its length, self-paced nature, the relationship with the belayer. The goal should be falling becoming as integral to the climber's session (Ilgner, 2003; Macleod, 2010). There would be benefit for future research exploring whether a long-term idiosyncratically developed clip-drop exercise would be effective for reducing anxiety and improving performance.

The results of this thesis specifically concern the responses of intermediate climbers. It is hypothesised that more advanced and elite climbers would better be able to differentiate between the perceived and actual risks of climbing indoors. While the work of Dickson (2013) did not find psychophysiological differences between ability groups, climbing performance was not assessed. There would be benefit to researchers, coaches and climbers alike to determine if differences anecdotally reported with experience occur because of successful habituation to the tasks of climbing or because of a natural predisposition. More advanced climbers may be naturally predisposed to a more rational appraisal of the perceived and actual risks and their coping resources relative to the task demands. This may be the case, as the more experienced participants of *Study Three* did not report the use of fall practice or similar techniques any more frequently than those of lower ability climbers, despite differences in their responses concerning falling. Considering the results of the present study, there would be benefit for future research examining differences in climbers' response to stressors between ability groups, considering the methodological advances made in the present study.

9.2.2 Methodological and theoretical considerations

This thesis has built on the substantive and important body of work already completed exploring the physiological and psychological challenges of indoor lead climbing (Dickson et al., 2012a; Draper et al., 2012; Fryer et al., 2013). In doing so it acknowledges the contribution of previous authors, while also making a number of advances. These including the assessment of climbers' behaviour on routes, the consideration of differences in climbers' performance between style of ascent and the qualitative evaluation of climbers' perceptions of the challenges of the sport. The research has also highlighted several implications and considerations for future research. Many are the same as discussed previously, namely individual differences, overt and discreet behavioural changes and avoidance behaviour.

The prevalence of descriptions of avoidance behaviour within the responses of the participants of *Study Three* has implications for future research designs. Both *Studies One, Two and Four* presented climbers with a description of the climb they were to attempt. Assessments were based on their cardiovascular responses to the task instructions, subjective assessment of demands and resources and then, in response to the climb itself, climbing performance and psychophysiological measures. While withdrawal was always an option, the climbers were only presented with a single task, which they attempted. From the responses of interviewees of *Study Three*, this is not typical of a recreational climbing session. Climbers *choose* the challenges of their session, based on a number of factors as previously described. While notable differences in the success rate of participants in the intervention groups of *Study Four* were observed, there were no significant differences in quantitative or qualitative determinants of performance. The experimental setup of *Study Four* facilitated the assessment of changes in performance on the routes themselves, however, it was not possible to assess decisions made prior to their ascents. Consequently, it may be the interventions addressed avoidance behaviour, but as the climbers of *Study Four* were asked to complete a specific route, there was no opportunity for the participants to display such behaviour. There would be significant benefit for (a) the development of measures to determine behavioural changes in decisions made prior to attempting routes; and (b) future research designs to take into consideration choices made prior to attempting route, to determine the significance of avoidance behaviour.

Further consideration should be made of individual differences in climbers' responses to the stressors present in the climbing environment. It is clear from the climbing psychophysiology research that has gone before this thesis that there is considerable variation within the results, even given the methodological advances made. The same was true of the results of this thesis. As an example, the repeated measures design of *Study One* attempted to take individual differences into consideration, while also controlling for climbers' route knowledge. Despite these advances there was still considerable variation. Considering the findings of *Study Three* there are a large number of factors, both short and long-term, which vary between individuals.

These including day to day variation in performance, choices about the types of routes attempted and the belayer, which are likely to have a substantive effect on performance. Further research is necessary to truly understand these factors, their implications for the decisions climbers make and their performance consequences. Specifically, (a) what influence do individual factors such as preferred discipline, previous climbing experience and introduction to the sport have on decisions climbers make; (b) how important are individual factors in variation in climber's performance; and, (c) the role and importance of the climber-belayer relationship?

The inclusion of cardiovascular and self-report measures of cognitive evaluations, as suggested by the BPS and TCTSA, provided evidence for demand evaluations occurring because of the nature of lead climbing indoors. Furthermore, while research testing the predictions of the theories of challenge and threat have explored situations believed to elicit differences in perceptions of uncertainty and effort, no evidence has been presented for situations eliciting differences in perceptions of danger. Both changes in the style of ascent (*Study One*) and the relative difficulty of a route (*Study Two*) were both hypothesised to bring about danger demand appraisals. However, as previously discussed, *Studies One and Two* produced conflicting results. Given the climber's discourse concerning the nature of the challenges of climbing, presented in *Study Three*, it is like demand appraisals occur for a number of reasons, including perceptions of uncertainty, effort and danger. The results of this thesis suggest on-sight lead climbing beyond the ability of participants, as investigated in *Study Two*, is a suitable means of instigating demand appraisals because of the perceived danger and the anticipation of a fall. Further research is necessary to determine if situations atypical of participants' recreational sessions, such as a supramaximal lead of a route, are more anxiety-inducing because of the increased chance of falling and resultant perceptions of danger.

9.3 Summary

The key findings from this PhD study are centred on the investigation of anxiety in climbers. Building on previous research in the field, including the use of novel to climbing markers, the studies included in this thesis highlight the difficulty that arises in attempting to quantitatively examine anxiety through the use of physiological and psychological markers. While there might not be (a) anxiety in climbers or (b) quantifiable differences between climbers of different abilities, it may be that what is possibly 'noise' in data arises due to weaknesses in the markers themselves. The findings of *Study Three* provide tangible insight as to the perceived reality of anxiety for climbers. An insight that appears to be unachievable through the use of existing quantitative markers. Furthermore, *Study Three* revealed the length climbers interviewed would go to, to avoid anxiety provoking situations. It was also clear from *Study Three* that climbers’ responses to anxiety were individualised, consequently, generalised interventions like clip-drop sessions may have a limited effect on reducing anxiety to a level which supports enhanced performance improvement. These are important findings for coaches and climbers alike. It may be that an individualised approach to anxiety reduction and avoidance behaviours has a more significant impact on performance improvement than any of the latest training programmes, equipment or nutritional strategies. This may have an impact of climbers of all levels, and given the inclusion of climbing in the 2020 Tokyo Olympic Schedule, the findings of this thesis may provide valuable information for coaches preparing athletes for this and similar events.

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Appendix A Confirmation of ethical approval

College of Life and Natural Sciences
Life Sciences Research Ethics Committee (LSREC)

UNIVERSITY *of* DERBY

ETHICAL APPROVAL GRANTED

Dr Callum Osler
N606, Kedleston Road
University of Derby
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Tel: 01332 59 1725
Email: c.osler@derby.ac.uk

Date: 9th February 2016
Ref number: LSREC_1516_06

Dear Dave Giles

Thank you for resubmitting your request for ethical approval to the Life Sciences Research Ethics Committee. The amendments and clarifications have been reviewed by the Committee Chair and we are pleased to grant ethical approval for the study.

If any changes to the study described in the application or supporting documentation are necessary, then you must notify the Committee and may be required to submit your request for ethical approval again.

As the study will be undertaken, at least in part, at Awesome Walls climbing centre, this approval is granted with the proviso that permission is gained from this organisation before recruiting participants and proceeding with the research.

I wish you all the best with the study.

Yours sincerely

Dr Callum Osler
On behalf of the Life Sciences Research Ethics Committee

E2b Revised Oct 2014

College of Life and Natural Sciences
Life Sciences Research Ethics Committee (LSREC)

UNIVERSITY of DERBY

ETHICAL APPROVAL GRANTED

Dr Callum Osler
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University of Derby
DE22 1GB
Tel: 01332 59 1725
Email: c.osler@derby.ac.uk

Date: 21 July 2016
Ref number: LSREC_1516_07

Dear David Giles

Re: A psychophysiological and behavioral comparison of on-sight lead climbing and the mediating role of participant ability.

Thank you for submitting your request for ethical approval to the Life Sciences Research Ethics Committee. The application has been reviewed and we are pleased to grant ethical approval for the study.

If any changes to the study described in the application or supporting documentation are necessary, then you must notify the Committee and may be required to submit your request for ethical approval again.

As the study will be undertaken, at least in part, at Awesome Walls climbing centre, this approval is granted with the proviso that permission is gained from this organisation before recruiting participants and proceeding with the research.

I wish you all the best with the study.

Yours sincerely

Dr Callum Osler
On behalf of the Life Sciences Research Ethics Committee

E2b Revised Oct 2014

Appendix B IRCRA grade scale

Climbing Group		Vermin	Font	IRCRA Reporting Scale	YDS	French/sport	British Tech	Ewbank	BRZ	UIAA	Metric UIAA	Watts
				1	5.1	1		4	I sup	I	1.00	
				2	5.2	2	2	6	II	II	2.00	
				3	5.3	2+		8	II sup	III	3.00	
				4	5.4	3-	3		III	III+	3.50	
Lower Grade (Level 1) Male & Female				**5**	5.5	3		10	IV	IV	4.00	
				6	5.6	3+	4	12		IV+	4.33	0.00
				7	5.7	4		14	V	V-	4.66	0.25
				8	5.8	4+				V	5.00	0.50
		VB	< 2	**9**	5.9	5	5a	16	V sup	V+ / VI-	5.33 / 5.66	0.75
				10	5.10a	5+		18		VI	6.00	1.00
	Intermediate (Level 2) Female	V0-	3	**11**	5.10b	6a	5b	19	VI	VI+	6.33	1.25
		V0	4	**12**	5.10c	6a+				VII-	6.66	1.50
Intermediate (Level 2) Male		V0+	4+	**13**	5.10d	6b	5c	20	VI sup	VII	7.00	1.75
		V1	5	**14**	5.11a	6b+		21	7a			2.00
			5+	**15**	5.11b	6c	6a	22		VII+	7.33	2.25
		V2	6A	**16**	5.11c	6c+			7b	VIII-	7.66	2.50
	Advanced (Level 3) Female	V3	6A+ / 6B	**17**	5.11d	7a		23	7c	VIII	8.00	2.75
		V4	6B+	**18**	5.12a	7a+	6b	24	8a	VIII+	8.33	3.00
		V5	6C / 6C+	**19**	5.12b	7b		25	8b	IX-	8.66	3.25
Advanced (Level 3) Male		V6	7A	**20**	5.12c	7b+		26	8c			3.50
		V7	7A+	**21**	5.12d	7c	6c	27	9a	IX	9.00	3.75
		V8	7B	**22**	5.13a	7c+		28	9b	IX+	9.33	4.00
	Elite (Level 4) Female	V9	7B+	**23**	5.13b	8a		29	9c	X-	9.66	4.25
			7C	**24**	5.13c	8a+		30	10a			4.50
Elite (Level 4) Male		V10	7C+	**25**	5.13d	8b	7a	31	10b	X	10.00	4.75
		V11	8A	**26**	5.14a	8b+		32	10c	X+	10.33	5.00
		V12	8A+	**27**	5.14b	8c		33	11a	XI-	10.66	5.25
		V13	8B	**28**	5.14c	8c+		34	11b	XI	11.00	5.50
	Higher Elite (Level 5) Female	V14	8B+	**29**	5.14d	9a	7b	35	11c	XI+	11.33	5.75
Higher Elite (Level 5) Male				**30**	5.15a	9a+		36	12a			6.00
		V15	8C	**31**	5.15b	9b		37	12b	XII-	11.66	6.25
		V16	8C+	**32**	5.15c	9b+		38	12c	XII	12.00	6.50

Appendix C Geometric entropy matlab code

```
clc
clear
format short

Line=0;CHull=0;counter=0;

% Defining name of data-file
data_folder = ([pwd,'\Data']);
data = dir(data_folder); % finds all data in folder
for counter = 3:size(data,1)
FILE = load([data_folder,'\',data(counter,1).name]);

% Changing data to X and Y values
X=FILE(:,2);
Y=FILE(:,3);

% Calculating length of data-line
L=length(X);
for i=1:1:(L-1)
    TempLine=sqrt((X(i+1)-X(i))^2+(Y(i+1)-Y(i))^2);
    Line=Line+TempLine;
end

% Calculating CONVEX HULL
CH=convhull(X,Y);
LCH=length(X(CH));
for i=1:1:(LCH-1)
    TempCH=sqrt((X(CH(i+1))-X(CH(i)))^2+(Y(CH(i+1))-Y(CH(i)))^2);
    CHull=CHull+TempCH;
end

% Calculating ENTROPY by means of natural logarithm function
ENTROPY_V=log(2*Line/CHull);

% Plotting results
clf
plot(X(CH),Y(CH),'r-',X(CH),Y(CH),'ko',X,Y,'b-')
Entr=num2str(ENTROPY_V);
%TitleString=['The geometric ENTROPY of file "',data(counter,1).name,'" = ',Entr];
%title(TitleString)
Lin=num2str(Line);CHu=num2str(CHull);
LabelString=['length of Line = ',Lin,'   &   length of Convex Hull = ',CHu];
xlabel(LabelString)
%ylabel(FilterString)
axis('normal')
    save('testresult.txt','ENTROPY_V','-ASCII')
menu('','Next');
end
```

Appendix D Climbing performance scale

	1	2	3	4	5
Base of Support					
Accuracy and precision hands	Messy and uncontrolled, never placed correctly first time / imprecise and noisy / constant adjustments		Placed precisely and appropriately first time, every time, quietly		
Accuracy and precision feet	Messy and uncontrolled, never placed correctly first time / imprecise and noisy / constant adjustments		Placed precisely and appropriately first time, every time, quietly		
TRANSITIONING					
Dynamic Balance	Always out of balance in movements / loss of control		Perfectly balanced throughout all movements		
Fluidity and linking	Thrutchy / jerky movement		Smooth and effortless – rising leaf		
Exploratory Movements	Frequent and extended exploration of possible holds		Deliberate and purposeful movement absence of exploratory moves		
Sequencing	Never in correct sequence / frequent unnecessary swaps / no plan		Movements always perfectly sequenced		
CO-ORDINATION					
Movement Initiation	Movement initiated with arms		Where possible movements initiated from lower body or momentum maintained		
Extension (Body tension)	Movement lacks tension and appears loose, no demonstration of full extension.		Movement demonstrates body tension and full extension when appropriate		
TECHNIQUE					
Personal Selection/ Repertoire of Movement	Limited repertoire of skill and technique. Movement selection appears inefficient for the individual and route		Demonstrates a broad repertoire of skill and techniques applied appropriately		
Arms	Arms are bent at inappropriate times		Straight arms when appropriate		
TACTICS					
Tempo	Inappropriate pace / does not change pace to reflect harder and easier sections		Varied pace appropriate to movements / climbs through harder sections / maximises opportunities for rest on easier ground		
Commitment and confidence (Hesitation)	Frequent hesitation / afraid to move above clip / does not fall – asking to be taken		Fully committed to every more / will continue climbing until point of failure		
Rests	Inefficient / poorly chosen / or not taken advantage of opportunities for rest		Maximises available rests / efficient and stable positions		
Clipping	Very poor clipping positions / inefficient / inappropriate / dangerous		Efficient / perfectly selected / effortless / part of movements		

Appendix E Audio transcripts

Study One climbing instructions: Top-rope

The task that you are about to complete is designed to assess your top-rope climbing performance. You are required to top-rope the route. The climb is designed to be close to your on-sight lead grade. You will be protected by an experienced, competent and capable belayer using a Petzl Gri-Gri. You will climb at your own pace until you either reach the top, or fall. Once you reach the top, or fall, you will be lowered back to the ground and your attempt at the route will be over. You can, of course, withdraw from the test at any-time, but for the moment please remain seated and as still as possible for about three minutes while you think about the task and prepare yourself mentally to take part.

Study One climbing instructions: Lead

The task that you are about to complete is designed to assess your lead climbing performance. You are required to lead climb the route, clipping every quickdraw. The climb is designed to be close to your on-sight lead grade. You will be protected by an experienced, competent and capable belayer using a Petzl Gri-Gri. You will climb at your own pace until you either reach the top, or fall. Once you reach the top, or fall, you will be lowered back to the ground and your attempt at the route will be over. You can, of course, withdraw from the test at any-time, but for the moment please remain seated and as still as possible for about three minutes while you think about the task and prepare yourself mentally to take part.

Study One climbing instructions: Run-out

The task that you are about to complete is designed to assess your lead climbing performance on a route with a run-out. You are required to lead climb the route, clipping every quickdraw except the last one before the lower off, which is marked with red tape. The climb is designed to be close to your on-sight lead grade. You will be protected by an experienced, competent and capable belayer using a Petzl Gri-Gri. You will climb at your own pace until you either reach the top, or fall. Once you reach the top, or fall, you will be lowered back to the ground and your attempt at the route will be over. You can, of course, withdraw from the test at any-time, but for the moment please remain seated and as still as possible for about three minutes while you think about the task and prepare yourself mentally to take part.

Study Two climbing instructions

The task that you are about to complete is designed to assess your on-sight lead climbing performance. You will be asked to lead a route graded French 6b, that has been set specifically for this study. You will be belayed by an experienced, competent and capable belayer. You will climb at your own pace until you either reach the top, or fall. Once you reach the top, or fall, you will be lowered back to the ground and your attempt at the route will be over. You can, of course, withdraw from the test at any time, but for the moment please remain seated and as still as possible for about four minutes while you think about the task and prepare yourself mentally to take part.

Study Four climbing instructions: Initial on-sight and 3rd novel on-sight

The task that you are about to complete is designed to assess your lead climbing performance. You are required to lead climb the route, clipping every quickdraw. The climb is designed to be close to your on-sight lead grade. You will be protected by an experienced, competent and capable belayer using a Petzl Gri-Gri. You will climb at your own pace until you either reach the top, or fall. Once you reach the top, or fall, you will be lowered back to the ground and your attempt at the route will be over. You can, of course, withdraw from the test at any-time, but for the moment please remain seated and as still as possible for about three minutes while you think about the task and prepare yourself mentally to take part.

Study Four climbing instructions: Repeat red-point

The task that you are about to complete is designed to reassess your lead climbing performance. You are required to lead climb the route, clipping every quickdraw. The climb is the same route that you completed previously. You will be protected by an experienced, competent and capable belayer using a Petzl Gri-Gri. You will climb at your own pace until you either reach the top, or fall. Once you reach the top, or fall, you will be lowered back to the ground and your attempt at the route will be over. You can, of course, withdraw from the test at any-time, but for the moment please remain seated and as still as possible for about three minutes while you think about the task and prepare yourself mentally to take part.

Appendix F Interview schedule

Open-ended semi-structured format questions (shown in bold, prompts in italics) were used flexibly and were omitted, adapted or elaborated according to the demands of the individual interview. The interview schedule was as follows:

1. **Could you tell me about your background in the sport and previous climbing experience?**
    a. *How long have you been climbing for?*
    b. *How were you introduced to the sport?*
    c. *What disciplines have you been/ are you involved in?*

2. **What proportion of your climbing is completed indoors?**
    a. *Boulder and sport?*
    b. *Lead or top-rope?*
    c. *Training?*

3. **Could you describe the challenges of indoor lead climbing to you?**
    a. *Physical and psychological?*
    b. *Before attempting a route?*
    c. *While on the route?*
    d. *Day to day variation?*
    e. *Influence of others?*

4. **What determines the type of routes you choose to attempt?**
    a. *List the factors?*
    b. *Top-rope or lead and on-sight or practice?*
    c. *Does anything influence these choices?*
    d. *What would make you choose a harder route?*
    e. *What role does your climbing partner and those at the wall play?*
    f. *Does your route choice influence your performance?*

5. **Do you have any goals or aims with your climbing?**
    a. *Short and long term?*
    b. *How are you working towards these goals?*
    c. *Do you go to each session with a plan?*

6. **Do you feel you are able to climb to your limit when leading?**
    - *If yes…When fatigued on a route what do you do?*
    - *If no… What limits this?*
        - *Would you climb to your limit on top-rope?*
        - *Have you tried anything to improve you performance?*

7. **Do you train for climbing?**
    a. *Physical?*
    b. *Psychological?*
        i. *Does this include falling?*
        ii. *Do you know of techniques to reduce anxiety when leading?*
        iii. *Do you use these techniques on a regular basis and why (or why not)?*

Appendix G Future progressive intervention

1. **Basic lead climbing skills**
   - It is important that the climber is a safe and confident climber.
   - They should be able to lead a route safely, without back clipping or z-clipping.
   - Importantly they should also be a competent and safe belayer. (n.b. it is highly beneficial if this process is completed with the same partner, or at least within a small group. Later, if necessary, branch out).
2. **Progressive fall exercise, as both the climber and the belayer:**
   - Choose an easy route the climber can completing the equivalent of 3 or 4 times the distance on. Begin on a slightly (~5 degree) overhanging wall.
   - Incrementally increasing fall practice. Ask the climber to ascend to the 3rd clip, clip in and sit on the rope. Climb to the fourth clip and drop with it at your head, 5th at chest, 6th at waist, 7th at mid-thigh, 8th at knee, 9th at ankle and drop the top.
   - The belayer should be attentive and aware of the process the climber is going through. Dynamic, belaying but not too much rope, being aware that the climb may change their mind.
   - The climber should aim for a safe falling position. Hands to protect chest and face and stabilise. Legs slightly bent. Do not hold rope.
   - The climber should not try and fight fall, push off slightly (cat like).
   - Complete every session (not necessarily all of the session) until it becomes second nature. When falling off and not completing the route starts to become tiresome then go onto stage two (it may be worth revisiting stage one, it makes a good warm up for a session).
3. **Unstructured fall practice.**
   - As with step number two, except during the climbers' normal session.
   - One or two falls per route. With the aim of building trust in the belayer, ensuring they are attentive and are able to arrest the climber at all times, even if they are unaware that the climber may fall.
   - Choose a variety of different angles – if the climber is unsure about a particular angle then perhaps go back and complete step two (n.b. I am not sure that doing this on a slab will result in anything but grazed knees and a bruised ego).

- Practice clipping at the chest or waist, forcing the climber to climb up, even if it means that the climber is clipping off of worse holds (the idea is body positions and habit, not climbing performance).

4. Falling off making moves

- The last step is applying everything that has been learnt to routes that at the climbers' limit, or above.
- Pick out routes that vary in terms of types of holds, angle, length etc. (perhaps keep a check list and try and attempt one of each. Or one on each different angle wall in the centre).
- Keep climbing until you have nothing more to give. Always attempt to make the next move. Do not, however, climb past a bolt. Clipping while tired is a skill in itself.

Appendix H Supporting studies

Giles, D., Draper, N., Gilliver, P., Taylor, N., Mitchell, J., Birch, L., Woodhead, J., Blackwell, G. & Hamlin, H. (2014). Current understanding in climbing psychophysiology research. Sports Technology, 7(3-4), 108-119. [doi: 10.1080/19346182.2014.968166].
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Current understanding in climbing psychophysiology research

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Abstract
The sport of rock climbing places a significant physiological and psychological load on participants. Psychophysiological analysis provides a unique insight into affective states arising from the demands of climbing, and the impact that they have on performance. This review provides an overview of climbing psychophysiology research completed to date. To summarise, an on-sight lead ascent of a route elicits the greatest psychophysiological response in climbers, whilst a red-point top-rope ascent produces the least. The effects of climbing stimuli on an individual's performance appear to be conditional on their experience. In general, experienced climbers show superior performance and are less anxious than their less practiced counterparts, with significantly lower cognitive and somatic anxiety, increased self-confidence and lower values of the steroid stress hormone cortisol. It is likely that the experience–stressor–performance relationship is due to advanced climbers' greater understanding of the risks associated with the sport, their habituation to the stressors gained through practice and their ability to perform well with higher levels of anxiety. This review outlines pertinent psychological climbing stimuli, summarises current methodologies and presents a detailed review of climbing psychophysiology research. It also concludes with suggestions for improving the depth and breadth of future research, including the need for the refinement of existing measures.

Keywords: *psychophysiology, rock climbing, experience, stimuli, stressors, anxiety*

1. Introduction

The challenges, or stimuli, of climbing include the significant physiological demands of the sport, including the difficulty, length and angle of a climb (Watts, 2004); the psychological demands, including the style of ascent, competition, height, fear of falling and climbing with an audience (Hague & Hunter, 2011); along with a significant element of skill (Seifert et al., 2013). These psychological stimuli must be responded to appropriately and effectively managed for athletes to complete a climb successfully (MacLeod, 2010). This review is concerned with research examining the effect of these psychological stimuli on climbers' physiology and performance. Through the psychophysiological analysis of the stimuli, researchers are provided with a unique insight into affective states arising from the demands of the sport, along with the impact that they have on individuals' performance (Draper, Jones, Fryer, Hodgson, & Blackwell, 2008; Hodgson et al., 2009).

Individual differences in interpretation mean that stimuli will not affect all climbers in the same way (Lazarus & Folkman, 1984). Stimuli may be perceived as benign, stressful (distress, anxiety inducing, resulting in a negative affective state) or positive (eustress, enhancing function and optimal arousal) (Apter, 1991). Distress and negative affect in response to a stimulus is likely due to a disparity between its demands and an individual's ability to

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meet them; conversely, eustress and positive affect are likely to arise when an individual is capable of meeting the demands of a stimulus (Lazarus & Folkman, 1984).

This review comprises four distinct sections. Section 2 summarises the key aspects of physiology and psychology research, which underpin our understanding of climbing psychophysiology. Section 3 addresses psychophysiological measures currently used in climbing research. Section 4 outlines relevant research that has been conducted in an applied climbing context. Finally, the Section 5 summarises future research directions.

2. The nature of climbing stimuli

The primary stimuli considered in this review relate to the significant psychological demands of climbing, in particular: the style of ascent; route knowledge and difficulty; and competition climbing and climbing with an audience (Section 2.1). This is followed by an outline of theories concerning the psychological bases of individual variation in responses (Section 2.2) and a summary of the relevant neurophysiological processes (Section 2.3).

2.1. *Stimuli within the sport of climbing*

2.1.1. Style of ascent. Climbing psychophysiology research has predominantly, but not exclusively, focused on alterations in the 'style of ascent' (e.g. Dickson, Fryer, Blackwell, Draper, & Stoner, 2012; Draper et al., 2012; Fryer, Dickson, Draper, Blackwell, & Hillier, 2012). The style of ascent describes the safety protocol protecting the climber in the event of a fall. Safety protocols include lower-height 'bouldering' routes, commonly protected by crash mats (Stiehl & Ramsey, 2004). Longer ascents may be protected by a 'top-rope' with which a fall is immediately arrested, considerably reducing the consequences (Bisharat, 2009). Alternatively, climbers may 'lead' a route, where a fall results in travelling some distance before being arrested by a trailing rope, attached to either intermittent pre-placed bolts, known as 'sport lead climbing', or climber placed protection 'traditional lead climbing' (Bisharat, 2009).

It is common for climbers to experience fear of falling, particularly whilst leading routes; this is especially common in lower-grade climbers (Hörst, 2008; MacLeod, 2010). MacLeod (2010) describes a fear of falling as a significant limiting factor in many climbers' performance. A fear of falling is a non-associative phobia, which may develop without the individual experiencing any direct or indirect trauma (Menzies & Clarke, 1993). Typically, the initial fearful response to falling will diminish over time due to habituation (Clarke & Jackson, 1983); however, poor habituates and individuals who do not get sufficient safe exposure may remain fearful (Clarke & Jackson, 1983). Climbers may habituate and desensitise themselves to falling through actively taking falls whilst practicing climbing, and through progressively increasing the fall length (Hörst, 2008; Macleod, 2010). Research is necessary to establish the effectiveness of fall training interventions, it is also not known if habituation to falling indoors transfers outdoors, to sport or traditional climbing, or vice versa.

The effect of fear of falling has not yet been examined in climbing psychophysiology literature, although contexts where it is inferred have been used (e.g. Draper et al., 2008). Alterations in height have also been used to manipulate anxiety levels, relying on individual's fear of falling and the presence of real physical danger to elicit negative affective states (Spielberger, 1966). These studies have examined the anxiety–performance relationship (Pijpers, Oudejans, Holsheimer, & Bakker, 2003), the affect of anxiety on visual attention (Nieuwenhuys, Pijpers, Oudejans, & Bakker, 2008), anxiety-induced changes in movement in a whole body task (Pijpers, Oudejans, & Bakker, 2005) and the role of anxiety in perceiving and realising affordances (Pijpers, Oudejans, Bakker, & Beek, 2006).

2.1.2. Route knowledge and difficulty. A climber's prior knowledge of a route impacts the way in which the ascent is completed, along with altering the relative psychological load (Draper et al., 2008). The principal forms of ascent are 'on-sight', without any prior knowledge, on the first attempt; 'flash' competing a route with prior knowledge on the first ascent; or a 'red-point', repeat ascent of a whole or partially climbed route (Goddard & Neumann, 1993). An on-sight is often considered the purest form of ascent, although it is speculated that a red-point, at a climber's absolute maximum climbing grade, may prove to be a greater physiological and psychological challenge (Hague & Hunter, 2011). Within published climbing psychophysiology literature the antipodal conditions of on-sight and red-point have been used exclusively (e.g. Draper et al., 2008; Hardy & Hutchinson, 2007).

The size and quality of hand and footholds available, and their spacing and the length and angle of the climbing itself usually dictate a climbs' difficulty. Climbs are 'graded' for ease of comparison, to judge performance and to allow climbers to choose suitable routes. Within climbing research the authors recommend the adoption of Draper, Canalejo, et al.'s (2011) convention for the summary of climbing grades and the standardised division of experience across these grades.

Climbing routes present a complex problem-solving task; the correct perception of affordances that a route offers plays a significant role in the success of an ascent (Pijpers et al., 2006). Affordances, in a climbing context, describe the link between the visual properties of holds and the more general climbing environment and the action, or actions, which may be performed with them (Gibson, 1979). The link may be based on stored information about a particular hold, but this is not always necessary (Humphreys & Riddoch, 2001). Significant differences between expert and more inexperienced climbers have been observed in the recall of information. Experienced climbers are able to recall more information, and clusters of information, and tend to fixate on the functional aspects of a climbing wall that are pertinent to a successful ascents of a route, whilst inexperienced climbers focus more on the holds themselves (Boschker, Bakker, & Michaels, 2002). It was also found, through the comparison of high and low traverse conditions, that anxiety narrows attention and a climber's emotional state plays an important role in the perception and realisation of affordances (Pijpers et al., 2006). Difficulties with the visual perception of climbing affordances may be compounded outdoors by the reduction in distinction of holds, in comparison to the typically coloured indoor holds, although due to the use of chalk outdoors, this may also vary (Luebben, 2004). Variation between rock types may also provide additional psychological difficulties with learning and perception of affordances and would be an interesting line of enquiry for future research.

2.1.3. Competition climbing and climbing with an audience. Competition is a potent psychological stimuli; a number of studies have examined competition climbers' precompetitive anxiety and affective states (Aşçi, Demirhan, Koca, & Dinc, 2006; Sanchez, Boschker, & Llewellyn, 2010). Climbing competitions, with few exceptions, take place on routes that are unknown to the competitors (International Federation of Sport Climbing [IFSC], 2007). Initial rounds of competitions allow those taking part to observe each other, gaining potentially useful information relating to the routes (Burbach, 2004). Climbers are placed into isolation in later rounds, forcing them to complete the routes on-sight. Emphasis is placed on climbing the routes without falling in order to receive the most points (IFSC, 2007); this places competitors under a great deal of pressure to perform optimally on their first attempt of the route (Goddard & Neumann, 1993).

Climbing is rarely completed in isolation; an audience, comprising of peers, spectators and/or competition judges, is usually present. To the authors' knowledge, research examining the effects of an audience on climbing performance has not yet been conducted. However, in other contexts, the performance of motor skills with audiences has been shown to produce varying responses. Murray (1983) demonstrated that executing a recently learnt motor skill in front of an audience was more effective for producing optimal performances than if it was completed in isolation; conversely, Butki (1994) demonstrated significantly inferior performance of a simple motor skill when it was completed in front of an audience. The issue is further complicated by the findings of Weinberg and Gould (2011), who demonstrated that the performance of new tasks with an audience negatively affected difficult skills, which had not yet been mastered, whereas for well-known or simple skills it helped performance. Climbing would provide an interesting medium in which to examine the effects of an audience on recently learnt and concrete motor skills.

2.2. Manifestation of stress in response to stimuli and climbers motivation

The interpretation of anxiety by climbers, the antecedents and benefits of optimal arousal and motivation for taking part in the sport may help to explain differences seen in individual's psychophysiology and its influence on climbing performance. This section will briefly outline several theories, applied in a climbing context, which explain aspects of the behaviour of climbers. Critically, climbing psychophysiology research has not discussed the results of studies in light of more general sport and pure psychology research; this section does not aim to present a comprehensive overview of theories, but instead start a discussion that may be addressed in future research.

2.2.1. Reversal theory. Climbers are required to effectively manage and respond to the significant risks associated with the climbing environment, in order to ensure their own safety (British Mountaineering Council, n.d.); an individual's response to risk depends on their ability to interpret, organise and execute an appropriate response. There are several theories that attempt to explain the stimuli–performance relationship and differences in the positive or negative affect individuals' experience, including Apter's (1989) reversal theory. Reversal theory is composed of bistable, telic and paratelic states; the telic state is characterised by planning and evaluating an activity on where it may lead in the future, whilst the paratelic state is spontaneous, evaluating an activity on the pleasure it gives at that moment (Apter, 1989).

Key to reversal theory is an individual's interpretation of stimuli as benign, stressful or positive. Reversal theory allows for individuals to display different personalities at different times depending on their interpretation (Apter, 1989). If the needs of the particular state, which the individual is experiencing, are fulfilled, then positive affect will result; conversely, if the needs are frustrated, then negative affect will result (Shepherd, Lee, & Kerr, 2006). The individual may also reverse back to a previous state at any given time if 'triggered' by an environmental event. In order to reduce anxiety, negative affect may be overcome not only by reducing arousal but also by inducing a reversal so that pleasant excitement is experienced instead. In a climbing context, climbers needlessly confront themselves with risk in order to achieve high arousal, this high arousal may be experienced as anxiety, but if the danger or challenge is overcome there may be a switch to the paratelic curve, resulting in excitement as intense as the anxiety (Shepherd, Lee, & Kerr, 2006). More generally, it has been found that those who are paratelic-dominant tend to choose and participate in risky and explosive sports, whereas a telic-dominant prefers safe and endurance sports (Chirivella & Martinez, 1994).

2.2.2. Flow experience. The potential for achieving a positive 'optimal experience', synonymous with a 'flow' state, resulting from successfully overcoming a challenge, provides a possible explanation for climbers motivation and their propensity for risk taking. Flow is defined as a state of optimal functioning and is characterised by deep involvement in an activity, feelings of immersion, loss of perspective of time and effortless ease and fluency of movement (Csikszentmihalyi, 1990). It is speculated that climbers may be motivated by flow, rather than directly by the risk that they take, although risk is still an integral part of the experience (Schüler & Nakamura, 2013). Flow is more likely to be experienced when there are clear goals, which are focused on aspects of their performance other than purely the outcome of the climb, a balance between challenge and skill and the possibility of immediate feedback (Delle Fave, Massimini, & Bassi, 2011; Hooper, Collins, & Eklund, 1998).

The importance of climbers' experience, for the correct appraisal of risk and their own competence, has been highlighted by Schüler and Nakamura (2013). Behind the 'lighter' optimal emotional state they describe a 'darker' side. In this darker state the individual is so involved in the activity that nothing else matters, they will complete the activity even if it results in great personal loss, they are addicted to the activity and may endanger their own physical integrity for the sake of experiencing flow (Schüler & Nakamura, 2013). Fear may be an emotional prerequisite for flow in beginner climbers, it has been found that flow experiences lead to the lowering of risk awareness and inappropriate risk taking, resulting in climbers 'letting-go' and 'just going for it' (Hooper et al., 1998; Schüler & Nakamura, 2013), whereas experience protects climbers from risk-taking behaviour, providing them with a more accurate appraisal of the correct balance between challenge and skill, which is influenced by past performances and their own perception and control of emotional arousal (Hooper et al., 1998; Schüler & Nakamura, 2013). Interestingly it was also found that climbers on traditional routes, in comparison to outdoor sport climbs, also experienced the same perceptions of danger and presented the same tensions as beginner climbers did when they were compared to their more experienced counterparts (Hooper et al., 1998).

2.2.3. General motivation. High achievement in climbing, with few exceptions, does not offer any extrinsic material rewards (Robinson, 1985). Climbers take part in the sport under their own volition, making choices that may increase the risk, including the style, difficulty, risk and exposure of ascents. Climbers' enjoyment of the sport appears to be unrelated to the associated fear, pain and strenuous muscular effort required (Hooper et al., 1998). With this in mind, climbers of all abilities take part, by choice, in riskier ascents, where the consequences of mistakes are more severe, likely motivated by the opportunity for optimal experiences, rather than the risk itself (Schüler & Nakamura, 2013). Climbers draw enjoyment from overcoming intense effort and through their own personal improvement (Papaioannou, Kourtesopoulou, & Konstandakatou, 2005). It is believed that competence, combined with hard effort, is a decisively important factor that leads to both successful ascents and the development of self-confidence in climbers (Papaioannou et al., 2005).

2.3. *Neurophysiological response*

The neurophysiological mechanisms and processes responsible for the cognitive, somatic and behavioural responses to stressors are complex (Gray & McNaughton, 2003). A brief outline of the response to a stressor, as described by Steimer (2002) begins with basolateral complex of the amygdala receiving the external stimuli, which is relayed by the thalamus, along with contextual information from the hippocampal formation and more elaborate cognitive information from the prefrontal cortex. The prefrontal cortex modulates the physiological, neuroendocrine and behavioural response, as well as being responsible for anxiety conditioned responses. The emotional stimuli received by the basolateral complex of the amygdala are processed, before the central nucleus of the amygdala activates different midbrain regions and nuclei, which provide the response to the initial anxiety stimulus. The central nucleus of the amygdala activates the locus ceruleus, the central and peripheral noradrenaline systems and the hypothalamus, activating the hypothalamo–pituitary–adrenocortical (HPA) axis, and sympathetic activation resulting in increases in respiratory rate, heart rate and blood pressure. Additionally, the central nucleus of the amygdala also directly activates midbrain regions responsible for 'fight or flight' responses. Activation of the HPA axis is responsible for neuroendocrine stress response and the release of glucocorticoids, including cortisol.

3. Measures of anxiety in current climbing literature

Through quantifying the neurophysiological and psychophysiological responses to climbing stimuli, it is possible to gain an insight into climbers' psychological performance. Research into psychophysiology, within climbing, has used a number of scales measuring arousal, anxiety and the direction of responses, including the Competitive State Anxiety Inventory and revisions (CSAI-2: Martens, Burton, Vealey, Bump, & Smith, 1990; CSAI-2R: Cox, Martens, & Russell, 2003), the Rock Climbing Anxiety Inventory (RCAI: Hardy & Hutchinson, 2007), the Profile of Mood States (POMS: McNair, Lorr, & Droppleman, 1981) and the Positive and Negative Affect Schedule (PANAS: Watson, Clark, & Tellegen, 1988). Further to this, the steroid hormone 'cortisol' has been used as an objective marker, through the comparison of basal and activated levels in response to climbing stimuli (Wittert, Livesey, Espiner, & Donald, 1996).

3.1. *Self report tools*

3.1.1. The Competitive State Anxiety Inventory. The CSAI was developed as a valid and reliable self-report tool for anxiety by Martens et al. (1990). The refined CSAI-2R (Cox et al., 2003) has been the instrument of choice for the measurement of anxiety in climbing (Aras & Akalan, 2011; Dickson, Fryer, Blackwell, et al., 2012; Draper et al., 2008, 2012; Draper, Dickson, Fryer, & Blackwell, 2011; Draper, Jones, Fryer, Hodgson, & Blackwell, 2010; Fryer, Dickson, Draper, Blackwell, et al, 2012; Fryer, Dickson, Draper, Eltom, et al., 2012; Hodgson et al., 2009; Maynard, MacDonald, & Warwick-Evans, 1997; Sanchez et al., 2010). It provides insight into the anxiety subcomponents of cognitive anxiety (e.g. I am concerned about losing), somatic anxiety (e.g. My body feels tense) and self-confidence (e.g. I'm confident about performing well), and the relationship between these three components and performance. Confirmatory factor analysis by Cox et al. (2003) and Raudsepp and Kais (2008) found a good fit of the collected data to the model with comparative fit index (CFI) values of 0.95 and 0.96, non-normed fit index (NNFI) of 0.94 and root mean squared error of approximation (RMSEA) of 0.054 and 0.046, respectively.

3.1.2. The Rock Climbing Anxiety Inventory. The RCAI is a development of Hardy and Whitehead's (1984) inventory, by Hardy and Hutchinson (2007). It measures cognitive anxiety, somatic anxiety and activation. To date, as far as the authors are aware, the RCAI has only been used in the initial study by Hardy and Whitehead (1984) and the more recent study by Hardy and Hutchinson (2007). It is likely that the limited use of the RCAI is due to the prevalence of the CSAI-2R within climbing research. Principal components analysis by Hardy and Hutchinson (2007) revealed three factors with eigenvalues greater than 1.00, accounting for 72% of the variance in the data. Cronbach's alphas for the final subscales were reported as acceptable with cognitive anxiety ($\alpha = 0.71$), somatic anxiety ($\alpha = 0.92$) and activation ($\alpha = 0.80$).

3.1.3. Profile of Mood State. The POMS questionnaire (McNair et al., 1981) is reasonably common in climbing psychophysiology literature (Draper et al., 2010; Draper, Dickson, et al., 2011; Fryer, Dickson, Draper, Blackwell, et al., 2012). The POMS measures individuals' perception of fatigue, vigour, anger, depression and tension. Research evidence suggests that mood state can influence physiological performance, and thus have an effect on climbing performance (Beedie, Terry, & Lane, 2000; McMorris et al., 2006). The reliability of the POMS has been confirmed by Grove and Prapavessis (1992), through comparing the mood states of winners and losers; it was found that all subscales, except fatigue, produced significant differences between these groups. Cronbach's alphas for the POMS subscales were largely satisfactory, with α values ranging from 0.664 to 0.954, with a mean of 0.798.

3.1.4. Positive and Negative Affect Schedule. Finally, the PANAS (Watson et al., 1988) is based on a bidimensional theory of emotion, which hypothesises that individuals can experience a mixture of positive and negative affect during a specific time period. Participants rate the extent to which they are experiencing each emotion just before performing; PANAS has found limited use in climbing research (Aşçi et al., 2006; Sanchez et al., 2010). PANAS internal consistency for the measurement of both positive and negative affect has been reported as adequate, with α values between 0.84 and 0.90 (Watson et al., 1988).

3.2. *Physiological and biochemical measures*

3.2.1. Sampling and assay of cortisol. The most commonly used biochemical marker of stress is the steroid hormone cortisol (hydrocortisone; Wittert et al., 1996). Cortisol is secreted by the adrenal cortex under the influence of the HPA axis in response to psychological and/or physiological stress (Wittert et al., 1996). Within climbing psychophysiology research, cortisol has been extensively used as a marker of stress (Aras & Akalan, 2011; Dickson, Fryer, Blackwell, et al., 2012; Draper, Dickson, et al., 2011; Fryer, Dickson, Draper, Blackwell, et al., 2012; Fryer, Dickson, Draper, Eltom, et al., 2012; Hodgson et al., 2009). The sampling and assay of cortisol is normally conducted on either salivary or plasma samples. Salivary cortisol is often used when the invasive collection of blood samples is not practical, or possible; however, saliva cortisol assay is less desirable, and its reliability may be questioned, due to the large degree of day-to-day intra-individual and inter-individual variation that is present (Hayes, Grace, Kilgore, Young, & Baker, 2012). However, plasma sampling is more invasive than saliva samples; Dickson, Fryer, Draper, et al. (2012) provide an overview of the sampling of plasma cortisol in a climbing context, suggesting the first toe as valid alternative sampling site for plasma cortisol, as the commonly used fingertip is inconvenient for climbers.

There are several issues with the assay of cortisol, beyond the difference between saliva and plasma sampling. Cortisol exhibits diurnal variation, with peak concentrations seen in the morning and reduced concentrations in the evening and overnight (Touitou & Haus, 2000). Hayes et al. (2012) found large inter-individual variation. Furthermore, cortisol reactivity in response to stimuli has been shown to differ between individuals (Smyth et al., 1998). Research has also questioned the emotions that cortisol measures, with Pollard (1995) suggesting that increased cortisol concentration might be indicative of arousal rather than just stress or anxiety. Pollard (1995) reviewed studies which have used cortisol as a stress marker, suggesting that although laboratory studies of acute stress have shown increases in cortisol concentrations, there was evidence that strong emotional arousal of any type may increase cortisol levels. Similarly, Brown, Sirota, Niaura, and Engebretson (1993) indicated that strong positive emotions might also elicit an increase in cortisol concentration. Further research is necessary to assess the impact of individual and diurnal variation in cortisol, responses to climbing specific stressors and the investigation of alternative biochemical markers.

4. Climbing psychophysiology

A number of studies have used psychophysiological techniques to examine the effects of climbing stimuli on climbers. A comprehensive literature search was conducted using PubMed, psycINFO and Google Scholar, using the following combinations of keywords: ‘Rock Climbing’ or ‘Climbing’ with each of the following terms ‘Psychophysiology’, ‘Anxiety’, ‘Plasma Cortisol’, ‘Cortisol’ ‘CSAI-2R’, ‘Physiology’ and ‘Psychology’. Results, from the search, were included based on the following criteria: (1) directly related to climbing, either indoors or outdoors, and (2) discussed climbing psychophysiology explicitly in the title or text, and or (3) discussed variables pertaining to psychophysiology, and or (4) used climbing tasks designed to elicit variations in stress. A summary of the 12 papers found using this search are presented in Table I.

4.1. *Outline of climbing psychophysiology literature*

Within climbing psychophysiology (Table I) researchers have assessed style of ascent (e.g. Dickson, Fryer, Blackwell, et al., 2012), differences between on-sight and red-point climbs (e.g. Draper et al., 2008), variation between successful and unsuccessful climbers (e.g. Draper, Dickson, et al. 2011) and the effect of competition (e.g. Sanchez et al., 2010). This research will be discussed in the following section.

4.1.1. Style of ascent. The style of ascent, with lead and/or top-rope conditions, is widely used as a stimulus and potential stressor in climbing literature (Dickson, Fryer, Blackwell, et al., 2012; Draper et al., 2010, 2012; Draper, Dickson, et al., 2011; Fryer, Dickson, Draper, Blackwell, et al., 2012; Hardy & Hutchinson, 2007). In further two studies, a more contrived top-rope with a trailing lead rope has been used (Aras & Akalan, 2011; Hodgson et al., 2009). Alternatively, Pijpers et al. (2003) used a high and low traverse protected by a top-rope. Within these studies climbing experience varied (Table I),

Table I. Overview of current climbing psychophysiology research.

Author (publishing date)	Participants (male♂ female♀)	Ability (Ewbank-converted)	Ability (Draper et al., 2011)	Context
Draper et al. (2012)	13♂ 6♀	RP 19–23 OS 18–19	Intermediate	LC or TR; OS
Fryer, Dickson, Draper, Eltom, et al. (2012)	18♂ 3♀	RP 23-25 OS 21–22	Intermediate/ advanced	LC or TR; OS
Dickson, Fryer, Blackwell, et al. (2012)	14♂ 1♀	OS 26.1 RP 28.7	Advanced	LC or TR; OS
Aras and Akalan (2011)	22♂ 4♀	15–17	Lower grade	LC and LCTR; 50% OS, 50% RP; randomised order
Draper, Dickson, et al. (2011)	12♂ 6♀	OS 18.4 RP 20.7	Intermediate	LC or TR; OS; success or failure
Draper et al. (2010)	9♂	19–23	Intermediate	LC and TR; 50% OS, 50% RP; randomized order
Sanchez et al. (2010)	19♂	26–31	Advanced/elite	Belgian climbing competition
Hodgson et al. (2009)	12♂	?	Intermediate -*as stated by paper*	LC, TR and LCTR; RP
Draper et al. (2008)	10♂	14–15	Lower grade	LC and repeat LC of same route
Hardy and Hutchinson (2007)	54♂	15–23	Lower grade/ Intermediate	Traditional outdoor LC and TR
Aşçi et al (2006)	37♂ 10♀	?	Intermediate - *taken from route grades*	Speed and difficulty climbs under competition conditions; OS
Pijpers et al. (2003)	16♂ 14♀	Non-climber	Lower grade	Low and high traverse

Notes: LC, lead climb; TR, top rope; LCTR, lead climb with TR; OS, on-sight; RP, red point.

with non-climbers (Pijpers et al., 2003), lower-grade climbers (Aras & Akalan, 2011; Draper et al., 2008; Hardy & Hutchinson, 2007), intermediate climbers (Draper et al., 2010, 2012) and advanced level climbers (Dickson, Fryer, Blackwell, et al., 2012; Fryer, Dickson, Draper, Blackwell, et al., 2012). The experience stated above, may differ from the experiences given in the original papers, as the abilities have been standardised, for ease of comparison, using the grading charts set out by Draper, Canalejo, et al. (2011). It should also be noted that no indication of climbing grades were given by Hodgson et al. (2009), other than the vague description of 'intermediate'; as with other papers, it is likely that the ability of participants according to Draper et al.'s grade tables were lower.

Significant differences in psychophysiological responses, between potentially anxiety inducing conditions, in non-climbers have been found by Pijpers et al. (2003), in lower-grade climbers by Hardy and Hutchinson (2007) and in intermediate climbers by Hodgson et al. (2009). Pijpers et al. (2003) found significantly greater heart rate (HR), movement entropy and blood lactate in high over low traverse conditions. Hardy and Hutchinson's (2007) first study demonstrated significantly greater Rating of Perceived Exertion (RPE), HR and RCAI measures of cognitive and somatic anxiety and activation, between an outdoor lead at a climbers limit minus two grades and at their on-sight limit; whilst Hardy and Hutchinson's (2007) third study showed significant elevation of cognitive anxiety and effort and reduction in activation and performance between a top-rope then top-rope climb and a lead then top-rope climb. Finally, Hodgson et al. (2009) demonstrated significantly increased somatic anxiety and decreased self-confidence, as reported by the CSAI-2R, and increased plasma cortisol concentration between a top-rope and lead climb.

Conversely, no significant differences between potentially anxiety inducing conditions, for intermediate climbers (Draper et al., 2012) and advanced climbers (Dickson, Fryer, Blackwell, et al., 2012; Fryer, Dickson, Draper, Blackwell, et al., 2012), have been demonstrated. Draper et al. (2012) did not report any significant alterations in the three components of the CSAI-2R of cognitive anxiety, somatic anxiety or self-confidence and no difference in measures of capillary cortisol, between top-rope and lead conditions. Draper, Dickson, et al. (2011) showed no significant differences in subjective mood state as measured by POMS, with alterations in style of ascent, between a lead and top-rope climbs, although no further details were given. Dickson, Fryer, Blackwell, et al. (2012) observed similar measures between a lead and top-rope condition of cognitive and somatic anxiety, all components of the NASA-TLX, VO_2 and HR; however, the CSAI-2R did report significantly lower self-confidence for the lead condition. Fryer, Dickson, Draper, Blackwell, et al. (2012) found a significant difference in climb time and HR at select points, but no difference in any components of the CSAI-2R, blood lactate or VO_2, between either an on-sight top-rope or lead climb.

To summarise the outcomes of previous climbing psychophysiology research, a relationship between high and low stress conditions and climbers' experience may be inferred. It would appear that as ability and/or experience increases, the difference in psychological anxiety in response to climbing stimuli decreases. Specifically, all climbers at or beyond an intermediate level, climbing at grades greater than approximately French 5 or Ewbank 18, showed no significant difference in measures of anxiety. This is an unexpectedly low grade, it is speculated that a reasonably fit non-climber would be able to climb at, or exceed, a grade of French 5. This draws into question the sensitivity of the measures used, particularly the commonly used CSAI-2R and the stress hormone cortisol.

Anecdotal evidence, cited by Dickson, Fryer, Blackwell, et al. (2012), supports the experience–anxiety relationship, reporting that climbing coaches do not see any change in the mind-set of experienced climbers with different forms of ascent. It is likely that this is due to experienced climbers being more accustomed to leader falls through habituation, as lead climbing and falling are often incorporated into their training (Fryer, Dickson, Draper, Blackwell, et al., 2012). Their habituation allows them to recognise the disparity between inflated perceived levels of risk that a lead condition provides and the actual level of risk that they are exposed to (Fryer, Dickson, Draper, Blackwell, et al., 2012; Dickson, Fryer, Blackwell, et al., 2012). Furthermore, it is possible that climbers have learnt to execute movements whilst still under the influence of elevated levels of anxiety, suggesting that more experienced climbers are still anxious, but that the anxiety does not impair their performance to the same degree (Pijpers et al., 2003).

To date, published research on the style of ascent in climbing, with the exception of Hardy and Hutchinson (2007), has been conducted exclusively on artificial walls. It is likely that this is due to the ease of data collection, potential safety issues and, possibly, the assumption that there are no physiological or psychological differences between indoor and outdoor climbing. In more general climbing research, only four other papers have collected data on natural rock (Booth, Marino, Hill, & Gwinn, 1999; Bunting, Little, Tolson, & Jessup, 1986; Bunting, Tolson, Kuhn, Suarez, & Williams, 2000; Williams, Taggart, & Carruthers, 1978). Further research is necessary in this area, as outdoor traditional and sport climbing affords unique opportunities for the study of psychophysiology and climbing performance, including decisions about the objective dangers, route finding and learning on real rock, which are not present indoors (Lewis & Cauthorn, 2002).

4.1.2. Route knowledge. Alterations in climbers' route knowledge, with either on-sight or red-point ascents, have been used to manipulate the amount of stress experienced. Draper et al. (2008) and Hardy and Hutchinson's (2007) third study both investigated the difference between an initial on-sight and a repeat ascent of the same route. Draper et al. (2008) found an on-sight lead climb condition more stressful and anxiety inducing than a subsequent red-point climb of the same route, with greater climbing time, cognitive and somatic anxiety as measured by the CSAI-2R and elevated HR and VO_2, in lower-grade climbers. This supports the earlier findings of Hardy and Hutchinson (2007), who established that cognitive anxiety, as reported by the RCAI, was equally elevated in an on-sight ascent in comparison to a subsequent repeat red-point top-rope ascent, regardless the style of ascent of the initial route; they theorise that the reduction in anxiety, with a repeat ascent, is due to both a reduction in the effort required and a learning effect, which subsequently reduces physiological and psychological load. It is also possible that experienced climbers have become conditioned to increasing their effort for on-sight climbs in comparison to those completed as a red-point, in order to ensure success, rather than anxiety-induced effort (Hardy & Hutchinson, 2007).

Whilst not entirely supporting the findings of the studies cited previously, Hodgson et al. (2009) speculate that, following an initial on-sight ascent, a repeat ascent of a route is open to interpretation by the climber. The repeat ascent of the route may either be perceived as inducing somatic and cognitive anxiety, resulting in greater markers of anxiety, or, conversely, be perceived more positively and result in feelings of higher self-confidence, whilst still eliciting relatively higher cortisol concentrations (Hodgson et al., 2009). This may depend on the difficulty of the climb and the initial amount of anxiety experienced on the first ascent. This would be an interesting line of enquiry for future research. It would also be of interest to investigate the dynamics of change in psychophysiology, over further repetitions of the same climb. Repetition of a route has previously been used to elicit a greater physical response in climbers, but data were not collected on each individual repetition of the route (Sherk, Sherk, Kim, Young, & Bemben, 2011). This will allow a better understanding of the relationship between anxiety and performance, how these factors are mediated by the experience of the route and how learning affects psychophysiological responses to stressors.

Differences in the psychophysiological response provoked by repeat ascents exposes potential issues with the methodology of three studies by Aras and Akalan (2011), Draper et al. (2010) and the second study in Hardy and Hutchinson (2007). These studies investigated anxiety in randomised conditions of lead, and a subsequent ascent of either a top-rope or a top-rope with a trailing lead rope; however, unlike Hodgson et al. (2009), no familiarisation trial was used in any of these studies. Thus, participants climbed either the lead or top-rope condition on-sight, before randomly repeating the same route in the alternative condition, as a red-point. As previously discussed, from the findings of Draper et al. (2008) and Hardy and Hutchinson's (2007) third study, it is known that an on-sight condition affects the physiological and psychological response of climbers differently to a red-point ascent. It is speculated that the lack of familiarisation, or a paired sample methodology, may have obscured trends that may otherwise have been found. As such, the findings of the research should be treated with caution; these studies were excluded from the earlier analysis in Section 4.1.1.

4.1.3. Competition and successful versus unsuccessful ascents. Performance differences between those who successfully complete an ascent and those who fall en route have been investigated by both Draper, Dickson, et al. (2011) and Sanchez et al. (2010). In both studies, significant differences between successful and unsuccessful climbers were found in climbing time, experience and pre-climb CSAI-2R measures of anxiety. Draper, Dickson, et al. (2011) reported that unsuccessful climbers climbed slower, taking longer to reach each bolt, than those who successfully completed the route; successful participants climbed faster and more efficiently, rather than in a more conservative considered approach (Draper, Dickson, et al., 2011). In contrast, Sanchez et al. (2010) found that successful competition climbers completed the most difficult part of the route significantly slower than their unsuccessful counterparts. Thus, expert climbers, in comparison to Draper et al.'s intermediate climbers, chose to climb slower and more carefully to control their equilibrium, although they were not necessarily more fluent than those who were unsuccessful. It was also shown, as previously established with differences in the style of ascent, that successful climbers were significantly more experienced, in terms of years participating in the sport and years lead climbing (Draper, Dickson, et al., 2011). It is likely that the more experienced climbers had reached an autonomous stage of learning, which had a stress-proofing effect, thereby increasing the likelihood of a successful ascent (Draper, Dickson, et al., 2011). Aşçi et al. (2006) highlighted further differences in psychological states preceding a climbing competition between male and female climbers: female climbers experienced significantly greater negative affect in comparison to male climbers, before both a speed and difficulty competition; additionally, a difference between the two competition types was also apparent.

In addition to differences in climbing time and experience, both Sanchez et al. (2010) and Draper, Dickson, et al. (2011) examined the psychological states preceding an on-sight ascent. Sanchez et al. (2010) discovered that, even when differences in baseline ability were accounted for, successful climbers reported higher levels of pre-performance somatic anxiety, which correlated positively with the final route scores. In addition to these findings, pre-performance emotions were also significantly associated with the participants' movement behaviour, as shown by increases in entropy (Sanchez et al., 2010). It has previously been stated that successful athletes are able to maintain a more positive affective state prior to competition than those who are less successful (Treasure, Monson, & Lox, 1996). This is supported by Sanchez et al., (2010), who observed that superior performers were climbers who experienced simultaneously high levels of somatic anxiety and positive affect. Similarly, Draper, Dickson, et al. (2011) found that whilst there were no significant differences in the subjective feelings of somatic or cognitive anxiety, as reported by the CSAI-2R, there were significant differences in reported self-confidence. Successful climbers reported much greater feelings of self-confidence before completing a climb, which may have improved route-planning decisions and the choice of technique and tactics employed, and, as a result, directly improved their performance (Draper, Dickson, et al., 2011).

4.2. *Alterations in movement performance*

Inappropriately high levels of anxiety have been shown to increase movement time, visual fixation, decrease visual search rate (Nieuwenhuys et al., 2008) and increase muscle tension (Pijpers et al., 2003). Approaches to quantify movement quality include measurement of the fluency of participants climbing movements by calculating the geometric index of entropy of the climber's trajectory (Cordier, France, Bolon, & Pailhous, 1993) and observing the proportion of time spent moving and maintaining static positions (Fryer, Dickson, Draper, Blackwell, et al., 2012). It is thought that alterations in physical behaviour from anxiety are caused by a reduction in information processing efficiency and regression to an earlier stage of motor learning, negatively influencing a climber's movement behaviour (Nieuwenhuys et al., 2008; Pijpers et al., 2003). Pijpers et al. (2003) suggested that under pressure an inward focus of attention occurs, resulting in more conscious control of the execution of well-learnt motor skills. Pijpers et al. (2003), as with

Dickson, Fryer, Blackwell, et al. (2012) and Draper et al. (2012), conclude that practice reduces the effects of motor learning regression, through a combination of habituation and learning to perform the task under the influence of higher levels of anxiety. These findings further support the benefits of experience: through becoming habituated with taking lead falls and the automation and stress proofing of movement skills, more advanced climbers are able to make tactical decisions regarding the route, holds and rests, minimising the physiological and psychological stress of a given climb.

5. Summary of future research directions

Climbing psychophysiology has emerged as a significant and distinct area of research over recent years. Further investigation of the effects of climbing specific psychological stimuli on performance will help us to further understand the relationship between individual climbers' experience and their ability to appropriately respond to stimuli. Importantly, it will also inform how climbers with less experience may improve their climbing performance. There are several areas of climbing psychophysiology research that would benefit from attention, both concerning climbing specific questions and more general psychophysiological methodologies.

Psychophysiology methodologies will benefit from research and refinement, especially concerning their sensitivity to differences between anxiety and arousal. In particular, assessing the sensitivity of the hormone cortisol and its ability to quantify stress responses in climbing; along with considering more sensitive alternatives, such as Leukocyte Coping Capacity (Shelton-Rayner, Mian, Chandler, Robertson, & Macdonald, 2012). Similarly, the investigation of potential alternative anxiety inventories to the CSAI-2R may help to clarify responses; alternatives may include the recently developed Three-Factor Anxiety Inventory (Cheng, Hardy, & Markland, 2011).

Several climbing-specific psychophysiology issues would benefit from further investigation: one area in particular, is the affect of the outdoor climbing environment on performance. Whilst only five papers (Booth et al., 1999; Bunting et al., 1986, 2000; Hardy & Hutchinson, 2007; Williams et al., 1978) have looked at climbing outside, only Hardy and Hutchinson (2007) have examined climbing psychophysiology. Furthermore, to our knowledge, as yet there has not been any research conducted comparing climbing indoors and outdoors. Similarly, differences in route finding, the perception of affordances and learning between indoor and outdoor climbing would be of interest. Finally, improving our understanding of the process by which climbers become habituated to taking lead falls indoors, and how/if this habituation transfers to other environments, would be of benefit to both climbers and coaches.

6. Conclusion

To conclude, the affects of climbing stimuli on an individual's performance appear to be conditional on their experience, with more experienced climbers suffering less anxiety and fewer decrements in performance. It is likely that the experience–stressor relationship is due to advanced climbers' greater understanding, and rationalisation of the risks associated with the sport, habituation to the stressors gained through practice and an ability to perform with higher levels of anxiety. However, it is speculated that individuals' responses to stimuli are more complex than those reported by the CSAI-2R anxiety inventory and the psychophysiological stress marker cortisol. Beyond an intermediate level of climbing ability (French 5 or Ewbank 18) no significant differences between lead and top-rope conditions have been found using these measures, with the exception of Hodgson et al. (2009). The lack of significance beyond an intermediate level is unexpected, given the low cut-off grade between lower-grade and intermediate climbers, drawing into question the sensitivity of the measures used. It appears that these measures are not subtle enough to differentiate between climbing groups and experience on a single climb and that they are also unable to explain all of the intra- and inter-individual variation seen in responses. Assessment of the viability of more subtle anxiety indices and psychophysiological markers is necessary, as previously discussed.

The findings of climbing psychophysiology research hold significant implications for coaching climbers: through seeking to reduce the disparity between individuals' expectation and the reality of climbing stimuli and promote a balance between anxiety and self-confidence, it will be possible to evoke positive emotions towards the task and enhance performance. For researchers, whilst several areas have been highlighted for further study, it is likely that research will also need to return to mainstream anxiety research to explore and develop more subtle, sensitive measures, beyond those that are currently in use. It is hoped that this will allow us to gain further understanding of the subtlety and complexity of psychophysiological responses to climbing stimuli.

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RAPID COMMUNICATION

Comparative grading scales, statistical analyses, climber descriptors and ability grouping: International Rock Climbing Research Association position statement

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Abstract
The research base for rock climbing has expanded substantially in the past three decades as worldwide interest in the sport has grown. An important trigger for the increasing research attention has been the transition of the sport to a competitive as well as recreational activity and the potential inclusion of sport climbing in the Olympic schedule. The International Rock Climbing Research Association (IRCRA) was formed in 2011 to bring together climbers, coaches and researchers to share knowledge and promote collaboration. This position statement was developed during and after the 2nd IRCRA Congress which was held in Pontresina, in September 2014. The aim of the position statement is to bring greater uniformity to the descriptive and statistical methods used in reporting rock climbing research findings. To date there is a wide variation in the information provided by researchers regarding the climbers' characteristics and also in the approaches employed to convert from climbing grading scales to a numeric scale suitable for statistical analysis. Our paper presents details of recommended

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standards of reporting that should be used for reporting climber characteristics and provides a universal scale for the conversion of climbing grades to a number system for statistical analysis.

Keywords: *rock climbing, ability grouping, climbing grade, comparative table, statistics*

Introduction

The International Rock Climbing Research Association (IRCRA) was formed in 2011 as a forum through which climbers, coaches and researchers, working in the area of rock climbing, could come together to share experience, collaborate over research and to provide a platform for knowledge exchange. To date the Association has held two congresses, the first in 2011 in Christchurch, New Zealand, and the second in Pontresina, Switzerland in 2014. The next congress will be held in the USA in 2016. Membership of the Association is free and includes climbers, coaches, climbing wall designers and researchers from around the world; the website for the IRCRA can be found at www.ircra.rocks.

Rock climbing is an increasingly popular recreational and competitive sport, with a growing research base (Baláš et al., 2014; Draper et al., 2011a; España Romero et al., 2009; Watts, 2004). As the sport has developed, the number of disciplines has increased and now includes such diverse activities as mountaineering, big wall climbing, bouldering, deep water soloing, sport climbing, traditional climbing, ice climbing and mixed climbing (Macleod et al., 2007). As the research base has grown, ~550 papers have been published on the sport, there has been an increasing diversity in the nomenclature to describe ability groups, the grading systems and climber characteristics reported, as well as a wide variety of grade conversion methods employed to enable statistical analysis of results (España Romero et al., 2009; Macleod et al., 2007; Schoeffl, Klee, & Strecker, 2004; Sherk, Sherk, Kim, Young, & Bemben, 2011). In 2011, Draper et al. (2011b) published a paper highlighting such discrepancies and the resultant problems consequently arising for researchers attempting to make comparisons between studies. However, since that paper was published, the inconsistency in reporting has continued (Amca, Vigouroux, Aritan, & Berton, 2012; Laffaye, Collin, Levernier, & Padulo, 2014; Morenas Martín, Del Campo, Leyton Román, Gómez-Valadés Horrillo, & Gómez Navarrete, 2013; Woollings, McKay, Kang, Meeuwisse, & Emery, 2014; Young, Eklund, Tenenbaum, Glueckauf, & Thompson, 2014). The climbers, coaches and researchers present at the 2014 International Rock Climbing Research Congress developed this position statement as a call to all involved in climbing research to follow a consistent method for reporting climber characteristics, nomenclature for ability grouping and to propose the use of one IRCRA scale in all statistical analyses. Such an approach will improve consistency in the field and facilitate comparison between studies.

Climbing scales and recommendations for statistical analysis

As can be seen from Table I, there are a variety of climbing scales used around the world and also for different disciplines. The Yosemite Decimal System (YDS) is used in the USA. The French/sport scale is used for sport climbing in Europe. The British technical grading scale, usually used in conjunction with an adjectival scale, is used to express the difficulty of traditional routes, where equipment is placed into the rock en route to protect the lead climber against a fall during ascent. The Ewbank scale is primarily used in Australia, New Zealand and South Africa, while the Union Internationale des Associations d'Alpinisme scale (UIAA) is primarily used to describe difficulty of short rock routes in Germany, Austria, Switzerland, Czech Republic, Slovakia and Hungary. The Vermin (V) and Font (Fontainebleau) scales are used to describe the difficulty of a bouldering climbing problem.

As can be seen from Table I, the climbing scales are subdivided by letters or +/− grades or are incomplete scales and as such make direct statistical analysis challenging. To overcome this difficulty, researchers have developed number-based scales, converting traditional climbing scales to number-based scales for statistical analyses (Draper, Brent, Hodgson, & Blackwell, 2009; Llewellyn & Sanchez, 2008; Michailov, Mladenov, & Schöffl, 2009; Padrenosso et al., 2008; Schöffl, Morrison, Hefti, Ullrich, & Küpper, 2010). The problem with this approach is that, again, there has been little consistency between methods. The first to develop such a scale were Watts, Martin, and Durtschi (1993) and this is presented in the Table for reference, however as an incomplete scale (the scale starts at 5.6 YDS rather than 5.1) it could not be used as a statistical scale for all rock climbing studies. The Ewbank and UIAA Decimal scale also had potential, however, both are incomplete scales, the Ewbank additionally starting at level 4. The Sport and YDS scales, the most widely used scales, have 32 grades and as such the Ewbank and UIAA decimal, having only 28 grades, would make conversion to either of

Table I. Ability grouping for males and females and a range of reporting scales shown alongside the IRCRA scale.

Climbing Group		Vermin	Font	IRCRA Reporting Scale	YDS	French/sport	British Tech	Ewbank	BRZ	UIAA	Metric UIAA	Watts
				1	5.1	1	2	4	I sup	I	1.00	
				2	5.2	2		6	II	II	2.00	
				3	5.3	2+	3	8	II sup	III	3.00	
Lower Grade (Level 1) Male & Female				**4**	5.4	3-			III	III+	3.50	
				5	5.5	3		10	IV	IV	4.00	
				6	5.6	3+	4	12	V	IV+ V-	4.33 4.66	0.00
				7	5.7	4		14		V	5.00	0.25
				8	5.8	4+				V+	5.33	0.50
		VB	< 2	**9**	5.9	5	5a	16	V sup	VI-	5.66	0.75
				10	5.10a	5+		18	VI	VI	6.00	1.00
		V0-	3	**11**	5.10b	6a	5b	19		VI+	6.33	1.25
	Intermediate (Level 2) Female	V0	4	**12**	5.10c	6a+	5c		VI sup	VII-	6.66	1.50
Intermediate (Level 2) Male		V0+	4+	**13**	5.10d	6b		20		VII	7.00	1.75
		V1	5	**14**	5.11a	6b+		21	7a	VII+	7.33	2.00
			5+	**15**	5.11b	6c	6a	22	7b			2.25
		V2	6A	**16**	5.11c	6c+				VIII-	7.66	2.50
	Advanced (Level 3) Female	V3	6A+ 6B	**17**	5.11d	7a		23	7c	VIII	8.00	2.75
		V4	6B+	**18**	5.12a	7a+	6b	24	8a	VIII+	8.33	3.00
		V5	6C 6C+	**19**	5.12b	7b		25	8b	IX-	8.66	3.25
Advanced (Level 3) Male		V6	7A	**20**	5.12c	7b+		26	8c			3.50
		V7	7A+	**21**	5.12d	7c	6c	27	9a	IX	9.00	3.75
		V8	7B	**22**	5.13a	7c+		28	9b	IX+	9.33	4.00
	Elite (Level 4) Female	V9	7B+	**23**	5.13b	8a		29	9c	X-	9.66	4.25
			7C	**24**	5.13c	8a+		30	10a	X	10.00	4.50
Elite (Level 4) Male		V10	7C+	**25**	5.13d	8b	7a	31	10b			4.75
		V11	8A	**26**	5.14a	8b+		32	10c	X+	10.33	5.00
		V12	8A+	**27**	5.14b	8c		33	11a	XI-	10.66	5.25
		V13	8B	**28**	5.14c	8c+		34	11b	XI	11.00	5.50
Higher Elite (Level 5) Male	Higher Elite (Level 5) Female	V14	8B+	**29**	5.14d	9a	7b	35	11c	XI+	11.33	5.75
				30	5.15a	9a+		36	12a			6.00
		V15	8C	**31**	5.15b	9b		37	12b	XII-	11.66	6.25
		V16	8C+	**32**	5.15c	9b+		38	12c	XII	12.00	6.50

Note: IRCRA stands for the International Rock Climbing Association; YDS for Yosemite Decimal System; BRZ for Brazilian scale, UIAA for the Union Internationale des Associations d'Alpinisme and Font for Fontainebleau. Sources: Watts, Martin, and Durtschi (1993), Benge and Raleigh (1995), Draper et al. (2011b), Schöffl et al. (2010), BMC (2007), Rockfax (n.d.), The American Alpine Club (2012).

these scales problematic. As a consequence the IRCRA scale, also shown in Table I and Figure 1, is proposed as the recommended scale to use for statistical analyses in future studies, as one that matches the number of grade steps in the most commonly used climbing scales. As can be seen from Figure 1, all existing scales, at least at higher difficulty levels, show a linear relationship with the IRCRA scale.

Ability grouping

In the climbing grades paper written by Draper and co-workers (2011b), the authors highlighted inconsistencies in language and ability grouping criteria used to describe climbers and the problems these cause when attempting to make comparisons between studies (Boschker, Bakker, & Michaels, 2002; Esposito et al., 2009; Grant, Hynes, Whittaker, & Aitchison, 1996; Grant et al., 2001; Limonta, Cè, Veicsteinas, & Esposito, 2009). Draper et al. (2011b) proposed the nomenclature for climbing ability as shown in Table I, establishing five groups from low grade to higher elite level climbers. Despite the publication of the paper by Draper et al. (2011b), studies continue to be published with inconsistencies in the language used to describe the groups in their studies. By way of recent examples, Laffaye et al. (2014) categorised their climbers as novice (<6a), skilled (6c–7b) or elite (≥8a) while Lechner, Filzwieser, Lieschnegg, and Sammer (2013) classified climbers as experienced or less experienced without stating the grounds upon which the categorisation was made. In 2014 Young et al. again used the experienced or inexperienced categorisation, however, in this study they classified each as having ascended more than 50 vertical climbs or fewer than 5 vertical ascents, respectively. While not of relevance to their study, this categorisation would leave a middle group of climbers who

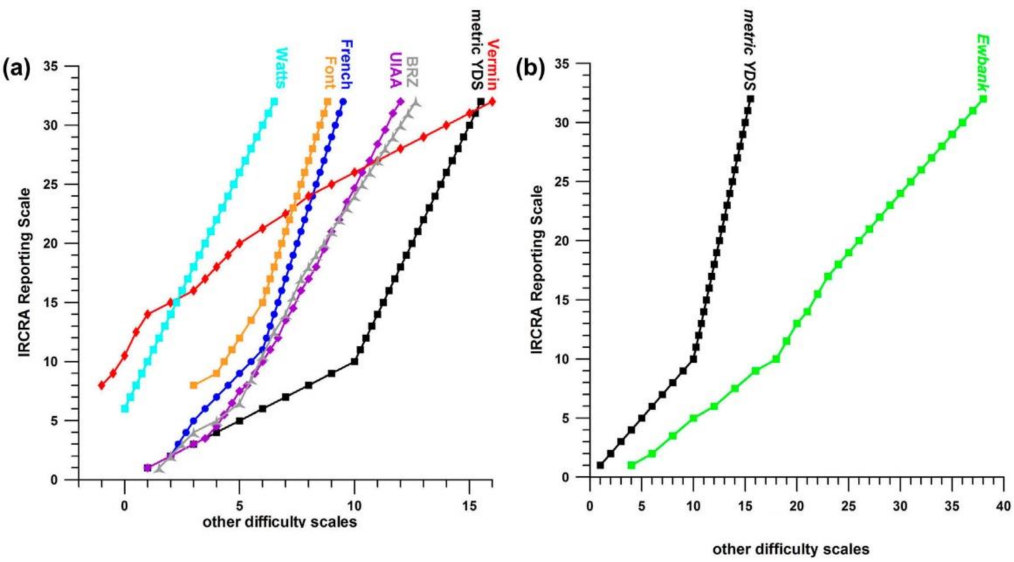

Figure 1. IRCRA Reporting Scale against existing difficulty scales; IRCRA stands for the International Rock Climbing Association; YDS for Yosemite Decimal System; BRZ for Brazilian scale, UIAA for the Union Internationale des Associations d'Alpinisme and Font for Fontainebleau.

ascended between 5 and 49 climbs in an unnamed group and would not differentiate between climbers who have climbed 50 routes and those with thousands. While this would not matter for the particular study reported by Young and colleagues (2014), it does not help readers to draw conclusions of findings between studies.

In a paper published in Wilderness and Environmental Medicine, Folkl stated (2013, p. 155):

> At the time of study design there was no known consensus regarding an appropriate approach to stratifying survey respondents based on level of difficulty climbed. Therefore, for the purposes of this report respondents were asked to categorize themselves as, on average, able to climb 5.0–5.9, 5.10a–5.10d, 5.11a–5.11d, 5.12a–5.12d, 5.13a–5.13d, or 5.14a and above.

This statement, not only identifies a further novel approach to classifying climbers, it also highlights the case for reaching consensus detailed in this IRCRA position statement. The consensus reached in this paper will enable future researchers to refer to an agreed system of categorising climber abilities and to employ a common language as descriptors for specific ability groups.

Draper et al. (2011b) created two tables of climber abilities, one for males and one for females. During the process of reaching the consensus for this position statement members of the IRCRA discussed the merits of having separate classifications of ability for male and female climbers. While there were a number of researchers and climbers who supported the notion of one table for all, the consensus suggested we should take note from previous research outside the field which sees separate fitness results, tables and performance records (such as athletics world records) for males and females. Rather than creating two tables as was the case for Draper et al. (2011b), for ease of comparison, Table I presents the groups and breakpoints between group for males and females in one table.

Climber characteristics: capturing the group

A further key aspect in reporting both climber abilities and the characteristics of climbers relates to which aspects should be reported. Again we see wide discrepancies between studies and this can be very problematic for making comparison between studies (Baláš, Pecha, Martin, & Cochrane, 2012; Donath, Roesner, Schöffl, & Gabriel, 2013; Fanchini, Violette, Impellizzeri, & Maffiuletti, 2013; Fryer, Dickson, Draper, Blackwell, & Hillier, 2012; Green, Draper, & Helton, 2013; Schoeffl et al., 2004; Schöffl, Hoffmann, & Küpper, 2013). In addition to the normal data collected such as age, gender, body mass and height, to better inform readers of future research papers and to facilitate comparison between studies a number of regular characteristics should be reported by authors. It should be noted that the classification of climbers in Table I relates to their highest self-reported redpoint ascent. A redpoint, from the German rotpunkt, refers to a successful lead climb ascent, without weighting the rope, of a previously practised route. Previous research by Draper et al. (2011a) indicates that the use of self-report grades is appropriate as climbers have been shown to accurately self-report their climbing ability in a research context.

A number of IRCRA members highlighted the need for clarity regarding what would constitute a highest redpoint grade, for instance as Fanchini (2014) stated, would making a successful ascent of one route which suited a particular climber's characteristics (anthropometry etc.) constitute a fair and accurate assessment of their ability? Drum (2014) proposed an excellent solution for reporting the 3:3:3 rule. When completing the climbing ability assessment, researchers should record the climber's highest redpoint grade for which they have completed 3 successful ascents on 3 different routes (at the grade) within the previous 3 months. For ease of comparison, this should be reported as local grade as well as sport/French, YDS and IRCRA. By way of example, as can be seen from Table I, a study in South Africa might report findings for a group of advanced level female climbers with a mean self-reported ability of 23 Ewbank (7a sport/French, 5.11d YDS, IRCRA 17). While for an equivalent group of boulderers (female advanced level), the mean climbing grade might be V6 (Font 7a, IRCRA 20). In addition, as a minimum, researchers should report answers to the following questions about the following characteristics of the climbers in a study to improve comparability between studies:

- Climbers' self-identity in the sport – how they see themselves in terms of predominant discipline (i.e. boulderer, sport climber, etc.)?
- Disciplines (i.e. bouldering, sport, traditional etc.) the climbers take part in (percentage of time devoted to each) in the past 3 to 12 months (include data for both time periods)?
- Percentage of time spent climbing indoors or outdoors in the past 3 months and over the past 12 months?
- Mean time (days per week and hours per session) spent climbing/training in a typical week in past 3 months and in the past 12 months?
- Time in the sport – the number of years/months experience?
- Are they involved in competition climbing, along with the disciplines and levels (i.e. bouldering, local vs. national competitions)?
- Additionally researchers might report the climbers' preference for style of ascent, (i.e. onsight, redpoint, top-rope) and for terrain (vertical, overhanging, slab climbing, varied).

Future research

Table I provides a conversion between climbing grade scales used in different countries or regions of the world. Those involved with climbing know that although these appear objective when viewed in a table such as this, the grading of a particular route is inherently more subjective in nature. Although perhaps made more objective over time through repeat ascents and confirmation (or often down-grading) of the original grade, there remains an element of subjectivity to grade assignment for any particular route. Conversion between scales, such as from YDS to Ewbank, should therefore be completed with some caution. Likewise, while the IRCRA scale might appear to represent a ratio scale and was developed in an objective manner, conclusions drawn in regard to the ability of climbers should, at this stage, also be made with some reservation. Furthermore, scales such as the British adjectival scale, appear to have psychological barriers which have arisen, often through climbing folklore, around specific grades. These may well affect the rate at which climbers move through grades, or appear to have sticking points in their progression due to such barriers. Examples of this might include the E1, the first 'extreme' grade climb in traditional climbing, the 21 grade in Australia using the Ewbank scale or the 5.13 YDS grade.

This raises two issues in this aspect of climbing research that, perhaps, merit further attention. Firstly, research into the presence of certain psychological 'sticking points' could usefully be undertaken in the near future. It may be likely that the steps between grades are not of a ratio scale nature, but more likely ordinal and should perhaps therefore be treated as such, which has implications for further statistical analyses. Secondly, it would seem beneficial, in attempting to quantify the ability of climbers to (a) agree on a battery of valid and reliable measures of climbing ability and then to (b), using a large sample of climbers across a range of abilities, assess performance on this battery of tests to create a more objective measure of climbing ability for use in future studies. Members of the IRCRA are in the process (April 2015–April 2016) of completing a multi-centre collaborative research project to accomplish such a large-scale study. The research is designed to identify valid and reliable measures of climbing ability and to examine the extent to which these can be utilised together to create a more objective measure of climbing ability. Researchers interested in being involved in this study should contact the corresponding author of this paper for details.

Conclusion

The increasing research attention on the sport of rock climbing highlights very clearly the continued discrepancies in reporting methods and approaches to statistical analysis evident between studies. The IRCRA scale, shown in Table I, has been developed to support a common approach to statistical analyses. In addition, the ability grouping nomenclature also detailed in Table I, along with the recommendations for reporting climber characteristics, if applied in reporting future studies will substantially increase the uniformity between papers and improve ease of comparison for readers. It is suggested that all future researchers follow the recommendations presented in this position statement and refer to Table I for statistical analysis and classification of the climbers in their studies.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Appendix H

Giles, D., Draper, N. & Neil, W. (2016). Validation of the Polar V800 heart rate monitor to measure RR intervals at rest. European Journal of Applied Physiology. [doi: 10.1007/s00421-015-3303-9] [*reproduced under the terms of the Creative Commons Attribution License*]

ORIGINAL ARTICLE

Validity of the Polar V800 heart rate monitor to measure RR intervals at rest

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Abstract
Purpose To assess the validity of RR intervals and short-term heart rate variability (HRV) data obtained from the Polar V800 heart rate monitor, in comparison to an electrocardiograph (ECG).
Method Twenty participants completed an active orthostatic test using the V800 and ECG. An improved method for the identification and correction of RR intervals was employed prior to HRV analysis. Agreement of the data was assessed using intra-class correlation coefficients (ICC), Bland–Altman limits of agreement (LoA), and effect size (ES).
Results A small number of errors were detected between ECG and Polar RR signal, with a combined error rate of 0.086 %. The RR intervals from ECG to V800 were significantly different, but with small ES for both supine corrected and standing corrected data (ES <0.001). The bias (LoA) were 0.06 (−4.33 to 4.45 ms) and 0.59 (−1.70 to 2.87 ms) for supine and standing intervals, respectively. The ICC was >0.999 for both supine and standing corrected intervals. When analysed with the same HRV software no significant differences were observed in any HRV parameters, for either supine or standing; the data displayed small bias and tight LoA, strong ICC (>0.99) and small ES (≤0.029).
Conclusions The V800 improves over previous Polar models, with narrower LoA, stronger ICC and smaller ES for both the RR intervals and HRV parameters. The findings support the validity of the Polar V800 and its ability to produce RR interval recordings consistent with an ECG. In addition, HRV parameters derived from these recordings are also highly comparable.

Keywords Heart rate variability · Polar V800 · Time domain analysis · Frequency domain analysis · Non-linear analysis

Abbreviation

ECG	Electrocardiograph(y)
ES	Effect size
HF	High frequency
HRM	Heart rate monitor
HRV	Heart rate variability
ICC	Intra-class correlation coefficients
LF	Low frequency
LFHF	Low frequency to high frequency ratio
LoA	Limits of agreement
NN	Normal to normal
nuHF	Normalised high frequency power
nuLF	Normalised low frequency power
T(1-6b)	Error type 1 to 6b
VLF	Very low frequency

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Introduction

Heart rate variability (HRV) is a non-invasive tool, which allows the exploration of cardiovascular autonomic function through the measurement of variations in RR intervals (Thayer et al. 2012). Heart rate variability was first employed in clinical settings (Akselrod et al. 1981; Fouad et al. 1984), before being applied to sport sciences contexts (Seals and Chase 1989). The use and analysis of HRV has become increasingly common, as it is simple, non-invasive and sensitive to physiological and psychological changes (Thayer et al. 2012).

In a clinical setting, reduced HRV has been shown to unfavourably reflect prognoses for cardiovascular disease, diabetic neuropathy, arterial hypertension, acute myocardial infarction and other heart conditions (Spallone et al. 2011; Thayer et al. 2010; Yi et al. 2014). Heart rate variability may also provide an insight into the capacity of an organism to function effectively in complex environmental, physiological and psychological conditions (Thayer et al. 2012). Heart rate variability has been found to be a valuable measure in a variety of sports settings with the measurement of many factors including overtraining, recovery, endurance training, and exercise (Makivić et al. 2013).

Advances in technology have provided athletes, coaches and researchers with an affordable, robust and reliable means of recording RR data in the form of heart rate monitors (HRM) worn on the wrist with wireless chest strap electrodes. Instruments such as Polar's HRMs (Polar OY, Finland), which are capable of recording RR intervals, are used not only by athletes, but also for HRV analysis in other fields such as sports science and medicine (Gamelin et al. 2006). The development of HRMs has enabled recording of RR data in situations where it was not previously possible with lab based electrocardiograms (ECG), or even ambulatory ECGs (Mateo et al. 2012; Morales et al. 2013). However, these HRM are consumer devices, which are not specifically designed for clinical or research application; as such, the validation their potential to accurately and reliably record RR intervals is essential.

Earlier Polar HRM have been validated, including the S810 (Gamelin et al. 2006, 2008; Nunan et al. 2008, 2009; Porto and Junqueira 2009; Vanderlei et al. 2008; Weippert et al. 2010) and more recently the RS800 (Quintana et al. 2012; Wallén et al. 2012). All studies demonstrated that recordings of RR intervals made by the Polar HRM are in good agreement with ECG systems, with small, but acceptable level of variation when compared to simultaneously recorded 2, 3 or 12 lead ECGs. This also holds true for HRV parameters derived from the RR intervals, as long as both signals are processed with the same software. It has been shown that software differences in signal processing and calculation of HRV indices results in unacceptable variation (Nunan et al. 2008; Radespiel-Tröger et al. 2003; Sandercock et al. 2004; Wallén et al. 2012; Weippert et al. 2010). The present study set out to validate the newly released Polar V800, which supersedes the discontinued S810 and RS800 and has not yet been examined in the literature.

The aim of the study was to assess the validity of the Polar V800 heart rate monitor to accurately measure RR intervals at rest, comparing: (1) resting raw data obtained during supine and standing measurements from the Polar V800 HRM and a 3 lead ECG recording; and, (2) linear and non-linear HRV parameters derived from both the V800 and ECG. The present study also aimed to improve on the methods for the identification and correction of RR intervals employed (Gamelin et al. 2006, 2008), using method representative of typical use in clinical and sports science settings.

Method

Participants

Twenty (3 female and 17 male) volunteers (age 28.7 ± 9.9 years; height 1.76 ± 0.09 m; mass 75.9 ± 9.5 kg) agreed to participate in the study. Non-smoking volunteers were selected for participation based on having no known cardiovascular or respiratory diseases or illnesses. No participant was known to be taking medication or have any cardiovascular problems that may have influenced the procedures carried out. Participants completed written informed consent and medical health questionnaires prior to taking part in the study. Approval for the study was granted by the University of Derby's Ethics Committee [LSREC_1415_16] and conformed to the principles of the declaration of Helsinki.

Procedure

Participants were asked to abstain from caffeine-containing food and drink prior to the test and to only consume a light meal 2 h prior to testing. Participant's skin was cleaned (shaved if necessary) and prepared for the attachment of the ECG electrodes. The electrodes were placed in a CM5 configuration [right fifth interspace, manubrium and left fifth interspace (Dash 2002)], ensuring that they did not interfere with the fit of the HRM strap (Polar H7). The electrode belt was dampened and placed following Polar's guidelines, tightly but comfortably just below the chest muscles. Resting measurements were conducted in two positions, supine and, following an active orthostatic challenge, standing in a quiet laboratory, with a temperature of 20.6 ± 1.0 °C. Recordings lasted for 10 min in the supine position and 7 min in standing position. In order to control for the influences of respiration on HRV (Song and Lehrer 2003) participants matched their breathing frequency to an auditory metronome set at 0.20 Hz (12 breaths min^{-1}). No attempt was made to control the participant's tidal volume (Pöyhönen et al. 2004).

Data recording

RR interval data were recorded simultaneously using a V800 Polar HRM with a Polar H7 chest strap and a three-lead ECG (MP36, Biopac Systems Ltd.), at a sampling frequency of 1000 Hz for both devices. R-wave peaks from the ECG were detected automatically using a custom peak detection algorithm in Matlab (Mathworks, Cambridge). The raw ECG traces and detected R waves were manually assessed to ensure that they had been correctly detected, missed beats were added in manually. Ectopic beats were noted, but not corrected at that stage of analysis. Data was saved as RR interval data files, with intervals in ms. For the Polar HRM raw unfiltered RR data was exported from the Polar Flow web service as a space delimited.txt file.

Data analysis—error identification

Both the ECG and HRM raw RR signal start points were manually matched before further analysis. The two signals were compared side-by-side to identify errors greater than 20 ms. Signals were analysed for errors caused by the data recording using the Polar HRM in comparison to the ECG and non-sinus beats. Non-sinus beats were replaced during analysis in both signals with interpolated data from adjacent RR intervals ($N = 1$). Before correction discrepancies between the two signals, were identified and synchronicity maintained with the insertion of a 0 ms interval. Following visual identification, discrepancies were assigned to one of the six types of errors given in Table 1. The errors identified are based on the research of Gamelin et al. (2006, 2008), with the addition of T6 (a and b) error which had not previously been detected (or were not identified) in previous HRM, but were found with the V800 recordings. A T6 error was identified as an RR interval entirely missed by the HRM, two types of T6 errors were labelled: T6-a were not detectable without a simultaneous ECG recording, whilst T6-b were identified by a discrepancy between the time stamp in the first column and the length of the interval in the second column of the.txt file exported from the PolarFlow web service.

Table 1 Types of error and methods for their correction

Type of error	Description	Correction for HRM data
T1	A discrepancy greater than 20 ms at a single interval, either positive or negative	Error recorded, but not corrected
T2	A long interval, followed by a short interval. Whilst the two points either side were unaffected (<20 ms)	Two uncorrected R–R intervals averaged
T3	Short interval, followed by a long interval. Whilst the two points either side were unaffected (<20 ms)	Two uncorrected R–R intervals averaged
T4	Missed interval(s) on the HRM, equivalent to two or three ECG RR intervals	RR interval divided by the number of undetected R waves
T5	Extra, short, RR intervals from the HRM, in the space of one on the ECG	RR intervals combined to approach the corresponding ECG value
T6-a	RR interval(s) entirely missed by the HRM, undetectable	Error recorded, but not corrected
T6-b	RR interval(s) entirely missed by the HRM, detectable	Interpolated value from the two adjacent points inserted

Data analysis—error correction

Once identified, it is necessary to correct errors in the RR time series. Previously, Gamelin et al. (2008) corrected all errors detected (T1–T5), however, this does not represent typical use, as, without the use of a simultaneous ECG recording it is not possible to detect T1 errors; equally, the newly identified T6-a error is undetectable without a simultaneous recording. Several issues with the method employed for the correction and processing of RR intervals were also identified by Nunan et al. (2008), who argued that exporting the Polar and ECG RR intervals to the same spreadsheet and applying the same editing, interpolation, resampling and detrending procedure to both data sets [as were performed by Gamelin et al. (2008) and the present study], rather than using each system's individual HRV processing capability, is unrealistic and not representative of typical use. Whilst a realistic 'real-world' approach to the correction of intervals and calculation of HRV parameters appears logical, the results of previous studies find issue with the use of different HRV processing software, as a large number of studies have shown that differences in HRV analysis software produce parameters with very poor agreement (Nunan et al. 2008; Radespiel-Tröger et al. 2003; Sandercock et al. 2004; Wallén et al. 2012; Weippert et al. 2010); further, polar no longer provide tools for the analysis of HRV through their PolarFlow service and RR intervals must be downloaded and analysed in a separate software package anyway. As such, in order to address some of the previous comments, the present study avoids the correction of unidentifiable errors (T1 and T6-b), whilst still correcting errors identifiable without a simultaneous ECG recording (T2–T5 and T6-b) following the guidelines given in Table 1, before analysing both data sets with freely available software [Kubios HRV, version 2.2 (Tarvainen et al. 2014)]. Following analysis of the Polar RR trace for errors and the replacement of ectopic, erroneous and noisy complexes, the RR interval data was considered normal, and thus described as NN data.

Data analysis—time and frequency domain and non-linear analysis

For the calculation of HRV parameters an identical 256-s segment of NN intervals was selected from the last 300-s of the ECG and corrected HRM recordings. These selected segments were analysed using Kubios HRV (Version 2.2) for time, frequency domain and non-linear components.

Time domain analysis

Time domain analysis concerns the statistical representation of the variation in NN intervals within the sample (Karim et al. 2011). A number of parameters may be calculated: SDNN is the standard deviation of the NN intervals, RMSSD the root mean squared of successive difference of intervals and pNN50 % the number of successive differences of intervals that differ by more than 50 ms, expressed as a % of the total (Karim et al. 2011).

Frequency domain analysis

Frequency domain analysis allows for the identification of sympathetic and parasympathetic contributions of HRV. Non-parametric power spectral density (PSD) analysis provides basic information on how power, and therefore the variance, distributes as a function of frequency using a fast Fourier transformation. A fast Fourier transformation allows the analysis of the components of the power spectrum density to be quantified into different frequency bands for further analysis (Achten and Jeukendrup 2003). Three spectral components were calculated, very low frequency (VLF; 0.00–0.04 Hz), low frequency (LF; 0.04–0.15 Hz) and high frequency (HF; 0.15–0.40 Hz). Additionally, normalised LF and HF power were calculated (as a percentage of the sum of LF and HF power) and the ratio LF:HF power.

Non-linear analysis

Given the complex control systems of the heart it is reasonable to assume nonlinear mechanisms are involved in the genesis of HRV; non-linear analysis of NN intervals describes the chaotic nature of the signal (Tarvainen et al. 2014). The data were analysed as a Poincare Plot, which is a widely used graphical representation of the correlation between successive NN intervals (Brennan et al. 2001). The analysis comprised of fitting an ellipse oriented according to the line-of-identity and computing the standard deviation of the points perpendicular to and along the line-of-identity, referred as SD1 and SD2, respectively (Brennan et al. 2001). Sample Entropy was also calculated, measuring the complexity of the NN series, low entropy arises from extremely regular time series, higher values reflect more complexity, and highest values are typical for stochastic data sets (Weippert et al. 2014).

Statistical analysis

Descriptive statistics were first calculated for all variables, all values are reported as mean ± SD. Normal distribution and homogeneity of variance was assessed through visual inspection of the frequency histogram, and with either a Kolmogorov–Smirnov (RR intervals) or Shapiro–Wilk test (HRV parameters) depending on the number of samples. Homoscedasticity was determined through the analysis of the plot of the standardised residuals. Depending on the distribution of data either a Student paired *t* test, or Wilcoxon matched pairs test, was used to determine the differences between the data obtained from the ECG and HRM for both the RR intervals and the calculated HRV parameters. The magnitude of the difference of the RR intervals and the HRV parameters was calculated by determining the effect size (ES) which represents the mean difference over the standard deviation of the difference (Thomas et al. 2010); the difference was considered small when ES $\leq$0.2, moderate when ES $\leq$0.5, and great when ES >0.8 (Cohen 2013). Relative reliability was assessed for all variables by calculating the intra-class correlation coefficient (ICC) (Weir 2005), and, as recommended by Atkinson and Nevill (1998), model 3.1 was used. Bland–Altman plots were constructed for supine and standing uncorrected and corrected RR intervals and 95 % limits of agreement (LoA) were calculated for all RR and HRV parameters (Bland and Altman 1986). If heteroscedasticity was present in any HRV data it was log-transformed before the calculation of the LoA. The level for accepting statistical significance of tests was set at $P < 0.05$ for all analysis. All data were analysed using SPSS (Version 22; Chicago, IL, USA).

Results

The total combined number of RR intervals detected in the supine position was 12247, and in a standing position 11240, with 10 errors detected in each of the positions (Table 2), this corresponds to an error rate of 0.082 and

Table 2 Clasification of measurement errors in the Polar V800 HRM signal in supine and standing positions

Type of error	Description of error	Supine	Standing
T1	Single interval of discrepancy	2	1
T2	Long interval and short interval	0	0
T3	Short interval and long interval	0	1
T4	Too few intervals detected	6	1
T5	Too many intervals detected	0	2
T6-a	Interval(s) missed entirely, undetectable	1	5
T6-b	Interval(s) missed entirely, detectable	1	0

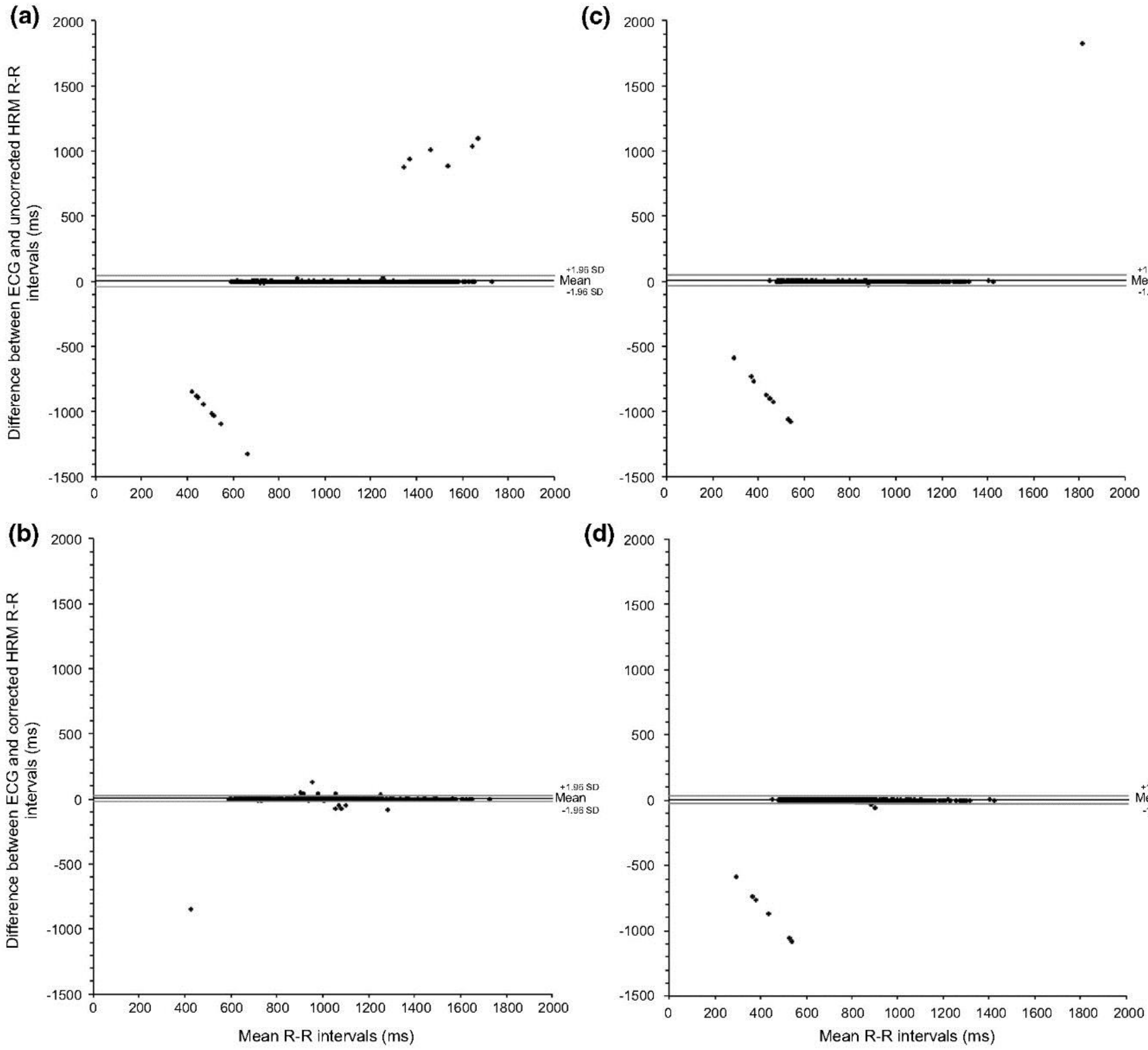

Fig. 1 Bland-Altman plots for supine uncorrected (**a**) and corrected (**b**) and standing uncorrected (**c**) and corrected (**d**) ECG and Polar V800 HRM RR interval data

Table 3 Heart rate variability parameters obtained from the ECG and Polar V800 HRM (mean ± SD), bias and limits of agreement (LoA), intra-class correlation coefficients (ICC) and 95 % confidence intervals and effect sizes in supine and standing positions

	ECG (mean ± SD)	Polar (mean ± SD)	Bias (LoA)	ICC (95 % CI)	Effect size (interpretation)
Supine					
SDNN (ms)	61.37 ± 32.00	61.36 ± 32.03	0.01 (–0.22 to 0.24)	1.00 (1.00–1.00)	0.000 (small)
RMSSD (ms)	55.92 ± 37.76	55.92 ± 37.81	0.00 (–0.32 to 0.32)	1.00 (1.00–1.00)	0.000 (small)
PNN50 (%)	29.05 ± 23.05	29.30 ± 23.04	–0.25 (–1.20 to 0.70)	1.00 (1.00–1.00)	0.011 (small)
VLF power (ms^2)	819.17 ± 777.33	820.05 ± 779.10	–0.88 (–7.52 to 5.76)	1.00 (1.00–1.00)	0.001 (small)
LF power (ms^2)	1050.87 ± 994.29	1051.82 ± 994.94	–0.95 (–6.25 to 4.36)	1.00 (1.00–1.00)	0.001 (small)
HF power (ms^2)	182.97 ± 2212.28	1826.52 ± 2216.23	0.45 (–27.95 to 28.84)	1.00 (1.00–1.00)	0.000 (small)
nuLF power	40.97 ± 15.93	41.05 ± 16.07	–0.08 (–0.72 to 0.56)	1.00 (1.00–1.00)	0.005 (small)
nuHF power	58.88 ± 15.88	58.81 ± 16.02	0.08 (–0.57 to 0.72)	1.00 (1.00–1.00)	0.005 (small)
LF:HF ratio	1.00 ± 1.43	1.05 ± 1.63	–0.04 (–0.43 to 0.35)	0.99 (0.98–1.00)	0.029 (small)
SD1	44.96 ± 33.54	44.95 ± 33.57	0.01 (–0.21 to 0.23)	1.00 (1.00–1.00)	0.000 (small)
SD2	83.98 ± 46.25	83.96 ± 46.27	0.02 (–0.20 to 0.24)	1.00 (1.00–1.00)	0.000 (small)
Sample entropy	1.46 ± 0.31	1.46 ± 0.31	–0.01 (–0.11 to 0.09)	0.99 (0.97–1.00)	0.021 (small)
Standing					
SDNN (ms)	52.03 ± 16.67	52.00 ± 16.67	0.02 (–0.17 to 0.22)	1.00 (1.00–1.00)	0.001 (small)
RMSSD (ms)	30.09 ± 18.24	30.06 ± 18.14	0.03 (–0.28 to 0.34)	1.00 (1.00–1.00)	0.002 (small)
PNN50 (%)	7.23 ± 7.84	7.26 ± 7.99	–0.04 (–1.42 to 1.34)	1.00 (0.99–1.00)	0.005 (small)
VLF power (ms^2)	923.78 ± 766.72	923.99 ± 765.73	–0.20 (–5.58 to 5.17)	1.00 (1.00–1.00)	0.000 (small)
LF power (ms^2)	1371.91 ± 1132.93	1371.33 ± 1133.29	0.58 (–6.67 to 7.83)	1.00 (1.00–1.00)	0.001 (small)
HF power (ms^2)	652.26 ± 753.96	647.93 ± 742.37	4.33 (–25.08 to 33.74)	1.00 (1.00–1.00)	0.006 (small)
nuLF power	70.14 ± 13.21	70.19 ± 13.13	–0.05 (–0.83 to 0.74)	1.00 (1.00–1.00)	0.004 (small)
nuHF power	29.75 ± 13.14	29.70 ± 13.06	0.05 (–0.73 to 0.83)	1.00 (1.00–1.00)	0.004 (small)
LF:HF ratio	3.22 ± 2.39	3.23 ± 2.44	–0.01 (–0.35 to 0.33)	1.00 (0.99–1.00)	0.004 (small)
SD1	21.31 ± 12.92	21.29 ± 12.85	0.02 (–0.20 to 0.24)	1.00 (1.00–1.00)	0.002 (small)
SD2	70.16 ± 20.85	70.13 ± 20.88	0.03 (–0.23 to 0.28)	1.00 (1.00–1.00)	0.001 (small)
Sample entropy	1.05 ± 0.28	1.05 ± 0.28	0.00 (–0.05 to 0.05)	1.00 (0.99–1.00)	0.012 (small)

0.089 %, respectively. A Wilcoxon matched pairs test demonstrated a significant difference between the non-normally distributed supine ECG and corrected Polar RR intervals ($P < 0.005$, ES = 0.000-small), and the uncorrected intervals ($P < 0.005$, ES = 0.001-small). Similarly, a Wilcoxon matched pairs test revealed a significant difference between the non-normally distributed standing corrected ECG and Polar RR intervals ($P < 0.005$, ES = 0.000-small), and the uncorrected intervals ($P < 0.005$, ES = 0.004-small). Effect sizes for the four comparisons were small, <0.004 in all cases.

Bland–Altman plots are presented in Fig. 1 for uncorrected and corrected ECG and Polar data. In both the supine and standing positions, the uncorrected and corrected ECG and HRM RR intervals displayed ICCs of 0.982 and 0.975 for uncorrected and 1.00 and 1.00 for the corrected supine and standing data, respectively. Comparisons between the time, frequency and non-linear HRV parameters, derived from the ECG RR and corrected Polar RR intervals with Student paired *t* test did not display any significant differences. Table 3 outlines the bias and limits of agreement (LoA), intra-class correlation coefficients (ICC) and 95 % confidence intervals and effect sizes; effect sizes for the supine and standing HRV data were <0.021 and <0.012, respectively, and were thus classified as small differences.

Discussion

In this present study raw RR intervals and HRV parameters derived from a Polar V800 HRM and a three-lead ECG were compared. The results suggest that the Polar V800 can produce RR interval recordings consistent with an ECG and that the HRV parameters derived from these recordings are comparable, in healthy subjects during a paced active orthostatic test.

Validity of the detected RR intervals

A significant difference existed between both the corrected V800 and ECG RR intervals and the uncorrected V800 and ECG RR intervals; the significant differences are likely due to the very large sample size of 12247 intervals in the supine position, and 11240 intervals in the standing position, as the effect sizes were small in all cases (uncorrected 0.001 and 0.004, respectively; corrected <0.001 for both). The bias (95 % CI and LoA) of the V800 RR intervals was 0.23 (±66.19; −65.96 to 66.43 ms) and 0.06 (±4.39; −4.33 to 4.45 ms) for uncorrected and corrected supine data, respectively; similarly, the standing intervals were 0.50 (±57.00; −56.50 to 57.50 ms) and 0.59 (±2.28; −1.70 to 2.87 ms) for uncorrected and corrected standing data, respectively. Further, the correction of the Polar HRM RR intervals may be considered highly successful, with a decrease in bias and smaller LoA and an improvement in the ICC from 0.982 (95 % CI 0.981–0.983) to 1.00 (95 % CI 1.00–1.00) and 0.976 (95 % CI 0.975–0.976) to 1.00 (95 % CI 1.00–1.00) for supine and standing intervals, respectively.

The most commonly detected errors (Table 2) were T4 (too few intervals detected) and T6-a (interval missed entirely, undetectable). It is not possible to determine the source of the above errors, but, as thought by Gamelin et al. (2006), it is probable that the T4 errors occurred because of a loss, or decrease in, contact between the skin and the electrode and a resulting reduction in the amplitude of the R wave. Errors in the T6 category (a and b) had not previously been detected when using Polar HRM, it is possible that they result because of software error due to a time asynchronicity in the HRM and/or because of a loss, or decrease in, contact between the skin and the electrode. The T6a error is undetectable without a simultaneous ECG recording, and as such was not corrected; conversely, the T6b error is visible in the.txt RR interval file exported from the PolarFlow website as a discrepancy between the time stamp in the first column and the length of the interval in the second column and, as such, is correctable. With the exception of T1 and T6a error, all other types of error may (and should) be recognised and corrected without the use of a simultaneous ECG recording; the correction of intervals is typical of normal use in a research setting, although further research is required to validate the most appropriate technique for the correction of RR time series. The uncorrected T1 and T6-a errors are visible on the corrected Bland–Altman plots (Fig. 1) as outliers; it is worth noting that in real-world usage, without a reference ECG signal, these would not appear as large discrepancies in the RR time series.

An improvement in RR detection over previous devices

The combined supine and standing error rate of 0.086 % RR interval detection of the Polar V800 was an improvement on previous Polar HRMs: Gamelin et al. (2006) reported an error rate of 0.40 % with the S810 in adults, Vanderlei et al. (2008) a rate of 6.93 % with the S810i, Gamelin et al. (2008) an error rate of 0.28 % with the S810 in children and Kingsley et al. (2004) an error rate of 0.32 % with the 810 s. The bias of the corrected intervals (0.06 and 0.59 ms for supine and standing, respectively), was small and was also an improvement on those recorded previously: Gamelin et al. (2006, 2008) who recorded a bias and LoA for the Polar S810 as 0.9 ± 12 ms in adults and 0.8 ± 10.4 ms in children; Kingsley et al. (2004) with limits of agreement of −5.92 to 5.89 ms for the Polar 810 s at rest; Nunan et al. (2009) bias of 2.5 ms (±61.8 ms) in the Polar S810; and Porto and Junqueira (2009) with a mean supine difference of 1.85 ms (−6.3 to 2.67 ms) and standing mean difference of −0.7 ms (−3.89 to 2.50 ms).

The small bias, tight limits of agreement, small effect size and large ICC of the ECG and Polar RR data suggests that the Polar V800 HRM is a valid tool for the detection of RR intervals at rest in both supine and standing positions. Any differences that are present are likely due to a combination of the use of the elasticated chest strap, which is not secured in position; differences in the means of the transmission of the data, with Bluetooth signal in the V800, and wired electrodes in the ECG; and differences in the R-wave peak detection algorithms used.

Validity of derived HRV parameters

The Polar V800 and ECG displayed excellent agreement between time, frequency and non-linear HRV parameters, similar to levels of agreement found in previous research with the Polar S810 (Gamelin et al. 2006, 2008; Nunan et al. 2009) and S810i (Vanderlei et al. 2008). In contrast, poor agreement has previously been found with the Polar Advantage (Radespiel-Tröger et al. 2003), S810 (Kingsley et al. 2004; Nunan et al. 2008), S810i and Suunto t6 (Weippert et al. 2010) and the RS800 (Wallén et al. 2012). It is apparent that the difference between the studies that have found good agreement between devices, and those that did not, is most likely the result of software: HRV parameters derived from differing software packages are simply incomparable. As such comparisons in the present study will be limited to discussing levels of agreement between the V800 and ECG-derived HRV parameters, and general similarities and trends found in previous studies that did not find poor agreement because of software difference (Gamelin et al. 2006, 2008; Nunan et al. 2009; Vanderlei et al. 2008).

When time domain HRV parameters (SDNN, RMSSD and PNN50) derived from the ECG and corrected Polar RR intervals were compared, excellent agreement were found with small bias, ICC in all cases equal to 1.00 regardless of body position and small effect size (<0.029). There were no significant differences in any parameters, including RMSSD, which had previously been found to be significant for the S810 by Gamelin et al. (2006). As RMSSD reflects short-term variability within the data, it is likely that the lower error rate in the present study (0.086 vs. 0.40 %) resulted in fewer differences in short-term variability, which in turn resulted in greater ICC and smaller effect size. Frequency domain components of VLF, LF, HF power, normalised power and LF:HF also displayed excellent agreement in supine and standings positions. As with both the Polar S810 and S810i (Gamelin et al. 2006, 2008; Vanderlei et al. 2008) there were no significant differences in frequency domain parameters, ICCs of frequency parameters were >0.99 and effect sizes <0.029 in all cases. The non-linear measures of SD1, SD2 and sample entropy, as with the time and frequency measures, displayed good agreement for both supine and standing, with ICC of at least 0.99 for all and effect sizes <0.029. No significant differences in any non-linear components were found, in contrast to the significant difference found in SD1 in Gamelin et al. (2006) and SD2 in Gamelin et al. (2008).

The strong ICCs, alongside the small magnitude of bias and LoA and small effect sizes confirm the validity of HRV parameters derived from the corrected V800 HRM RR intervals for HRV analysis. The HRV parameters bias, ICC and ES appear to support an improvement in the V800 over previous HRM models; as the RR intervals, which the HRV parameters were derived from, displayed very good agreement, and the two signals were analysed with the same software the very small differences found were to be expected. Any differences that did exist are likely because of the very small difference between the ECG RR and Polar V800 intervals. Researchers should be cautious about making comparisons between HRV parameters derived from different software packages, particularly when software packages such as Kubios HRV are freely available that support data exported directly from a large number of ECGs, as well as RR interval data (Tarvainen et al. 2014).

Conclusion

In conclusion, the strong ICC, small bias and tight LoA and small ES found between the ECG and Polar RR data suggest that the Polar V800 HRM is a valid tool for the detection of RR intervals at rest. The Polar V800 also appears to improve on previous HRM models with regard to measurement against ECG. The correction of Polar V800 RR intervals is recommended in order to decrease both the bias and LoA, as it is not only simply applied, but also possible without the simultaneous recording from an ECG. Furthermore, the small bias, narrow LoA, strong ICC (≥0.99), and small ES (≤0.029) also support the use of HRV parameters derived from the corrected Polar V800 signal.

Compliance with ethical standards

Conflict of interest No funding was received for the purposes of this study. The authors declare no conflicts of interest.

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