Effect of ability, ascent style, and route type on psychological and physiological markers in rock climbing

A thesis
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Tabitha Gwendoline Dickson

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Abstract of a thesis submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy.

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by

Tabitha Gwendoline Dickson

Rock climbing is thought to rely upon the interaction of various performance components, and has previously been described as a complex multi-faceted sport. It has been suggested that psychological aspects of performance, such as task perception and the interaction of resulting pre-climb anxieties, contribute greatly to the physiological responses and the overall performance during ascent. However, research which seeks to investigate both psychological and physiological responses during specific bouts of rock climbing are few in number. This thesis attempts to contribute to the novel yet limited body of field based psychophysological research relating to rock climbing. To this end, the studies contained within this thesis investigated psychological and physiological responses as a result of difficult on-sight rock climbing. Elaborating upon previous research, additonal factors which are thought to influence these responses were explored. More specifically, differences in responses between ability groups, style of ascent, and route type were investigated.

In study one, differences in psychological and physiological responses with respect to ability level and ascent style were investigated, during a single on-sight ascent. Seventy-two climbers were split into ability groups defined as lower-grade, intermediate, advanced and elite based on self-reported on-sight grades (Ewbank) of ≤17, 18-20, 21-24 and ≥ 25 respectively. Each climber attempted an on-sight ascent of a designated test route set on an indoor artificial climbing wall. A separate test route was set for each ability group which targeted their self-reported ability with respect to best on-sight. Participants were randomly assigned to either a lead or top-rope ascent and climbers were not informed of their style of ascent until 15 min prior to climbing.

Responses to the climbing task were measured pre, during, and post-climb using a number of psychological and physiological markers.

In total fifty-two participants successfully completed their on-sight ascents, and data for successful ascents were analysed and compared. Pre-climb variables were considered together in order to investigate pre-climb state, more specifically levels of anxiety, prior to ascent. Results indicated that there were no significant differences for grouped pre-climb variables with respect to ascent style. These results suggest that irrespective of ascent style, successful climbers exhibited similar psychophysiological responses prior to attempting an on-sight ascent. Furthermore, this trend was replicated across all ability groups. These findings were thought to be indicative of the high demand and level of unceraínty imposed by the on-sight condition of ascent, lending support to previous suggestion that an on-sight ascent induces the highest anxiety response. During the climb, HR and $\dot{V}O_2$ were measured and averaged across the entirety of the ascent. When expressed as a percentage of $\dot{V}O_{2max}$ and HR_{max} the average HR and $\dot{V}O_2$ responses during ascent were found to be comparable across ability groups. As such, all ability groups appeared to utilise similar fractions of maximal capacity, with elite climbers successfully ascending a route up to eight difficulty grades harder than those of lower ability, whilst still performing at the same workload intensity. It would appear that oxygen uptake during rock climbing may not be directly related to difficulty or personal ability. A technical advantage, personal climbing style, and possible physiological adaptations may be contributors to more strategic and efficient ascents resulting in the capacity to climb at higher grades of difficulty.

The second study presented within this thesis was comprised of two phases of investigation; (1) to investigate whether psychological and physiological responses to competition-style climbing differed with respect to ability level, and (2) to investigate potential psychological and physiological differences based on route type and outcome (success and failure). In phase 1 of study two, intermediate, advanced and elite climbers attempted an lead on-sight ascent of a competition-style route which increased in difficulty as the climber progressed. The route was set with the intention of being just beyond the upper limits of the elite climbers self-reported best on-sight ability (~26 Ewbank). This was done in order to ensure that a fall from the route was highly likely, even for the elite climbers. All climbers failed to successfuly ascend the test route and as such all climbed to the point of failure resulting in a fall. The results obtained both prior to, and during ascent suggest that the intermediate and advanced climbers in the current study may have been limited by technical ability as opposed to physical exhaustion, or increased levels of anxiety. Elite climbers were to be able to maintain a more sustained physical effort during the more difficult phases of the climb. This appeared to be reflected in post-climb blood lactate concentration and ratings of task demand with respect to both physical demand and effort. As such it may be that elite climbers are more accustomed to maximal effort and demonstrate an increased tolerance to the higher exercise intensity required during more difficult ascents.

In the second phase of study two the psychological and physiological responses of climbers in a competitive setting obtained in phase 1, were compared with those exhibited by participants during both successful and unsuccessful lead on-sight ascents in study one. The aim of study two phase 2 was to determine whether the responses of successful climbers differed from those who succeeded by reaching the top of a route, and performances in a competitive context where success is denoted by the distance achieved by a climbers on their ascent. The main findings in this instance were that although there were no significant differences observed between categories of ascent (successful, unsuccessful and competition) for grouped pre-climb variables, trends in CSAI-2R responses indicated high cognitive anxiety coupled with lower self-confidence prior to unsuccessful ascents. As such it may be that self-confidence acts as a buffer in moderating success in rock climbing, demonstrating the role of positive emotions and their impact upon performance as opposed to the detrimental effect of the negative. A second finding of this study was that there appeared to be a differing HR-$\dot{V}O_2$ relationship based on ascent category. Modest increases in $\dot{V}O_2$ were shown for all ascents, irrespective of ability level. A plateau in $\dot{V}O_2$ response was accompanied by a similar plateau in HR response during successful ascents, yet HR was shown to increase in a linear fashion until point of failure during unsuccessful ascents. It is possible that these findings highlight the presence of a climbing specific $\dot{V}O_2$ limitation.

Keywords:

Rock climbing, psychophysiology, ability, ascent style, on-sight, anxiety, self-confidence, cortisol, oxygen consumption, blood lactate.

Preface: Author's Contribution to Multi-Authored Publications

1. DRAPER, N., DICKSON, T., BLACKWELL, G., FRYER, S., PRIESTLEY, S., WINTER, D. & ELLIS, G. 2011. Self-reported ability assessment in rock climbing. ***Journal of Sports Sciences,*** 29, 851-858.

2. DRAPER, N., CANALEJO, J. C., FRYER, S., DICKSON, T., WINTER, D., ELLIS, G., HAMLIN, M., SHEARMAN, J. & NORTH, C. 2011. Reporting climbing grades and grouping categories for rock climbing. ***Isokinetics and Exercise Science,*** 19, 273-280.

3. FRYER, S., DRAPER, N., DICKSON, T., BLACKWELL, G., WINTER, D. & ELLIS, G. 2011. Comparison of lactate sampling sites for rock climbing. ***International Journal of Sports Medicine***, 32, 428-432.

4. DRAPER, N., DICKSON, T., FRYER, S. & BLACKWELL, G. 2011. Performance differences for intermediate rock climbers who successfully and unsuccessfully attempted an indoor sport climbing route. ***International Journal of Performance Analysis in Sport***, 11, 450-463.

5. DICKSON, T., FRYER, S., DRAPER, N., WINTER, D., ELLIS, G. & HAMLIN, M. 2012. Comparison of plasma cortisol sampling sites for rock climbing. ***The Journal of Sports Medicine and Physical Fitness***, 52, 688-688.

6. DRAPER, N., DICKSON, T., FRYER, S., BLACKWELL, G., WINTER, D., SCARROTT, C. & ELLIS, G. 2011. Plasma cortisol concentrations and perceived anxiety in response to on-sight rock climbing. ***International Journal of Sports Medicine***, 33, 13-17.

7. FRYER, S., DICKSON, T., DRAPER, N., BLACKWELL, G. & HILLIER, S. 2012. A psychophysiological comparison of on-sight lead and top rope ascents in advanced rock climbers. ***Scandinavian Journal of Medicine & Science in Sports.***

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Method and approach to the study

Proof reading

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Please detail the nature and extent (%) of contribution by the candidate:

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Please detail the nature and extent (%) of contribution by the candidate:

Design of the study

Participant recruitment and data collection

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Data analysis and interpretation (compiling data set)

Statistical analysis

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Definition of Terms

Abseil - a controlled descent down either a single or double rope, usually completed in retreat after ascending a rock face.

Adjective Grading system (British) - the part of the British grading system, which denotes the severity of a route (traditional only) for the *lead* climber.

Aid Climbing – the climber pulls directly onto a piece of *protection* such as a *piton, bolt,* or *chock,* rather than climbing the rock.

Alpenstock – a long iron-tipped staff typically used by hikers and climbers.

Alpine climbing – term originates from the exploration of the Alps during the1900's, often used to represent a category of climbing best described as mountain climbing in the purest essence. This style of climbing requires movement across mixed terrain; rock, snow and ice from 1-day routes to 8000m multi-day ascents.

Alpinism - a term often used to denote mountaineering usually implies climbing with difficulty in high mountains such as the Alps. The word originated in the 19th Century to refer to climbing for the purpose of enjoying climbing itself as a sport or recreation.

Anchor – a way of attaching the climber, the rope, or a load to rock or ice, either permanent or temporary. The goal of an anchor depends on the type of climbing under consideration but usually consists of stopping a fall.

Arete – a ridge like feature or an outward facing corner on a steep rock face.

Ascender - a device used for a climbing rope that slides freely in one direction and grips the rope when pulled in the opposite direction.

Belaying – a process carried out by the person at the bottom or top of a route. The rope passes through a device on the *seconds* harness. This device when activated stops the rope being *paid out* if the climber were to fall.

Beta – information gathered about a climbing route.

Big-wall climbing – see *aid climbing.*

Bolt – expansion bolt often referred to as a *running belay*. A bolt is used in *sport climbing* to protect the *leader* if they fall. The leader attaches a rope to the bolt with a *carabiner* or *quickdraw*.

Bouldering – climbing relatively low to the ground without a rope for protection. Usually a *crash pad* is placed below the *problem* as a form of protection.

Bridge – a climber uses two walls of close proximity, to oppose forces and ascend a section of a route.

Buttress – a prominent feature that juts out from rock face or mountain.

Carabiner – a metal snap link that links two things together such as the climber to a *rope*, *protection* to the *rope* and *belay plate* to *harness*.

Chalk – climbers often use powdered gymnastic chalk to alleviate sweaty hands whilst climbing, generally placed in a small bag and clipped to the *harness* using a *carabiner*.

Chock – a wedge or hexagonal shaped piece of metal that is attached to a *wire* or *sling*. Often referred to as an *anchor* or *running belay*. These are placed into cracks in rock to protect the climber should a fall occur.

Clean climbing – the opposition of *aid climbing* where routes are climbed without using *gear* such as *pitons* directly to ascend the route, may also be referred to as *free climbing*.

Clipping – the action performed when the climber attaches their rope to a *runner* using a quickdraw.

Closed Crimp – when a climber pulls a hold with the distal parts of their fingers and their thumb is wrapped over the top of the fingertips.

Crag - a word often used to describe an outdoor rock face, which may have several routes on it.

Crash pad - a climbing equipment word for a portable thick mat used to cushion bouldering falls.

Crimp – when a climber grips a hold using almost entirely finger strength from the distal parts of the fingers.

Crux – a term often used by climbers to describe the most difficult section or the most difficult move on any given route.

Deep water solo (DWS) – climbing without protection of ropes and a harness, similar to *bouldering* but takes place above water (usually the sea).

Dry-tooling – technique used in *mixed climbing* where an axe is used for hooking and torquing on rock for leverage as opposed to using the hands.

Dyno – a term used to describe a dynamic move in climbing such as jumping from one hold to the next.

Ewbank – the grading system named and developed by John Ewbank in the 1960s is used in New Zealand, Australia and South Africa.

Exposure – the increasing sense of height as a climb ascends. This is often felt more on steep open rock faces. The feeling a climber gets can be debilitating.

First ascent – the term used to describe the first successful completion of a climbing route.

Flash – completing an ascent on first attempt with some prior knowledge of the route (*beta*) such as grade or having watched a prior ascent.

Free Climbing – climbing a rock face without weighting *protection*. These pieces of *protection* are not used in any way to aid the upward progress of the climber.

Gully - a deep ditch or ravine which is in-cut into the earth.

Head pointing - a play on the term redpoint, used to describe any lead climb which is more of a mental challenge than a physical one. As such the route is practiced numerous times before any attempt of *leading* is made.

Hexcentric - an item of rock climbing equipment used to protect climbers from injury during a fall. They are intended to be wedged into a crack or other opening in the rock.

High-ball – Particularly high *bouldering problem,* generally evaluated based on personal assessment.

Ice climbing – roped and protected climbing on features such as ice-falls, frozen waterfalls, cliffs and rock covered in ice.

Leader (Leading) – the first person to climb a *pitch*. The *leader* is potentially exposed to significant falls depending on where the *anchors* are placed.

Lower-off – an anchor point at the top or just below the top of the route.

Mixed climbing – an ascent requiring moves on snow, ice and rock using a combination of both summer and winter techniques.

Multi-pitch – where a rock face is too high to be climbed in one rope length the route is climbed in a number of *pitches*.

Nut – a small metal block with a wire on it. It is placed into cracks in the rock face as a *runner* to protect the *leader* in a fall.

On-sight – a route that is attempted with no prior knowledge or inspection.

Open Crimp – similar to a *closed crimp* however, the thumb is not wrapped over the top of the fingertips. The hand is in an open position on the hold.

Pinch – when a climber must use their thumb and fingers to squeeze the sides of a hold.

Pitch – a stretch of rock face between two belay positions or the ground and the top of the climb.

Piton – a metal peg with a hole in the end for attachment of a *Carabiner*. A *piton* is usually hammered into a small crack in a rock face before *clipping* the rope to it using a *Carabiner*. Pitons are used for *protection* (*running belays)* whilst climbing a route.

Portaledge - a portable sleeping cot or 'ledge' made of nylon that is snugly fitted over a lightweight aluminium frame. It can be hung from gear like *nuts* or *pitons* on a rock wall, allowing a comfortable place for climbers to sleep on *big-wall* ascents.

Problem – used to describe a *bouldering* route.

Protection – any form of *anchor* or *runner* which attaches to the rock to help protect the climber if they fall, these may include, but are not limited to: *pitons, bolts, chocks* or *slings*.

Psicobloc – see *deep water solo.*

Quickdraw – a small piece of webbing with a *Carabiner* on each end. It is generally used to connect *protection* (*bolt/wire/nut* etc) in the crack to the rope of the *leader.*

Redpoint – when a climber has practiced a specific route over and over again until it has been ascended *cleanly* with no falls or weighting of the rope.

Route – a word commonly used to denote the path of a particular rock climb

Runner – a *bolt, chock, sling* or any form of *protection* on a route, which attaches the climber to the wall.

Scrambling - a method of ascending rocky faces and ridges. It is an ambiguous term that lies somewhere between hill-walking and rock climbing. It is often distinguished from hill-walking by defining a scramble as a route where hands must be used in the ascent.

Seconding – generally considered the *second* person to climb a *pitch,* following the *leader*. The *second* is attached to a rope from the top, which prevents a fall and is considered much safer than *leading*.

Single-pitch – routes climbed predominantly in one rope length from the base to the top.

Slab – a section of rock which is less than vertical.

Solo – style of climbing in which the climber climbs without a belayer, harness or any form of protection.

Speed climbing - climbing in which speed is the ultimate goal.

Sport climbing – specially prepared routes with pre-placed in-situ protection in the form of *bolts* offered every few meters. Common in Europe, America and New Zealand but not as prominent in the United Kingdom.

Spotter – name given to individual(s) who aid a climber into a safe landing when attempting a boulder *problem.*

Static move – a term used to describe the slow, steady and balanced nature of a climbing move. No fast dynamic movement *(dyno)* is performed.

Technical grade (British) – the part of the British grading system, which purely denotes the technical difficulty of a route. The technical grading system is also used in the French grading system.

Top-rope – climbing with a rope anchored from above.

Traditional Climbing – climbing a *pitch* or more, using only removable forms of *protection (runners)* such as *wires* and *nuts* NOT *bolts* as seen in *sport climbing*. The *leader* places these *running belays* in the rock to protect them if they fall; the *second* removes them as they climb up. This form of climbing is considered far more dangerous that *sport climbing,* as the *running belays* are more likely to fail in a fall.

Treadwall – a rotating climbing wall that moves by the application of body weight, may also be referred to as a 'climbing ergometer'. A vertical treadmill with modular holds attached that can be manipulated to afford differing angles of ascent.

Yosemite Decimal System (YDS) – the grading system was developed by the Sierra Club in the 1930s for walkers in the Sierra Nevada. The rock climbing section was added in the 1950s in California.

List of Abbreviations

Abbreviations

ACSM	American College of Sports Medicine
ANCOVA	Analysis of covariance
ANOVA	Analysis of variance
APFT	Army Physical Fitness Test
ATP-PCr	Adenosine Triphosphate – Phosphocreatine
ATP	Adenosine Triphosphate
BLa	Blood lactate
BMC	British Mountaineering Council
CI	Confidence interval
CNS	Central nervous system
CSAI-2R	Competitive State Anxiety Inventory – 2 Revised
CV	Cardiovascular
D	Difficult (climbing grade)
df	Degrees of freedom
E	Extreme (climbing grade)
EE	Energy expenditure
ELISA	Enzyme-linked immunosorbent assay
EMG	Electromyogram
Eta^2	Proportion of variance
F	Fixation incidences
HCL	Hydrochloric acid
HPA	Hypothalamic-pituitary-adrenal axis
HR	Heart rate
HS	Hard severe (climbing grade)
HVS	Hard very severe (climbing grade)
ICC	International Council for Climbing Competition
IFSC	International Federation of Sport Climbing
IOC	International Olympic Committee
LSD	Least significant difference
MANOVA	Multi analysis of variance
M	Moderate (climbing grade)
MVC	Maximal voluntary contraction
n	Number
N/A	Not applicable
NASA-TLX	NASA Task Load Index
NZ	New Zealand
NZAC	New Zealand Alpine Club
NZSF	New Zealand Sport Climbing Federation
p	Probability statistic

PANAS	Positive and Negative Affect Schedule
POMS	Profile of Mood States
R^2	Coefficient of determination
RNPFS	Report of National Physical Fitness Surveillance
SD	Standard deviation
t	Ratio of an estimated parameter
TMB	Tetramethylbenzidine
UIAA	Union international des associations d'alpinism
UK	United Kingdom
USA	United States of America
V	V scale (climbing grading system)
VD	Very difficult (climbing grade)
$\dot{V}O_2$	Volume of oxygen consumed
$\dot{V}O_{2peak}$	Peak volume of oxygen consumed
$\dot{V}O_{2max}$	Maximal volume of oxygen consumption

Units of measurement

$bts \cdot min^{-1}$	Beats per minute
$kcal \cdot kg^{-1} \cdot min^{-1}$	Kilocalorie per kilogram per minute
$kcal \cdot min^{-1}$	Kilocalorie per minute
$kcal \cdot m^{-1}$	Kilocalorie per meter
$mL \cdot kg^{-1} \cdot min^{-1}$	Millilitres per kilogram per minute
$mmol \cdot L^{-1}$	Millimols per litre
N	Newton
ng/mL	Nanograms per millilitre
nmol·L	Nanomols per litre
RPM	Revolutions per minute
W	Watts

Chapter 1
Introduction

Rock climbing as a sport was first established during the mid to late 19th Century by adventurous mountaineers seeking first ascents across challenging new terrain. It was not initially considered a pursuit in its own right, but as a means of gaining skill in climbing exposed rock faces for more daring alpine ascents (Wilson, 1992). Beyond its practical capacity in this sense, rock climbing was considered to be a small and inferior facet of mountaineering, described as a poor substitute for alpinism. Yet by the early 20th Century the allure to complete new routes, coupled with advances in methods and tools for aided ascents, saw increasingly daring routes being climbed. The rapid development of the sport continued, and by the late 1980's extreme climbers emerged with dedicated attitudes towards greater personal achievement but also pushing the boundaries of technical difficulty worldwide. It was during this time that specialisation within the sport occurred with various sub-divisions, diverse styles, demands, rules and ethics emerging. Competitive climbing also gained international recognition at this time, with the first successive annual World Cup taking place in 1989.

An increased effort towards organising competitive events worldwide ensued, both at senior and junior levels. With growing participation in competitive climbing, the International Council for Climbing Competition (ICC) was created in 1997, followed in close succession by the International Federation of Sport Climbing (IFSC). The main focus of the IFSC is to facilitate the necessary development of the sport in order to meet Olympic Games requirements. In 2007 this was achieved, with the International Olympic Committee (IOC) granting provisional recognition to the IFSC as the governing body for the sport. This status was upgraded to definitive recognition in 2010, and sport climbing was welcomed to the Olympic family. As a result, competitive rock climbing reaching the Olympic stage is a realistic and not too distant possibility.

The evolution of rock climbing from its conception as an almost obsolete division of mountaineering to an internationally competitive sport, encompassing a number of disciplines, is further evidenced in the development of its research base. Early rock climbing literature (pre-1990) was predominantly available in the form of books and magazines, offering anecdotal training tips and technical advice. The scientific research base during this time was dominated by reports of accident occurrences and injury specificity in climbers (Addiss and Baker, 1989; Bollen, 1988; Bowie et al., 1988). With the introduction of the first annual World Cup climbing event in 1989 a small number of studies emerged with a different focus. These were concerned with profiling elite climbers, with the aim of determining which key characteristics were prerequisites for successful performance (Grant et al., 2001; Grant et al., 1996; Watts et al., 1993). Over the next two decades research efforts intensified and included investigating trainable characteristics, physiological responses, and biomechanical analysis of performance. Catalysed by the introduction of climbing specific test apparatus, and the development of instruments which allow for better methods in relation to field testing, the specificity and depth of investigations into physiological responses to rock climbing has increased greatly. Despite these advances some methodological limitations such as standardisation of grading criteria, style of ascent and ability classification render comparisons between studies and interpretation of findings problematic (Giles et al., 2006; Sheel, 2004; Watts, 2004).

Rock climbing is often described as a multi-faceted sport which relies upon the interactions of various components of performance in order to succeed. The influence of psychological state with respect to perception of the task has been suggested as a key contributory factor in the physiological responses and resulting performance of climbers (Goddard and Neumann, 1993; Hörst, 2003; Hurni, 2003; Sagar, 2001). However, research which directly investigates possible interactions between the psychological and physiological mechanisms of performance during ascent is scarce. A number of suggestions as to the extent and nature of these responses, particularly between differing levels of ability remain speculative. Only three known studies have systematically attempted to quantify both psychological and physiological responses during climbing tasks (Draper et al., 2008b; Draper et al., 2010; Hodgson et al., 2008), all of which have investigated these responses in 'intermediate' climbers exclusively. As such it would appear that the understanding of the psychological and physiological demands which underpin successful climbing performance is limited.

1.1 Thesis overview

This thesis aims to provide a historical and contextual overview of rock climbing coupled with a comprehensive review of literature, both from a coaching perspective and with respect to the development of scientific research. This thesis aims to contribute to the limited body of field based research within the sport by investigating differences in ability group with respect to psychological and physiological responses incurred as a result of difficult on-sight sport climbing. In addition, factors which are thought to affect psychological and physiological responses and subsequent performance outcomes, such as style of ascent and route demand are also investigated. To this end the research presented within this thesis is comprised of two main studies, referred to collectively as experimental chapters. Study one investigates ability group and ascent style differences in the pre, during and post-climb responses to an on-sight lead ascent completed on a route set relative to best on-sight performance. Study two investigates (1) ability group differences in psychological and physiological responses to a competitive ascent whereby an on-sight attempt of a route of increasing difficulty was attempted and, (2) differences in psychological and physiological responses for intermediate, advanced and elite climbers with respect to route type and outcome.

1.1.1 Structure

Chapter 2 presents a review of literature which aims to provide an overview of the development of rock climbing as both a recreational activity and competitive sport, followed by a comprehensive review of relevant literature to date. The former sections of this chapter serve to initiate the reader into the complexity of the sport. Particular attention is focused on providing an overview of the different disciplines, styles of ascent and associated climbing terminology. These describe key features and terms central to the subsequent review of literature, and the main body of research within this thesis. Chapter 2 then progresses to review past and present literature with particular emphasis on the psychological and physiological components of performance.

Chapter 3 provides details of the methods and procedures common to both experimental chapters in this thesis. This chapter is initiated with the presentation of a number of preliminary studies which were conducted in order to justify and validate some of the approaches used in the procedures and experimental design of the main investigations.

Chapters 4 and 5 are experimental chapters which detail the specific methods and procedures, results, and discuss the findings for study one and two respectively.

Chapter 6 concludes the thesis by providing a summary of the main findings from study one and two collectively, and suggests areas of future research.

1.2 Significance of studies

Investigations seeking to characterise both the psychological and physiological responses to rock climbing utilising a cross disciplinary approach are limited. Moreover the assessments of these markers of performance with respect to ability level are almost non-existent within current literature. To date, studies which have commented upon the psychological and physiological contributions to climbing performance are limited to intermediate climbers only. Assessments of such responses have not been conducted with respect to difficult climbing at the limits of ability level. This is in relation to lead on-sight sport climbing in particular, which is thought to represent a greater physical and mental demand than top-rope or redpoint ascents. The interactions of ascent style and style of route have been cited as factors which should be considered in the overall demands of an ascent. Previous studies have investigated responses to ascents differing in displacement, wall angle and grade. However, the effect of relative ability level on ascents which differ in demand have not been substantiated. Finally a majority of studies present results based on the responses of climbers who successfully complete ascents. No known research to date identifies potential performance differences between climbers who complete a route and those who fall. It would appear that understanding the psychological and physiological differences between success and failure may result in key findings with respect to which components of performance contribute to successful rock climbing. It is hoped that gaining a greater understanding of the interaction between psychological and physiological responses in these contexts will enable more accurate conclusions to be drawn with respect to performance differences and subsequent suggestions for future enhancement.

1.3 Purpose statement

The purpose of study one was to determine whether there were any differences in psychological and physiological responses to difficult on-sight sport climbing with respect to ability level and style of ascent. The purpose of study two was to ascertain whether psychophysiological responses to competition-style climbing differed with respect to ability level, and to assess psychological and physiological markers of performance based on route type and outcome (success or fall).

1.3.1 Aims

The specific aims for study one (Chapter 4) are:

Aim 4.1 Determine to what extent objective and subjective anxiety responses differ between lower-grade, intermediate, advanced and elite climbers prior to and during difficult on-sight ascents.

Aim 4.2 Determine whether lower-grade climbers exhibit a greater intensity of anxiety response compared to elite climbers.

Aim 4.3 Investigate the effect of ascent style (lead and top-rope) on psychological and physiological responses during on-sight ascents with respect to a range of climbing abilities.

The specific aims for study two (Chapter 5) are:

Aim 5.1 Investigate intensity of anxiety in response to competition-style climbing in intermediate, advanced and elite climbers.

Aim 5.2 Investigate whether successful and unsuccessful climbers exhibit different psychological and physiological responses.

1.4 Strengths of studies

- The studies contained within this thesis are the only investigations to date which present findings in relation to four strictly defined ability groups: lower-grade, intermediate, advanced and elite.

- The experimental chapters within this thesis present the largest known investigation to employ a cross-disciplinary approach in assessing the physiological and psychological demands of rock climbing.

1.5 De-limitations, assumptions and limitations

Careful consideration was exercised in order to ensure that valid and reliable methods could be devised which accurately assessed on-sight top-rope, lead and competition-style aspects of indoor rock climbing. This is evidenced in the preliminary studies presented within Chapter 3. However, due to the dynamic, multi-faceted, and often subjective nature of rock climbing, some limitations, de-limitations and assumptions remained within studies one and two.

1.5.1 De-limitations

- Findings of the current studies are specific to the four ability groups: lower-grade, intermediate, advanced and elite only.
- Findings are specific to indoor on-sight lead, top-rope and competition-styles of climbing only.
- Data is representative and specific to the individual route profiles used within study one and study two.

1.5.2 Assumptions

- All participants refrained from either inspecting or climbing the routes before their testing session, as requested.
- All participants refrained from strenuous training 48 hours prior to testing, and had observed a period of complete rest for at least 12 hours before each testing session.
- All participants arrived having refrained from consuming alcohol for 24 hours, and having consumed no food or caffeine in the 3 hours prior to each testing session

1.5.3 Limitations

- Familiarisation climbs whilst wearing the $K4b^2$ (which involved wearing a mask) were conducted by all participants before the final climbing testing session. However, as lead climbing often involves the climber placing the rope in the mouth to clip protection (quickdraws), a slightly unnatural style of ascent cannot be ruled out.
- Immediately post-climb blood lactate (BLa) concentrations represent those sampled 30 s post-climb, as the participants had to be lowered to the ground before sampling could take place.

Chapter 2
Review of Literature

The following chapter begins by presenting a brief historical overview of rock climbing both worldwide and with respect to New Zealand specifically. As such these sections aim to provide the reader with key contextual background information with regard to the evolution of rock climbing as both a recreational activity and competitive sport. Following on from this particular attention is paid to explaining climbing disciplines, styles of ascent, difficulty rating and grading systems unique to the sport. It is hoped these sections will provide the reader with an appropriate overview of rock climbing and its associated terminology which will subsequently referred to throughout this thesis.

Finally a review of relevant coaching and research literature is presented, with particular emphasis on the physiological and psychological components of performance. This review serves to highlight key findings, research limitations and comparisons between rock climbing research to date in these areas. As such a number of topics are reviewed; anthropometry, fitness and physical characteristics, heart rate and oxygen consumption, energy system contributions, energy expenditure and psychophysiology.

2.1 History of rock climbing

The first ascent of Mont Blanc in 1786 by Michel Paccard and Jaques Balmat is widely considered the birth of true modern-era mountaineering in the Western world, and gave way to what is described as the golden age of mountaineering during the 1900's (Hattingh, 1998). During this period mountaineers sought to ascend peaks using previously unrecognised routes, with the action of doing so being purely for its own sake and sense of achievement. The formation of the Alpine Club in 1857 elevated the status of alpine mountaineering. By the late 19th century the 'sport' of mountaineering was born, and became increasingly popular and respectable pastime, particularly amongst the British gentry. This was to be one of the driving forces behind alpinism and later the development of rock climbing.

With adventurous mountaineers seeking new ascents across challenging terrain consisting of snow rock and ice, the realization that gaining skill in climbing rock faces would be advantageous became apparent. Whilst these methods were only considered a small facet of mountaineering, a select number of climbers set about training on small crags and cliffs prior to alpine ascents. At this time the activity was considered a poor substitute and inferior practice in relation to the real thing, and was merely identified as a training aid for alpine mountaineering (Peter, 2004; Wilson, 1992). In time, further clubs were established with local affiliations within main mountain areas. Here the emphasis on Alpinism was diminished and local climbing began to emerge as the main focus. Initial ascents were limited to easier gullies and ridge lines emulating the terrain often encountered as part of long alpine ascents. Whilst still not considered anything more than good practice, the allure to complete new unclimbed routes soon gave way to climbers seeking more complex routes on face walls, buttresses and ridges (Wilson, 1992).

During the latter part of the 19th Century intensity and intent amongst this new band of climbers rose and new ascents on rocky outcrops were sought further afield. In 1886 W. P. Haskett Smith made the first ascent of the 70 foot Napes Needle in the Lake District of England, and is thought to have paved the way for the sport of rock climbing (Middendorf, 1999; Wilson, 1992; Wilson, 1997). This ascent was completed on his own as a free solo attempt, with no aid and for the sheer fun and accomplishment of completing the climb. The resulting publicity surrounding this feat introduced the general public to the new sport of rock climbing, inspiring others and generating a new attitude toward such ascents.

Climbers in Europe were the first to seek and embrace great advances in the development of new methods and tools to aid them in increasingly daring ascents. From the mid to late 19th Century the mountaineers' set of tools consisted mainly of a long alpenstock, spiked or nailed boots and thick heavy ropes (Wilson, 1992). At this time ropes were not used to catch a falling climber but generally served to create human chains for travel through exposed or dangerous terrain. Occasionally climbers would resort to the use of an artificial aid, most commonly a crude spike driven in by hammering with a rock. Such aids were only used as additional hand or footholds and were not designed to support a climbers full weight (Middendorf, 1999). Around the turn of the century the first pitons designed specifically for inserting into cracks in the rock faces were produced. At this time, emphasis was still firmly centred on the purity of climbing and such aids were used primarily to facilitate safe descents (Wilson, 1992). However, it was not long before those seeking new experiences shifted the means and methods of ascent. In Europe, the use of pitons for the ascent of steeper technical unclimbed faces soon became acceptable. New technology also emerged in the form of stronger manila ropes, climbers secured the rope to the ring of pitons during ascent with a short length of cord, allowing for short leader falls (Middendorf, 1999).

In 1910 with Eastern Europe leading the way on harder ascents, a trio of inventive German climbers contributed greatly to the development of climbing aids. Otto Herzog created the first steel carabiner for climbing, and Hanz Fiechtl reinvented the piton, replacing the old ring design with an eyelet. With this new technology Hans Dulfer worked on new methods for safeguarding the leader, with revisions of belay techniques and the possibility of sturdier anchors (Middendorf, 1999; Peter, 2004). These advances and newly found confidence in equipment brought forward a bolder style of climbing combining traditional ‘free’ methods with the benefit of technical aid, affording new opportunities to advance on steep and overhanging routes which had previously been unthinkable. With this, Austrian and German climbers continued to put up considerably harder routes than those being accomplished elsewhere. Whilst there was a surge in aid-assisted ascents, the mountaineering and climbing community continued to harness a band of individuals who were dramatically opposed to any reliance on such equipment. Impressive free solo ascents were still being completed by leaders who were morally opposed to artificial aid. This was a prevalent viewpoint amongst British climbers, where there was an aversion to unnatural techniques (a point of view still upheld amongst many British climbers in the present day) and consequently the difficulty of routes in Britain did not increase greatly during this time (Wilson, 1992).

Despite the advances seen overseas, aided ascents did not filter through to British climbing easily due to conflicts surrounding climbing ethic, and instead different techniques and styles slowly evolved. By the 1920’s shorter European climbing crags were heavily pegged and abandoned, serving only as training grounds. Meanwhile, the absence of such aid in British climbing led to similar locations affording challenging ascents, with this style of climbing becoming a pursuit in its own right (Wilson, 1992). Top climbers of this period began pioneering a pitonless craft on short crags in rural areas, signalling the beginning of a clean climbing revolution (Middendorf, 1999).

During the 1930’s the clean climbing movement saw a new generation of climber emerge, concentrating on balance climbing. Here the emphasis was placed on footwork rather than upper body strength, aided by the introduction of soft soled climbing shoes.

Although these routes weren't particularly steep they were challenging, featuring long unprotected leads (Wilson, 1992). As well as changes in climbing style, one of the most prominent mechanical developments was that of one by Fred Piggott, who began experimenting with placing and slinging natural chockstones during the late 20's known as 'pebble protection'. Later, around the 1950's, the use of pebbles was replaced as innovative climbers began using left over machine nuts which were drilled out and slung (Peter, 2004). These soon evolved into custom made aluminium 'chocks' with different sizes and shapes produced to enable better placements (Fyffe et al., 1990). This style of climbing proved popular among those seeking harder climbing yet wishing to maintain their non-destructive principles. The use of chocks provided an additional challenge yet they weren't damaging to the rock and were removed post ascent. These methods ensured the disappearance of pitons from the free climbing scene in a relatively short time frame, relegating their use to last resort.

With the acceptance and growing popularity of new styles and methods of protection during the 1930's, British climbing saw a revival over the next two decades, with harder and better routes being discovered. This revival was spurred on post-war as equipment and shared knowledge became more readily available. In addition, social change post-war meant that climbing evolved to include a greater range of athletes. Where previously mountaineering and rock climbing had been reserved for the upper classes, working class individuals were now afforded the opportunity to engage in the sport with a new breed of climber emerging (Middendorf, 1999; Peter, 2004; Wilson, 1992). By the mid 1950's the difficulty rating of British climbing was increased to a similar standard as seen across Europe. Advances in equipment, such as Nylon and Perlon ropes, vibram soled boots, and later specialized French rock shoes knows an P.A (developed by Pierre Allain) which allowed delicate climbing on small holds contributed greatly to new ascents. Working class climbers such as Joe Brown pioneered scores of excellent routes, climbing difficult rock for a long way without protection. One of Joe Brown's most important first ascents of the time was Cenotaph Corner in Wales in 1952, a feat which captured the imagination of climbers and served as a test piece over the next decade (Peter, 2004; Wilson, 1992; Wilson, 1997). Other influential climbers of this time were those such as John Gill who introduced new dynamics to the sport of rock climbing with the use of chalk, training methods and movements not dissimilar to those encountered in formal gymnastics. Gill also advocated the sport of bouldering as an activity in its own right, a branch of climbing which will be discussed later in this review.

Over the next two decades new routes with names reflecting their character captured climbers imaginations and many big rock routes were pioneered during this time, particularly in America as new techniques and knowledge filtered through from overseas (Hattingh, 1998; Middendorf, 1999). However, it was not until the 1970’s that the next major turning point in the development of rock climbing took place, with the introduction of sport climbing in France. This involved placing bolts on rock faces in order to afford climbers protection on some of the harder routes possible. Although the method of inserting bolts had been invented many years prior to this by Laurent Grivel in the 1930’s with the introduction of the rock drill and expansion bolt, the use of bolts was sporadic up until this time (Middendorf, 1999) and many climbers were still in opposition to such techniques. A notable ascent of this nature was that by Cesare Maestri in 1971 where he took the idea to its limit during his ascent of Cerro Torre in Southern Patagonia. In order to succeed, Maestri placed a ‘bolt ladder’ using a compressor driven drill across blank rock for 90 metres. The ascent sparked controversy as a wave of protest followed from those opposed to the bolted technique, with the route ascended 3 years later in a classic bolt free style by a group of Italian climbers (Hattingh, 1998). Nevertheless, climbers saw the opportunity to be able to attempt new lines with relative safety on impossible sections of rock, and bolted routes soon became the norm in Europe. This development and embracing of new technology allowed climbers to push their technical limits and improve fitness, resulting in a new style of climbing.

Elsewhere, British climbing and in particular free climbing saw improvements of its own in the 1970’s. It was a period noted for applying the free climbing ethic to previously aided routes (Peter, 2004). New devices for protecting free climbing were pioneered around this time, adding to the climbers’ equipment list. The invaluable Hexcentric was co-patented in 1971 affording protection in parallel sided cracks. Similarly Ray Jardine developed a spring loaded opposing multiple cam unit during this time allowing effortless protection placement on hard routes (Fyffe et al., 1990; Middendorf, 1999).

In the 1980’s the French-styled bolted routes of sport climbing were fully introduced to the US and Britain. During this time bolting became extremely popular, prompting passionate debate about where its use was acceptable. This led to fixed equipment policies being drawn up by mountaineering councils, and bolts were largely confined to areas such as quarries and limestone cliffs. Despite this ruling, it was not uncommon for bolts to appear and later be chopped, particularly on routes that had previously been completed without the aid of bolts (Peter, 2004). This style of climbing adopted from the continent brought with it the revelation of safer lines which were well protected. Not surprisingly, this method of ascent was popular among those seeking to push themselves and perform at the limit of ability (Atchison-Jones, 2004; Peter, 2004). Equipment also progressed during this time with the first 'sticky' climbing shoes developed just for rock climbing, and new styles of climbing harnesses becoming available. Kernmantle ropes were now common, and the use of chalk to aid grip as advocated by John Gill in the 1950's was standard practice by this time.

Over the next two decades modern extreme climbers began to emerge, with a competitive and dedicated attitude to accomplishing routes of the highest technical standards. The art of head pointing became extremely fashionable during the 1990's as a means to achieving ascents of the hardest routes possible by practicing before leading the climb. This was prevalent on poorly protected traditional routes on grit stone, and the most challenging sport routes (Peter, 2004). Another notable characteristic of this time was specialization, those who considered themselves rock climbers could quite easily be participating in very different sports. Diverse climbing styles containing different ethics, 'rules' and demands had evolved. The term 'rock climber' became a generalization that said little about the climber as attitudes and training towards different branches of climbing were established (Creasey et al., 2001).

The 1990's saw a great level of interest in the art of bouldering, particularly among British climbers. This sub division involved ascending demanding and powerful short routes without the need for a harness or rope. This popularity was generated with the arrival of crash pads from the US and new guide book publications dedicated specifically to bouldering locations. In fact, many leading sport climbers of this era such as Jerry Moffat and Ben Moon abandoned roped climbing, choosing to focus their talent and efforts on increasingly challenging boulder problems (Peter, 2004). In contrast to this, a small pocket of climbers at this time were focused on repeating established routes in a 'purer style' by completing them on first attempt. This style of climbing is still highly regarded amongst the climbing community today, and represents the ultimate challenge even for cutting edge climbers.

As well as experienced climbers pushing the boundaries of what was technically possible, a new innovation at this time brought breakthroughs in the accessibility and safety of climbing for all. Indoor venues specifically created for climbing began to appear around this time. These walls emulated rock faces, featuring holds manufactured from a mixture of sand and resin that could be placed in a number of different configurations, with the ability to create and change routes (Atchison-Jones, 2004). Such venues offered a training ground for dedicated climbers or those without regular access to real rock, but also offered up a safe closed environment for those wanting to take part in the activity at a recreational level.

Competitive climbing was at the forefront of the sport during the 1980's. Although competitive climbing had been taking place in small pockets with organized speed climbing events from as early as the 1940's in the USSR, such gatherings were generally closed affairs. In 1985 the first difficulty-orientated events were held not far from Torino, Italy. Only a year later over 10,000 spectators gathered to attend the finals of the same event, and even attracted media coverage (Middendorf, 1999). In the same year the first indoor event was organised by the French, showcasing the growing interest in the sport at the time. The first recognized successive annual world cup climbing event was arranged in 1989 by the International Union of Alpinist Associations (Union Internationale d'Associations d'Alpinisme (UIAA)) and took place on an artificial climbing wall. By the early 90's events were being organized worldwide with circuits in Europe, Japan and the US. International events were standardized after deciding that they should be run exclusively on artificial indoor walls to eliminate environmental impact. In 1991 and 1992 the first senior and youth world championships were held respectively. With the increasing attraction and popularity of sport climbing, the International Council for Competition Climbing (ICC) was created in 1997 as a sub division within the UIAA to ensure its continuing development. The new discipline of bouldering was added to competitive climbing in 1998, and this was later elevated to a World Cup event a year later in 1999 (IFSC, 2012).

As rock climbing entered a new millennium the events calendar swarmed with regional circuits and International gatherings in a variety of disciplines. In 2006 the UIAA endorsed the creation of the International Federation of Sport Climbing (IFSC) to administrate, regulate and develop all aspects of competition climbing in order to meet Olympic games requirements (Morrison and Schoffl, 2007). In 2007 the International Olympic Committee (IOC) granted provisional recognition to the IFSC welcoming sport climbing to the Olympic movement. More recently in 2010 the IOC gave definitive recognition to the IFSC as the governing body for sport climbing, and the IFSC is now considered part of the Olympic Family with the possibility of competitive climbing making an appearance at the Olympic Games in the not too distant future (IFSC, 2012).

2.2 Development of rock climbing in New Zealand

The development of rock climbing as a sport in its own right was somewhat slower in New Zealand when compared with the progress of Europe and Britain, probably due to New Zealand's modest population and relatively small number of climbers. However, the pathway to the emergence of technical and challenging rock climbing in New Zealand began in a similar manner to that overseas. New Zealand alpine climbers began seeking challenges on shorter crags in order to practice technique in preparation for bigger ascents of the surrounding peaks. The first true recorded rock climb is thought to have been completed by Tom Fyfe in the 1890's in scrambling up Sebastopol Bluffs Red Arete above Mount Cook Village, an ascent that was completed just prior to his famous first ascent of Mount Cook in 1894 (Sedon, 2007). By the 1900's scrambling and pushing ascents of new routes and peaks among areas such as the Darran Mountains were extremely popular amongst mountaineers. The 1920's and 1930's saw small emergent groups of climbers pioneer new routes in a number of locations across the North and South Island. With the equipment available at the time, much of these are perhaps better described as ascents in hobnail boots. Despite small pockets of local enthusiasts seeking new routes, the main focus was still mountaineering, with particular emphasis on the Southern Alps (Sedon, 2007).

During the 1940's-50's some of the earliest rock climbing ascents were made at locations such as Castle Rock and Mt Taranaki (Lee, 2001). However it was not until the 1960's and the two decades that followed that a greater effort could be seen in pursuit of rock climbing. In 1968 the country's first guide book was produced by Don Hutton, which focused on Castle Rock and the Port Hills area of the South Island (Lee, 2001). Similarly Graeme Dingle's 1970 guidebook to Titahi Bay was the first to apply grades to rock climbs in New Zealand, using the British adjectival system classifying routes as 'severe', 'hard severe', hard very severe' and so forth (Sedon, 2007). Despite these developments, rock climbing remained a fringe sport in New Zealand until the

1970's when modern era climbing took off, becoming an independent activity. Areas such as Whanganui Bay and Mt Eden quarry were developed during this time, with the latter now considered the birthplace of hard rock climbing in New Zealand (Sedon, 2007). By the mid 1970's climbers had adopted the grading system invented by Australian John Ewbank utilizing a single number as an indicator of difficulty (Wethey, 1989).

A stream of new ascents and developments followed, and in 1976 notable events include the first ascent of the Mt Eden climb 'supergroove', given a grade of 26 (Ewbank), and considered the hardest climb in Australasia at the time (Sedon, 2007). Rock climbing locations in New Zealand and new first ascents increased in number by the end of the decade and into the early 1980's. During this time the universal application of bolted techniques, coupled with the use of chalk and sticky rubber climbing shoes resulted in a contemporary approach to climbing and claiming first ascents. In Whanganui Bay alone a total of 96 first ascents were recorded during the year 1981. Many areas benefitted from overseas influence such as Taranaki, where in the year 1982 twenty new routes were set over one weekend during a mountain safety course led by two Brits Nigel Shepherd and Nick Banks (Lee, 2001). Between 1986 and 1988 the coastal pearl of Charleston on the West coast gained 140 new routes (Lee, 2001).

Whilst the climbing in New Zealand is hugely varied and scattered over a variety of locations throughout the North and South Island, areas of particular importance and interest include Castle Hill, Golden Bay, The Darrans and The Cave. Castle Hill is considered one of New Zealand's finest climbing areas, featuring fields of limestone boulders in a large basin only an hours' drive from Christchurch (Main and Wethey, 2004). The first visits by climbers to Castle Hill occurred between 1975 and 1979 but the lack of traditional conventional protection meant the area was devoted to bouldering above anything else. Only a small number of routes were claimed here up until the mid 1980's and early 1990's (Lee, 2001). The addition of bolting technology and 'sticky' rubber climbing shoes hit the country at this time, just as it did in Europe, producing a never ending stream of challenging boulder problems and a string of sport routes graded in the upper 20's (Ewbank) that remain classics to this day, not forgetting 'Angel of Pain' graded 32 and considered one of the hardest routes to date (Sedon, 2007). Mirroring the trend in Britain and Europe at the time, bouldering became extremely prominent during the 1990's and as such Castle Hill became renowned for its smooth slabs, pocketed walls, and rounded blank faces, providing lifetimes supply of boulder problems and attracting attention from international climbers (Main and Wethey, 2004).

Golden Bay, more specifically Paynes Ford, has been described as the country's finest sport crag. The area was first approached in the early 1980's but did not see much development until later that decade, when a number of new routes were put up, helped by the use of high powered Bosch hammer drills to place bolts (Sedon, 2007). In the early 90's the area became a popular stomping ground for climbers seeking routes with ease of access and a likely first ascent. It soon attracted the attention of European climbers who added harder, more sustained lines to an ever growing list of new routes (Lee, 2001). The area is now almost fully developed and regarded as one of New Zealand's most enjoyable and important rock climbing destinations.

The Darran Mountains in Fiordland were first approached for their alpine rock routes, yet the area has much more to offer climbers with long routes, aid climbing, multi pitch, sport climbing and even bouldering, thus catering for the most adventurous climbers. Here rock climbing in the modern sense began in the 1960's with climbers attempting new routes on the big alpine faces of high peaks. The first technical rock route in the Darrans was completed by Murray Judge and Harold Jones in 1967 and given a grade of 17 (Cleddau Buttress of Moir) (Sedon, 2007). Murray Judge dominated climbing during this era and continued to push the level of technical rock climbing during the late 1960's. By 1974 new routes on bigger less accessible walls were completed, some of which are still regarded as the best alpine rock routes in the country. During the 1980's climbers continued to look for new natural lines of weakness, affording quality routes and new ascents. American influence played a huge role at this stage with climbers returning from areas such as Yosemite and Tuolomne Meadows initiating a profound change in climbing style (Sedon, 2007). These climbers returned with lightweight bolts and drills designed for multi pitch climbing from the ground up, meaning climbers could seek attractive routes on challenging sections of rock without having to worry about natural protection.

Although popular for a short period, this style of climbing from the ground up diminished towards the 1990's with the exception of abseil bolting, which became commonplace. A new century and millennium brought with it a progression in difficulty and quality of new routes in the area, including what can only be described as an outstanding route named 'Armageddon' which features two grade 28 pitches.

Furthermore, the exploration of the more isolated faces brought about some of the most committing and sustained free climbs in the Darrans, with ‘A map of draughts’ boasting ten pitches up to grade 23 which was completed as an on-sight without placing bolts (Sedon, 2007). This achievement and many others in the area signify a nearly limitless future for hard free routes in the Darrans.

The Darrans also host two world class rock climbing crags, Chasm and Babylon. Here most of the climbing is protected by bolts, yet it is not a true sport climbing crag as naturally protected routes and bolted test pieces sit side by side (Sedon, 2007). These two areas offer bold climbers steep rock faces with maximum exposure. Development at Chasm crag began as recently as the early 1990’s when Paul Rogers and a visiting Brit Steve Walker decided to take a closer look at the smaller hidden crags. The first route completed at Chasm was a two pitch grade 22 climb called ‘High ideals and crazy dreams’ (Main and Wethey, 2004). Further activity between 2000 and 2005 utilizing drilling and bolting technology combined with a renewed enthusiasm has resulted in the crag becoming a well developed location by today’s standards (Sedon, 2007). In contrast, establishing new routes at Babylon was much slower owing to limited opportunities for natural protection coupled with difficult climbing. In 2002 the first route was climbed at Babylon utilizing marginal protection resulting in a three pitch grade 26 climb (Birdsong), which paved the way for further visionary routes both free and bolted. This included Derek Thatcher bolting and climbing ‘rage’ and ‘requiem’ both grade 30 and later ‘Hammurabi’ and ‘Katalepsis’ both receiving grade 32 and among the hardest graded routes in the country (Sedon, 2007). The Darrans still offer up a vast amount of potential for new routes with projects that could push the highest level of difficulty in New Zealand above the current limit of 32. This area will undoubtedly see continued growth and development and could potentially result in the first grade 33 and 34 route.

Currently the greatest concentration of hard routes in New Zealand can be found at The Cave (also known as the ‘Superbowl’) near Sumner on the Eastern Outskirts of Christchurch. Whilst this area is slightly hidden and unassuming it holds a number of climbs ranging from 25-32 , (including ten routes graded 30-32) and are best described as hard test pieces on severely overhanging walls (Lee, 2001; Main and Wethey, 2004; Sedon, 2007). Development started here in 1993 with the first of the climbs to be graded in the 30’s established in 1994 with Peter Taw’s ‘Bogus Machismo’ closely followed by ‘Space Boy’ climbed by Matt Everard and graded 31 which was later extended by Kaz

Pucia in 1995 to create one of New Zealand's first grade 32 climbs (Main and Wethey, 2004). These remained the hardest set routes until 2003 where a flurry of first ascents at the highest grades were completed, A year later Derek Thatcher added two more grade 32 climbs 'The Enigma of Caspar Hauser' and 'Buffy' increasing the list at this grade to six (Main and Wethey, 2004). Today The Cave is well developed and provides the most talented climbers with hard climbs, even by world standards.

The development of competitive climbing In New Zealand began in the 1980's. Doug Carson and Murray Judge held the country's first sport climbing competition at the soft limestone crags of Duntroon manufacturing 'Fawlty Towers' (Main and Wethey, 2004). This also led to the discovery of the Duntroon boulder field: Elephant Rocks (Lee, 2001; Main and Wethey, 2004). Similar competitions were held in 1988 and 1989, expanding to Castle Hill and Baring Head. The first International event was held in 1990 and was soon followed by New Zealand Nationals in 1991 (ClimbingNZ, 2012). Three years later in 1994 The New Zealand Sport Climbing Federation (NZSF) was formed, and took responsibility for the organization and running of events which were previously controlled by the New Zealand Alpine Club (NZAC) (ClimbingNZ, 2012). Considerable effort has been directed at the development of rock climbing in New Zealand with both the NZSF and NZAC contributing greatly to the maintenance of access, equipment, route setting, grading, guide book publication, and the organization of competitive events. NZSF has since become a fully independent body, changing its name to Climbing New Zealand in 2008 and it is now a member country of the IFSC. Today New Zealanders compete in Australian, Oceania, European and World Championships and the country plays host to a popular series of events (NZAC, 2012).

2.3 Climbing disciplines

The term 'climbing' and more specifically 'rock climbing' is synonymous with a number of sub divisions and categories within the sport. Not surprisingly each branch of climbing has a distinct set of demands and 'rules' or ethics. As is evident from reading the previous sections, different techniques have evolved over time to become specialist categories of climbing in their own right. The focus of this section will be to provide an overview and understanding of the various sub divisions of climbing coupled with an explanation of associated terminology which will be referred to later in this review of literature.

2.3.1 Traditional and sport climbing

Often both referred to as forms of free climbing, traditional or ‘trad’ climbing and sport rock climbing use natural holds for hand and foot placements. Both forms require the use of a rope and harness to safeguard the climber, and are examples of lead climbing. This involves the climber or ‘leader’ clipping the rope to which they are attached to anchors or ‘runners’ as they ascend the route, whilst being belayed from the ground by another climber – often called the ‘second’ or ‘belayer’ (Peter, 2004). This system requires the use of a belay device; a friction device fitted to the rope used to control the energy generated by a falling climber, arresting their fall (Creasey et al., 2001).

Figure 2.1 Climbing harness and protective 'gear' used during trad climbing ascents (Photo; Dave Short).

Figure 2.2 Nuts/wires (left) and Hexcentrics (right) used in trad climbing.

Figure 2.3 Camming devices or 'friends' used to protect the leader during trad climbing ascents.

Figure 2.4 Quickdraws used during trad and sport climbing in order to attach the climber to temporary and fixed protection with the aid of a rope, also referred to as 'runners'.

The types of anchors and procedures used in trad and sport climbing differ. During trad climbing ascents, routes are climbed from bottom to top without the use of aids such as bolts or pegs. Instead the climber places temporary protection or ‘gear’ (see Figure 2.1 – Figure 2.3) at various intervals throughout the climb (wires, camming devices, slings). The rope is clipped to these points using a ‘quickdraw’ (see Figure 2.4), protecting the climber in the event of a fall (Paige et al., 1998). Typically placements are afforded where there are weaknesses in the rock such as cracks or chockstones (see Figure 2.5). The equipment is later removed by the ‘second’ who follows up the route (Figure 2.6). This type of climbing is only possible outdoors on natural rock and has close links with mountaineering and the origins of rock climbing, fostering a minimal impact approach (Giles et al., 2006). During ascents of this nature any given fall by the leading climber will be twice the distance from the climber to the last piece of adequate equipment (Peter, 2004). This consideration is of great importance, as finding gear placements at regular intervals is not always possible on natural rock, thus providing the climber with an additional challenge. It is this challenge of engineering safe gear placements for runners, plus the heightened psychological demand of dealing with the danger and possibility of a long fall that are regarded as central elements of traditional rock climbing (Atchison-Jones, 2004). In trad climbing leaders generally adopt a 'no fall' mentality and climb within their ability level, with some exceptions.

Figure 2.5 Climber placing protection during a trad lead ascent (left) and an example of a nut/wire placement (right) (Location; Peak District, UK, photo; Ellis Bird).

Figure 2.6 The second ascending a trad route in order to remove temporary protection placed by the lead climber (Location; Pembroke, UK. photo; Rebecca Wilkinson).

Sport climbing relies on permanent fixed protection as anchor points for placement of runners. This is usually provided in the form of in-situ bolts and a ‘lower-off’ (Figure 2.7) which have been pre drilled and set into the rock (Sheel, 2004). In a similar fashion to trad climbing the leader attaches the rope to each successive bolt using quickdraws (Figure 2.8). This discipline of climbing is seen as the ultimate convenience, with the fixed protection at regular or critical points reducing the element of risk and uncertainty present in trad climbing. Here the distractions of engineering a safety system and relative danger are minimized, and focus is placed upon the development of athletic ability and attempting the most difficult moves possible (Paige et al., 1998). Climbers rely heavily upon the protection offered from this form of free climbing, which can sometimes allow for frequent yet minor falls whilst climbing at the limit of physical and technical ability (Atchison-Jones, 2004).

Figure 2.7 Sport climbing; bolt and clipping hanger (left) and example of an in situ lower- off (right) (Photo courtesy of NZAC and Craig Jefferies).

Figure 2.8 Sport climbing (Location; Swanage, UK, photo; Dave Short).

Sport Climbing is one of the most commonly pursued disciplines of rock climbing, possibly owing to its accessibility and relative safety. In addition, this style of climbing is popular both outdoors on natural rock and indoors on artificial surfaces. Interestingly, indoor sport climbing has become a style of climbing in its own right, with a number climbers specializing in 'gym climbing' (Atchison-Jones, 2004). This is due in part to the nature and demand of competitive lead sport climbing, which takes place on artificial walls. This modality of climbing is often used in rock climbing research when attempting to investigate psychological, physiological and technical demands of the sport (Bertuzzi et al., 2007; Billat et al., 1995; Booth et al., 1999; Draper et al., 2008a; Draper et al., 2008b; Hodgson et al., 2008).

Traditional and sport climbing can consist of either single or multi pitch ascents. Here the term 'pitch' is used to denote a rope length, Single pitch routes are those climbed predominantly in one rope length from the base to the top (Fyffe et al., 1990; Peter, 2004). Where a rock face is too high to be climbed in one rope length the route is broken down into a number of pitches, varying from two or three up to double figures (Atchison-Jones, 2004). During multi pitch ascents the rope work required is similar to that on smaller crags, with the main considerations being route finding, communication, and belaying from ledges, where space and choice of anchors may be limited (Peter, 2004). Here climbing partners alternate the role of 'leader' and 'second' and need to be of relative or equal standard to be successful. When ascending routes requiring multiple pitches, the second is anchored to the rock face, ideally a ledge creating a 'stance' and belays the leader. Once the pitch is complete the leader sets another stance and belays the second up the climb, who removes the protective gear and proceeds to complete the next pitch, repeating the process until reaching the top (Fyffe et al., 1990; Peter, 2004).

2.3.2 'Big wall' and aid climbing

Big wall climbing is characterized by the need for large amounts of gear, with long multiple pitches often requiring multiple day ascents (Hattingh, 1998). There are some walls in the Yosemite Valley in California which boast 3000ft cliffs taking anywhere from 3-10 days to complete an ascent. In big wall climbing the objective is to ascend the route by any means possible, utilizing a full range of equipment. Here climbers complete technically demanding pitches involving free (traditional and sport) and aid climbing (Atchison-Jones, 2004).

Aid climbing is generally a method adopted when time is limited or where the route is too hard to be climbed in a purer style. It is carried out with the use of pegs (pitons), nuts and other protection to directly help an ascent rather than to arrest a fall (Hattingh, 1998). In most instances, successful big wall ascents are achieved by drilling holes for bolts and inserting pegs into the rock that the climber uses as attachment points and to pull on to progress up the route. On the whole, 'clean' aid climbing is encouraged (i.e. using gear which does not damage the rock when inserted or removed). Whilst standard gear seen in traditional ascents is used during ascents of this nature (chocks, camming devices and slings etc), they are required in much greater quantity. Typically a long 'big wall' or aid pitch may require up to 50 nuts/chocks and camming devices and around 80 carabiners, In addition, climbers utilise pitons which come in an array of styles and sizes (Hattingh, 1998). The modern approach is to use pitons only in cracks which are too small to take free climbing gear. As well as pitons and traditional gear, aid climbers may also utilise bolts, yet often only in order to create a belay stance or as a final back up (Creasey et al., 2001).

In contrast with typical single and multi pitch ascents discussed previously where a second also completes the route, only one member of the climbing team or duo is required to climb each pitch in big wall aid climbing. Those following the route after the leader will generally use mechanical ascenders and ropes rather than the rock face, removing gear as they progress, thus saving time and energy (Fyffe et al., 1990; Hattingh, 1998). There is also an added challenge in hauling sacks of food, and additional equipment up the route, without which the ascent would be impossible. Climbers also have to contend with setting up overnight bivouacs suspended on portaledges before being able to continue the next day (Hattingh, 1998).

2.3.3 Bouldering

Bouldering (Figure 2.9 – Figure 2.11) focuses on the gymnastic act of climbing, seeking to combine small sequences of powerful and demanding moves in order to move across the most difficult sections of rock (Josephsen et al., 2007). Here there are no ropes or harnesses to safeguard the climber, instead protection is afforded by portable mats or crash pads with the aid of a spotter (Figure 2.10) in a similar manner to gymnastics (La Torre et al., 2009). Here the spotters' job is not to catch a falling climber but to guide them to a safe landing, effective spotting will often give the climber confidence to commit to climbs requiring awkward landings and difficult moves (Peter, 2004).

Figure 2.9 A short sequence of climbing moves demonstrating the nature of bouldering; note the climber is not protected by a harness or rope. (Location Flock Hill, NZ, photo; Paul White).

Figure 2.10 Safeguarding the climber during an attempt at a boulder 'problem' with the aid of portable crash mats and 'spotters'. (Location; Llangollen, UK, photo; Phil Stubbington).

A boulderer will typically perform repeated ascents on the same section of rock, generally around 8 to 15 feet high. Problems finishing a long way off the ground are referred to as ‘high-ball’ (Figure 2.11) and each climber will make a personal assessment as to what they deem appropriate to attempt without the safety of a rope (Peter, 2004). Bouldering routes or ‘problems’ as they are commonly referred to, often require repetitive attempts at the same sequence of climbing moves. This aids in creating muscle memory, building strength and improving movement efficiency (Josephsen et al., 2007). This is the most compact form of climbing yet is extremely addictive owing to its dynamics; here a climber can push their physical limit in a few feet. As such, pushing the body too hard during ascents of this nature is a common hazard, wrenching muscles and tendons in the arms and fingers. Conversely, many boulder problems will require balance and delicate moves, replacing pure power with grace and accuracy on the smallest holds (Atchison-Jones, 2004).

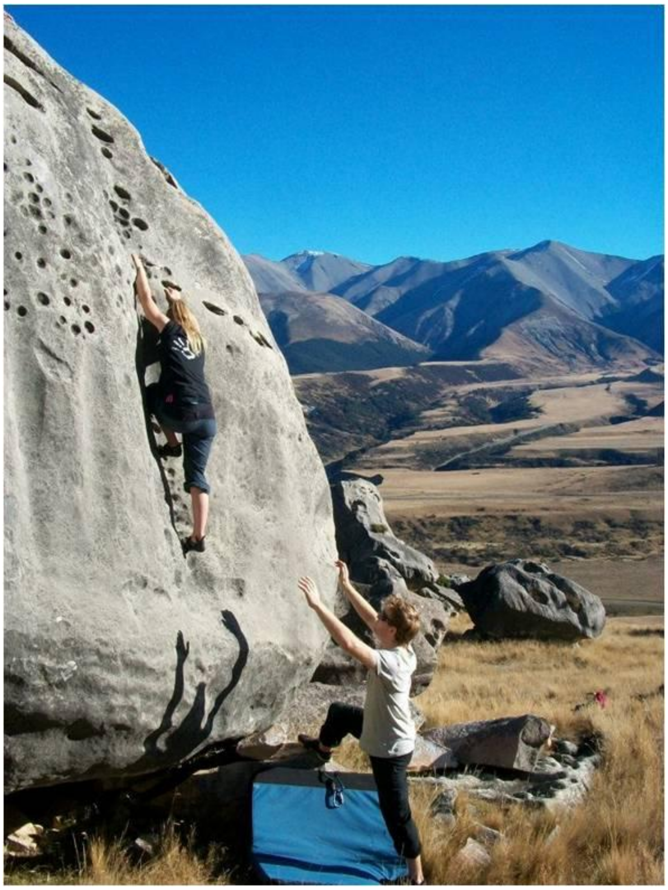

Figure 2.11 Bouldering; climber attempting a 'highball' problem. (Location; Flock Hill, NZ, photo; Paul White).

Bouldering is practiced on artificial walls (both indoors and outdoors) and on natural rock. Many climbers participate exclusively in this discipline of rock climbing and it is considered a sport in its own right. Since 1998, bouldering has been included as an official competition discipline held according to the rules of the IFSC. The primary challenge in competitive bouldering is the accomplishment of hard, single moves and complex motion sequences, with the aim to master as many boulders in as few attempts as possible (Niegl, 2009).

2.3.4 Free solo and deep water solo

Variations of the bouldering theme where ascents are made with little more than a pair of climbing shoes and bag of chalk can be extended to include free solo climbing and deep water soloing. During free solo ascents climbers ‘boulder’ on anything ranging from normal height, to huge rock faces where a fall could result in certain injury or death. This style of climbing is considered a pure form, given the nature of the route and the physical and mental state required to execute such an ascent (Hattingh, 1998). Climbing in this manner allows freedom of movement without the interruptions of placing protection, rope work or the need for a climbing partner. Routes are often 'soloed' in a fraction of the time it would take to climb them using traditional methods (Peter, 2004).

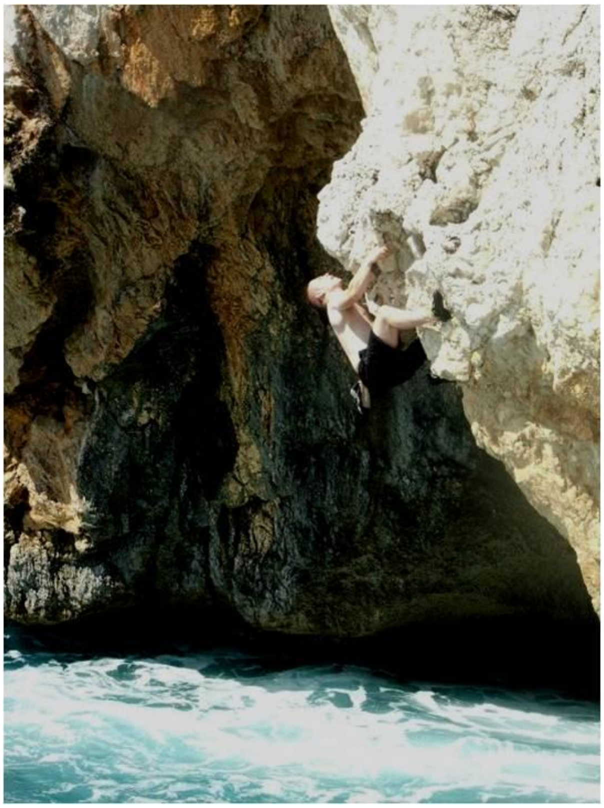

Figure 2.12 Climber attempting a deep water solo route. (Location; Kalymnos, Greece, photo; Phil Stubbington).

As the name suggests, deep water soloing (DWS) or 'psicobloc' as it is referred to in parts of Europe, involves climbing routes or 'problems' without ropes above water, usually the sea (Figure 2.12). This branch of climbing became popular in the 1980's, originating on the south coast of England with Connor Cove regarded as the birthplace of DWS (Hattingh, 1998; Peter, 2004). Today, it is an increasingly popular sub division with a growing number of participating climbers, and new areas such as Mallorca, Spain at the forefront of the sport. In a similar fashion to bouldering and soloing, the attraction of DWS is due to its simplicity. Many climbers have an affinity for this style of climbing owing to the unhindered movement and lack of time-consuming rope work. Unlike ordinary solo attempts where the consequences of a lapse of concentration or the slightest error would result in disaster, climbing above deep water provides a more suitable landing. This type of soloing still presents certain problems, often as a result of poor depth judgment or awkward landings. Climbers require a great deal of spatial awareness in ensuring a safe landing as entry into the water is key, and opting to jump is often the safest and more sensible option. Commonly, DWS ascents are undertaken in small groups, or with the aid of at least one other, and a safety boat to offer assistance to an injured climber if required (Peter, 2004).

2.3.5 Vertical ice and mixed climbing

Whilst most disciplines of climbing are focused on ascents on natural rock or artificial surfaces, climbing can also be extended to include snow and ice. Ice climbing typically refers to roped and protected climbing of features such as ice falls, frozen waterfalls, cliffs and slabs of rock covered in ice (Chouinard, 1978). Here the challenge is represented in the variable and ever-changing nature of the environment, and ascents can be extremely complicated with experience playing a key role in determining success. Conditions can vary greatly on ice routes, and types of ascent range from low angled (60 degree) consistent ice to overhanging with no opportunity for rest (Alpinist, 2012).

Many of the techniques and the rope work described in previous subsections relating to movement on rock are required during ascents on snow and ice (Fyffe et al., 1990; Hattingh, 1998). Equipment such as ropes, belay devices, and protection or 'gear' are used in a similar manner, although the equipment is specialized. The equipment and techniques used during such ascents are generally determined by the slope and texture of the ice. Often this type of terrain is divided into two types, alpine ice and water ice. Alpine ice is generally encountered in a mountain environment and is often climbed as part of a summit attempt. This type of ice is formed from frozen precipitation, with sections of alpine ice ascent being more commonly associated with longer less technical routes, in a similar manner to glacier travel. Water ice is usually associated with the greater technical challenge of ascending vertical or overhanging ice (Figure 2.13) and is highly demanding (Lowe, 1996).

Figure 2.13 Vertical ice climbing (Location; Norway, photo Ellis Bird).

During vertical ice ascents climbers utilise crampons and ice axes (more specifically referred to as technical axes or 'ice tools') to climb (Figure 2.14). Crampons for these ascents generally have twelve or thirteen points and are of a rigid or semi rigid construction and must be fitted to a rigid boot in order to afford the required stability (Fyffe et al., 1990; Hattingh, 1998). The most common technique is to kick the front points of the crampon into the ice, and subsequently stand up, referred to as 'front pointing' (Fyffe et al., 1990). Technical axes as opposed to walking axes are shorter in length, featuring a 'pick' and an 'adze'. The pick is driven into the ice whilst the adze is used to aid placing protection. During vertical ice ascents climbers use two axes, becoming the equivalent of handholds with the arms bearing a majority of the load (Fyffe et al., 1990). During ascents of this nature energy conservation is key, with success ultimately relying on strength coupled with good technique (Atchison-Jones, 2004).

Figure 2.14 Specialized ice climbing equipment; climbing axes (left) and rigid crampons featuring front points (right).

In order to safeguard the climber, protection is placed in the ice, and a rope attached to runners in a similar manner to that of trad and sport climbing. The most common form of protection is an ice screw (Fyffe et al., 1990; Hattingh, 1998; Lowe, 1996). Ice screws are hollow threaded tubes with sharp teeth on the front end, and a hanger eye on the back for clipping into (Figure 2.15). The screws are inserted into the ice at various intervals to protect the lead climber in the event of a fall, and are later removed by a second climber. On solid ice these can provide a very strong anchor point, however this form of protection is reliant on the quality and consistency of the surrounding ice, making finding and placing gear a key factor during ascents (Hattingh, 1998).

Vertical ice climbing is also recognised by the UIAA as a competitive discipline of climbing, with the International Ice Climbing Commission having been responsible for organising the International World Cup (IWC) event since 2002 (UIAA, 2012). Prior to this, competitive ice climbing had been taking place in Russia (Soviet Union) from as early as the 1970’s. Such events were held each winter, with winners announced at the end of each season. Competition categories included speed, difficulty and long course speed (100m+) which was completed in groups with the lead climber changed every 40m. Later, the first official National speed climbing competition was held in Russia in 1987. Elsewhere, interest in the sport gained momentum during the mid 1990’s, with more competitions held in Europe. Courchevel in France was synonymous with difficult ice climbing events at this time, and indeed right up until the year 2000. During events of this nature, climbers were required to ascend as high as possible in the fewest number of moves and were given a limited timeframe. Similarly, North America played host to a number of competitive events at this time, namely the Winter X games, which included speed and difficulty ice climbing up until 1999. The first common rules for the sport were applied in 1998, with the first International World Cup instigated by a private German company in 2000. This company was later to be replaced as event organisers by the UIAA in 2002, as stated previously (UIAA, 2012). Despite this the competitive realm of ice climbing is a limited one, and a fairly new sport in terms of worldwide competition and participation.

Figure 2.15 Ice climbing screws.

The application of ice climbing techniques has also been extended to mixed climbing. Here, mixed climbing refers to an ascent requiring moves on snow ice and rock requiring a combination of summer and winter techniques (Gadd and Chayer, 2003). This type of climbing often requires more technical climbing than pure ice routes, calling on a range of skills. During ascents of mixed routes climbers must be proficient in axe and crampon use, yet have a good level of experience with regard to rock techniques. In mixed climbing the axe is not only used on ice but is also used in hooking and torquing (using the axe in cracks for leverage) on rock; this is referred to as 'dry tooling' (Fyffe et al., 1990). In addition the ability to rock climb wearing crampons is fundamental, with rock often providing footholds as opposed to reliance on front pointing as in pure ice climbing. In mixed climbing decision making is a key factor for climbers. Here they may be required to clear areas of snow and ice to afford better hand, foot or protection placements and be able to identify the most suitable option (Gadd and Chayer, 2003). In this environment every situation is unique, with routes varying in demand with changing conditions. Some of the hardest mixed routes rely entirely upon set conditions, and are often not considered approachable unless a certain criteria is met (Fyffe et al., 1990).

2.3.6 Alpine climbing

The term 'Alpine climbing' originates from the exploration of the European Alps during the 1900's, considered the golden years of climbing. Since then many other alpine style areas have been pioneered such as New Zealand, North America, Canada and parts of South America, and as such alpine climbing now represents a whole category of climbing with its own specific set of demands and style (Atchison-Jones, 2004; Hattingh, 1998). Many of the modern rock climbing disciplines that are popular among climbers today evolved from alpine climbing. However, today alpinism is often the final progression for rock climbers seeking new challenges, as it brings together all aspects of climbing on rock, snow and ice described previously (Fyffe et al., 1990).

Alpine style climbing is best described as mountain climbing reduced to its purest essence. Ascents of this nature require movement across mixed, rock, ice and snow climbs and cover everything from one-day routes to 8000m multi day ascents on Himalayan peaks (Hattingh, 1998). At the extreme end this involves climbing the hardest routes, with the least gear, as fast as possible. The main consideration in alpine ascents is self sufficiency, that they are completed in a single push by climbers carrying all of their own equipment (Twight and Martin, 1999). The distinction between where crag climbing ends and alpinism begins is difficult to pinpoint. Typically, where a route features an approach, an ascent and subsequent descent all requiring navigational and mountaineering skills, the term alpine climbing would be deemed appropriate (Fyffe et al., 1990). Although alpine ascents often bring together technical skills from a range of summer and winter climbing disciplines it is inherently different to any other ascent. The sheer scale of the challenge represented by many alpine ascents, coupled with the remoteness and character of the routes ensures an entirely different experience (Twight and Martin, 1999). During such ascents speed is of the essence and any given party of climbers must be capable of moving together rapidly over mixed terrain. It is essential that a pair or party are well matched in their ability and harbour a good level of experience, much of which can only be obtained through trial and experimentation (Fyffe et al., 1990). A good degree of mountain awareness and the ability to cope with committing situations are a key determinant of success in alpine climbing.

2.3.7 Other styles of ascent and associated terminology

Figure 2.16 Top roping; climber is provided with a rope from the belayer above. (Location; Lake District, UK, photo Rebecca Wilkinson).

Lead climbing, more specifically traditional and sport climbing, have been outlined previously and are both categories of climbing which can take place on single pitch crags. Other methods of ascent on single pitch crags include top and bottom roping. Although not considered a category of rock climbing as such, these types of ascents are commonly used by groups or novice climbers, often as an introduction to the sport

(Atchison-Jones, 2004; Peter, 2004; Richardson, 2001). In both top and bottom roping there is no need for a 'lead' climber or placing protection. During a top-rope ascent the belayer is anchored at the top of a route in order to provide the climber with a secure rope from above (Figure 2.16). The climber at the foot of the route ties to the end of the rope. As the climber moves up the route slack is generated and this is taken in by the belayer with the use of an appropriate device (Peter, 2004). In a top-rope ascent the climber will generally 'top-out' once reaching the end of the route and untie from the system. This allows a succession of climbers to attempt the same climb with very little exposure.

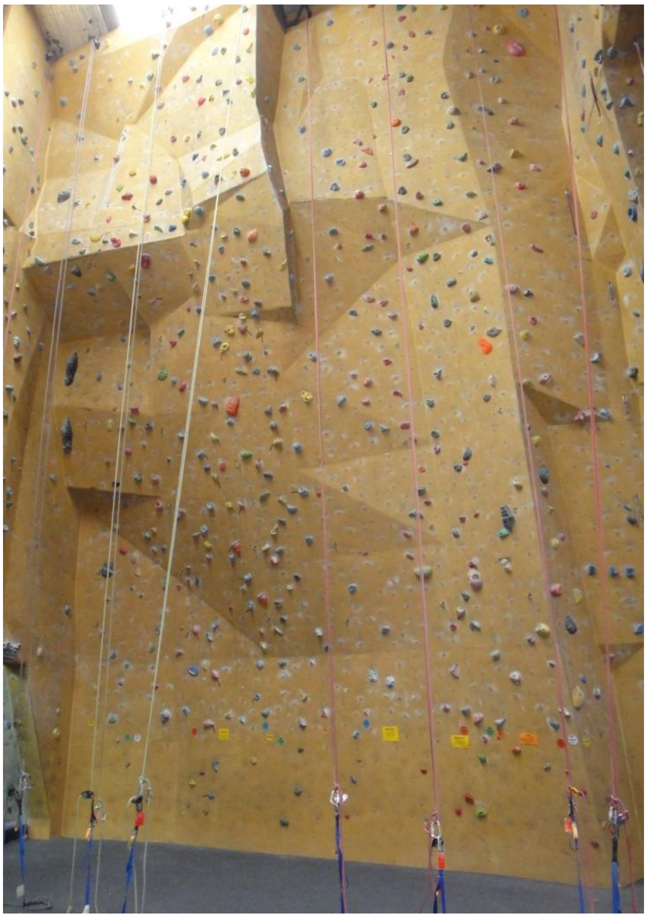

Figure 2.17 Bottom-rope systems at an indoor artificial climbing wall venue.

A system which is also often referred to as 'top-roping', but for the sake of clarity will here be defined as 'bottom-roping', is where the belayer is positioned on the ground. Here a fixed rope runs from the climber to an anchor point or runner at the top of the crag and back to the belayer. Again the climber ties in to one end of the rope and climbs to the anchor point just below the top of the route, also called the 'lower off'. As the climber moves up the route the belayer takes in the slack. Once the climber reaches the lower-off, the belayer holds the climbers' weight and subsequently feeds the rope, lowering the climber back down to the ground (Peter, 2004). Again, in contrast to lead climbing, this system offers little exposure and when done correctly is extremely safe. This system is popular among novices and groups, but is also widely used for safeguarding climbers on artificial walls and indoor venues (Figure 2.17). As well as this, some natural climbing venues only permit the use of top or bottom roping techniques due to environmental considerations.

The protocol used prior to and during a successful ascent is also of great significance. This is true across all categories of climbing but is particularly prominent in bouldering, traditional and sport climbing. Within these disciplines, climbers often use the terms 'on-sight', 'flash' and 'redpoint' to describe the nature of an ascent (Creasey et al., 2001; Hattingh, 1998; Peter, 2004). An on-sight is considered by most to be the 'best' style of ascent. Here the route is completed from bottom to top on first attempt with no falls, rests on rope, or prior knowledge of the route. Prior knowledge could be seeing another climber complete it, knowing its difficulty rating, or having examined the route for key holds. These things are commonly referred to as 'beta'(Peter, 2004). When attempting an on-sight, the climber should not be given any information (beta) about the route at all. This style of ascent is commonly used during competitive climbing, and is considered the most demanding and technically challenging. Where a climber completes a route on first attempt having been given some form of beta the term 'flash' is applied, and it is still a highly regarded ascent (Creasey et al., 2001).

The term redpoint is used to denote a successful ascent after having practiced the route a number of times, working out the critical holds and sequences or 'crux'. The redpoint is officially achieved when the climber finally completes the route from bottom to top with no falls or rests. The practice of the route is generally done either by leading with frequent rests on the rope, or with the aid of a top-rope (Hattingh, 1998). In addition, climbers may opt to pre-place gear or quickdraws before leading the route, however there is not a common distinction between ascents of this nature. Redpoint ascents are considered normal for harder routes at the upper limits of ability and difficulty rating; however some climbers view this as 'bad' style and believe it detracts from the true nature of rock climbing.

2.4 Difficulty rating and grading systems in rock climbing

In rock climbing, mountaineering and other climbing disciplines various grading scales are used to describe the difficulty and danger in climbing any given route (Alpinist, 2012). Each category of climbing has its own grading system with no universal application or criteria, and many nationalities have developed their own rating systems. The main focus of this review of literature will be rock climbing, with particular emphasis on research relating to free climbing and bouldering. Difficulty rating and grading systems relating to these disciplines of climbing will be introduced in this section.

2.4.1 Grading Overview

Typically the grade of a route is suggested by the first ascensionist (the person who climbs the route first) and later confirmed by those who manage to repeat the ascent. In some instances climbs will be downgraded during this process as new ways to climb routes are found (Peter, 2004). As such, all grading systems and given grades are subjective, and direct comparisons from climb to climb, and between grading systems are often inaccurate and controversial (Hattingh, 1998), yet most guide books provide charts for this purpose (Main and Wethey, 2004; Montchaussé et al., 2001; Sedon, 2007). The difficulty in comparing grades and disciplines is due to differing styles of climbing and the logic attached to each individual system. As mentioned previously, grading is a subjective issue with simple things such as differences in heights, builds, climbing styles and opinions of individuals making it impossible to have a standardized system. The discrepancy between breadth of grades and arbitrary points at which grades overlap are also problematic.

Grading on the hardest climbs tend to be speculative until other climbers complete the route and a consensus on grade can be reached. This becomes increasingly difficult as the grade increases due to the number of climbers able to pass judgment on the highest grades being limited. A typical example of such ascents includes James Pearsons route ‘Walk of Life’ at Dyer’s lookout, North Devon (UK). The ascent was performed without bolts or pitons using only leader placed protection in traditional style and graded E12/7a, considered the hardest route of this nature. A year later the route was repeated by Dave MacLeod who downgraded the route to E9/6c, demonstrating how provisional and subjective a route grading can be at the upper extremes (UKClimbing, 2009). It should also be noted that a ‘true’ grade and how difficult a route or boulder problem may feel can be very different. Often climbers may succeed at a given grade yet not be able to complete climbs rated as being 'easier'. The type of route (i.e. slab, overhanging) combined with a climbers particular intrinsic qualities, technical, physical or mental are all relevant during an ascent. In many instances there may also be several ways of completing a route or problem, with new solutions found regularly (Montchaussé et al., 2001).

There are currently in excess of ten different grading systems used worldwide to categorize the difficulty of different types of rock climbing. For free climbing (traditional and sport ascents) the most popular systems include the British, Yosemite Decimal System (YDS), Union Internationale des Associations d'Alpinisme (UIAA), French (Sport) and Ewbank scales (Rockfax, 2012). Similarly, bouldering has two main grading systems; Fontainebleau and the 'V' scale (Hueco) (Montchaussé et al., 2001). Comparison charts for free climbing and bouldering grades are presented in Table 2.1 and Table 2.2 respectively.

2.4.2 British system

The British, or trad system as it is commonly referred to combines an adjectival grade which describes the overall difficulty of the climb with a numerical technical grade (Peter, 2004). The adjectival grade provides some indication as to how sustained or well protected a climb or route is, and is open ended ranging from 'easy', 'moderate', 'hard very severe' to 'extremely severe'. As climbing standards increased and further classification was needed, the extreme or 'E' grades were extended to include a number system E1, E2, E3 and so on up to E11 at the time of writing. The technical grade describes the hardest individual move or sequence of moves included in the route. Technical grades are not normally given to easier routes (below 4a); whilst at the other end of the scale it is open-ended. Here the number ascends every third letter: 4a,4b,4c,5a,5b,5c and so forth (Peter, 2004). The technical grades used in this system have also been applied to bouldering problems in the UK in the past. Given the criteria used to assign this grade (hardest individual move), its application proved somewhat problematic and as such Fontainebleau or 'V' grades are now commonplace (Montchaussé et al., 2001).

Table 2.1 Grade comparison chart for the most popular systems used in rating free climbing routes.

British Trad Adj	British Trad Tech	Yosemite Decimal System (YDS)	UIAA	French/Sport	Ewbank
D	1	5.1	I	1	9
VD	2	5.2	II	2	10
HVD	3a	5.3	III	2+	11
S	3b	5.4	IV	3-	12
HS	4a	5.5	IV+	3	13
VS	4b	5.6	V	3+	14
VS	4c	5.7	V+	4	15
HVS	5a	5.8	VI-	4+	16
E1	5b	5.9	VI	5	17
E1	5b	5.10a	VI+	5+	18
E2	5c	5.10b	VII-	6a	19
E2	5c	5.10c	VII	6a+	20
E3	6a	5.10d	VII	6b	21
E3	6a	5.11a	VII+	6b+	22
E4	6b	5.11b	VIII-	6c	23
E4	6b	5.11c	VIII-	6c+	23
E4	6b	5.11d	VIII	7a	23
E5	6b	5.12a	VIII+	7a+	24
E5	6c	5.12b	IX-	7b	25
E6	6c	5.12c	IX-	7b+	26
E6	6c	5.12d	IX	7c	27
E7	7a	5.13a	IX+	7c+	28
E7	7a	5.13b	X-	8a	29
E7	7a	5.13c	X-	8a+	30
E8	7a	5.13d	X	8b	31
E8	7a	5.14a	X+	8b+	32
E9	7a	5.14b	XI-	8c	33
E9	7b	5.14c	XI	8c+	34
E10	7b	5.14d	XI+	9a	35
E10	7b	5.15a	XI+	9a+	36
E11	7b	5.15b	XII-	9b	37
E11	7b	5.15c	XII	9b+	38

Table 2.2 Bouldering comparison chart.

Fontainebleau	‘V’ scale
4	V0
4+	V0+
5	V1
5+	V2
6a	V3
6a+	V3/4
6b	V4
6b+	V4/5
6c	V5
6c+	V5/6
7a	V6
7a+	V7
7b	V8
7b+	V8/9
7c	V9
7c+	V10
8a	V11
8a+	V12
8b	V13
8b+	V14
8c	V15
8c+	V16

2.4.3 Yosemite Decimal System

The Yosemite Decimal System (YDS) of grading routes was initially developed from a rating scale for hikes and climbs, and was extended to include rock climbing in the 1950's. The scale can consist of three categories; class, grade and protection, however use of all three varies greatly between regions and guide books (Secor, 2009). Typically, the grade given or discussed refers to class, with five classes used to indicate the technical difficulty of the hardest section of a route. In this system, true rock climbing does not begin until class 5, indicating vertical or near vertical rock requiring skill and rope to proceed safely (Fyffe et al., 1990).

Originally, classes were subsequently divided decimally, for example 5.9 would be the hardest rock climb. With increased standards and improved equipment, routes which were given a grade of 5.9 during the 1960's soon only provided a moderate level of difficulty relative to new routes. Instead of opting to re-grade existing routes, additional grades were added at the upper limits. Initially, the grade 5.10 was included which then soon led to the realization that an open ended system would be needed and more appropriate and further grades of 5.11 and 5.12 and so forth were added. Where the top grade remained at 5.10, a large number of routes were classified as such and climbers recognized the need for further divisions. As such, letter grades were added to climbs at 5.10 and above by the inclusion of 'a' (easiest), 'b', 'c', or 'd' (hardest) (Fyffe et al., 1990; Secor, 2009). Currently, the hardest YDS rating is tentatively set at 5.15b (MacDonald, 2007; MacDonald, 2008).

The YDS system originally took into consideration only the hardest move on a particular route; a route of mainly 5.8 moves but with one 5.12b move would be graded as the latter. Similarly, a route consisting of 5.12b moves throughout would also be given 5.12b overall. Today, the modern application of the grading system, particularly at the upper end of the scale, also considers how sustained or strenuous a climb is in addition to the hardest single move.

2.4.4 UIAA system

The UIAA grading system is generally applied to short bolted routes in Western Germany, Austria, Switzerland, Czech Republic, Slovakia and Hungary. It is also often used to rate longer routes in the Alps and Himalayas. The scale uses Roman numerals and initially was intended to run from I (easiest) to VI (hardest), providing a standardized grading scale. However, as with a number of the other grading systems, improvements in climbing standards led to the system becoming open ended, with the grade VII first accepted in 1977. In addition an optional + or – is used in order to differentiate difficulty. Currently, the hardest climbs rated using this system are XII- (Fyffe et al., 1990).

2.4.5 French numerical scale (sport)

The French system of route classification is the main rock climbing grading scale used in Europe and in many international events. As the name suggests, the system utilises a numerical scale starting at 1 (very easy) and is again open-ended. Each numerical grade can be subdivided by the addition of a letter (a, b, c), for example 5, 5a, 5b, 5c. In this system there is also an optional '+' which can be included for further differentiation between grades (Peter, 2004). Classification of grade is based on technical demand only and describes the difficulty of the climb with no reference to the nature of protection (Atchison-Jones, 2004). It is also important to note that French or 'sport' technical grades are not the same as British 'trad' technical grades discussed previously and therefore do not compare or translate directly between systems.

2.4.6 Ewbank

The Ewbank (Australian) grading system was introduced by Sydney climber John Ewbank in 1967 and is currently used in New Zealand, Australia and South Africa (Wethey, 1989). The system is an open-ended numerical scale with no letters or secondary grades as is common among the other scales. The single number afforded to any given route encompasses factors of technical difficulty, exposure, length, quality of rock, and protection, providing one general grading. This system appears logical as the factors listed are generally related to each other. Quite simply, in this instance, the grade number increases as the routes get harder resulting in a simple and consistent scale (Wethey, 1989). Should the route feature any outstanding demand or specific requirement then this is stated in a short description of the route. Current practice is to make mention of all factors affecting the climber's experience in the description of the climb contained in the guide. The Ewbank grading scale starts at 1 (which theoretically can be walked up) to 34, at the time of writing.

2.4.7 Fontainebleau (Font)

This system was first devised to classify sandstone climbing (bouldering) in the Fontainebleau region, France. The Fontainebleau or 'Font' grading is the most widely used in Europe (Montchaussé et al., 2001). In a similar manner to the French scale, a numerical system has been employed to grade each boulder problem. The grades are expressed as a figure which is subdivided by the addition of a letter ‘a’ being lowest, ‘b’ intermediate and ‘c’ the highest. In addition, for grades of 6a and above, a further sub division of plus (+) is included, thus refining the grade further (Hattingh, 1998; Montchaussé et al., 2001). The scale runs from 1a to 8c+, however grades below 2b are extremely rare. It should also be stressed that although similar to the French numerical scale, the grades have a different meaning. For example, an 8a sport climbing route is significantly easier than an 8a boulder problem. In order to maintain a distinction between route grades and bouldering grades the prefix ‘Font’ may be included, or alternatively bouldering grades may be presented in upper case letters (e.g. 8B+ vs. 8b+) (Peter, 2004). As well as grading individual problems, the area itself is categorised via a coloured ‘circuit’ system and an adjectival system is used to describe difficulty (similar to alpine ratings). The colours and categories used are as follows; white (children’s routes), yellow (Facile Inf), orange (Assez difficile), blue (Difficile), red (Tres difficile), black (Extremement difficile) and white (Extremement difficile plus) (Montchaussé et al., 2001).

2.4.8 The ‘V’ scale (Hueco)

The ‘V’ scale of grading boulder problems originated in Hueco Tanks (Texas, USA) during the early 1990’s (Kidd and Hazelrigs, 2009). It is synonymous with bouldering in North America and has since become widely accepted and used by the bouldering community in other parts of the world owing to its simplicity and practicality. Using this scale, problems are rated purely on the physical challenge required and elements of danger or fear are not taken into account. Interestingly, it is therefore implied that problems have the same difficulty rating on a top-rope as they do when bouldered (Sherman, 1991). As such, guidebooks or problem descriptions often include additional information highlighting the nature of the problem, for example the term ‘highball’ may be included to denote tall problems. Details of awkward or hazardous landings or spotting may also be included (Sherman, 1991).

The ‘V’ scale is open ended, beginning at V0 (although some problems may be given VB-beginner, or VE-easy if considered below V0 standard) and ending at the current highest grade of V16, which will continue to increase as harder problems are completed (Kidd and Hazelrigs, 2009). This system is similar to the Ewbank free climbing grading system discussed previously in that both have no pre-defined upper limit and no artificial divisions.

2.5 Development of coaching and research literature

Early sources of rock climbing literature comprised mainly of climbing guides and instructional 'how-to-climb' books (Creasey et al., 2001; Fyffe et al., 1990; Hattingh, 1998; Montchaussé et al., 2001; Sherman, 1991; Wethey, 1989; Wilson, 1992; Wilson, 1997). These resources typically offered information on basic technique and equipment requirements of the sport. These texts were often aimed at the beginner climber looking to take part in the sport. In 1993 Goddard and Neumann published one of the first specific training guides for climbing; '*Performance Rock Climbing*'. In contrast to much of the literature available at this time, the book was not a resource aimed at those 'learning-to-climb' but was instead written for climbers already immersed in the sport hoping to hone the athletic abilities that climbing demands. The authors placed emphasis on strength, endurance, tactics and technique in order to improve climbing performance. Much of the content was anecdotal, written by climbers for climbers, yet it served as an important training resource at the time. Although some of the methods of training are now considered somewhat outdated, twenty years later many of the training principles presented are still adopted and referred to in some current training guides (Gresham, 2007; Hague and Hunter, 2006; Hörst, 2003; Hörst, 2008; MacLeod, 2010).

Initial research focused on both general and specific injury patterns within the rock climbing population (Bollen, 1988; Bollen and Gunson, 1990). The introduction of an annual international world cup competition circuit beginning in 1989 led to significant developments in the scope and quality of rock climbing research. Prior to the mid 1990's there had been scant research investigating rock climbing performance. Whilst a small number of studies had attempted to discern which key performance factors were important when training for successful rock climbing, much of the literature remained anecdotal. Once considered a recreational activity, rock climbing has since become a popular new sport in its own right. Elite level climbers have continued to push difficulty levels and grading boundaries around the world, resulting in an increased interest in further understanding the demands of the sport.

A new wave of research seeking to identify factors that contribute to high-level rock climbing performance soon emerged. The initial focus centered on identifying the physical and anthropometrical characteristics of elite level climbers (Grant et al., 1996; Lohman et al., 1991; Watts et al., 1993), with the belief that successful climbers may possess certain desirable attributes that could aid in determining ability. This type of athlete profiling was common amongst other sports but was not actualized with respect to rock climbing until the 1990's and is still an active area of research today (Cheung et al., 2011; Grant et al., 2001; Michailov et al., 2009). As well as profiling climbers based on physical characteristics, efforts soon moved to investigating trainable components such as flexibility, strength and endurance (Draper et al., 2009; Grant et al., 2001; Grant et al., 1996). Research in this area generally utilised a battery of tests adopted from other sports and activities. More recently, sport-specific tests and measures have been developed to accurately reflect the demands of rock climbing, and therefore provide a better insight into the physical components linked to ability (Draper et al., 2011a; Grant et al., 2003; MacLeod et al., 2007; Quaine et al., 2003; Schöffl et al., 2004b).

Developments in equipment and testing protocols have led to an increased effort in field based testing, affording the opportunity to investigate the physiological demands and responses to rock climbing (Bertuzzi et al., 2007; Billat et al., 1995; de Geus et al., 2006; España-Romero et al., 2009; Giles et al., 2006; Janot et al., 2000; Mermier et al., 1997; Sheel, 2004; Watts, 2004; Watts et al., 1996). In 1995 a paper was published by Billat et al. (1995) reporting on the energy specificity of rock climbing and aerobic capacity in competitive rock climbers. This was the first study aimed at characterizing responses of higher level climbers using measures such as oxygen consumption ($\dot{V}O_2$), heart rate (HR), and capillary blood lactate (BLa) concentration. Over the past two decades, several studies have also researched such responses among climbers varying in ability and also differing environmental demands. As the research base for the sport increases, growing interest in understanding the 'specialized' fitness required for climbing is apparent. As such, areas of interest have now progressed to topics such as evaluating metabolic cost, hormonal responses and biomechanical analysis (Bertuzzi et al., 2007; Booth et al., 1999; de Geus et al., 2006; Draper et al., 2009; Draper et al., 2011b; España-Romero et al., 2009; Heyman et al., 2009; Mermier et al., 1997; Sherk et al., 2011; Watts et al., 2000).

Much of the early research concerned with investigating the physiological demands of rock climbing had inherent limitations, particularly in relation to standardizing protocols and specificity and sensitivity. The subjective nature of grading criteria, as discussed previously within this chapter has also led to conflicting results. This has made it difficult to draw comparisons between studies and in turn provide definitive conclusions. The development of sport-specific measures and more applicable field testing in rock climbing is still somewhat in its infancy, with a comparatively small research base when compared to other sports.

Rock climbing has been described as a complex sport, with overall climbing performance thought to be influenced by many components (Giles et al., 2006; Goddard and Neumann, 1993; Sheel, 2004). Research suggests that factors such as style of ascent, type of surface, individual demands of the climb and environmental conditions all have implications for the overall demand of any given climb or ascent. In addition over the last decade the effects of psychological factors such as anxiety on climbing performance have attracted attention, with climbers' perceptions of physical and mental demand impacting on performance. This has introduced a cross-disciplinary approach to investigating rock climbing performance, with the psychophysiology of rock climbing a growing area of investigation (Draper et al., 2008b; Draper et al., 2010; Ferrand et al., 2006; Llewellyn and Sanchez, 2008; Sanchez et al., 2009).

Over the past three decades the nature of rock climbing has changed, and today a wide variety of disciplines, each with specific demands are evident. The popularity of the sport continues to rise, with climbers continually seeking harder first ascents, and competitive climbing becoming more prominent. This is reflected in the shift in the nature of the scientific research relating to the sport. The focus of this thesis is physical performance with respect to rock climbing. In exercise physiology, optimizing physical performance is said to require the matching of an appropriate athlete type with a specific individualized training program. Athlete profiles are constructed and reviewed in relation to anthropometric characteristics of high-level performers. Such characteristics are considered alongside comprehensive activity analysis to determine primary bioenergetic systems, energy expenditure, oxygen consumption and strength endurance requirements (Watts, 2004). The following sections present a review of rock climbing literature with regard to athlete profiling and activity analysis from both a physiological and psychophysiological perspective.

2.6 Anthropometric and physical characteristics of rock climbers

Anthropometric profiling of athletes is a popular area of research, with specific somatic predispositions often considered a key element in the process of sport selection and talent identification (Aitken and Jenkins, 1998; Gil et al., 2007). A sport-specific somatic build is thought to be one of the determinants of top performance, with a growing appreciation that anthropometric characteristics can play a major role in determining sporting success (Reilly et al., 1990). Attempts at describing the physical characteristics of rock climbers were not actualized until the early 1990's (Watts et al., 1993). Since then, several studies have focused upon this topic of research. A summary of physical characteristics and anthropometric data taken from studies seeking to investigate anthropometric characteristics of rock climbers are presented in Tables 2.3 and 2.4

2.6.1 Body composition

Elite climbers are reported to be small in stature with low percentage body fat (BF %) (Table 2.3). Watts et al (1993) were the first to compile a set of anthropometric data for rock climbers who were thought to be of 'elite' standard. Participants in the study were made up of thirty nine world class climbers (21 males and 18 females) all of whom were in attendance at an International World Cup sport climbing championship, and had progressed to the semi-finals. The findings of their study indicated that when compared to other athletic groups climbers were of small to moderate stature and exhibited very low percentage body fat measures. The male climbers within the study averaged 177.8 ± 6.5 cm in height, 66.6 ± 5.5 kg in body mass whilst females averaged 165.4 ± 4.0 cm and 51.5 ± 5.1 kg. Calculated percentage body fat values were 4.7 ± 1.3% and 10.7 ± 1.7% for male and female semi finalists respectively. Indices of height and mass obtained for the climbers contained within the study were found to be similar to those reported for distance runners and ballet dancers (Watts et al., 1993).

Of the thirty-nine semi-finalists who participated in the study, 7 men and 6 women advanced to the finals. It was found that both the male and female climbers in the finalist group tended to be lighter than the semifinalists, however no notable difference in height was found. Interestingly, finalist female rock climbers possessed a mean Sum of Skinfolds (SSF) almost equal to that that of male finalists (36.3 ± 6.4 mm and 36.7 ± 10.5 mm respectively). Lastly, it was noted that the female finalists included in the study possessed extremely low percentage fat values (9.6 ± 1.9%), highlighting their ability to maximize the reduction in non-essential tissue weight. The authors identified this as an advantageous reduction in weight when taking into consideration the workload and force required to support and move the body during instances of rock climbing. The reduction of body mass and percentage body fat were cited as potential primary adaptations, particularly in female elite climbers. Percentage body fat was also identified as a significant independent variable when predicting ability and performance in rock climbing.

In a later study by Watts (1996), similar data for a group of 11 male rock climbers were reported, supporting previous findings. The climbers in the study were defined as 'expert-level' with an ability range of 5.12a/7b to 5.13d/8b (YDS/Sport). As in the previous study by Watts (1993), percentage body fat was extremely low and was calculated at 5.4 ± 1.5% with a range of 3.5-7.7% and a mean sum of skinfolfds (SSF) of 40.8 ± 7.3 mm. Height and weight were also similar to that previously reported among elite climbers, averaging 175.6 ± 8.9 cm and 65.9 ± 8.6 kg respectively.

In a study conducted by Grant et al. (1996), anthropometric, strength, endurance and flexibility characteristics were compared in three groups of male subjects. Group 1 (n = 10) was comprised of climbers defined as elite, having reportedly led a climb of the 'E1' standard (minimum) within the previous 12 months; Group 2 (n = 10) included rock climbers who had climbed at a standard no better grade 'Severe'; and group 3 (n = 10) consisted of physically active individuals who had no previous rock climbing experience. The purpose of the study was to determine which characteristics (if any) could distinguish between differing levels of ability. This was based on suggestions that certain characteristics may be essential for the attainment of a high standard of rock climbing (Watts et al., 1993). In this instance, results relating to body composition did not yield any significant differences between elite climbers and non-climbing groups with respect to body mass and percentage body fat, with substantially higher percentage body fat values (14.0 ± 3.7%) reported for elite climbers than in earlier studies published by Watts et al (1993; 1996). The discrepancy between studies was attributed to ability classification methods and seasonal influence. Whilst the climbers in the study by Grant et al. (1996) were classified as elite, the pre-requisite for inclusion (competent on grade 'E1' and above) only equates to approximately >5.10a/6a (YDS/Sport) in looking across grading comparisons (see Table 2.1). This would appear to be substantially lower given the 5.14a/8c and 5.13b/8a (YDS/Sport) mean ability reported by elite climbers in the studies of Watts et al. (1993; 1996). The authors commented on the possible interaction of training status on body composition, noting that the climbers included in the report by Watts et al. (1993) were assessed during an international World cup event during which it was highly likely that they were at the peak of their training and conditioning (Grant et al., 1996).

The anthropometric measures of forty-four climbers (24 male, 20 female) of various skill levels (self-reported 5.6 – 5.13c YDS) were reported by Mermier et al. (2000) in a study where physiological and anthropometric determinants of sport climbing performance were investigated. Whilst the climbers included in the study appeared to be similar in stature to those in the study by Watts et al. (1993) (refer to Table 2.3), similarities ended there. Both the male and female climbers in the study by Mermier et al. (2000) were shown to have on average higher body mass (72.8 versus 66.6 kg for males, 60.1 versus 51.5 kg for females), and higher percentage body fat (9.8 versus 4.7% for males, 20.7 versus 10.7% for females) than those in the Watts et al. (1993) study and were more comparable to those reported by Grant et al. (1996). However, it should be noted that the sample of climbers selected to participate in the study by Mermier et al. (2000) served to reflect a broader and more diverse population of climbers, in order to be to apply the findings to climbers of various ability. Mermier et al. (2000) assessed climbing ability based on progress achieved on a competition-style route alongside a number of physiological variables (grip and pincer strength, bent arm hang, grip endurance, hip and shoulder flexibility and upper and lower body anaerobic power). This was in order to determine which components best explained the variance in sport rock climbing performance using the principal components analysis procedure (PCA). Interestingly anthropometric components were found to explain only 0.3% of total variance in climbing performance, and therefore did not support the belief that a climber must necessarily possess specific anthropometric characteristics to excel in rock climbing.

Table 2.3 Summary of studies and data reported for rock climbers presented as mead ± SD and (range).

Study	Ability	Sex	*n*	Age (years)	Height (cm)	Mass (kg)	Body fat (%)	BMI
Watts et al. (2003)	Junior National Championships Mean self reported ability 5.11d YDS (Top-rope/redpoint)	M/F	T = 90 M = 52 F = 38	13.5 ± 3.0	T = 158.5 ± 15.2 M = 162.2 ± 15.6 F = 151.3 ± 11.9	T = 47.8 ± 15.2 M = 51.5 ± 13.6 F = 40.6 ± 9.6	T = 7.8 ± 4.4 M = 4.4 ± 2.2 F = 12.2 ± 2.6 Jackson & Pollock T = 13.0 ± 3.7 M = 11.0 ± 2.8 F = 15.9 ± 2.9 Slaughter	T = 18.6 ± 2.3 M = 19.1 ± 2.2 F = 17.5 ± 2.1
Grant et al. (2001)	Elite climbers reported leading 'Hard Very Severe' within last 12 months	F	10	31.3 ± 5.4	1.66 ± 0.07	59.5 ± 7.4	24.8 ± 3.7 Durnin & Womersley	
Grant et al. (2001)	Recreational climbers reported leading 'Severe' within last 12 months	F	10	24.1 ± 3.8	1.64 ± 0.04	59.9 ± 5.7	26.0 ± 3.6 Durnin & Womersley	
Mermier et al. (2000)	Self reported rating 5.10c YDS (5.8 – 5.13d)	M	24	30.4 ± 6.0 (21.0 – 45.0)	177.4 ± 8.8 (163.5 – 193.5)	72.8 ± 11.6 (40.1 – 94.2)	9.8 ± 3.5 (3.3 – 17.2) Jackson & Pollock	
Mermier et al. (2000)	Self reported rating 5.9 YDS (5.6 – 5.12c)	F	20	32.2 ± 9.2 (18.0 – 49.0)	166.4 ± 5.7 (157.8 – 192.5)	60.1 ± 5.9 (50.2 – 69.9)	20.7 ± 4.9 (14.1 – 29.6) Jackson & Pollock	
Michailov et al. (2009)	Bouldering World Cup Boulder grade: 8a+ (7b+ - 8c) On-sight: 8a+ (7b+ - 8b) Redpoint: 8b+ (7c+ - 9a)	M	18	25.8 ± 5.1 (20 – 39)	174.6 ± 5.6 (165.7 – 187.3)	67.3 ± 6.0 (55.8 – 75.6)	5.8 ± 1.8 (3.4 – 10.6) Jackson & Pollock	22 ± 1.4 (19.9 – 24.4)
Michailov et al. (2009)	Bouldering World Cup Boulder: 7b+(7a+ - 7c+) On-sight: 7b (7a - 7c) Redpoint: 7c (7a+ - 8a)	F	7	25.1 ± 5.3 (16 – 30)	162.6 ± 11.6 (146.2 – 176)	54 ± 6.8 (45.7 – 64.5)	16.6 ± 3.6 (12.1 – 21) Jackson & Pollock	20.4 ± 1.1 (18.2 – 21.4)
Macdonald and Callender (2011)	Highly accomplished boulderers achieving Fontainebleau grade 7b at least 5 times within last 12 months	M	12	25.3 ± 4.9	177.7 ± 4.9	70.2 ± 6.2	12.1 ± 4.3 Dual energy x-ray absorptiometry	22.3 ± 2.0

Study	Ability	Sex	*n*	Age (years)	Height (cm)	Mass (kg)	Body fat (%)	BMI
Cheung et al. (2011)	National competition level climbers On-sight: 7a+ (6c – 7c+) Redpoint: 8a (7b – 8c)	M	11	30.2 ± 6.3 (21.0 – 40.0)	172.7 ± 6.2 (162 – 181)	58.4 ± 5.6 (50.6 – 70.2)	11.0 ± 3.2 (5.8 – 17.2) Durnin & Womersley	19.6 ± 0.9 (17.7 – 21.4)
Cheung et al. (2011)	National competition level climbers On-sight: 7a (6b – 7c) Redpoint: 7c (6c+ - 8a+)	F	10	32.2 ± 5.5 (25.0 – 41.0)	158.6 ± 4.6 (147.5 – 163.5)	48.7 ± 3.5 (43.2 – 55.5)	27.3 ± 3.4 (22.9 – 33.5) Durnin & Womersley	19.4 ± 1.0 (18.3 – 20.8)
Grant et al. (1996)	Elite rock climbers Minimum standard – led grade E1 (British Adj) within previous 12 months	M	10	27.8 ± 7.2	178.9 ± 8.5	74.5 ± 9.6	14.0 ± 3.7 Durnin & Womersley	
Grant et al. (1996)	Recreational climbers Having led up to grade ‘severe’ (British Adj) within previous 12 months	M	10	32.0 ± 9.2	179.4 ± 7.9	72.9 ± 10.3	15.3 ± 3.0 Durnin & Womersley	
Watts et al. (1993)	World cup finalists 8a+ French grade	F	6	27.3 ± 1.9	162.3 ± 4.6	46.8 ± 4.9	9.6 ± 1.9 Jackson & Pollock	
Watts et al. (1993)	world cup Semi-finalists 8b French grade	M	21	26.6 ± 4.2	177.8 ± 6.5	66.6 ± 5.5	4.7 ± 1.3 Jackson & Pollock	
Watts et al. (1993)	World cup Semi-finalists 7c/7c+ French grade	F	18	27.8 ± 2.0	165.4 ± 4.0	51.5 ± 5.1	10.7 ± 1.7 Jackson & Pollock	

In the only study to date specifically aimed at comparing the anthropometric, strength, endurance and flexibility characteristics of female elite, recreational and non-climbers (Grant et al., 2001) reported no significant differences between groups for mass, height, percentage body fat and SSF In fact, although non-significant it was the non-climbers (physically fit individuals who participated in physical exercise for a minimum of 20 min three times per week) who were reported to have the lowest body mass (59.1 ± 7.5 kg), body fat (22.8 ± 5.3%) and SSF (38.7 ± 12.2 mm) of the three groups. As expected the female climbers had greater body fat than previously reported for males in a similar study by Grant et al. (1996). The percentage body fat of the three groups was considerably higher (10%) than that reported for female world cup competitors in a study by Watts et al. (1993) and were more comparable to those reported for a heterogeneous group of climbers ranging in ability by Mermier et al. (2000). Discrepancies in findings relating to elite climbers were attributed firstly to the use of different skinfold equations (Jackson Pollock versus Durnin and Womersley) to estimate body fat, and secondly with respect to methods of ability classification. The authors argued that there was a clear distinction between the elite and recreational groups, with categorization based on their self-reported ability to climb grade ‘severe’ (Recreational) versus ‘hard very severe’ (elite). However, in reviewing grade comparisons (see Table 2.1) alongside abilities reported in previous studies, this would appear to be much lower, and therefore perhaps not representative of high-level climbers, particularly by today’s standards.

In a large scale study conducted by Watts et al. (2003) anthropometric data were presented for ninety young competitive climbers (52 boys, 38 girls) with a mean age of 13.5 ± 3.0 years and an average of 3.2 ± 1.9 years climbing experience. All were competitors at the junior Competition Climbers Association US National Championship, with a mean self-reported climbing ability of approximately 5.11d YDS. Anthropometric variables including height, mass, body mass index (BMI), and skinfold thickness were measured and compared against the results obtained from an age matched physically fit control group (n = 45). Previously only the characteristics of adult climbers had been presented and thus the study conducted by Watts et al. (2003) served to fill a proportion of the information void with respect to young rock climbers. The authors found that despite similarity in age there were significant differences ($p <$ 0.01) between climbers and control subjects for height, mass, centile scores for height and mass, sum of seven and sum of nine skinfolds and estimated body fat percentage.

No differences were found between climbers and controls for absolute BMI or BMI expressed as a centile score. Findings of this study indicated that as in previous studies with adult climbers, young climbers were relatively small in stature with low body mass. Differences in % body fat scores were observed with no BMI related differences, suggesting that young climbers posses similar characteristics to adults and appeared proportionately heavier in lean mass and lower in fat than non-climbers.

In a recent study by Cheung et al. (2011), anthropometrical characteristics of Chinese elite sport climbers were compared with sex and age matched Chinese population and previous data reported for western elite climbers. It is evident from reviewing the studies discussed previously that much of the existing research was authored by Europeans or North Americans (Grant et al., 2001; Grant et al., 1996; Mermier et al., 2000; Watts et al., 2003; Watts et al., 1993; Watts et al., 1996). With the existence of significant ethnic differences between normative Chinese and western populations it was suggested that data available courtesy of such studies may not provide an appropriate reference for Chinese climbers. As such, the study by Cheung et al. (2011) served to provide evidence based references for competitive Chinese climbers, whilst also investigating whether there were any great differences between ethnic groups.

The results obtained by Cheung et al. (2011) for height, mass, percentage body fat and BMI are presented in Table 2.3 alongside data collated from other anthropometrical studies. As was seen with western climbers, when compared with normative values, Chinese climbers were characterized as being small in stature with low BMI. According to the norms for corresponding age groups in the Report of National Physical Fitness Surveillance (RNPFS), the body height and weight of both male and female climbers in the study by Cheung et al (2011) were at the 75th and 25th percentile, respectively. The reported BMI values for male and female climbers were at 10th and 25th percentile respectively and bordered the ‘under-weight’ category. The authors attributed the lower BMI and body weight to a lower body fat content supported by lean skinfold measure, particularly with respect to the triceps and sub-scapular sites which were found to be at the 25th percentile of related norms in RNPFS for both males and females. In comparing the physical characteristics of Chinese climbers in the study with those reported for western climbers, Cheung et al. (2011) noted that despite lower height and weight values seen for Chinese climbers, there was no real difference with respect to BMI and percentage body fat.

Much of the literature already presented investigates the physical characteristics of climbers who participate in either traditional or sport climbing disciplines, yet rarely notes the predominant form of climbing undertaken by their participants. More recently, with the growing perception that each discipline of rock climbing is characterized by its own specific demands, researchers have also investigated the anthropometry of boulderers specifically (Macdonald and Callender, 2011; Michailov et al., 2009). Bouldering is fast becoming a distinct climbing sub discipline, having been included as a climbing competition discipline by the IFSC since 2006 (Michailov et al., 2009). Whilst competitive sport climbing is characterized by climb ascent times of up to 7 min, with route length up to 18 m, bouldering routes are much shorter. In competitive bouldering routes rarely exceed 3 m, with the sequence of movements required for success often involving strenuous, powerful and intense intermittent effort (Josephsen et al., 2007; La Torre et al., 2009). As such, the activity profiles of sport climbing and rock climbing differ considerably, resulting in potential differences in athletic profiles of climbers who partake in only one discipline exclusively.

The first study to investigate anthropometric and strength characteristics among world class boulderers was conducted with competitors at the 2007 bouldering world cup held in Sofia, Bulgaria (Michailov et al., 2009). Participants (n = 25; 18 male, 7 female) were recruited during the qualification round of the World Cup. The measures obtained during the study with respect to body composition included height, body mass, BMI, percentage body fat and also percentage muscle mass. In general, boulderers were found to have similar characteristics to elite sport climbers (see Table 2.3). However, both male and female climbers in the study were shown to have higher body fat (21% and 73% difference respectively) compared to elite sport climbers (Watts et al., 1993) yet were lower than those reported in other studies with lower ability climbers. The authors attributed this to the exercise demand imposed by bouldering, being more intensive and lasting a matter of seconds as opposed to minutes.

Michailov et al. (2009) measured boulderers percentage muscle mass using an anthropometric skeletal muscle mass prediction model (Lee et al., 2000). Height, age, sex, ethnicity, skinfold thickness at the triceps, thigh, and calf, as well as circumferences of the arm, thigh and calf are taken into consideration. The values obtained for percentage muscle mass were 41.6 ± 4.3% and 47.4 ± 1.8% for women and men respectively. These values were comparable to those reported for elite sport climbers in a previous study by Berrostegieta (2006), although a different method of calculation was used (GREC). The lack of data for percentage muscle mass in rock climbers made it difficult for the authors to draw comparisons within the sport, however, they noted that the climbers in their study had lower muscle mass than elite weight lifters, yet was similar to elite wrestlers and light weight rowers. Due to the strength demands and nature of bouldering, it could be assumed that boulderers would be more muscular than other climbers, yet there may be an optimal range above and below which increased muscle mass would be disadvantageous (Michailov et al., 2009).

There is a widespread anecdotal view among climbers that reduced body fat improves performance, however it should be noted that although elite climbers have been found to have low levels of body fat (Berrostegieta, 2006; Grant et al., 2001; Grant et al., 1996; Mermier et al., 2000; Mermier et al., 1997; Schöffl et al., 2005; Watts et al., 2003; Watts et al., 1993) the direct influence of weight loss on climbing performance has not been investigated. When investigating body composition, climbers, more specifically ‘elite’ climbers, have been characterised as small in stature, with low percentage body fat (Giles et al., 2006; Sheel, 2004; Watts, 2004). Figures as low as 5% body fat have been found in elite climbers (Watts et al., 1993). Whilst this appears to be a characteristic common to high level climbers, there is still little evidence to support the suggestion that low percentage body fat contributes to successful climbing. As such, low body fat may only be a desirable attribute and not a performance pre-requisite. Grant et al. (1996) concluded that in activities such as rock climbing, where body mass is repeatedly lifted against gravity, extra mass in the form of fat or large muscle mass is disadvantageous, requiring extra upper body strength for movement. Watts (2004) was also in agreement, proposing that higher body mass would increase the muscular strength requirement for maintaining contact with holds and therefore increase the workload imposed when moving along climbing routes. More specifically, it would appear that a reduction of body fat or maintenance of low body fat would be advantageous as this would further reduce body mass and does not contribute to movement and support during rock climbing ascents.

Differing conclusions have been put forward with respect to the varying percentage body fat values reported for rock climbers. Factors such as subject ability, method of assessment and method used to calculate body composition may account for discrepancies between studies (Giles et al., 2006). The definition of and distinction between ability levels in rock climbing research is highly subjective. Although groups of participants will often be defined as ‘elite’, ‘expert’ or ‘recreational’ for the purposes of categorization within a study, mean ability or range of ability varies greatly (Table 2.3). This inconsistency makes it difficult for authors to draw comparisons between previous research or provide definitive conclusions. Variations in data with respect to body composition in rock climbers may also in part be due to method of assessment and calculations used to obtain values. Estimates of body fat have typically been determined via two different methods; Jackson and Pollock, and Durnin and Womersley. The variance in methods used inhibits the ability to make direct comparisons between previous research and therefore limits the conclusions that can be drawn from any given study.

2.6.2 Body dimensions

A small number of studies concerned with determining physical characteristics of rock climbers have investigated and compared body dimensions of elite, recreational and non-climbing groups (Cheung et al., 2011; Mermier et al., 2000; Watts et al., 1993). Rock climbers are often described as being of ectomorph somatatype and are generally small in stature, with significant height differences reported between climbing and non–climbing control groups. Watts et al. (1993) commented that that the likely increased mass in taller climbers may impact on climbing performance, resulting in earlier climbing fatigue owing to the greater loading placed on limbs and increased strength required for movement of larger mass. It was also suggested that increased height would provide an advantage in facilitating longer reaches between moves. Interestingly, in a much later study, Morrison and Schoffl (2007) suggested that the resistance forces associated with moments would be greater for taller climbers whose extremities were further from their torsos’ centre of gravity, resulting in a possible disadvantage.

Watts et al. (1993) were the first to compile anthropometric profiles of elite male and female climbers. Apart from height, no other measures relating to limb length or ratio were reported in their studies. In 1996 a study published by Grant et al. was the first to include measurement of limb length in a battery of anthropometric, strength, endurance and flexibility tests and measures seeking to compare values obtained for elite and recreational climbers with a non-climbing control group. Arm length and leg length on the right hand side was measured for each participant in all three groups. No significant differences were observed and as such provoked little discussion. These findings were replicated in a subsequent study by Grant et al. (2001) investigating the same measures with respect to female elite and recreational climbers and a non-climbing control group.

Measures such as ape index and biiliocristal/biacromial ratio have been included in more recent literature concerned with investigating the anthropometry of rock climbers. Ape index is the ratio of an individual's arm span relative to their height, with a typical ratio being 1.00. Anything above this value is generally noted as being of relevance. Whilst a ratio value is given in most instances, ape index is also reported as the difference in arm span in relation to height (generally given in cm) and can be a positive or negative value. The biiliocristal/biacromial ratio provides an indication of torso dimensions; where biiliocristal breadth is measured as the distance between the most lateral points on the iliac tubercules (hip width) and biacromial breadth is the distance measured between the most lateral points on the acromion processes (shoulder width).The ratio is calculated by dividing biiliocristal breadth with biacromial breadth, with a lower value indicating a triangular torso (Cheung et al., 2011). These measures have been reported in a small number of rock climbing studies concerned with investigating anthropometry of rock climbers, and are summarised for comparative purposes in Table 2.4. Interestingly, the studies presented all report values greater than 1.00 for ape index. The possession of a long reach relative to height in climbers is generally considered a positive attribute and has been highlighted as a selective trait in elite climbers (Sheel, 2004; Watts, 2004). One of the first studies to investigate ape index as a determinant of sport climbing performance was Mermier et al. (2000) who noted that despite a common belief among climbers that success depends on certain untrainable characteristics (stature, ape index, somatotype), when such variables were entered into a multiple regression model only percentage body fat was considered to be a significant predictor of climbing ability. In support of this, Watts et al. (2003) reported significantly higher ape index scores for climbers compared with non-climbing control groups, yet a low correlation between ape index and rock climbing ability (r = 0.05). The authors suggested that the lack of significance was due to the small variability seen within the large sample of ninety climbers; however ape index may become a more important factor when considered alongside other traits.

Table 2.4 Summary of studies and data reporting ape index and biliocrist/biacrom ratio for rock climbers, presented as mean ± SD and (range).

Study	Ability	Gender	*n*	Height (cm)	Arm Span (cm)	Ape Index	Biliocrist/Biacrom Ratio
Watts et al. (2003)	Junior National Championships Mean self reported ability 5.11d YDS (Top-rope/redpoint)	M/F	90	158.5 ± 15.2		1.01 ± 0.02	0.86 ± 0.08
Watts et al. (2003)	Junior National Championships Mean self reported ability 5.11d YDS (Top-rope/redpoint)	M	52	162.2 ± 15.6		1.02 ± 0.02	0.87 ± 0.08
Watts et al. (2003)	Junior National Championships Mean self reported ability 5.11d YDS (Top-rope/redpoint)	F	38	151.3 ± 11.9		1.01 ± 0.02	0.86 ± 0.08
Mermier et al. (2000)	Self reported rating 5.10c YDS (5.8 – 5.13d)	M	24	177.4 ± 8.8 (163.5 – 193.5)	185.4 ± 9.6 (168 -207)	1.0 ± 0.02 (1.0 – 1.08)	
Mermier et al. (2000)	Self reported rating 5.9 YDS (5.6 – 5.12c)	F	20	166.4 ± 5.7 (157.8 – 192.5)	168.6 ± 8.4 (157 – 192.5)	1.0 ± 0.03 (0.96 – 1.11)	
Cheung et al. (2011)	National competition level climbers On-sight: 7a+ (6c – 7c+) Redpoint: 8a (7b – 8c)	M	11	172.7 ± 6.2 (162 – 181)	181.1 ± 8.0 (170 – 195)	1.05 ± 0.03 (0.99 – 1.08)	0.76 ± 0.03 (0.71 – 0.80)
Cheung et al. (2011)	National competition level climbers On-sight: 7a (6b – 7c) Redpoint: 7c (6c+ - 8a+)	F	10	158.6 ± 4.6 (147.5 – 163.5)	166.5 ± 11.7 (152 – 196)	1.05 ± 0.06 (1.0 – 1.22)	0.90 ± 0.04 (0.84 – 0.96)

In a study by Cheung et al. (2011), Chinese climbers, both male and female were found to have an ape index ratio greater than 1.00. This was a prominent finding as Asians are generally found to be short in stature with a negative arm span in relation to height (Cheung et al., 2011). Despite being shorter than western climbers, the Chinese climbers possessed similar anthropometrical characteristics with ape index cited as a favourable variable for elite climbing performance. In the same year Tomaszewski et al. (2011) sought to clarify the anthropometric characteristics of competitive sport climbers. Supporting the findings of previous research, they noted that climbers within their study had a significantly greater arm span and ape index ($p < 0.001$) when compared to a group of untrained individuals (1.05 versus 1.02 respectively). This was a similar finding to that of Mermier et al. (2000) who suggested that a greater ape index could be considered beneficial for sporting success in rock climbing.

Ape index has been considered alongside biiliocristal/biacromial ratio when reviewing the anthropometry of rock climbers, as shoulder width (biacromial breadth) contributes to arm span. Values reported for biiliocristal/biacromial ratio in the studies of Watts et al. (2003) and Cheung et al. (2011) are given in Table 2.4. Both reported a higher ratio amongst competitive junior climbers when compared to age matched control groups. Watts et al. (2003) suggested that the higher biiliocristal/biacromial ratio found in climbers compared to controls was due primarily to narrower biacromial breadth (28.1 ± 2.5 versus 35.7 ± 4.1 mm) relative to biiliocristal breadth (24.1 ± 2.6 versus 26.2 ± 2.6 mm) respectively. A narrower shoulder structure is thought to contribute to the typically lower body mass reported in climbers as discussed in the previous section. A narrow shoulder breadth exhibited by climbers when found in conjunction with large ape index is thought to be of importance as the presence of both would indicate a longer arm component and therefore hold implications for reach distance when ascending routes. Cheung et al. (2011) were the first to report values for biiliocristal/biacromial ratio in adult elite climbers. Results were similar to those reported amongst adolescent climbers by Watts et al. (2003). Adult climbers possessed a narrower shoulder structure and enhanced ape index compared with controls, characteristics deemed beneficial with respect to reach distance when climbing (Morrison and Schoffl, 2007).

Contrary to the findings of Watts et al. (2003) and Cheung et al. (2011), a study attempting to provide a somatic profile of competitive sport climbers by Tomaszewski et al. (2011) hypothesized that a lower biiliocristal/biacromial ratio (indicating a more triangular torso) would be advantageous in rock climbing, and therefore present itself among elite rock climbers. This was confirmed with climbers shown to have a significantly lower (p <0.001) pelvis-to-shoulder ratio when compared with untrained individuals (Tomaszewski et al., 2011). However this variable was not highlighted as a contributor or determinant of climbing success. Results were presented as mean standardized values (z-score) and as such raw mean ± SD values for data were not available, making it difficult to comment upon the measures obtained relative to those reported in previous studies.

2.6.3 Strength, endurance, power and flexibility

Rock climbing has been described as an activity with a complex physical demand (Goddard and Neumann, 1993). A number of key physical characteristics have been identified for successful rock climbing. Initially these factors were identified anecdotally through elite climbers and coaches seeking to develop guidelines for training (Bollen, 1994; Goddard and Neumann, 1993; Hörst, 2003). In reviewing the desirable physiological components consistently cited by elite climbers and climbing coaches, Draper and Hodgson (2008) identified four key components considered essential to rock climbing performance. A summary of the components identified is presented in Table 2.5. Although some small inconsistencies are evident with respect to the terminology used in testing or training, the four dominant components identified were strength, endurance, power and flexibility.

Table 2.5 Key physiological components consistently identified as essential to performance in rock climbing (adapted from Draper and Hodgson (2008))

Binney and McClure (2006)	Bollen (1994)	Goddard and Neumann (1993)	Hörst (2003)	Kascenska et al. (1992)	Peter (2004)	Sagar (2001)
Strength	Strength	Strength	Sport specific strength	Muscular strength	Maximum strength	Strength: Grip Back and shoulder Abdominal
Power	Power	Power	Power	Power	Power	Power
Local endurance Strength endurance	Anaerobic endurance	Local endurance Power endurance	Anaerobic endurance	Muscular endurance	Power endurance	Power endurance
Flexibility	Flexibility	Active flexibility	Flexibility	Flexibility	Flexibility	Flexibility

Muscular strength, endurance, power and flexibility have been investigated in rock climbers in order to provide a better understanding of trainable characteristics which may contribute to increased performance (Cutts and Bollen, 1993; Grant et al., 2001; Grant et al., 1996; Michailov et al., 2009; Schöffl et al., 2006; Schweizer and Furrer, 2007; Watts et al., 2003; Watts et al., 1993; Watts et al., 1996). The importance of upper body strength and endurance for rock climbing is consistently highlighted (Sheel, 2004). To date, a growing body of research focusing on strength and endurance characteristics of the forearm and hands of rock climbers is evident (Cutts and Bollen, 1993; Grant et al., 2001; Grant et al., 1996; Green and Stannard, 2010; Helliwell et al., 1988; Lopera et al., 2007; Michailov et al., 2009; Schweizer and Furrer, 2007; Schweizer et al., 2007; Watts et al., 1996). Strength is generally evaluated as maximum handgrip force using some form of handgrip dynamometry. This typically involves an isometric contraction of the fingers in opposition to the thumb and base of the hand

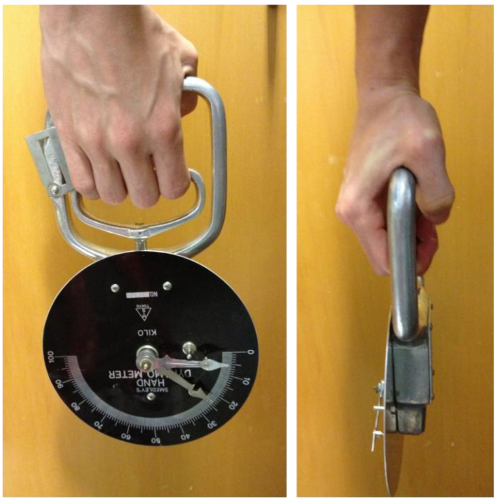

Figure 2.18 Handgrip dynamometry

A summary of forearm and hand strength data obtained by handgrip dynamometry is presented in Table 2.6. Studies seeking to investigate strength endurance characteristics among climbers have employed varying methods. It has been suggested that the measurement of strength in relation to just one hand is lacking in specificity and validity as both hands are used in maintaining contact with the wall when climbing (Giles et al., 2006). As such a number of studies have obtained values for both the left and right regardless of dominance.

Table 2.6 Summary of forearm/hand strength data in rock climbers presented as mean ± SD and (range).

Study	Ability	*n*	Gender	Test Mode	Strength (N)	Strength:Weight
Watts et al. (1993)	World Cup semi-finalists 8b sport grade	21	M	Handgrip Dynamometer	506.0 ± 62.8	0.78 ± 0.06
Watts et al. (1993)	World Cup semi-finalists 7c/7c+ sport grade	18	F	Handgrip Dynamometer	335.4 ± 60.0	0.65 ± 0.06
Cutts and Bollen (1993)	Not Specified (5b – 7b)	13	M	Handgrip Dynamometer	519.8 ± 56.9	0.75 ± 0.10
Grant et al. (1996)	Elite rock climbers Minimum standard – led grade E1 (British Adj) within previous 12 months	10	M	Handgrip Dynamometer	Right: 532 ± 23 Left: 526 ± 21	
Grant et al. (1996)	Recreational Climbers Having led up to grade 'severe' (British Adj) within previous 12 months	10	M	Handgrip Dynamometer	Right: 472 ± 23 Left: 445 ± 21	
Watts et al. (1996)	Expert level rock climbers 5.13b/8a	11	M	Handgrip Dynamometer	581.6 ± 69.6	
Ferguson and Brown (1997)	Elite rock climbers Fontainebleau 7a – 8a+ thought to be within top 10% graded difficulty in competitive sport rock climbing	5	M	Modified Handgrip Dynamometer	715 ± 34	
Watts et al. (2000)	Expert sport rock climbers, self reported best redpoint ascent 5.13b (5.12c – 5.14b) YDS	15	M	Handgrip Dynamometer	507 ± 73.6 (460.9 – 578.6)	0.77 ± 0.07 (0.67 – 0.87)
Mermier et al. (2000)	Self reported rating 5.10c (5.8 – 5.13d) YDS	24	M	Handgrip Dynamometer		0.65 ± 0.14 (0.39 – 0.95)
Mermier et al. (2000)	Self reported rating 5.9 (5.6 – 5.12c) YDS	20	F	Handgrip Dynamometer		0.49 ± 0.1 (0.35 – 0.65)
Grant et al. (2001)	Elite climbers reported leading 'Hard Very Severe' within last 12 months	10	F	Handgrip Dynamometer	Right: 338 ± 12 Left: 307 ± 14	
Grant et al. (2001)	Recreational climbers reported leading 'Severe' within last 12 months	10	F	Handgrip Dynamometer	Right: 289 ± 10 Left: 274 ± 13	
Watts et al. (2003)	Junior National Championships Mean self reported ability 5.11d YDS (Top-rope/redpoint)	52	M	Handgrip Dynamometer	357.9 ± 126.5	0.70 ± 0.13
Watts et al. (2003)	Junior National Championships Mean self reported ability 5.11d YDS (Top-rope/redpoint)	38	F	Handgrip Dynamometer	246.1 ± 66.7	0.62 ± 0.08
Sheel et al. (2003)	Elite competitive rock climbers	9	M/F	Handgrip Dynamometer Dominant hand Non-Dominant hand	 471.9 ± 116.7 449.3 ± 114.7	 0.75 ± 0.12 0.75 ± 0.10

Study	Ability	*n*	Gender	Test Mode	Strength (N)	Strength:Weight
Michailov et al. (2009)	Bouldering World Cup Boulder grade: 8a+ (7b+ - 8c) On-sight: 8a+ (7b+ - 8b) Redpoint: 8b+ (7c+ - 9a)	14	M	Handgrip Dynamometer	574.7 ± 111.8 (421.7 – 745.3)	0.9 ± 0.2 (0.6 – 1.3)
Michailov et al. (2009)	Bouldering World Cup Boulder: 7b+(7a+ - 7c+) On-sight: 7b (7a - 7c) Redpoint: 7c (7a+ - 8a)	7	F	Handgrip Dynamometer	274.6 ± 85.3 (98.1 – 362.8)	0.5 ± 0.1 (0.2 – 0.7)
Green and Stannard (2010)	Trained indoor rock climbers, minimum 3 years climbing training history, trained 4 days per week. Recruited from university climbing club	9	M	Electronic grip strength Transducer	559 ± 72	
Cheung et al. (2011)	National competition level climbers On-sight: 7a+ (6c – 7c+) Redpoint: 8a (7b – 8c)	11	M	Handgrip Dynamometer	Right: 471.7 ± 93.2 (343.2 – 666.9) Left: 454.0 ± 84.3 (362.8 – 598.2)	0.81 ± 0.17 (0.63 – 1.19)
Cheung et al. (2011)	National competition level climbers On-sight: 7a (6b – 7c) Redpoint: 7c (6c+ - 8a+)	10	F	Handgrip Dynamometer	Right: 229.5 ± 40.2 (166.7 – 304.0) Left: 236.3 ± 52.0 (156.9 – 333.4)	0.49 ± 0.09 (0.35 – 0.59)
Macdonald and Callender (2011)	Highly accomplished boulderers achieving Fontainebleau grade 7b at least 5 times within last 12 months	12	M	Handgrip Dynamometer	562 ± 69	

Findings relating to handgrip strength and climbing performance have been contradictory; studies have reported significant and non-significant differences between climbing abilities, and climbers versus non-climbers. In one of the first studies to provide an anthropometric profile of elite male and female competitive sport rock climbers Watts et al. (1993) reported that climbers possessed only 'moderate' grip strength when compared to that of other athletic groups. However, when expressed relative to body mass it was found that climbers exhibited a high strength to weight ratio, which was also found to be a predictor of performance. This finding highlights the added importance of the reduction in body mass discussed in the previous section. Other studies, similar to that of Watts et al. (1993) which have used handgrip dynamometry as a measure of strength, have not reported particularly high scores (see Table 2.6). Mermier et al. (2000) identified a weak association between handgrip strength and performance. Scores for climbers and non-climbers were seemingly comparable, supporting the previous findings of Ferguson and Brown (1997). The authors noted that absolute grip strength between climbers and non-climbers remained non-significant, unless discussed in relation to body mass. As such, the importance of body composition was highlighted as opposed to grip strength characteristics. This was mirrored in later research conducted by Cheung et al. (2011) which revealed that absolute handgrip scores were not significantly different between climbers and controls, yet when expressed as a handgrip/mass ratio yielded a significance.

The first study to report grip strength and endurance characteristics relevant to the demands of rock climbing specifically was published by Cutts and Bollen (1993). Measures of whole hand maximum grip strength and endurance were obtained alongside 'pinch' strength and endurance as this was thought to better replicate hand positions used during rock climbing. In contrast to the typical handgrip position used in dynamometry (Figure 2.18), the pinch grip involves the opposition of the thumb against the fingers. Tests were carried out using a pinch/grip meter consisting of a torsion dynamometer linked to personal computer (PC) as described by Helliwell et al. (1988). The results showed climbers possessed significantly greater ($p < 0.05$) whole hand maximal grip strength (left: 532 N ± 85 N, right: 507 N ± 17 N) when compared with non-climbers (left: 412 N ± 74 N, right: 445 N ± 59 N). This significant difference ($p < 0.05$) was also replicated in the maximum pinch grip scores for climbers (left: 135 N ± 16 N, right: 143 N ± 20 N) and non-climbers (left: 107 N ± 24 N, right: 101 N ± 17 N). When comparing results of grip endurance tests (with a target of 80 percent of previous best performance) expressed as integrals of the force-time curve for each test, rock climbers performed significantly (p <0.05) better with the left hand (climbers: 13.8 kN ± 5.2 kN versus non-climbers:8.0 kN ± 4.1 kN) . Interestingly, mean pinch grip endurance (with a target of 50 percent of previous best performance) was found to be significantly greater in climbers than non-climbers for both the left (climbers: 6.6kN ± 1.4 kN vs. non-climbers: 3.7 kN ± 1.3 kN) and right (climbers: 6.4 kN ± 2.0 kN vs. non-climbers: 3.8 kN ± 1.4 kN) hand.

Although all participants in the Cutts and Bollen (1993) study were right hand dominant, raw scores among individuals and groups appeared to be greater for the left hand for some measures. The authors suggested that the very nature of climbing alone may contribute to enhanced strength and endurance, particularly with respect to the non-dominant side (in most instances the left hand) and pinch grip. During climbing the left arm is often required to support the body whilst the dominant right hand is used to negotiate technical aspects of the climb, such as inserting protection and clipping quickdraws during lead ascents. It may also be that climbers subconsciously set about training the 'weaker' left arm to a greater extent owing to the belief that it is likely to be weaker than the dominant side (Cutts and Bollen, 1993).

Despite these findings, the authors were quick to highlight the limitations of their study stating that the tests used to determine grip strength were only loosely related to the reality of rock climbing as the fingertips were not loaded with the participants bodyweight, nor were the arms positioned above the head as in climbing. Contrary to Watts et al. (1993), it was concluded that the overall performance in laboratory based tests of hand strength did not relate directly to climbing achievement. Whilst it was acknowledged that there must be a strength requirement to climb at a certain level (with pinch grip strength thought to increase with climbing experience), strength above a given level was not thought to provide any additional advantage and was therefore not a requirement of climbing performance (Cutts and Bollen, 1993).

Handgrip dynamometry has been well used and is still prevalent in rock climbing research today as a method of evaluating forearm strength, yet its application has been deemed questionable with respect to specificity (Giles et al., 2006; Sheel, 2004; Watts, 2004). During an ascent a climber may adopt a number of different hand configurations or 'grips' when maintaining contact with the wall, examples of which are presented in Figure 2.19. Of the four hand positions shown, only the pinch grip (depicted in Figure

2.19D) involves the opposition of the thumb and palm against the fingers in a similar manner to dynamometry. In response to this problem, sport specific measures and apparatus have been developed to quantify finger strength as opposed to grip strength, using a configuration which better replicates those used in rock climbing.

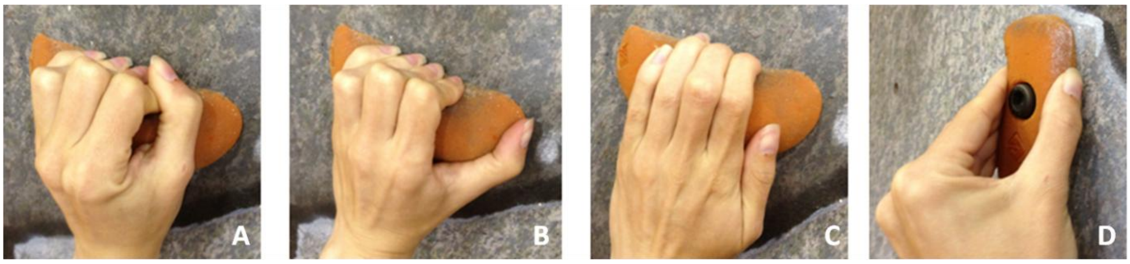

Figure 2.19 Common hand positions used in rock climbing: A; closed crimp, B; open crimp, C; extended, D; pinch.

In two separate papers published by Grant et al (2001; 1996) a measure of climbing specific finger strength was obtained alongside grip and pincer strength for male and female elite climbers respectively. These values were compared with those measured in recreational climbers and non-climbers. In both instances, finger strength was assessed using an innovative apparatus, developed in an attempt to better simulate the positions climbers adopt when gripping a rock face. In brief, the apparatus consisted of a strain gauge attached to a flexible steel plate where force was applied. The apparatus was positioned and fixed such that only the fingers in isolation applied direct force. A summary of the results obtained for both studies is presented in Table 2.7. Standard measures of handgrip and pincer grip, as described previously within this section, were also taken. Finger strength refers to scores obtained using the climbing specific test apparatus and this was conducted with four fingers and two fingers. All measures were taken on both the left and right hand.

Table 2.7 Mean SD for grip strength, pincer strength and finger strength tests (adjusted for body mass).

	Grant et al. (1996)			Grant et al. (2001)		
Characteristic	Elite	Recreational	Non-climbers	Elite	Recreational	Non-climbers
Grip strength (*R*) (N)	532 ± 23	472 ± 23	478 ± 23	338 ± 12[b]	289 ± 10[b]	307 ± 11
Grip strength (*L*) (N)	526 ± 21[a,b]	445 ± 21[b]	440 ± 21[a]	307 ± 14	274 ± 13	285 ± 1
Pincer strength (*R*) (N)	95 ± 5[a,b]	96 ± 5[b]	70 ± 5[a]	34.8 ± 8.2	38.1 ± 8.9	29.2 ± 6.9
Pincer strength (*L*) (N)	93 ± 6[a,b]	75 ± 6[b]	74 ± 6[a]	32.8 ± 7.6	33.4 ± 7.7	24.2 ± 5.6
Finger strength (*4R*) (N)	446 ± 30[a]	359 ± 29	309 ± 30[a]	321 ± 18[a,b]	251 ± 14[b]	256 ± 15[a]
Finger strength (*4L*) (N)	441 ± 34[a]	346 ± 33	309 ± 34[a]	307 ± 14[a,b]	248 ± 12[b]	243 ± 11[a]
Finger strength (*2R*) (N)	329 ± 24[a]	249 ± 23	224 ± 24[a]	193 ± 17[a]	171 ± 15	136 ± 12[a]
Finger strength (*2L*) (N)	313 ± 26[a]	238 ± 25	222 ± 26[a]	186 ± 20	141 ± 15	136 ± 15

[a]Elite climbers performed significantly better than the non-climbers
[b]Elite climbers performed significantly better than the recreational climbers

In both instances finger strength was highlighted as a distinguishing feature between groups, particularly with regard to finger strength and grip strength. These characteristics were thought to represent an aspect of performance which could be trained to produce a potential advantage. A small number of studies seeking to evaluate finger strength specific to rock climbing have developed their own methods of quantifying finger strength using different devices (Michailov, 2005; Michailov, 2006; Schweizer, 2001; Schweizer and Furrer, 2007; Wall et al., 2004). Michailov et al. (2009) sought to determine strength and endurance characteristics of world-class boulderers. With this aim in mind the authors adopted a method first described by Köstermeyer and Weineck (1995), and later evaluated by Schöffl et al. (2006). In this procedure climbers are required to stand on an electronic scale before placing two fingers (middle and ring finger) of the dominant hand on a small edge (typically a small climbing hold). The climber is then asked to transfer their weight from the scales to the hold by flexing at the legs. The specific maximum strength is calculated by subtracting the remaining value displayed on the scales from body mass. This method could be easily reproduced without the need for specific apparatus, and was a turning point in facilitating comparisons between research where previously there had been a degree of ambiguity and inconsistency.

The role of power and flexibility in successful rock climbing is not as well researched or documented as strength and endurance characteristics. This is due in part to the limited number of sport-specific measures available for rock climbing. Power, particularly in relation to the upper body has been cited as an important aspect of rock climbing performance owing to the often dynamic nature of the activity (Bertuzzi et al., 2007; Giles et al., 2006; Mermier et al., 2000; Sheel, 2004). In a dynamic move a climber must use their arms and legs to gain height and distance in fast fluid movements, often targeting holds that are out of reach statically (Bollen, 1994; Goddard and Neumann, 1993; Hörst, 2003; Sagar, 2001). Power is required to provide the propulsion necessary to release and then catch a higher or otherwise unattainable hold. Such movements can range from a simple lunge and release of a hand to a full body leap where the climber is described as 'cutting loose' (Richardson, 2001).

Studies reporting the direct measurement of upper body power in rock climbers are scarce (Giles et al., 2006). One of the first do so was Mermier et al. (2000) who assessed upper and lower body anaerobic power among forty four climbers varying in skill level. Upper body anaerobic power measures were obtained using a Wingate protocol on an adapted Monark cycle ergometer (arm crank). The study aimed to identify physiological determinants of sport climbing performance and as such utilised a Principal Components Analysis (PCA) procedure whereby variables were combined into components (Training, Anthropometric, and Flexibility) to explain the variance in performance. The authors concluded that the absolute measures of peak, mean, and decrease in power for the upper and lower body Wingate tests were outliers with respect to climbing performance. It was acknowledged that the relevance of anaerobic power needed further clarification and perhaps consideration alongside other variables, but was not an important factor in determining performance (Mermier et al., 2000).

Bertuzzi et al. (2007) investigated training status, route difficulty and upper body aerobic and anaerobic performance in elite and recreational climbers in an attempt to understand the influence of these on the energetics of rock climbing. Upper body power was measured using a Wingate anaerobic test where external power output was measured every 1s and peak power (PP), mean power (MP) and fatigue index (FI) were calculated. Results showed that PP and MP were significantly higher (p <0.05) in elite climbers (PP: 8.0 ± 0.5 Wkg^{-1}, MP: 6.2 ± 0.4 W kg^{-1}) compared to recreational climbers (PP: 7.0 ± 0.7 Wkg^{-1}, MP; 5.3 ± 0.5 Wkg^{-1}). However, the focus of the study was to investigate factors affecting climbing economy and percentage contributions of energy systems and therefore the authors did not comment upon power as a measure to determine or distinguish between abilities.

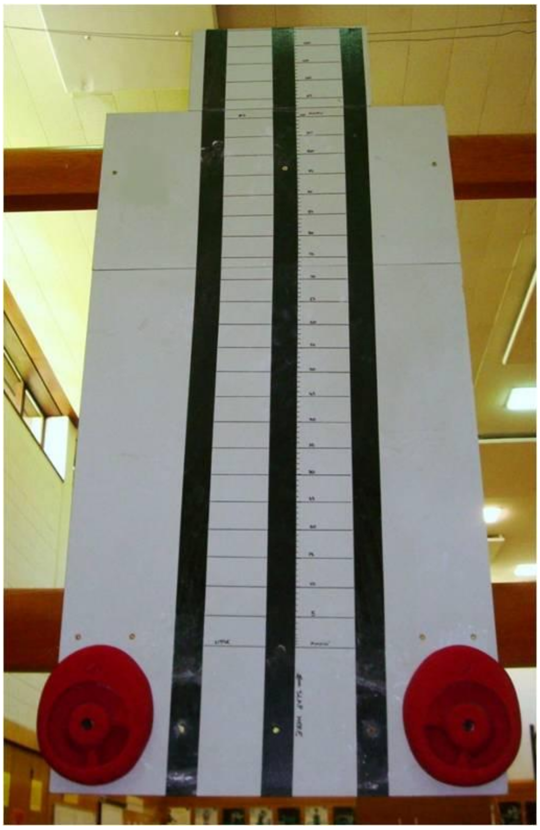

Figure 2.20 Revolution board test apparatus

Finally, a study aimed at developing a novel sport-specific test for measuring power was presented by Draper et al. (2011a). The powerslap test was created in order to better replicate the dynamic movement and demands placed upon the upper body during rock climbing. A specific test apparatus was developed using a revolution board (Figure 2.20) with a scaled back-board for scoring purposes (marked at increments of 1 cm). The test starts with the climber hanging at full extension from two holds from which a pull up movement is made, releasing one hand to slap the scaled board above (Figure 2.21). Draper et al. (2011a) assessed the validity and reliability of the powerslap test as a performance measure. There was a significant relationship between powerslap scores and assessed climbing ability, with scores significantly differentiated by climber ability. Limits of agreement and intra class correlation also indicated that the powerslap test was a reliable performance measure. These results highlighted not only the inclusion of power as a key factor of performance but also emphasised the importance of sport-specific tests. Although the powerslap test was presented as a measure of upper body power alone, the authors suggested that its future inclusion in a battery of sport specific tests would be beneficial when attempting to asses performance and training.

Figure 2.21 The starting and finishing positions for the powerslap test.

The role of flexibility with respect to climbing performance and the manner in which it is assessed has varied (Draper et al., 2009; Grant et al., 2001; Grant et al., 1996; Kascenska et al., 1992; Lopera et al., 2007; Mermier et al., 2000; Mitchell et al., 2011; Watts et al., 2003; Watts et al., 1993). Rock climbing training guides have emphasized the importance of increased flexibility in order to enhance climbing ability (Bollen, 1994; Goddard and Neumann, 1993). The interest in developing flexibility and its potential to improve climbing performance was largely based on anecdotal reports and remained as such until the mid 1990's. Although often highlighted as a key fitness component of rock climbing due to the movement demands and range of motion required to execute certain positions, the assessment of flexibility in rock climbing remains somewhat limited.

The sit and reach test is widely included in test batteries for various sports and in the health sector as a performance assessment tool (Jackson and Baker, 1986; Jones, 2001; Jones et al., 1998; Kokkonen et al., 1998). Grant et al. (1996) evaluated flexibility in elite, recreational and non-climbers using the traditional sit and reach method. No distinction was found between groups with the scores for all three groups noted as 'average' according to Pollock et al. (1984). Although the differences between groups were non-significant, there was a tendency for the elite climbers to perform best. The lack of significance between group scores for the sit and reach test was thought to be attributed to the form of flexibility measured. In rock climbing the key aspects of flexibility are thought to be hip flexion, hip abduction and external rotation. In contrast to this the sit and reach test, was developed as a measure of low back and hamstring flexibility (Jones et al., 1998). Reviews of rock climbing literature have repeatedly commented upon the lack of specificity in relation to flexibility measures (Giles et al., 2006; Sheel, 2004; Watts, 2004). The lack of appropriate sport specific measures means that evaluating the role of flexibility in rock climbing performance is often viewed as problematic.

Flexibility is highly specific to particular activities and defining its role in any given sport is a complex issue. In suggesting that the sit and reach test may not be applicable to the forms of flexibility beneficial in rock climbing, researchers have attempted to develop a measure indicative of the range of motion required during rock climbing. The 'foot raise' was developed by Grant et al. (1996) as a measure of climbing-specific hip flexion replicating movement demands seen in rock climbing. The evaluation of hip flexibility via leg span was also used as it was thought to replicate the 'bridging' movements often used by climbers during ascents. Other studies which have evaluated flexibility amongst rock climbers have used tests such as leg-span, range of motion at the hip and shoulder, and foot raise (Cheung et al., 2011; Grant et al., 2001; Mermier et al., 2000; Michailov et al., 2009; Watts et al., 2003). In most instances authors have reported higher scores for elite climbers when compared with those classed as recreational climbers; however these differences have remained non-significant.

In seeking to identify a more positive relationship between flexibility and performance, Draper et al. (2009) developed four novel tests of climbing flexibility and assessed their validity and reliability alongside two existing flexibility measures. In total, six tests were included in the study; the Grant foot raise, the sit and reach test, and four new adaptations; adapted Grant foot raise, climbing specific foot raise, lateral foot reach, and a foot loading flexibility test. As anticipated results showed that mean scores for high-level climbers were greater that those with lower ability for all tests. With the exception of the climbing specific foot raise, all measures were shown to have good reliability (ICC = 0.90 – 0.97). The existing flexibility measures used in previous studies (Grant foot raise and sit and reach test) were shown to have a poor correlation with climbing ability, which may explain the disappointing and inconclusive results presented in previous studies. The foot loading flexibility test had the strongest correlation with climbing ability (r = 0.65) and was also able to differentiate between climbing abilities in a laboratory setting ($F_{(3,42)} = 8.38$, $p < 0.0005$). However, this test also required special apparatus (climbaflex board) limiting its ability to be easily replicated in subsequent research. The lateral foot reach and the adapted Grant foot raise were also significantly correlated with climbing ability (r = 0.30 and r = 0.34 respectively), and if used together were thought to provide good field measures of flexibility. To conclude, the authors emphasized the importance of flexibility with respect to rock climbing, with results highlighting flexibility as a key performance component for the sport when a climbing specific or sport-specific test is used.

2.6.4 Aerobic fitness

Several studies have reported peak $\dot{V}O_2$ or $\dot{V}O_{2max}$ obtained via traditional test methods, such as treadmill running and cycle ergometry, in order to provide an insight into aerobic capacity and fitness of rock climbers. Often, incremental tests to exhaustion are also completed in order to determine to what extent maximal whole body cardio respiratory capacity is used during bouts of rock climbing. A table summarizing maximal values reported in rock climbers and protocols used is presented in Table 2.8. It is evident that a majority of studies have used running to assess whole body maximal $\dot{V}O_2$ and define HR responses. It has been suggested that adopting such methods with respect to assessing the responses of climbers may be inadequate, given the specific nature of the exercise and work requirements of the upper body during rock climbing (Bertuzzi et al., 2007; Pires et al., 2011).

Booth et al. (1999) were the first to assess climbing specific peak $\dot{V}O_2$ ($\dot{V}O_{2\text{climb-peak}}$) using an incremental test to exhaustion conducted on a climbing ergometer fitted with artificial hand and foot holds. A three stage protocol was used to assess steady state climbing $\dot{V}O_2$ and HR at different velocities, as well as $\dot{V}O_{2\text{climb-peak}}$. The three trials were interspersed with a 20 min rest period. Trials 1 and 2 lasted for 5 min at a climbing velocity of 8 and 10 m/min respectively, and this also served as a warm up and familiarisation for the third trial. During the final trial speed was kept at 12 m/min for 5 min and increased to 14 and 16 m/min at 5 and 6 min respectively, where it remained until exhaustion. During the final trial subjects were verbally encouraged to climb until volitational fatigue and the highest $\dot{V}O_2$ over a one minute interval was used to define $\dot{V}O_{2\,climb\text{-}peak}$. Typically exhaustion was elicited within 8 to 10 min (mean ± SD; 7 min 44s ± 40 s), which is considered an optimal timeframe when attempting to evaluate aerobic power (McArdle et al., 2010). When viewed in relation to maximal $\dot{V}O_2$ and HR values reported amongst previous research (Table 2.8), it can be seen that the incremental climbing specific test to exhaustion elicited lower values than traditional methods.

In a more recent study España-Romero et al. (2009) utilised the same assessment method as set out by Booth et al. (1999) to determine the level of cardio respiratory fitness of sixteen high-level climbers. In addition to the protocol described previously, the authors confirmed exhaustion when (1) climbing specific peak HR ($HR_{climb\text{-}peak}$) was greater than theoretical maximum HR (HR_{max} = 220 - age) and (2) respiratory exchange ratio (RER) was greater than 1.1. The $\dot{V}O_{2\,climb\text{-}peak}$ values for climbers in the study by España-Romero et al. (2009) were higher than those reported by Booth et al. (1999). This was attributed to discrepancies in participant ability level between studies, with those involved in the study by (España-Romero et al., 2009) able to climb at grade 7b and 8b (Sport) for expert and elite climbers respectively. This was in contrast to an ability level of 6b+ reported among the climbers in the Booth et al. (1999) study. Although the differences in peak values between studies were thought to relate to ability level, no significant difference was observed in $\dot{V}O_{2\,climb\text{-}peak}$ between expert and elite climbers in the study by España-Romero et al. (2009). The authors suggested that this indicated that at higher levels of climbing ability $\dot{V}O_{2max}$ is not necessarily a distinguishing factor of climbing performance. Moreover, climbing time to exhaustion was identified as a determinant of performance as opposed to measurements of cardio respiratory fitness. By using the protocol set out by Booth et al. (1999) $\dot{V}O_{2\,climb\text{-}peak}$ was registered for a given speed, producing a measure of climbing economy as opposed to $\dot{V}O_{2max}$. As such, the values obtained may not represent the highest attainable $\dot{V}O_2$ for subjects and should be taken into consideration when comparing the results with those obtained via traditional assessment methods (España-Romero et al., 2009).

Table 2.8 $\dot{V}O_{2max}$ and HR_{max} data reported for climbers during maximal tests to exhaustion (mean ± SD).

Study	Participants	Method of Assessment	$\dot{V}O_{2max}$ (mL·kg^{-1}·min^{-1})	HR_{max} (bts·min^{-1})
Billat et al. (1995)	*n* = 4 Ability: High level climbers Grade 7b (sport)	Running Pulling	54.6 ± 5.2 (Running) 22.3 ± 2.6 (Pulling)	205 ± 10.3 (Running) 190 ± 9.7 (Pulling)
Watts and Drobish (1998)	*n* = 16 Ability: Experienced; 10 days climbing minimum	Running	50.5 ± 7.0	
Booth et al. (1999)	*n* = 7 Ability: 8.9 years experience, Grade 6b-7a (British)	Climbing	43.8 ± 2.2	190 ± 4
Sheel et al. (2003)	*n* = 9 Ability; Elite competitive rock climbers Grade 5.12a – 5.14c YDS	Cycling	45.5 ± 6.6	192 ± 11
de Geus et al. (2006)	*n* = 15 Ability; On-sight range 7b-8a French	Running	52.20 ± 5.06	192 ± 13
Nicholson et al. (2007)	*n* = 10 Ability: Recreational, Grade < 5.10 YDS	Running	50.73 ± 9.73	193.70 ± 12.94
Magalhaes et al. (2007)	*n* = 14 Ability: Grade range, 6c+ - 8b+ YDS	Running	54.5 ± 2.1	197.5 ± 6.2
Bertuzzi et al. (2007)	*n* = 13 Ability:n6 Elite, 7 Recreational Grade 5.11c – 5.12d YDS	Upper body (Arm crank)	Elite 36.5 ± 6.2 Rec 35.5 ± 5.2	
Rodio et al. (2008)	*n* = 13 Ability: 8 Male, Grade 7a, 5 Female, Grade 5b	Cycling	M; 39.1 ± 4.3 F; 39.7 ± 5.0	M; 171 ± 8 F; 177 ± 4.5
Draper et al. (2008a)	*n* = 10 Ability: Intermediate, Grade 4b/4c British Tech	Running	57.96 ± 6.08	195 ± 8
España-Romero et al. (2009)	*n* = 16 Ability: High level sport climbers Expert; Grade 7b Elite; Grade 8b	Climbing	Expert;51.3 ± 4.50 Elite; 51.9 ± 3.42	Expert; 119.4 ± 29.67 Elite; 123.9 ± 19.70
Draper et al. (2010)	*n* =9 Ability: Intermediate Grade 4a – 5a British Tech	Running	58.7 ± 6.0	195 ± 6.0
Pires et al. (2011)	*n* = 14 Ability: 7 Elite > 5.12d YDS/ 7a+ French (EC) 7 Intermediate < 5.11c YDS/ 6c+ French (IC)	Upper body (Arm crank)	EC; 36.8 ± 5.7 IC; 35.5 ± 5.2	EC; 184.3 ± 7.3 IC; 175.0 ± 8.9

Despite the suggestion that sport specific protocols for assessing $\dot{V}O_{2max}$ would be more appropriate given the nature of rock climbing, only España-Romero et al. (2009) have endorsed the protocol proposed by Booth et al. (1999) to determine $\dot{V}O_{2max}$ in climbers. As can be seen upon reviewing Table 2.8, maximal oxygen consumption has since been measured predominantly using traditional methods. The results, summarized in Table 2.8, suggest that when the same modes of exercise are used (i.e. running, cycling) to evaluate maximal oxygen consumption, $\dot{V}O_{2max}$ values among groups of climbers are similar. Although some discrepancies between studies exist in terms of method of assessment, differences in the values obtained are generally discussed in relation to participant ability.

2.7 Physiological demands of rock climbing

Investigating the physiological responses to bouts of rock climbing did not become a prominent area of research until the mid 1990's. Prior to this, only two studies concerned with evaluating physiological responses to climbing were published. The first, a paper by Rushworth (1972), investigated rock climbing efficiency amongst experienced and non-experienced climbers. The aim of the study was twofold; (1) to produce experimental evidence of the constituents of an efficient climbing style, and (2) to investigate the possibility of skills analysis via the use of video tape and heart rate recordings. Whilst the authors noted a number of observations with regard to climbing style and resultant speed and economy of effort, much of the discussion was aimed at providing a critique of the method of investigation.

In a second early study, Williams et al. (1978) presented observations on the electrocardiogram and plasma catecholamine concentrations of eleven men during two rock climbing ascents. Mean HR values were reported for the two climbs prior to which a placebo was administered for the first climb and a dose of the beta blocking agent oxprenolol for the second. HR (mean ± SD) for the first and second climb were 166 ± 20.4 bts·min^{-1} and 120 ± 10.2 bts·min^{-1} respectively. No significant difference was observed in the adrenaline and nor-adrenaline concentrations before and after climbing following oxprenolol administration. Climbing of itself did not appear to require physical fitness in its everyday sense, but the authors suggested that a particular type of psychological fitness may be required instead. To conclude it was suggested that the sport of rock climbing appeared to represent an anxiety-type of psychological stress as opposed to physical stress and as such was not deemed applicable in developing general fitness, but more a controversial ‘specialized’ fitness.

In contrast to this, two later studies by Nicholson et al. (2007) and Rodio et al. (2008) investigated physiological responses to rock climbing, potential health benefits and its use as an alternative activity aimed at maintaining a good level of aerobic fitness. In the first of these studies, Nicholson et al. (2007) assessed the physiological responses of college–aged recreational climbers. Participants were selected based on previous experience and to be considered for inclusion individuals must have climbed more than five routes below a grade of 5.10 YDS. A basic fitness assessment was completed by all participants, including assessment of running $\dot{V}O_{2max}$. On a separate occasion, participants attempted an ascent of a 5.7 YDS route on an artificial surface. HR and $\dot{V}O_2$ responses were measured continuously using a polar HR monitor and portable metabolic analyzer. Mean ± SD data for running $\dot{V}O_{2max}$ and percentage of $\dot{V}O_{2max}$ utilised during the climb were 50.73 ± 9.73 $mL \cdot kg^{-1} \cdot min^{-1}$ and 48.63 ± 2.44% respectively and fulfilled American College of Sports Medicine (ACSM) guidelines. Climbing HR expressed as percentage of HR_{max} (69.50 ± 3.32%) was also within the (ACSM) guidelines for exercise intensity. However, this was considered to be dependent on an individual’s ability to complete a climbing route. From this the authors suggested that rock climbing provides a suitable alternative form of exercise which meets ACSM guidelines and recommendations for physical activity.

Rodio et al. (2008) reported similar findings to that of Nicholson et al. (2007). The aim of their study was to investigate whether non-competitive rock climbing fulfils sports medicine recommendations for maintaining a good level of aerobic fitness. As was the case in the study of Nicholson et al. (2007), ACSM recommendations were used to classify exercise suitability. Based on measures of HR and $\dot{V}O_2$, the aerobic profile of rock climbing was classified as excellent to superior. In accordance with standards stipulated by the ACSM, non-competitive rock climbing was described as a typical aerobic activity with $\dot{V}O_2$ during climbing ascents being 70 ± 6% in men and 72 ± 8% in women when expressed as a percentage of peak $\dot{V}O_2$. In reviewing the findings of the current study and that of Nicholson et al. (2007), it is suggested that the intensity during bouts of rock climbing is comparable to that recommended by the ACSM in maintaining cardio respiratory fitness. This appears to contradict the conclusions drawn by earlier research which reported that climbing did not represent an activity which had the possibility of developing physical fitness (Billat et al., 1995; Williams et al., 1978).

2.7.1 Oxygen consumption and heart rate

Table 2.9 presents a summary of studies that have reported HR, $\dot{V}O_2$ and BLa concentration responses during controlled bouts of rock climbing. In reviewing the data presented, $\dot{V}O_2$ has been shown to average between 20 and 30 mL·kg^{-1}·min^{-1} with $\dot{V}O_{2peak}$ values reaching in excess of 40 mL·kg^{-1}·min^{-1}. Billat et al. (1995) were the first to investigate $\dot{V}O_2$ and HR responses during rock climbing ascents. Four high-level climbers (ability grade 7b Sport) attempted two designated test routes (R1 and R2) of the same grade (5.12a YDS/ 7b sport) yet differing in technical versus physical demand. R1 was considered to be technically complex, with smaller holds and difficult moves. R2 was steeper and deemed to be more physically demanding. A Douglas bag system was used to collect expired air each 30 s during the last half of each route. The authors reported that the first and second routes required 45.6% and 37.7% of $\dot{V}O_{2max}$ elicited through running, yet this also corresponded to 111.6% and 92.3% of a pulling $\dot{V}O_{2max}$. Climbing was not thought to demand a significant contribution from aerobic metabolism based on the low fraction of treadmill $\dot{V}O_{2max}$ used. This was thought to be due to the minimal input from the legs and large demand placed upon the upper body, possibly indicating that an arm-specific $\dot{V}O_{2max}$ could have been attained (Billat et al., 1995).

Table 2.9 Values (mean ± SD) presented for climbing HR $\dot{V}O_2$ and capillary BLa concentration reported in previous studies.

Study	Participants	Climbing style	$\dot{V}O_2$ Climb (mL·kg^{-1}·min^{-1})	HR Climb (bts·min^{-1})	BLa (mmol·L^{-1})
Billat et al. (1995)	*n* = 4 Ability: High-level climbers Grade 7b (sport)	Two designated test routes (R1, R2) 15m; Grade 7b	24.9 ± 1.2 20.6 ± 0.9	176 ± 14 159 ± 14.7	3 min post-climb 5.75 ± 0.95 4.3 ± 0.77
Mermier et al. (1997)	*n* = 14 Ability: Experienced	Easy;90º Wall, Grade 5.6 YDS Moderate;106º Wall, Grade 5.9 YDS Difficult;151º Wall, Grade 5.11+	20.7 ± 8.1 21.9 ± 5.3 24.9 ± 4.9	142 ± 19 155 ± 15 163 ± 15	15 min post-climb 1.64 ± 0.63 2.40 ± 0.68 3.20 ± 0.97
Watts and Drobish (1998)	*n* = 16 Ability: Experienced Total 10 days climbing minimum	Five four minute bouts of climbing using Treadwall at the following angles: 80º, 86º, 91º, 96º and 102º 6 minute rest between each bout	Peak $\dot{V}O_2$ 31.3 ± 4.0 31.7 ± 4.6 31.2 ± 4.6 29.5 ± 5.2 30.9 ± 3.7	156 ± 17 165 ± 16 171 ± 17 173 ± 15 171 ± 16	1 min post-climb 3.6 ± 11.2 4.0 ± 1.3 4.9 ± 1.6 5.1 ± 1.3 5.9 ± 1.2
Booth et al. (1999)	*n* = 7 Ability: 8.9 years experience Grade 6b-7a (British)	Outdoor sport climbing 24.4m Grade 5c	Peak $\dot{V}O_2$ 32.8 ± 2.0	Peak HR 157 ± 8	4.51 ± 0.5
Watts et al. (2000)	n = 15 Ability: Range 5.12c – 5.14a YDS	Competition-style 20m Grade 5.12b YDS Active Recovery (N=8) Passive Recovery (N=7)			Passive Post; 6.8 ± 1.9 10min; 5.5 ± 1.7 20min; 4.3 ± 2.1 30min; 3.5 ± 2.1
Sheel et al. (2003)	n = 9 Ability; Elite competitive rock climbers Grade 5.12a – 5.14c YDS	Two routes on top-rope Easy ;5.10c YDS Hard ;5.11c YDS	20.1 ± 3.3 (Easy) 22.7 ± 3.7(Hard)	129 ± 13(Easy) 144 ± 14(Hard)	
de Geus et al. (2006)	n = 15 Ability; On-sight range 7b-8a French	Four test routes, Grade 7c	Peak $\dot{V}O_2$ 41.62 ± 4.19 44.10 ± 5.82 40.50 ± 4.36 39.14 ± 5.38 Mean; 41.34 ± 4.90 Average $\dot{V}O_2$ 35.9 ± 3.2 35.9 ± 3.6 34.9 ± 3.1 32.0 ± 3.8 Mean; 34.7 ± 3.4	Peak HR 175.1 ± 13.9 173.8 ± 8.8 167.3 ± 9.9 164.5 ± 10.5 Mean; 170.0 ± 11.7 Average HR 168.7 ± 8.0 167.5 ± 9.5 160.3 ± 8.8 161.8 ± 8.4 Mean; 164.6 ± 8.7	Peak Lactate 6.19 ± 1.61 5.95 ± 1.80 5.55 ± 1.66 4.84 ± 1.30 Mean; 5.63 ± 1.59

Study	Participants	Climbing style	$\dot{V}O_2$ Climb (mL·kg^{-1}·min^{-1})	HR Climb (bts·min^{-1})	BLa (mmol·L^{-1})
Draper et al. (2008b)	*n* = 10 Ability: Intermediate Grade 4b/4c British Tech	Outdoor artificial wall 9.38m Grade 5b Two ascents	26.54 ± 2.46 (On-sight lead) 25.98 ± 2.48 (2nd Lead Climb)	161 ± 6 (On-sight lead) 159 ± 6 (2nd Lead Climb)	Mean ± SD values not presented
Draper et al. (2010)	*n* = 9 Ability: Intermediate Grade 4a – 5a British Tech	Randomized lead (LD) and top-rope (TR) 9.38m, Grade 6a (sport)	Peak $\dot{V}O_2$ LD; 40.87 ± 6.63 TR; 38.29 ± 5.92 Average $\dot{V}O_2$ LD; 25.9 ± 2.6 TR; 25.1 ± 1.3	LD; 159 ± 6 TR; 151 ± 5	Post-climb LD; 3.1 ± 0.6 TR; 2.5 ± 0.9 15 min post-climb LD; 1.2 ± 0.4 TR; 0.8 ± 0.4
España-Romero et al. (2012)	*n* = 9 Ability: Experienced Grade 5.11a – 5.12b YDS	Nine consecutive ascents over 10 weeks Grade 5.10a YDS	Peak $\dot{V}O_2$ 36.9 ± 4.9 (Ascent 1) 36.0 ± 5.2 (Ascent 4) 36.1 ± 3.7 (Ascent 6) 36.8 ± 3.7 (Ascent 9)	Peak HR 157 ± 20.8 (Ascent 1) 155.6 ± 19.4 (Ascent 4) 156.1 ± 15.1 (Ascent 6) 148.9 ± 16.7 (Ascent 9)	

Billat et al. (1995) noted that HR values represented 85.8% and 93% for R1, 77% and 84% for R2 of HR_{max} obtained during maximal treadmill running and pulling respectively. No significant differences were found between routes. Given the high HR for a relatively low $\dot{V}O_2$, it was suggested that upper body work was perhaps the most prominent contributor to performance during rock climbing. As well as commenting upon HR and $\dot{V}O_2$ responses with respect to upper and lower body $\dot{V}O_{2max}$ contributions, the study investigated static and dynamic proportions of ascents. For this, interruption times (static) were differentiated from that during which progress of the hips was observed (dynamic). This was achieved through video analysis and showed that effective time for ascending and immobilization time were equal to 63 ± 9.4% and 36.3 ± 9% of total ascent time respectively. This inferred that isometric contraction purely for positive control during the ascent represented more than a third of the ascent duration.

Mermier et al. (1997) investigated the physiological responses to indoor rock climbing in fourteen experienced climbers. Participants were required to perform three climbing trials on an indoor climbing wall. The angles of the routes were manipulated to promote increasing difficulty across three different ascents; (1) an easy 90º vertical wall, (2) a moderately difficult negatively angled wall (106º) and (3) a difficult horizontal overhang (151º). The difficulty rating for routes 1, 2 and 3 were 5.6, 5.9 and 5.11^+ YDS respectively. Participants climbed each of the routes on top-rope (up and down continuously) for five minutes with 15 min rest between trials. During each trial expired air was collected during the last minute using a Douglas bag and was subsequently analyzed. HR was measured continuously and was captured using a small telemetry unit. The average HR from the final minute of each trial was used for analysis. Mean ± SD values for average HR and $\dot{V}O_2$ for all three trials are presented in Table 2.9. HR values corresponded to 74 – 85% of predicted maximal HR (HR_{max} = 220 – age). The relatively high HR responses detected during climbing were noted by the authors, citing intermittent muscular contraction and reliance on the arm muscle groups as a possible explanation for the results as isometric work elicits a disproportionate rise in HR in relation to $\dot{V}O_2$ (Lind et al., 1966). Mermier et al. (1997) identified significant differences in HR response between all three climbing trials in their study which was attributed to increased isometric upper body imposed by the increasing of each successive climb.

In a study designed to evaluate physiological responses to simulated rock climbing Watts and Drobish (1998) were the first to use a climbing treadmill to assess the responses of sixteen climbers to intermittent bouts of climbing at different angles. The climbing protocol required subjects to attempt five 4 min bouts on the Treadwall at angles of 80º, 86º, 91º, 96º and 102º relative to vertical, with a 6 min rest period imposed between each bout. HR was monitored continuously and $\dot{V}O_2$ was determined at 20 s intervals during each climbing bout. In addition to a maximal running test used to determine peak HR and $\dot{V}O_2$ responses, each subject completed a steady state treadmill running bout at a HR equal to that observed at the 86º angle climbing test. In agreement with Mermier et al. (1997), HR increased with climbing angle yet $\dot{V}O_2$ did not vary significantly (Table 2.9) and a disproportionate rise in HR for a given $\dot{V}O_2$ was observed. Comparisons of rock climbing and steady-state running responses at the same HR intensity revealed a higher $\dot{V}O_2$ during running. This highlighted that modification of a running derived $\dot{V}O_2$ relationship would be necessary in using HR to prescribe and monitor training intensity in climbing due to its non-linear relationship. Contrary to the prior findings of Williams et al. (1978) and Billat et al. (1995), Watts and Drobish (1998) suggested that rock climbing could invoke $\dot{V}O_2$ demands high enough to encourage positive adaptations in aerobic fitness. Values for $\dot{V}O_2$ reported across all angles ranged between 55.5% and 63.4% of $\dot{V}O_{2peak}$ (Treadmill) and these fractions were higher than those presented by both Billat et al. (1995) and Mermier et al. (1997).

Owing to the nature of rock climbing and the difficulties imposed during field testing; only a small number of studies have investigated the responses of climbers outdoors on natural surfaces. Booth et al. (1999) measured $\dot{V}O_2$ and HR responses of seven climbers on an outdoor sport climbing route (Grade 5c Sport). Climbers were asked to ascend a 24.4 m long route protected by a top-rope system. The route was identified by following a line of fixed protection (bolts) as a guide. A portable telemetry system was used to measure expired air (Cosmed K2) with ventilation (V_E) and $\dot{V}O_2$ measured at 15 s intervals alongside HR. All subjects completed the route without fall. Mean ± SD ascent duration for the climb was 7 min 36 s ± 33 s with times ranging from 6 min 28 s to 9 min 54 s. Results indicated that resting HR increased from 74 ± 5 bts·min^{-1} to 107 ± 12 bts·min^{-1} at the start of the climb. After the initial minute of exercise HR showed a further increase to 145 ± 10 bts·min^{-1} and reached a peak of 157

± 8 bts·min^{-1} after 5 min of climbing. Peak HR values measured during climbing corresponded to 83% of $HR_{climb\text{-}peak}$ obtained via a sport specific climbing test to exhaustion. Similarly $\dot{V}O_2$ increased at 1 min and throughout the remainder of the climb reaching 32.8 ± 2 mL·kg^{-1}·min^{-1} at its peak, representing approximately 75% of $\dot{V}O_{2climb\text{-}peak}$ (refer to Table 2.8 and Table 2.9 for mean ± SD values). Results indicated that outdoor climbing required a significant portion of $\dot{V}O_{2climb\text{-}peak}$, suggesting that contrary to previous belief, outdoor climbing may in fact require a large fraction of a climber's peak oxygen uptake. The authors attributed the higher percentage of $\dot{V}O_{2climb\text{-}peak}$ in their study to the methods used to calculate $\dot{V}O_{2max}$. Prior to the study by Booth et al. (1999), climbing $\dot{V}O_2$ had only been expressed as a percentage of pulling or running $\dot{V}O_{2max}$. With the suggestion that $\dot{V}O_{2max}$ is directly related to the amount of contracting muscle during activity, this may not be considered relevant. Rock climbing is expected to use more contracting muscle than pulling or arm crank exercise yet less than running. It was therefore concluded that climbing $\dot{V}O_2$ expressed as a fraction of climbing specific peak aerobic power may provide a more meaningful measure of relative workload (Booth et al., 1999).

In a another study to continuously assess $\dot{V}O_2$ during difficult climbing, Watts et al. (2000) presented peak and average $\dot{V}O_2$ and HR data over an entire climb. Fifteen male expert sport climbers attempted a competition-style route on an artificial indoor climbing wall. The climbers completed the route under lead conditions, clipping a safety rope through a succession of bolt anchors along the route. During the ascent HR was recorded every 5 s, downloaded and averaged over 20 s intervals. Expired air was analyzed continuously using a lightweight metabolic battery-powered analyzer worn in a harness system. Calculations of $\dot{V}O_2$ were also performed over 20 s intervals. Average values were calculated as the sum of data for all completed 20 s intervals divided by the number of intervals. Peak values were identified as the highest observed value during any completed 20s interval.

In agreement with the findings of Watts and Drobish (1998), $\dot{V}O_2$ appeared to increase over the initial 100 s of the climb then tended to plateau during the remainder of the ascent. However, it was difficult to determine whether a metabolic steady state had been reached or if plateau signalled the attainment of arm specific $\dot{V}O_{2max}$ as suggested by Billat et al. (1995) and Mermier et al. (1997). Mean ± SD values for average climbing $\dot{V}O_2$ (presented in Table 2.9) were in agreement with the findings of previous studies that report a $\dot{V}O_2$ of approximately 25 $mL \cdot kg^{-1} \cdot min^{-1}$ during difficult rock climbing (Billat et al., 1995; Mermier et al., 1997). With the aid of continuous analysis, peak $\dot{V}O_2$ of over 30 $mL \cdot kg^{-1} \cdot min^{-1}$ was also noted. The authors did not discuss HR responses in this study, nor were $\dot{V}O_2$ and HR data presented as fractions of maximal values, making it difficult to comment upon the results in this respect.

In a large scale study involving thirty four participants Janot et al. (2000) were the first to look at HR and Rating of Perceived Exertion (RPE) for beginner and recreational climbers. The authors investigated the responses of seventeen recreational climbers (with previous climbing experience and familiarity) and seventeen beginner climbers (no previous climbing experience). The study was aimed at clarifying the physiological demands of sport climbing by comparing the characteristics and responses of climbers differing in ability and experience. To this end, each subject climbed two separate test routes with a 20 min rest period separating the two climbing trials. Routes 1 and 2 were given a difficulty rating of 5.6 and 5.9 YDS respectively, and both were considered achievable by the beginner climbing group. HR was measured immediately pre-climb, at the completion of the route (or at the moment of failure) and finally following a 10 min rest period. Data analyses revealed HR pre-climb and during ascents were significantly greater for beginner climbers. On average pre-climb and climbing HR were respectively 15.5% and 12.4% higher in beginner climbers compared to recreational climbers. In addition, it was stipulated that climbing HR for beginner and recreational groups ranged from 76 – 90% and 71 – 79% of participants age predicted maximum (220 – age) respectively. These fractions of maximal HR were comparable to those reported by Mermier et al. (1997) for experienced climbers. Differences between groups were attributed to varied efficiency in climbing technique, pressor response, anxiety, and route familiarity which have all been cited in previous studies (Billat et al., 1995; Cutts and Bollen, 1993; Ferguson and Brown, 1997; Mermier et al., 1997; Rushworth, 1972; Watts and Drobish, 1998; Williams et al., 1978). However, the contributions of these factors were not directly assessed by Janot et al. (2000).

In all of the research reviewed so far, HR and $\dot{V}O_2$ during rock climbing have been expressed as a fraction of values obtained in maximal running, pulling and climbing. Sheel et al. (2003) were the first to quantify cardio respiratory responses to indoor climbing in relation to maximal cycle ergometry. Nine elite competitive rock climbers completed two data collection sessions. At the first session subjects were randomly assigned to climb two routes defined as 'harder' and 'easier', safeguarded by a top-rope. The two climbing routes were selected on an individual basis from a total of twelve set for the purposes of the study. The study was the first known to assign climbers to different test routes that were standardized to individual ability. This was in order to ensure that relative workload during each climb was consistent between subjects, and minimize variability. The angle of the wall was consistent for all routes and the difficulty of climb was altered by positioning and size of modular hand and foot holds. The average difficulty for harder climbing was 5.11c YDS and 5.10c YDS for easier climbing. During the climbs, subjects wore a portable metabolic system which allowed measurement of $\dot{V}O_2$, V_E, RER, and HR. At the second session, subjects completed an incremental cycle test to exhaustion where maximal values for V_E, RER, and HR were determined. It was found that climbing HR and $\dot{V}O_2$ expressed as a percent of cycling maximum were significantly higher during harder climbing compared with easier climbing. During harder climbing percentage of HR_{max} was significantly higher than percentage of $\dot{V}O_{2max}$ (89.6% versus 51.2%), and this was also the case during easier climbing (66.9% versus 45.3%). These $\dot{V}O_2$ values were comparable to those reported in previous rock climbing studies (Billat et al., 1995; Booth et al., 1999; Mermier et al., 1997; Watts et al., 2000; Watts and Drobish, 1998). Although the subjects were climbing below their maximum reported ability, they achieved approximately 50% of cycling $\dot{V}O_{2max}$. Given these results, the authors considered it reasonable to suggest that indoor sport climbing did require a significant contribution from aerobic metabolism (Sheel et al., 2003).

Billat et al. (1995), Booth et al. (1999) and Mermier et al. (1997) have all cited a disproportionate rise in HR for a given $\dot{V}O_2$ during rock climbing. This was also observed by Sheel et al. (2003) and subsequently discussed in relation to repetitive isometric contraction of the forearm musculature required during rock climbing. The authors suggested that subjects may have stimulated the metaboreflex, providing an explanation for the dissociation. It has been shown that in response to isometric handgrip exercise there is an increase in cardiac output and preferential redistribution of blood flow to working skeletal muscle (Kaufman and Forster, 1996; Rowell, 1993). Metabolites can accumulate within working tissue and stimulate feedback to the central nervous system (‘metaboreflex’) to elicit a powerful sympathetically mediated pressor response consisting of increased HR, ventricular performance, central blood volume mobilization and cardiac output, vasoconstriction in renal and inactive skeletal muscle vasculatures, and increased systemic arterial pressure (O'Leary et al., 1997; O’Leary et al., 1999; Rowell et al., 1996). Based on the demands imposed by climbing and the observations of the study, the authors suggested it is likely that the muscle metaboreflex is active during rock climbing, and may even be enhanced by climbing specific training (Sheel et al., 2003).

In the first known study to systematically explore the effect of differing displacement and/or steepness, de Geus et al. (2006) assessed the physiological responses of climbers who completed four sport climbing routes over two separate occasions (two routes per test day). HR and $\dot{V}O_2$ responses during climbing were also compared to those obtained for a maximal treadmill running test to exhaustion. The objective of the study was to ascertain whether climbing routes of the same difficulty that differed in displacement would affect physiological demand. All four test routes were graded at 7c (Sport) yet possessed distinctly different characteristics, details of which are presented in Table 2.10. During each ascent HR and gas exchange were continuously measured using a portable cardiopulmonary indirect breath-by-breath calorimetry system in a chest harness worn by the participant. Data for HR and $\dot{V}O_2$ obtained during maximal exercise, and during the four test routes climbed are presented in Tables 2.8 and 2.9 respectively.

Table 2.10 Characteristics of the test routes used in the study conducted by de Geus et al. (2006)

Route	Description	Gradient	Length (m)	Course
OR	Vertical displacement on overhanging wall	120º - 139º	17	↑
VR	Vertical displacement on vertical wall	90º	15.5	↑
OT	Horizontal displacement on horizontal non-overhanging roof	135º - 180º	16	→
VT	Vertical displacement on vertical wall (traverse)	90º	13	→

Significantly higher peak and average HR was found in response to the routes which featured vertical upward displacement (OR and VR) compared with horizontal displacement (OT and VT). In agreement with the findings of (Billat et al., 1995), relative peak HR and average HR were 86 – 91% and 84 – 88% of HR_{max} respectively. Average $\dot{V}O_2$ for the whole climb was significantly lower in the traversing route (VT) when compared with the other three routes. Peak $\dot{V}O_2$ during climbing was between 75 and 85% of running $\dot{V}O_{2peak}$, whilst climb average $\dot{V}O_2$ was reported to represent 62 – 70% of running $\dot{V}O_{2peak}$. The higher HR values were attributed largely to the positioning of the body during ascents as those invoking vertical upward displacement were likely to involve extending the arms above the level of the head which is known to elicit such a response (Astrand et al., 1968). The authors concluded that as was previously hypothesized, relative intensity is influenced by climbing style, with traverse climbing conducted at a significantly lower fraction of maximum capacity. These findings support those presented by Sheel et al. (2003) who observed that HR and $\dot{V}O_2$ expressed as a percent of cycling $\dot{V}O_{2max}$ were significantly higher during harder more demanding bouts of climbing.

2.7.2 Blood lactate concentration

A summary of studies that have measured BLa accumulation in response to rock climbing and the values obtained are included in Table 2.9. Typically rock climbing elicits lower BLa levels than running or cycling (Giles et al., 2006). Blood lactate has been measured in a number of studies using various post-climb sampling times; immediately post-climb, 1, 3, 5, 10 and even 30 min into recovery (See Table 2.9). Blood lactate samples taken immediately post-climb range from 2.4 to 11.3 $mmol{\cdot}L^{-1}$. This range of values represents both responses measured after a single ascent of a route, and continuous bouts of climbing to exhaustion. However, there are considerable variations in the methods of assessment, style of climbing adopted during testing and the ability level of participants, making it difficult to compare results across studies.

Billat et al. (1995) were the first to report BLa concentration in response to climbing for a small group (n = 4) of high-level rock climbers. The testing was designed such that climbers completed two ascents on two separate routes differing in nature. Route 1 was more complex from an informational aspect, whilst route 2 was thought to represent a considerably higher physical demand featuring a steeper profile. Mean ± SD capillary BLa concentration collected three minutes after the end of the two ascents were 5.75 ±

0.95 mmol·L^{-1} and 4.3 ± 0.77 mmol·L^{-1} respectively, with a significant difference reported between ascents despite both routes being classified as grade 7b (Sport). Based on a fixed anaerobic threshold of 4.0 mmol·L^{1}, these levels of BLa concentration are suggestive of activity which takes place above the lactate threshold and is indicative of anaerobisis in the muscle, therefore involving a degree of anaerobic energy production. The authors highlighted the capacity to tolerate high lactic concentrations in the forearms and hand flexors as essential, supporting initial suggestions by Watts et al. (1993).

Blood lactate concentrations in response to sub-maximal ergometer climbing and outdoor climbing were examined by Booth et al. (1999). During the sub-maximal climbing test participants completed two bouts of climbing, each 5 min in duration paced at 8 and 10 m/min. The outdoor climbing was completed on a route 24.4 m long and given a technical grade of 5c. The mean ± SD ascent time for the route was 7 min 36 s ± 33 s. For all climbing bouts BLa concentration was measured at rest and immediately post-climb (mean ± SD; 2 min 32 s ± 8s). Results for ergometer climbing showed that BLa increased from 1.43 ± 0.1 mmol·L^{-1} at rest to 4.54 ± 0.46 mmol·L^{-1} and 6.50 ± 0.69 mmol·L^{-1} after climbing for 5 min at 8 and 10 m/min respectively. Similarly, BLa concentration measured in response to the outdoor climb increased from 1.3 ± 0.1 mmol·L^{-1} at rest to 4.5 ± 0.5 mmol·L^{-1} post-climb. These values were in agreement with those reported by Billat et al. (1995) for BLa sampled 3 min post-climb. Coupled with this, a relevant finding cited was that during continuous climbing on the vertical ergometer, and in the absence of repeated isometric contractions, more work was performed before BLa reached a similar concentration compared with outdoor climbing. More specifically, during continuous climbing on the ergometer the vertical distance climbed was 40 m compared with 24 m outdoors for BLa value of 4.5 mmol·L^{-1}. This led the authors to the conclusion that climbing performance could be extended or improved by minimising immobilisation (isometric contraction) time during ascents (Booth et al., 1999).

In an investigation into the influence of climbing style on physiological responses during rock climbing, Watts and Drobish (1998) required subjects to attempt five 4min bouts of climbing on a Treadwall (climbing ergometer) at angles of 80, 86, 91, 96 and 102º relative to vertical, interspersed with a 6 min rest period provided between bouts. Immediately following termination of climbing at a given angle, each subject was asked to perform a single trial right and left handgrip force test. Within 1 min of termination of each ascent, a blood sample was obtained and analyzed for BLa concentration. Blood lactate did not begin to increase substantially until the angle climbed was overhanging, in turn showing a slight increase at each angle above 90º. Results also indicated a significant accumulation of BLa and reduction in handgrip strength at angles beyond vertical. It was therefore suggested that the ability to resist and/or tolerate BLa is of importance to climbing performance, particularly during successive bouts of rock climbing involving limited recovery time. This was in support of the previous findings of Watts et al. (1993) and Billat et al. (1995) who cited the capacity to maintain high lactate concentrations in the forearm musculature as essential for enhanced climbing performance.

Blood lactate concentration measured post-climb in a study conducted by de Geus et al. (2006) ranged from 4.84 to 6.19 $mmol \cdot L^{-1}$ (see Table 2.9). In this study BLa appeared to be influenced by the difficulty and style of climbing, with lower concentrations in response to a traverse route (VT) compared with three others. More specifically, BLa concentration measured upon completion of a route which featured vertical displacement on an overhanging wall (120º - 135º) were significantly higher compared to that reported at the end of a traverse (vertical displacement on vertical wall). When expressed as a percentage of maximal BLa (BLa_{max}) measured in response to an exhaustive exercise test (running), mean BLa measured immediately post-climb represented 49 to 63% of BLa_{max}. However, when expressed in this form there were no significant differences between the four styles of route. Climb times revealed significantly faster ascents for overhanging routes (OR and OT) compared to routes on vertical walls (OR: 189 ± 25 s, OT: 190 ± 68 s versus VR: 244 ± 38 s, VT: 195 ± 47 s). It would therefore appear that BLa increased in response to style of climbing as opposed to time spent climbing. These findings were in agreement with those of Watts and Drobish (1998) who noted that BLa did not begin to increase until the wall angle climbed became overhanging. This was also the case for the results presented by Mermier et al. (1997) where BLa concentrations rose with increasing angle which was used to promote route difficulty. The authors concluded that the relative intensity of climbing is influenced by climbing style and difficulty of climbing, possibly as a result of type of muscle contraction, more demanding technique, and/or better resting positions afforded during an ascent based on the displacement of the route (de Geus et al., 2006).

Blood lactate concentrations in response to continuous or maximal bouts of rock climbing have been presented by a small number of studies (Watts et al., 1996) (Booth et al., 1999; España-Romero et al., 2009; Sherk et al., 2011). In the first of these Watts et al. (1996) investigated changes in BLa concentration with sustained rock climbing in eleven expert climbers. Subjects completed continuous ascents (laps) of a pre-set competition-style route (increasing in difficulty) on an indoor wall until a fall occurred. The test route used for the sustained bout of rock climbing was rated as 5.12a YDS and was at the limit of each subjects on-sight lead climbing ability. Post-climb BLa concentrations were measured immediately post and at 5, 10 and 20 min of recovery. Results showed that mean (± SD) climbing time to exhaustion was 12.9 ± 8.5 min and was accompanied with a peak BLa increase to 6.1 ± 1.4 $mmol \cdot L^{-1}$ post-climb. These values did not appear to be hugely different from those reported for BLa concentrations reported after single ascents (Table 2.9).

In opposition to the findings of Watts et al. (1996), Booth et al. (1999) reported BLa concentration of 10.2 ± 0.6 $mmol \cdot L^{-1}$ for highly skilled climbers in response to maximal ergometer climbing. Climbing velocity was incremented from 12 m/min to 16 m/min and Mean ± SD time to exhaustion was 7 min 44 s ± 40 s. This value of approximately 10 $mmol \cdot L^{-1}$ is a lot higher than values reported for single ascents (Table 2.9). Although the measures obtained (coupled with $\dot{V}O_2$ and HR responses) indicated that climbers were working maximally during the test, localised muscle fatigue in the upper limbs could have been a primary factor of fatigue. This was thought to provide an explanation as to the lower maximal BLa values seen during climbing when compared to those obtained for running. In support of this, España-Romero et al. (2009) investigated physiological responses to climbing to exhaustion in sixteen high-level climbers, using the same incremental test to fatigue protocol set out by Booth et al. (1999). Subjects were grouped based on ability and defined as either expert (*n* = 12, on-sight ability; 7b Sport) or elite (*n* = 4, on-sight ability: 8b Sport). Blood lactate was measured 1 min post-climb and was 11.1 ± 3.2 $mmol \cdot L^{-1}$ and 10.5 ± 5.48 $mmol \cdot L^{-1}$ for expert and elite groups respectively.

Similar values for BLa concentration to that reported for climbing to exhaustion by Booth et al. (1999) and España-Romero et al. (2009) were observed in a subsequent study by Sherk et al. (2011). In this instance, a continuous bout of rock climbing was imposed by completing laps on a designated test route for 30 min, or until exhaustion, whichever occurred first. Test routes were assigned relative to participants' self-reported on-sight climbing ability and ranged from 5.8 to 5.10a on the YDS scale. Subjects reportedly climbed for a duration of 24.9 ± 1.9 min (507.5 ± 87.5 feet). Eight of the ten climbers who agreed to take part in the trial had a final post-climb BLa greater than 8 $mmol \cdot L^{-1}$ (a criterion for maximal effort), with Mean ± SD values of 11.1 ± 1.0 $mmol \cdot L^{-1}$. As in the previously discussed studies of Booth et al. (1999) and España-Romero et al. (2009), post-climb BLa was well above lactate threshold (3.8 – 4.2 $mmol \cdot L^{-1}$) and was in line with that observed during high intensity performance. The authors were also the first to comment upon the possibility of climbing specific lactate threshold training, and the potential need to determine whether lactate threshold occurs at a different percentage of $\dot{V}O_2$ or HR during climbing, owing to the disproportionate changes in HR and $\dot{V}O_2$ during the activity (Sherk et al., 2011).

2.7.3 Energy system contributions

In an early paper which presented anecdotal fitness guidelines for rock climbing students Kascenska et al. (1992) stipulated that rock climbing requires the development of the body's three energy systems; the adenosine triphosphate-creatine phosphate (ATP-CP) system, lactic acid system, and the oxidative (aerobic) system. The authors further highlighted that when developing strength and power the ATP-PC and lactic systems are used, providing immediate and short term energy, whilst the development of muscular endurance for sustained movement depends upon the oxidative and lactic acid systems, all of which are required in rock climbing (Kascenska et al., 1992). It has long been suggested that determining the relative use of aerobic and anaerobic metabolic pathways for energy production during an activity is beneficial in activity analysis. However, quantifying energy system specificity in rock climbing has received little attention to date and is often cited as an area requiring further investigation (Bertuzzi et al., 2007; Billat et al., 1995; Booth et al., 1999; Mermier et al., 1997; Sheel et al., 2003).

The results of studies analysing the contribution of energy metabolism during rock climbing are discordant. Billat et al. (1995) suggested that rock climbing does not imply oxidative metabolism given the low fraction of running $\dot{V}O_{2max}$ required for an ascent duration of > 3 min. In contrast to this, relative contributions from the aerobic and anaerobic energy systems were commented upon by Booth et al. (1999) who noted that climbing appeared to elicit 70% of peak $\dot{V}O_2$ determined by a climbing specific test to exhaustion ($\dot{V}O_{2climb\text{-}peak}$). This was in opposition to the current belief at the time that aerobic fitness was not required for rock climbing (Billat et al., 1995; Rushworth, 1972; Williams et al., 1978). In addition, the authors also acknowledged the contribution from anaerobic energy production owing to the increased BLa and stipulated that the relative contributions from each system would likely be dependent on route profile and difficulty. In response to this, Sheel et al. (2003) conducted a study aimed at quantifying the cardio respiratory responses to indoor climbing, during two climbs of differing difficulty. $\dot{V}O_2$ expressed as percent of cycling maximum indicated a significantly larger (6%) fraction of maximal values were required during the harder climb, and as such proposed a predominance of the aerobic system during climbing.

Previous studies have generally commented on the predominance of energy systems based on percentage of maximal oxygen uptake (%$\dot{V}O_{2max}$) as discussed earlier within this review of literature. Bertuzzi et al. (2007) were the first to systematically calculate the fractions of the aerobic [W_{AER}], anaerobic alactic [W_{PCR}] and anaerobic lactic [$W_{[La\text{-}]}$] systems during rock climbing based on oxygen uptake, the fast component of excess post-exercise oxygen uptake, and changes in net BLa concentration respectively. Based on measurements that permit the assessment of these contributions (Beneke et al., 2004; Beneke et al., 2002; di Prampero and Ferretti, 1999), the authors cross-sectionally investigated the effects of training status on the energy profile of subjects climbing an easy (5.10a YDS), moderate (5.11b YDS) and difficult route (5.12b YDS). In addition, it was determined whether the aerobic and anaerobic components measured during arm-crank exercise are associated with the energy metabolism required during climbing. Working on the assumption that exercise intensity and training status may influence energy system interaction, it was hypothesized that energy expenditure and anaerobic contribution would be higher in accordance with route difficulty.

Six elite climbers (EC) attempted all three routes whilst a group of seven recreational (RC) climbers completed only the easy route. The respective contributions of the [W_{AER}], [W_{PCR}] and [$W_{[La\text{-}]}$] systems in EC were: easy route 41.5 ± 8.1, 41.4 ± 11.4 and 17.4 ± 5.4%, moderate route 45.8 ± 8.4, 34.6 ± 7.1 and 21.9 ± 6.3%, difficult route 41.9 ± 7.4, 35.8 ± 6.7 and 22.3 ± 7.2%. The contribution of the [W_{AER}], [W_{PCR}] and [$W_{[La\text{-}]}$] systems in RC climbing the easy route were 39.7 ± 5.0, 34.0 ± 5.8 and 26.3 ± 3.8% respectively. In general, the relative and absolute contributions of the aerobic and anaerobic alactic systems in the two groups were significantly higher ($p < 0.05$) than the contribution of the glycolitic system in all situations. In addition, on the easy route the anaerobic lactic system showed a significantly greater percent contribution in RC than EC ($p < 0.05$). The relationship between these two predominant bioenergy systems were discussed with reference to the studies of Margaria et al. (1933) and Piiper and Spiller (1970), who have both commented on their interdependence. The authors suggested that the increased contribution of the oxidative system in rock climbing probably occurs to meet the energy demand imposed by short rests used to reduce the process of fatigue of the muscles of the forearms, or when chalking hands to dry sweat. More specifically, it was thought likely that partial resynthesis of the high-energy phosphate stores in muscle would be facilitated during these nonsystemized resting periods (Bertuzzi et al., 2007). However, it was also acknowledged that the inexistence of a method universally accepted for the measurement of the contribution of anaerobic metabolism during exercise presented a problem. Specifically as the use of net BLa and the fast component of excess post-exercise oxygen consumption to estimate anaerobic systems contribution may be criticized, owing to indications that O_2 availability is only one of several interacting factors that can cause increases in BLa during exercise (Gladden, 2004).

Upper body anaerobic power also differed significantly between the groups studied, yet despite prior speculation, this variable showed no significant correlation with the percent contributions of the energy systems during indoor rock climbing. The authors therefore concluded that the energy systems required during indoor rock climbing are the aerobic and anaerobic alactic systems. The contribution of these energy systems does not depend on the training status, route difficulty or upper body aerobic and anaerobic performance of climbers. As such, the authors stipulated that climbing economy may be more important for climbing performance than improvement of the energy systems. This finding is in stark contrast to the early ideas surrounding the fitness guidelines for rock climbing presented by Kascenska et al. (1992).

2.7.4 Energy expenditure

The $\dot{V}O_2$, HR and BLa responses of climbers are among the most studied physiological parameters in rock climbing research to date (Billat et al., 1995; Booth et al., 1999; de Geus et al., 2006; Draper et al., 2008b; España-Romero et al., 2009; Hodgson et al., 2008; Mermier et al., 1997; Rodio et al., 2008; Sheel et al., 2003; Watts and Drobish, 1998). Although it has received considerably less attention, energy expenditure (EE) has been cited as a valuable measure when attempting to establish training volumes and designing training programs (de Geus et al., 2006; España-Romero et al., 2012). Janot et al. (2000) suggested that differences in responses between beginner and recreational climbers could be attributed to climbing efficiency, yet this was not investigated during their study. Only a small number of studies have investigated EE during rock climbing, and as such, limited data is available on the topic (Bertuzzi et al., 2007; España-Romero et al., 2012; Mermier et al., 1997; Nicholson et al., 2007; Rodio et al., 2008; Watts and Drobish, 1998).

In a study by Mermier et al. (1997), rock climbing EE values were reported for three separate ascents increasing in difficulty. Mean (± SD) EE was (0.622 ± 0.393 kJ/kg per min) for easy, moderate (0.665 ± 0.318 kJ/kg per min) and difficult (0.844 ± 0.309 kJ/kg per min) ascents when expressed relative to mean bodyweight (62.3 kg). These values were thought to reflect energy expenditures similar to those for flat running at speeds of 10:30, 10:15 and 8:00 min per mile respectively (Passmore and Durnin, 1955). Average EE reported for ascending the easy route was found to be significantly less than that measured during the difficult route. The large differences in angle of wall (Easy; 90º, moderate; 106º and difficult; 151º) used to promote the increasing difficulty between test routes were cited as the cause of the disparity in EE between ascents.

Watts and Drobish (1998) estimated EE from $\dot{V}O_2$ $L\cdot min^{-1}$ and RER in response to intermittent climbing bouts at different angles 80, 86, 91, 96 and 102º) on a Treadwall climbing ergometer. In contrast to Mermier et al. (1997), EE values were expressed as kcal per minute ($kcal\cdot min^{-1}$) and also kcal per meter climbed. Absolute EE fell within a narrow range of 10.4 ± 2.5 $kcal\cdot min^{-1}$ and 11.2 ± 2.8 $kcal\cdot min^{-1}$ for all angles of ascent, with climbing classed as 'very heavy' work according to (McArdle et al., 2010). EE values expressed as kcal per minute were not significantly different between angles, yet when expressed relative to distance climbed EE was found to be significantly greater where the angle of climb surpassed vertical.

Two further studies to report EE among other physiological responses were published by Bertuzzi et al. (2007) and Nicholson et al. (2007) in the same year. Metabolic cost was reported in kJ for elite (EC) and recreational climbers (RC) by Bertuzzi et al. (2007), where total metabolic work (W_{TOTAL}) was measured for multiple ascents. Both groups (EC and RC) completed an ascent of an easy route rated as 5.10a

YDS with a 90º wall angle. In addition to this, the EC group completed two further ascents on routes of increased difficulty. One was rated as moderate (5.11b YDS) and featured on overhanging wall angle of approximately 120º the other was given a grade of 5.12b YDS and was set on a wall angle of 110º. The mean ± SD W_{TOTAL} measured for the easy route in EC and RC were 71.4 ± 9.7 kJ and 97.1 ± 18.9 kJ respectively. The moderate and difficult climbing routes elicited mean ± SD W_{TOTAL} values of 81.0 ± 12.9 kJ and 92.1 ± 15.4 kJ respectively for the EC group. The authors reported that metabolic cost was significantly lower in EC than in RC for the easy route. This would appear to support the suggestions of Janot et al. (2000) that climbing economy may contribute to differences in performance between groups differing in ability. However, in contrast to the previous findings of both Mermier et al. (1997) and Watts and Drobish (1998), it was not the route featuring the greatest angle but the route with the highest rating (YDS) which demanded the greatest metabolic cost.

Nicholson et al. (2007) concluded that moderate levels of physical exertion were reached during rock climbing, with EE for a 55 min climbing session ranging from 135.80 to 302.25 kcal (mean ± SD; 202.89 ± 17.72 kcal). The authors suggested that additional caloric energy expenditure could result from increased climbing difficulty or duration of climb. In support of this, Rodio et al. (2008) highlighted time spent on the rock face as the most important parameter with respect to caloric expenditure in non-competitive rock climbers, with EE results directly correlated with time spent ascending the route (r = 0.92). Mean ± SD total caloric expenditure for ascent and recovery for climbing outdoors on a natural rock route with a grade of 5.7 YDS was 475 ± 56 $cal \cdot kg^{-1}$ and 871 ± 275 $cal \cdot kg^{-1}$ for men and women respectively. The authors noted that ascent times varied between subjects (mean ± SD; 288 ± 133 s) but stipulated that according to their data caloric expenditure for 1 min was approximately 9.8 kcal (based on an individual with 70kg bodyweight).This would appear comparable to that reported by Mermier et al. (1997).

All of the studies discussed within this section so far have investigated physiological responses, more specifically energy expenditure, during a single ascent or when attempting multiple routes differing in demand. However, the question of whether or not a climber becomes more economical with repeated ascents of the same route was addressed in a recent study by España-Romero et al. (2012). The study was focused on analyzing physiological responses including EE in a sample of experienced rock climbers during repeated ascents of the same climbing route over a 10-week period. The authors adopted an applied perspective involving a typical climbing situation under normal training conditions. Each participant (*n* = 9) completed nine ascents of a designated test route (5.10a YDS) spaced 1 week apart over a 10-week period. During this time, climbers were allowed to continue their habitual climbing activity between ascents; however they were not permitted to ascend the designated test route other than during data collection. Of the nine ascents, data for test sessions 1, 4, 6 and 9 were selected for statistical analysis. In order to calculate EE for ascents, breath-by-breath data for V_E, $\dot{V}O_2$, expired carbon dioxide and RER were recorded using a portable expired air analysis system (Oxycon Mobile; CareFusion/Jaeger, CA). Expired air data were recorded continuously during climbing and during a 10 min seated recovery period immediately post-climb. All data were averaged over 10 s intervals for final analysis. From this an EE rate in kcal·min^{-1} was calculated via the methods of Weir (1949) and Zuntz (1901) and subsequently converted to absolute EE given in kcal by dividing EE rate by 6 for each 10 s interval. EE for climbing (EE_{CLM}) and recovery (EE_{REC}) in kcal were calculated as the sums of the 10 s interval data for the period spent climbing and the 10 min recovery period respectively. Total EE (EE_{TOT}) was also calculated, taken as the sum of all 10 s interval data for climbing and recovery combined.

Although there were no significant differences observed in V_E $\dot{V}O_2$, HR and $\dot{V}CO_2$ between ascents, significant differences were found for EE_{CLM} in ascent 1 compared with ascents 6 and 9 (17.16 ± 4.56 versus 13.05 ± 4.39 and 11.59 ± 3.22 kcal respectively) and ascents 4 versus 9 (14.6 ± 4.9 versus 11.6 ± 3.2 kcal respectively) when using the Zuntz equation, with similar values reported using the Weir method. These significant differences were also apparent when EE_{CLM} was expressed as a percentage of EE_{TOT}. The relative EE values reported in the study ranged from 7.3 to 7.9 kcal·min^{-1}, and these were lower than those reported in previous research by Mermier et al. (1997) (9.31 ± 12.61 kcal·min^{-1}) and Watts and Drobish (1998) (10.4 ± 11.2 kcal·min^{-1}). As well as significant decreases in EE_{CLM} across ascents, the authors reported that climb time was significantly higher for ascent 1 (2.02 ± 0.55 min) compared with ascents 4, 6 and 9 (1.56 ± 0.40, 1.50 ±0.35 and 1.38 ± 0.31 min respectively). It would therefore appear climbing time, EE_{CLM} and %EE_{CLM} decrease over repetitions without modification in other physiological peak parameters.

The significant differences between ascents for EE_{CLM} were attributed by Rodio et al. (2008) to the time spent climbing. The authors related decrements in absolute EE_{CLM}

and $\%EE_{CLM}$ to the fact that progressively faster climbing resulted in less energy expended during climbing. Reference was also made to the workload imposed during rock climbing, with ascents involving dynamic moves interspersed with periods of isometric muscular contraction (Booth et al., 1999; España-Romero et al., 2009; Ferguson and Brown, 1997; Mermier et al., 1997). The authors suggested that faster movement over each of the repeated ascents probably reduced overall time spent in isometric contraction and thereby lowered total climbing energy expenditure.

2.8 Psychophysiology

Initial research aimed at determining the demands of rock climbing focused on the physicality of the task alone, and related little of the responses observed to cognitive or emotional processes. Hodgson et al. (2008) commented that during rock climbing ascents, climbers must follow a defined route using limited features for support and progression. This imposes not only a physical demand but requires cognitive processing and emotional control. These include technical and tactical decisions on completing moves, speed of ascent, use of rests, and clipping stances when lead climbing. In one of the earliest studies to focus on physiological responses to rock climbing, Williams et al. (1978) measured adrenaline and noradrenalin concentrations during rock climbing and found significant increases in adrenaline following a single ascent of an outdoor route, yet the authors did not attempt to discuss this response in relation to emotional state. This demonstrates that although it is clear that some physical responses are likely to be combination of physical and psychological factors, studies initially ignored any psychological element of the task. This approach was replicated in much of the physiological research contained within earlier studies, despite speculation and appreciation that emotional aspects such as anxiety could modify responses, in particular heart rate (Billat et al., 1995; Booth et al., 1999; Mermier et al., 1997).

The anxiety that participants can experience during rock climbing has been cited as a key aspect of the activity by Goddard and Neumann (1993) and Hörst (2003). These writers considered anxiety management to be a fundamental skill for any accomplished rock climber, dedicating book chapters to discussion and strategies surrounding psychological control and its impact on performance. However, it is often argued whether anxiety or 'fear' should be implicated with respect to the psychological demands of rock climbing owing to the presence of real physical danger. Pijpers et al.

(2003) suggested that both posses similar characteristics and are therefore synonymous. This would appear to fit with the broad definition of anxiety by Schwenkmezger and Steffgen (1989) which stipulates that anxiety can be regarded as a broad concept for a number of very complex emotional and motivational states and processes that occur as a result of a threat. This threat is related to the subjective evaluation of a situation, and concerns jeopardy to ones self-esteem during performance or social situations, physical danger, or insecurity and uncertainty. As such, anxiety in rock climbing has been discussed in relation to a 'fear of falling' (Binney and McClure, 2005; Boorman, 2008). Hurni (2003) commented that one of the most difficult mental challenges to be overcome in climbing is the 'fear of falling'. In support of this, Binney and McClure (2005) highlighted fear as the single factor holding most climbers back from reaching their potential, suggesting that the skill in managing this component of performance lies in being able to differentiate between rational and irrational fear and perceived and actual risk.

Anxiety is presented as a multi-faceted construct that involves three separate and interacting response components: psychological (e.g. cognitive worry, perceived somatic anxiety), physiological (e.g., rapid heartbeat, increased muscle tension), and behavioural (e.g., performance decrements) (Borkovec et al., 1977). In addition, the psychological component of anxiety is thought to consist of cognitive worry and somatic anxiety subcomponents which are thought to change prior to and during an activity (Liebert and Morris, 1967). The anxiety-performance relationship in rock climbing has been explored based on subjective experience of anxiety and concomitant physiological changes, thus relating to the first two components of anxiety listed previously. Pijpers et al. (2003) investigated manifestations of anxiety with respect to these two components by comparing low and high anxiety conditions during rock climbing. The authors manipulated anxiety by defining routes on a climbing wall at different heights. The two identical horizontal routes (traverse) were set on an inclined (10º) artificial wall. The mean height of the footholds on the low traverse was 0.3 m; mean height of the high traverse was 5.1 m. Thirteen participants volunteered to take part in the experiment, all of whom had no experience in rock climbing. Participants climbed each traverse route 6.5 times with a total climbing time of 2 min 10 s on two separate days, with the order of the conditions (high/low) reversed on the second day. In order to determine the manifestations of anxiety on a subjective level an 'anxiety thermometer' was used (Houtman and Bakker, 1989). This was in the form of a continuous scale upon which participants were asked to rate their anxiety feelings at a particular moment, ranging from 0 (not anxious at all) to 10 (extremely anxious). This was adopted as a quick measure of anxiety in contrast to use of the Competitive State Anxiety Inventory (CSAI-2) questionnaire, and does not take into account the distinction between cognitive and somatic anxiety. Anxiety was measured pre-climb and during the climb, with the mean of the two readings taken as a score. State anxiety on a physiological level was assessed via HR which was recorded during climbing every 5 s, with mean HR calculated post-climb. In addition, capillary BLa concentration was also measured three minutes post-climb.

The authors reported data as mean ± SD values across the two days for high and low conditions, with significant differences in subjective anxiety, state anxiety (physiological) and muscle tension. Self-reported anxiety scores for the high condition (4.3 ± 2.39) were significantly higher than the low condition (1.5 ± 1.28). Mean HR was also significantly higher in the high condition (164.8 ± 14.06 $bts \cdot min^{-1}$) compared to the low condition (146.1 ± 18.07 $bts \cdot min^{-1}$). Lastly, measures of BLa concentration were also significantly higher in the high condition (high: 7.2 ± 1.91 $mmol \cdot L^{-1}$, low: 6.0 ± 1.26 $mmol \cdot L^{-1}$). It was therefore shown that, as expected, both subjective and physiological manifestations of anxiety were higher in a high anxiety situation. In order to investigate whether these manifestations of anxiety have repercussions at a behavioural state (the third level) and therefore appear to affect performance, the authors measured the fluency of participants climbing movements by using a 'Geometric Index of Entropy'. It was found that participants exhibited a higher entropy of climbing trajectory whilst climbing high on the wall, indicating a less smooth placement of the body's centre of gravity which was thought to be characteristic of less skilled climbing behaviour (Cordier et al., 1993; Cordier et al., 1994). This resulted in slower climbing times and rigid and jerky climbing movements. Whilst entropy investigated the movements of the centre of gravity, the authors were unable to comment on movements made with the limbs which would have contributed to a decrement in performance. It was concluded that physiological and movement behavioural changes displayed under anxiety conditions reflected a regression to movement execution characteristic of earlier stages of skill acquisition. It would therefore seem that performing a task in a threatening situation can be considered as performing a 'new' unfamiliar task, providing a simple explanation as to why repeated exposure to anxiety-provoking situations would result in a decrease on the effects of anxiety on performance (Pijpers et al., 2003). This view would appear to resonate with 'fear of falling' with respect to climbing, and the necessity for repeated exposure in order to overcome the anxiety associated with the inherent risks of falling.

In the study by Pijpers et al. (2003), climbing was selected as an ecologically valid environment and activity with which to investigate the relationships between anxiety and performance. However, the climbing task in the study was not representative of the true demands of rock climbing, and despite prior practice the participants in the study were not climbers. It should be appreciated that climbing encompasses different protocols which can have a large impact on the physical, cognitive, and emotional demands that a climber might encounter during an ascent. During lead climbing it is the climbers responsibility to safeguard the climb themselves by clipping into anchors along the route, whilst also focussing on completing the set of movements necessary to ascend. Failure during a lead climbing ascent results in a fall until slack in the system is taken up and the climber is caught. In contrast, failure on a top-rope ascent where the rope is placed through a fixed anchor point above the climber only results in a little rope stretch before the climber is caught, presenting itself as a less stressful situation (Hodgson et al., 2008). As such, this form of climbing is often used for induction to the sport as there is little actual risk of harm. In addition, climbing routes are graded according to demand and completing an ascent at the upper limits of ability would represent both a differing psychological and physiological demand than one well below.

In support of this suggestion, Hardy and Hutchinson (2007) reported on three studies that examined the anxiety-induced effort and performance of rock climbers in the context of processing efficiency theory. All three studies differed in the way that anxiety was manipulated. In the first of the three studies, anxiety was manipulated by assessing climbers leading climbs that were at the limit of their ability compared with climbs that were below this limit. In the second study all participants led routes that were at the limit of their ability, and those who responded with high levels of state anxiety were compared with those who responded with lower levels. In the third study, comparisons were made between experienced climbers leading a route at the limit of their ability and them seconding a similar route of the same difficulty. In all instances anxiety, effort and performance were measured via self-report, an integrated HR measure, and belayer observation. It was found that in the first and second studies, anxiety response was characterized by increases in both cognitive and somatic anxiety. More specifically in the first study climbers were more cognitively anxious when they were lead climbing at their ability limit than when they were leading a climb two grades below their maximum. This increase in cognitive anxiety was accompanied by a corresponding increase in effort. Study two confirmed that the high cognitive anxiety group were significantly more anxious than the low cognitive anxiety group, and also that participants were significantly more anxious leading than top-roping. Finally, an unexpected finding resulting from the third study was that cognitive anxiety was equally elevated when climbers were about to climb a difficult unknown route regardless of whether the protocol was a top-rope or lead ascent (Hardy and Hutchinson, 2007).

As well as being a highly popular recreational activity, it should be emphasized that rock climbing is also a competitive sport. The influence of psychological variables upon competitive sport performance has been well documented and researched within traditional sports (Balague, 2000; Vealey, 1994). As such, pre-competition levels of anxiety and self-confidence have been highlighted as two potentially important psychological variables that may have a significant impact on competitive sport performance. Only a small number of studies have sought to determine psychological requirements of climbing performance, particularly in a competitive context. Aşçi et al. (2006) compared gender differences on pre-competitive anxiety and affective states and found that women's negative affect levels were higher than men's negative affect before a climbing competition. Whilst Ferrand et al. (2006) presented qualitative findings by interviewing elite climbers who reported pre-competitive anxiety to be detrimental to successful performance in climbing competition.

Elaborating upon these suggestions, Sanchez et al. (2009) were the first to examine psychological variables in relation to actual competitive climbing performance. This entailed examining elite climbers actual performance in a naturalistic setting. Their study was aimed at examining the relationship between pre performance psychological states and measured performance in non-traditional sport, with rock climbing used as a case study. In their study, nineteen male elite climbers who had all qualified for the finals of the Belgian climbing championship participated in the study. Ability was reported to be extremely high, ranging from 7b+ to 8b (Sport). The championship competition was organized conforming to the rules of the UIAA and IFSC. As such, professional certified route setters designed the routes, and these remained hidden from climbers, coaches and spectators until the contest began. The route assessed in the study was the first to be climbed on the day of the finals, and was approximately 16 m high and consisted of 50 handholds placed over 26 m of climbing (grade 7c+ sport).

Psychological states were evaluated using both the CSAI-2 (Martens et al., 1990) and the Positive Negative Affect Schedule (PANAS; Tellegen et al. (1988)). Competitors were asked to individually complete the CSAI-2 and PANAS approximately 15-30 min before proceeding to examination of the climbing route (5 min), after which they returned to isolation and were individually called to climb. As in the study of Pijpers et al. (2003), climbing performance was examined by means of the fluency of the curve produced from the displacement of the climbers centre of gravity when climbing (Cordier et al., 1993; Cordier et al., 1994), coupled with ascent times. All ascents were captured on video for later analysis. In addition, the official output performance (climber route score) was obtained; this is based on the total number of points given to competitors in relation to the number of handholds reached on the route (highest obtainable score was 50).

Findings from the study conducted by Sanchez et al. (2009) revealed that successful climbers reported higher pre-performance levels of somatic anxiety and climbed the most difficult part of the route (crux) more slowly than their unsuccessful counterparts. As such, psychological states preceding elite climbing competition appeared to be an important factor in determining success. Controversially, high levels of somatic anxiety were not found to be detrimental to performance in elite climbers, in fact high levels of pre-performance somatic anxiety were positively correlated to positive affect with both variables correlated positively with output performance (route score). It appeared that those who performed better experienced simultaneously high levels of physiological arousal coupled with moods associated with full concentration, eagerness and pleasurable engagement. Significant associations between successful performance and movement frequency, as highlighted previously by Pijpers et al. (2003) and Hardy and Hutchinson (2007), were not replicated in this study. The authors suggested that at this level (elite) heightened emotional arousal as opposed to fear, stress or anxiety determined success, with more successful climbers maintaining a more positive affective state. Here the anxieties could be related to feelings such as jeopardy to self-esteem during competition, as opposed to physical danger and fear of falling imposed by the climb, particularly given the skill and experience level of the participants. The authors also expressed that the current study did not account for specific differences within rock climbing and therefore could not be generalized to other forms where psychological and physiological demand could present itself quite differently.

Much of the literature discussed so far in relation to this topic show a predominant reliance on subjective measures of anxiety, either through the use of validated questionnaires or observations. Hodgson et al. (2008) identified the lack of an objective marker of stress in such studies as a missing link in understanding the relationship between the subjective experience of rock climbing and the situation itself. As rock climbing is an activity which has the potential to elicit strong mood states, the authors suggested that the measurement of plasma cortisol concentration could be beneficial as an objective marker of stress. Cortisol levels had been used previously as an objective marker of stress, with acute stressors such as examinations and exhaustive exercise resulting in increases in cortisol levels (Hellhammer et al., 1985; Pollard, 1995). Hodgson et al. (2008) utilised the measurement of plasma cortisol concentration alongside subjective emotional responses when examining climbers responses to three differing climbing conditions. As in the study conducted by Hardy and Hutchinson (2007), the three differing conditions were designed to provide combinations of higher and lower levels of mental and physical stress. As such, top-roping was employed as a low cognitive, emotional and physical stress condition. Lead climbing was employed as a high stress condition and a third intermediate condition was constructed which possessed physical and cognitive demands identical to the lead climbing but an emotional demand similar to top-roping. This was achieved by using a combined lead and top-rope system whereby climbers trailed a rope that they clipped into the en route anchors but were also secured by a top-rope so that if they were to fail, rather than fall onto the lead rope the top-rope would safeguard the climber. Whilst considered unusual as an ascent style, it was hoped that the condition would provide a unique insight into the contribution of the emotional control element to the task demands of lead climbing. The authors predicted that this would provide an intermediate stress level, with cortisol and subjective anxiety rating expected to be greater under more demanding conditions. It was also hoped that cortisol concentrations would relate to subjective emotional state. Subjective anxiety assessment was in the form of the Competitive State Anxiety Inventory 2 (revised edition; CSAI-2R) which measures levels of anxiety (on 2 subscales; cognitive and somatic) and self-confidence. Although the climbing situation presented was non-competitive, climbers were asked to respond to the questionnaire with completion of the test route and condition in mind. Plasma cortisol concentrations were calculated from capillary blood samples taken from the little finger and assayed using a cortisol Enzyme Linked Immunosorbent Assay (ELISA) kit.

Results of the study by Hodgson et al. (2008) indicated significant differences for somatic anxiety and self confidence. Somatic anxiety was highest in the leading condition and lowest in the top-rope condition. In contrast, self-confidence was highest in the top-rope condition and lowest in the lead condition. Contrary to expectations, there was no significant difference in subjective scores for cognitive anxiety, although it was noted that values were greatest under the high stress leading condition and lower in the top-rope condition. Cubic relationships between self-confidence, somatic and cognitive anxiety, and plasma cortisol concentration were evidenced. It was suggested that there is a different impact on anxiety and confidence levels when participants are required to manage their own safety rope (leading), where falling represents a greater consequence. This further emphasized the indication in previous studies that physical and psychological load need to be considered in studies aiming to investigate rock climbing responses or performance.

Draper et al. (2011b) further investigated the use of plasma cortisol as an objective marker of stress during on-sight lead and top-rope climbing. In contrast to the study conducted by Hodgson et al. (2008), where climbers practiced the climbing route before the test trial was conducted and any measures were obtained, the on-sight condition imposed in the study by Draper et al. (2011b) required participants to attempt a route with no prior practice or knowledge. This is generally cited as the most stressful style of ascent, and as such the authors felt that investigating the relationship between subjective measures and plasma cortisol levels under this condition warranted further attention. To this end, nineteen intermediate climbers each completed one on-sight randomised ascent either on lead (n = 8) or top-rope (n = 11). The test route was set at the upper limits of participants' self-reported on-sight ability, and as such not completing the route (falling) was a realistic possibility for the climbers. Measurements obtained for the purposes of the investigation included state anxiety (somatic and cognitive) and self-confidence with the use of the CSAI-2R and cortisol concentration, all of which were evaluated immediately pre-climb. Results indicated that there were no significant differences between lead and top-rope ascents for any of the variables. However when regression analysis were employed, significant linear relationships between self-confidence and plasma cortisol concentration ($r = 0.52$, $R^2 = 0.267$, $p = 0.024$), cognitive anxiety and plasma cortisol concentration ($r = 0.5$, $R^2 = 0.253$, $p = 0.028$), and subjective somatic anxiety and plasma cortisol concentration ($r = 0.46$, $R^2 = 0.210$, $p = 0.049$). These results indicated that in an on-sight climbing context, relationships between plasma cortisol concentrations, subjective anxiety and self-confidence differed to that reported in pre practiced routes in the study by Hodgson et al. (2008) as they were linear rather than cubic. For an on-sight climb, the higher the feelings of anxiety and the lower the self-confidence prior to climbing, the greater the plasma cortisol concentration, regardless of style of ascent.

In the wake of a growing appreciation for the psychological demand imposed during rock climbing, coupled with explorative studies seeking new methodologies for its evaluation, a cross disciplinary approach to investigating rock climbing performance has emerged. A small body of recent research has focused on evaluating rock climbing performance through investigating the interaction between psychological aspects and the physiological demand of the sport. Much of this has been with respect to style of ascent in an attempt to understand the interaction between ability, anxiety and performance. A summary of the psychophysiological studies conducted by Draper et al. (2008b); (2010), the conditions investigated and the measures obtained is presented in Table 2.11.

Table 2.11 A summary of the psychophysiological studies conducted by Draper et al. (2008b), (2010), the conditions investigated and the measures obtained.

Study	Participants	Conditions	Measures
Draper et al. (2008b)	*n* = 10 Intermediate Highest 'trad' grade 4b/4c (British Tech)	On-sight lead climb (OSLC) Second lead climb (LC2)	Climb time, $\dot{V}O_2$, HR, BLa CSAI-2R
Draper et al. (2010)	*n* = 9 Intermediate Highest 'trad' grade 4a-5a (British Tech) 6a – 6c (Sport)	Lead Top-rope	Climb time, $\dot{V}O_2$, HR, BLa POMS, CSAI-2R, NASA-TLX

Draper et al. (2008b) recognised that whilst there had been a major focus on explaining physiological function in rock climbing owing to responses such as disproportionate rises in HR, a lesser focus was aimed at investigating the possible interaction of psychological and physiological factors. With increasing evidence that anxiety levels are elevated for less experienced climbers, particularly during lead ascents, the authors undertook a study to examine the effects of on-sight lead climbing compared with a subsequent lead ascent. Prior to this, a systematic approach to investigating the influence of prior practice on both the physiological and psychological responses to rock climbing had not been conducted. Significant differences were reported for pre-climb somatic and cognitive anxiety, climb time and post-climb BLa between the on-sight lead climb and second lead climb. It was suggested that the higher anxiety levels associated with an on-sight lead were likely to have influenced the physiological responses of intermediate climbers in their study. This was in support of previous suggestions that style of ascent may impact on responses, with on-sight lead climbing often referred to as the most stressful style of ascent (Hardy and Hutchinson, 2007; Hodgson et al., 2008). More importantly, the authors stipulated that as expected, style of climbing and experience appeared to have a significant effect on psychological and physiological responses to climbing. This would indicate that these factors should be considered in future research attempts as well as when drawing comparisons between studies.

In a similar subsequent study published by Draper et al. in 2010, the authors systematically investigated the physiological and psychological responses to lead and top-rope climbing in intermediate climbers using a cross disciplinary approach. The aim of their study was to build upon previous findings with the hypothesis that the climbers within the study would show a greater physiological and psychological response to lead climbing than when top roping the same route. In their study, nine intermediate climbers ascended the same pre-practiced 6a (sport grade) climb on an outdoor artificial wall during two randomly assigned (lead or top-rope) climbing trials. Before climbing, HR, perception of anxiety (CSAI-2R) and BLa concentration were measured. Climb time, HR, $\dot{V}O_2$, BLa concentrations, and task-load index (NASA-TLX) in response to each trial were also recorded. Results indicated significant differences between trials for climb-time (lead 3.13 min ± 30 s, top-rope 1.27 min ± 22 s), BLa immediately post-climb (lead 3.1 ± 0.6 mmol·L^{-1}, top-rope 2.5 ± 0.9 mmol·L^{-1}) and 15 min post-climb (lead 1.2 ± 0.4 mmol·L^{-1}, top-rope 0.8 ± 0.4 mmol·L^{-1}) and in HR 1 min after climbing. These results indicated that the physiological demand of lead climbing was higher than that for top-rope climbing, and was discussed in relation to increased climb time during lead climbing. This was in support of previous findings which suggest that an increase in technical difficulty of climbing, imposed by angle of wall, style of ascent, or route difficulty, results in heightened physiological response (Bertuzzi et al., 2007; Booth et al., 1999; de Geus et al., 2006; Giles et al., 2006; Morrison and Schoffl, 2007; Sheel et al., 2003; Watts, 2004; Watts and Drobish, 1998).

Results for responses to the CSAI-2R indicated that climbers experienced higher somatic and cognitive anxiety and perceived themselves to have lower self-confidence just before the lead climb, however when compared with the top-rope climb these differences were not significant. In evaluating task load (NASA-TLX), participants indicated that the mental and physical demands were significantly higher for the lead (mental 11 ± 4, physical 13 ± 3) than for the top-rope (mental 9 ± 4, physical 8 ± 4) climb. With respect to time and pressure subscales, participants felt more time pressure during the lead climb and rated their performance as being better during top-roping, however in both instances these differences were non-significant. Finally, the participants believed that the lead climb required significantly greater effort (lead 13 ± 4, top-rope 9 ± 5) and resulted in significantly more frustration (lead 10 ± 5, top-rope 5 ± 3) than the top-rope climb. The authors noted that in the study discussed previously by Draper et al. (2008b), higher somatic and cognitive anxiety measured via the CSAI-2R were reported for an on-sight lead climb compared with a subsequent lead climb on the same route. Contrary to responses reported by Hardy and Hutchinson (2007) in a previous study, this was not the case when comparing a pre-practiced lead climb with a top-rope climb. Taken together, it was suggested that these findings highlighted that for intermediate climbers an on-sight lead climb was the most anxiety-provoking situation, yet with prior knowledge of a route their perception of anxiety is diminished regardless of style of ascent. However, despite lack of significant differences in anxiety between the two styles of ascent (lead versus top-rope) participants still perceived the lead climb to be more mentally and physically demanding, supporting anecdotal suggestions and findings from previous psychological studies (Hardy and Hutchinson, 2007; Hodgson et al., 2008).

2.9 Summary

Over the past three decades rock climbing literature has evolved from anecdotal training and coaching guidelines to include field based scientific research. Increasingly researchers are broadening their investigations in seeking to define which attributes or characteristics underpin successful climbing performance. Despite a growing research base, particularly with respect to athlete profiling and the physiological demands of rock climbing, further investigation is needed. Currently findings are limited to particular ability groups or difficulty grades of climb. Researchers have emphasised the diverse nature of rock climbing and the potential for differing demands and responses depending on style of ascent, athlete profile and route style. The physiological support for performance in rock climbing is thought to be influenced greatly by the diversity of the task. Furthermore, consistency between studies with respect to methodological approach appears to be a limiting factor, possibly owing to the subjective nature of rock climbing. As such, difficulties are presented when attempting to draw comparisons between studies, particularly as many have adopted differing styles of ascent, grade of difficulty and ability classification. Assessment methodologies and guidelines that are repeatable and easy to administer need to be explored in order to unify approaches to rock climbing research.

Finally it is also appreciated that overall climbing performance may feature a number of components. Recent approaches to investigating rock climbing in a field based context have evaluated psychological responses alongside physiological responses, introducing a cross disciplinary approach. Investigating interacting components of performance in this manner is relatively novel in rock climbing research. A growing appreciation that success is not related to individual physiological variables, but the result of a complex interaction of psychological and physiological variables is emerging. Research indicates that the form of ascent has an effect on anxiety levels of climbers which may in turn influence physiological responses. Anecdotally there is the suggestion that experienced or elite climbers may not exhibit the same intensity of anxiety in response to climbing as those of lower ability. Whether relative contributions of physiological and psychological factors during ascents increase or decrease with respect to ability level is not known.

Chapter 3
General Methods

The following chapter details the methods and procedures common to the studies presented in Chapter 4 and Chapter 5 referred to as study one and study two respectively.

In the former sections a number of preliminary studies are presented. These investigations were conducted in order to explore, and in some instances validate the methods used in the main experimental chapters. These include the validation of self-reported ability assessment, methods for ability classification, and capillary sampling sites for rock climbing. Preliminary studies are introduced individually; in each instance the details of participants, methods, results and findings are presented.

In order to avoid repetition in the experimental chapters the latter part of the chapter details the methods and procedures where considered applicable to both studies presented in Chapters 4 and 5. These latter sections provide details with respect to participant recruitment, laboratory based testing, measurement of variables which are included in both studies, capillary blood sampling and assay and psychological assessment. This chapter should be referred to where appropriate when reading the experimental chapters.

Details of data analysis, statistical analysis, experimental design and protocols unique to studies one and two are detailed within their respective chapters.

3.1 Health and safety

Ethical approval for all procedures and experimental design was obtained in full from the University of Canterbury Human Ethics Committee prior to undertaking each study.

All experimentation for this thesis was performed in two locations. Collection of anthropometric data and $\dot{V}O_{2max}$ assessments were conducted in the laboratories of the School of Sport and Physical Education at the University of Canterbury, Christchurch. All climbing trials were conducted at The Roxx artificial indoor climbing wall facility, Christchurch.

During all experimental procedures, care was taken to ensure that the environments and equipment used were appropriately clean and safe for the assessment of human participants. All equipment such as ergometers, trolleys and benches were cleaned pre- and post-experimentation. Apparatus used for the purpose of breath-by-breath gas exchange analysis, such as masks and turbines, were submerged in disinfectant for a minimum of 20 min then placed to dry in a drying cupboard before being re used. Where blood sampling and analysis were carried out, gloves were worn by the experimenter, with appropriate care and attention paid to prevent cross contamination. All contaminated equipment and biohazardous materials were disposed of into appropriate containers for incineration.

All climbing trials were conducted under the supervision of an experienced and qualified person holding *Rock 1* (New Zealand Outdoor Instructors Association – NZOIA) certification or equivalent and valid first aid certification. The climbing trials were conducted with the full co-operation of The Roxx indoor climbing wall facility, involving full compliance with their safety policies and standard operating procedures.

3.2 Preliminary studies

Prior to commencing data collection for the main studies described in this thesis, a small number of sub-studies were conducted in order to determine or justify the methods employed. This section provides an overview of these preliminary studies and their findings.

3.2.1 Self-reported ability assessment

Assessment and categorization of rock climbing ability presents some difficulty for research and comparison due to the nature of the sport. Climbing routes are subjectively graded and there is variation in rating systems employed. Despite this, grading systems are widely used as an indicator of performance and to discriminate between ability groups in rock climbing studies (Bertuzzi et al., 2007; Brent et al., 2009; de Geus et al., 2006; Draper et al., 2006b; España-Romero et al., 2012; España-Romero et al., 2009; Grant et al., 2001; Grant et al., 2003; Hardy and Hutchinson, 2007; Janot et al., 2000; Llewellyn and Sanchez, 2008; MacLeod et al., 2007; Mermier et al., 2000; Noé et al., 2001; Schöffl et al., 2006; Schöffl et al., 2004a; Schöffl et al., 2004b; Sheel et al., 2003; Wall et al., 2004; Watts et al., 2003). In all of these studies, climbing grade performance has been used as a key grouping variable for subsequent analysis. Although the ambiguity surrounding grading systems is often addressed using readily available conversion charts, obtaining an observed and assessed grade for individual climbers is considered problematic.

Assessing climbing ability during a competition generally involves the climber previewing and then attempting the route with a single ascent. The height the climber achieves determines the number of points awarded for the climb, with the difficulty increasing as the climber ascends (IFSC, 2012). Although it is accepted that this method provides a good measure and distinction between ability, it is difficult to apply in a research context owing to time restraints and participant ability. It also has the potential to impose an additional physiological and psychological demand beyond the protocol of the main research project. Instead, most rock climbing studies have employed a self-report method of measurement as a convenient and practical solution to the requirement.

The validity of self-report or self-estimation questionnaires has received much attention in relation to large epidemiological studies when reporting variables such as height, and weight due to the difficulties posed by large sample sizes (Mikkelsson et al., 2004). They have also been employed with regard to other physical fitness tests such as the Army Physical Fitness Test (APFT) (Jones et al., 2007). Sulheim et al. (2007) examined the use of self-report measures for classifying ability in skiers and snowboarders when examining potential injury risk factors. They found that the validity of self-report questionnaires depends on the respondents ability to accurately assess and recall previous experience (Mikkelsson et al., 2004). In the context of climbing this is in relation to previous climbing ascents at different grades. Due to the nature of the sport, climbers are regularly exposed to grades as they are considered the primary indicator of performance and ability (Giles et al., 2006). Rock climbers habitually place themselves on climbing grade scales and use grade categories for current and future performance targets and are therefore aware of their use from initial experiences, making their use as a self-report measure a logical choice.

Whilst previous researchers have used self-report for measuring climbing ability, it is evident that the method and questions employed have varied considerably. This inconsistency and the use of redpoint and on-sight grades make it clear that there is no gold standard for obtaining self-reported grades. Furthermore, no work has been completed to validate self-reported ability with respect to rock climbing research. Therefore, for the present study, preliminary work was conducted to examine the validity of self-reports of climbing ability through the use of climbing grades. This was done with the secondary objective of hoping to recruit and classify ability level for the main studies based on self-reported grade responses. To this end, climbers self-reported grades were compared with those obtained via an assessed climb.

Participants

The participants consisted of twenty nine competitive climbers (male = 17, female = 12) who were competing at regional, national and international levels and who had been involved in the sport for 3.5 ± 1 years. The mean ± SD age, mass, height and percentage body fat as measured by bioelectrical impedance analysis (In body 230, Biospace, Korea) were 24.1 ± 8.2 years, 64.4 ± 10.4 kg, 1.70 ± 0.08 m and 17.4 ± 7.5% respectively. The mean ± SD self-reported climbing grade (highest on-sight lead ascent in the past 6 months) was 22.6 ± 3.4 (Ewbank).

Self-reported grade

In order to assess the validity of self-reported climbing grades participants were asked to report their current ability grade. For the purposes of this study this was defined as the most difficult indoor (artificial wall) on-sight lead ascent achieved in the past 6 months. As described previously, the term on-sight is used within climbing to denote the completion of a route on first attempt without prior instruction, knowledge or practice of the route. Grades were reported using the Ewbank grading system. This grading scale was selected not only because it was familiar to the participants, but also because the numerical scale can be used in statistical analysis without the need for conversion.

Climbing routes and measurement

In order to obtain an observed assessed climbing grade for participants, a specific route was devised. The route was a sport lead set on an artificial indoor climbing wall and was attempted under the supervision of the research team (n = 4). The route involved ascent of an 8 m vertical section that led to a 6 m roof section and onto a final 5 m vertical section, requiring 19 m of climbing in total for a complete ascent. During the ascent, climbers could use the prescribed (colour coded) holds or the natural features on the wall surface to progress on the climb. The climbing holds were made from moulded resin (Uprising Ventures Ltd., Christchurch, New Zealand). The research team was comprised of individuals with 5-20 years experience in climbing, instructing, route setting and the manufacture of climbing specific apparatus. The route was modelled on those that are used in competitive climbing. The distance ascended by the climber corresponded to a climbing grade (Ewbank) agreed upon by those responsible for setting the route, with the climb increasing in difficulty as the climber progressed. The route setter ascribed an ability grade to each climber based on the distance they reached on the route before failure (fall).

Warm-up

Each climber was required to follow a climbing-specific warm up prior to their attempt on the designated route. The prescribed warm up was adapted from methods previously described by Binney and McClure (2006); Gresham (2007); Tenke and Higgins (1999). The warm up was initiated with 5 min of light aerobic exercise, walking and jogging. This was followed by 5 min of mobilising exercises. The climbers then completed light climbing for 10 min. The warm up was conducted away from the assessed route to avoid any preview or knowledge of the route as this would contravene the on-sight condition.

Procedure

Climbers were first asked to report their current on-sight climbing grade (Ewbank) as defined previously. Participants were then informed of the nature of the climb (i.e. to climb as far as possible) and completed the prescribed warm-up. Participants were permitted to use their own climbing equipment (harness, climbing shoes, hardware and chalk) in order to preserve personal climbing patterns. Prior to testing, the participants were not informed of the corresponding levels of difficulty along the route and were neither allowed to physically rehearse nor observe others using the route. Each climber was allowed one attempt at the route with the furthest point reached noted and translated into a corresponding Ewbank assessed grade.

Statistical analysis

All variables were assessed for normality of distribution using the one-sample Kolomogorov-Smirnov goodness-of-fit test before any further statistical analysis. In order to determine the validity of self-reported climbing grades, paired samples *t*-tests were used to examine whether there was a significant difference between self-reported and assessed grades. The limits of agreement method proposed by Altman and Bland (1983) and advocated by Nevill and Atkinson (1997) for a sports science context was used to confirm agreement between self-reported and assessed climbing grades. A more detailed explanation of the method is described by Bland and Altman (1999). In addition to this, regression modelling was employed to identify the predictive potential of self-reported grades. These were calculated using the self-reported current grades and assessed grades. All statistical analyses were carried out using Microsoft® Excel 2007 (Microsoft Corp. Redmond, WA) and SPSS 19.0 (IBM Corp. Armonk, NY) for Windows. An alpha level of $p < 0.05$ (2-tailed) was set to accept statistical significance for all inferential tests.

Results

Results of the Kolomogorov-Smirnov test indicated that all variables displayed normality of distribution. The mean ± SD grades for self-reported and assessed ability are displayed in Table 3.1.

Table 3.1 Self-reported and assessed climbing grades (Ewbank) for males, females and group total (mean ± SD).

		Climbing grade (Ewbank)	
	n	*Self-reported*	*Assessed*
Males	17	23.9 ± 2.4	22.9 ± 2.7
Females	12	20.1 ± 3.7	20.7 ± 3.1
Total	29	22.6 ± 3.4	22.0 ± 3.0

Paired samples *t*-tests revealed no significant difference between the self-report grade and assessed grade in both males ($t_{(15)} = 1.208$, $p = 0.246$), and females ($t_{(8)} = 1.357$, $p = 0.212$). The limits of agreement plot for self-reported and assessed climbing grades is given in Figure 3.1. The Altman and Bland plot indicated relatively close agreement between the two assessment methods with the standard deviation of the differences being ± 1.8 grade points.

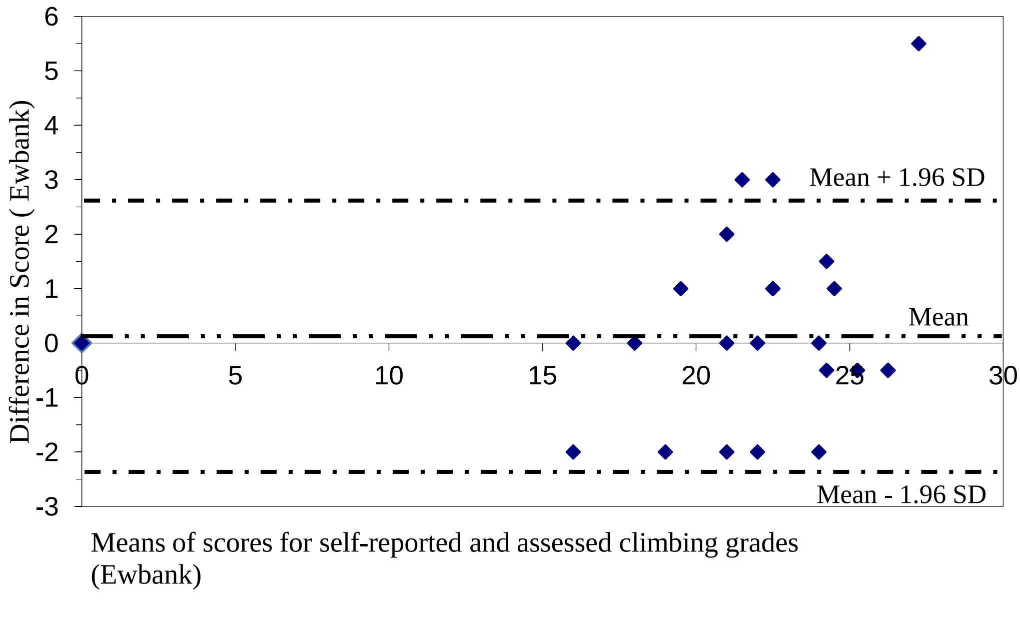

Figure 3.1 Limits of agreement for self-reported climbing ability and assessed climbing grade.

The regression model for self-reported climbing grades is presented in Figure 3.2. The regression equation for the model was $y = 0.73x + 5.78$ ($R^2 = 0.72$, $p < 0.0005$).

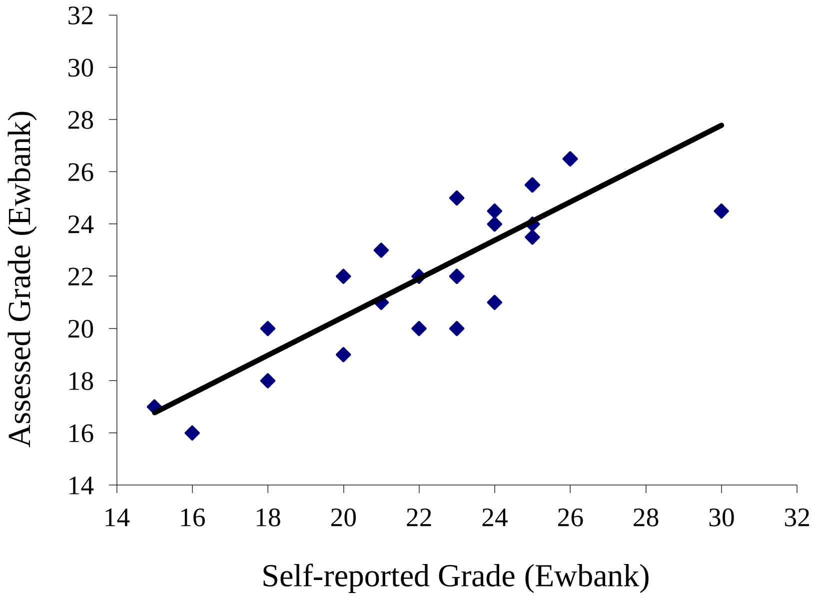

Figure 3.2 Regression model for self-reported climbing ability using self-reported climbing grade against assessed climbing grade.

Findings

The results indicated that there were no statistically significant difference between the self-reported on-sight climbing grade and assessed climb grade in both men and women. As can be seen from Figure 3.1 and Figure 3.2 there was close agreement between reported and assessed climbing grades for most climbers. One male climber reported his climbing grade at 30 but was assessed at 24 (Ewbank). This participant was recovering from an injury sustained some months earlier and it is likely that he had not fully recovered. Considering the data with this point removed, differences between self-reported and assessed grades for the male and female climbers were minimal.

These findings would suggest that self-reported climbing grades provide valid and accurate reflections of climbing ability, and as such their use appears justified. In addition, it could be anticipated that the effectiveness and accuracy of self-reported grades will translate to other disciplines and styles of ascent, providing the climber is familiar with the grading system, terminology and environment in which the data collection is to take place. Lastly, the outlier in this study suggests that it may be beneficial to consider any recent injuries or impairments which may limit an individuals' current ability, particularly when being asked to self-report ability based on performance within the last 6 months.

3.2.2 Ability classification

Often in rock climbing research it is helpful to describe the ability of the participant group(s). The nomenclature used by researchers to describe individual climber and group abilities has varied widely between studies. In the interest of ascertaining the level of ambiguity with respect to grouping categories and definitions used in rock climbing studies, 31 climbing related studies from various fields of research (e.g. psychology, physiology, biomechanics, injury) between the years 2000 and 2010 were reviewed (Table 3.2). Particular attention was paid to the terminology used to describe participant groups and their ability grades in each of these studies.

As can be seen from reviewing Table 3.2, common examples include the use of the term 'recreational' to describe a wide variety of climber ability groups from beginner to elite. In the context of climbing, this term would appear unhelpful as anyone who is not a full time climber is by definition recreational. As a consequence this group could include climbers just starting out in the sport or those who have been climbing for many years at a high level. Another example of confusion that can be created through a lack of agreement in the meaning of terminology is the use of the terms 'elite' or 'expert' to describe an ability group. The ability of a climber classified as elite or expert has varied greatly between studies (Bertuzzi et al., 2007; Draper et al., 2009; España-Romero et al., 2009; Ferrand et al., 2006; Grant et al., 2001; Michailov et al., 2009; Quaine et al., 2003; Sanchez et al., 2009). The term 'novice' is fraught with the same problems associated with the term 'recreational'. In this context, the term could apply to someone starting out in the sport, but could equally refer to a recreational climber who is unconcerned with climbing high grades. As such, this latter type of climber might have many years of experience and a past on-sight or redpoint grade much higher than that of another 'novice'.

Table 3.2 Summary of ability grades and grouping categories reported in rock climbing studies between the years 2000 and 2010.

Study	Participants	Climbing Grades (Ewbank)
Janot et al. (2000)	Beginner and recreational	Not Reported
Mermier et al. (2000)	Mixed Ability	Male M = 21, R= 16-32 Female M = 17, R = 13-27
Grant et al. (2001)	Elite and recreational	Traditional, Elite 17+, Recreational 13-17
Noé et al. (2001)	International competitors	Not Specified
Wright et al. (2001)	Previous indoor experience	Not specified
Grant et al. (2003)	Intermediate	≥20
Quaine et al. (2003)	Elite	Not specified
Sheel et al. (2003)	Experienced competitive climbers	On-sight, 26-34
Watts et al. (2003)	Experienced junior competitive climbers	Redpoint, 25
Schöffl et al. (2004b)	High-level climbers	Redpoint M = 30, R=29-32
Schöffl et al. (2004a)	Junior national team and recreational	Redpoint Elite 24-30, Recreational 18
Wall et al. (2004)	Moderate, intermediate and expert	Not Specified
de Geus et al. (2006)	Competitive climbing experience	On-sight, 26-30
Draper et al. (2006b)	Recreational	Not Reported
Ferrand et al. (2006)	Junior elite	26
Noé (2006)	International competitors	Not specified
Schöffl et al. (2006)	Not specified (rock climbers)	Redpoint, 25, On-sight, 23
Bertuzzi et al. (2007)	Elite (Top ten national ranking) and recreational	Elite 28-33, Recreational 20-24
Hardy and Hutchinson (2007)	Experienced rock climbers	Traditional, 16-25
MacLeod et al. (2007)	Intermediate	On-sight M = 25, R = 21-28
Schöffl et al. (2007)	Junior national team and recreational	Redpoint Elite 28, Recreational 18
Schweizer et al. (2007)	Not specified (rock climbers)	Redpoint, 25 On-sight, 22, Boulder, 21
Draper et al. (2008b)	Intermediate	Traditional, 13-16
Llewellyn and Sanchez (2008)	Not specified (rock climbers)	20
Watts et al. (2008)	Experienced climbers	23
Draper et al. (2009)	Novice, intermediate, advanced and elite	21
España-Romero et al. (2009)	High-level sport climbers	On-sight Male = 30, Female = 25
Heyman et al. (2009)	Competitive club level	21-27
Michailov et al. (2009)	World cup competitors	Boulder Male = 33, Female = 30 On-sight Male = 32, Female = 28 Redpoint Male = 34, Female = 30
Sanchez et al. (2009)	Elite (Belgian climbing championship)	27-32
Draper et al. (2010)	Intermediate	Traditional, 13-18

Draper et al. (2009) have previously published a grades grouping and comparison table developed for a study considering the assessment of the validity and reliability of a series of novel, sport specific measures of flexibility for rock climbing. Divisions were created in the tables in order to classify the climbers in the study into one of four groups (novice, intermediate, advanced or elite) which was considered useful for climbing research. However, there are a number of problems with this scheme and it could be improved upon. In the study by Draper et al. (2009), divisions for each ability grouping were agreed by a small group of expert climbers (n = 3). A wider consultation process would perhaps have led to the development of different division points for the classification of each ability group. Secondly, the table was considered appropriate for classifying male and female climbers, rather than separate tables being created for each gender. Thirdly, the climbers did not state (particularly in the case of sport climbing) whether the highest recorded route was for an indoor or outdoor natural rock climb. Finally, no indication was given as to whether the highest climbing grade recorded for each climber was in relation to redpoint or on-sight ascent.

In order to classify participants ability group with respect to self-reported grades, two classification tables were developed using the Delphi technique in consultation with over 40 expert climbers and researchers worldwide. The classifications are presented separately for males (Table 3.3) and females (Table 3.4) as the overwhelming feeling amongst respondents was that such a classification system should be developed as two separate tables. Upon reviewing the classification systems it can be seen that for lower-grade climbers the set boundary for division are similar for both males and females, however for all other categories suggested boundaries differ by gender. These divisions were agreed upon through consultation with the expert climbers and researchers involved in the development of the tables. The divisions are intended to reflect as well as possible natural breaks in climber ability levels. The expert respondents believed there were differences in the climbing abilities for each of these groupings. As with grading of climbs themselves, there is a degree of subjectivity in making such distinctions and as such, all efforts were made to remain as objective as possible in this process by consulting a wide number of experts. Evidently, there remains some overlap in abilities which are close to a boundary, however respondents indicated that different ability groupings were in existence across the climber ability continuum. These tables are an attempt to establish such groups for the purposes classifying and grouping participants in the main studies of this thesis and to assist with future research.

These tables also provide a suggested framework for comparative grading scales. Whilst there are a number of grading scales employed throughout the world, given the need to complete statistical analyses of research data, a number-only grading scale is beneficial. As such, researchers have also developed their own scales, using numerical values to represent a given grade in order to simplify analysis. The Watts scale presented in Table 3.3 and Table 3.4 is an example of this, and was used in subsequent research by España-Romero et al. (2009). As the studies included in this thesis were conducted in New Zealand, the Ewbank numerical grading scale was used. This was implemented not only because it was familiar to the participants, but also because it was ideal for statistical analysis owing to the fact that it uses whole numbers at each grade and therefore does did not require conversion.

Table 3.3 Climbing grade and climbing group divisions comparison table for male climbers.

Climbing group	USA	French Sport	British Trad Adj	British Trad Tech	BRZ	Ewbank	UIAA	UIAA Metric	Watts
Lower-grade (Level 1)	5.1	1	D	1	Isup	9	I		
	5.2	2	VD	2	II	10	II		
	5.3	2+	HVD	3a	IIsup	11	III		
	5.4	3-	S	3b	III	12	IV		
	5.5	3	HS	4a	4	13	IV+		
	5.6	3+	VS	4b	5	14	V		0.00
	5.7	4	VS	4c	5	15	V+		0.25
	5.8	4+	HVS	5a	5sup	16	VI-	5.66	0.50
	5.9	5	E1	5b	6	17	VI	6	0.75
	5.10a	5+	E1	5b	6sup	18	VI+	6.33	1.00
	5.10b	6a	E2	5c	6sup	19	VII-	6.66	1.25
	5.10c	6a+	E2	5c	6sup	20	VII	7	1.50
Intermediate (Level 2)	5.10d	6b	E3	6a	6sup	21	VII	7	1.75
	5.11a	6b+	E3	6a	7a	22	VII+	7.33	2.00
	5.11b	6c	E4	6b	7b	23	VIII-	7.66	2.25
	5.11c	6c+	E4	6b	7b	23	VIII-	7.66	2.25
	5.11d	7a	E4	6b	7c	23	VIII	8	2.50
	5.12a	7a+	E5	6b	8a	24	VIII+	8.33	2.75
	5.12b	7b	E5	6c	8b	25	IX-	8.66	3.00
Advanced (Level 3)	5.12c	7b+	E6	6c	8c	26	IX-	8.66	3.25
	5.12d	7c	E6	6c	9a	27	IX	9	3.50
	5.13a	7c+	E7	7a	9b	28	IX+	9.33	3.75
	5.13b	8a	E7	7a	9c	29	X-	9.66	4.00
	5.13c	8a+	E7	7a	10a	30	X-	9.66	4.25
	5.13d	8b	E8	7a	10b	31	X	10	4.50
Elite (Level 4)	5.14a	8b+	E8	7a	10c	32	X+	10.33	4.75
	5.14b	8c	E9	7a	11a	33	XI-	10.66	5.00
	5.14c	8c+	E9	7b	11b	34	XI	11	5.25
	5.14d	9a	E10	7b	11c	35	XI+	11.33	5.50
Higher Elite (Level 5)	5.15a	9a+	E10	7b	12a	36	XI+	11.33	5.75
	5.15b	9b	E11	7b	12b	37	XII-	11.66	6.00
	5.15c	9b+	E11	7b	12c	38	XII	12	6.25

N.B. *USA system is the Yosemite Decimal System (YDS). The French/European system is also known as the 'Sport Grade System'. The Ewbank System is generally common to Australia, New Zealand and South Africa (with some minor differences). UIAA is applied to short bolted routes in Western Germany, Austria, Switzerland, Czech Republic, Slovakia and Hungary. BRZ is the Brazilian grading system which is similar to that of the French/sport system with the exception of the use of 'sup' grades to distinguish between lower grades. British Adj and Tech grades are used to classify Traditional style routes mainly in the United Kingdom, the Adj grade provides an indication of exposure and protection whilst the Tech grade denotes the technical difficulty of the climb. The Watts scale is an example of a grading scale conversion adapted to allow for ease of comparison and statistical analysis within rock climbing research and literature (Watts et al., 1993).*

Table 3.4 Climbing grade and climbing group divisions comparison table for female climbers.

Climbing group	USA	French Sport	British Trad Adj	British Trad Tech	BRZ	Ewbank	UIAA	UIAA Metric	Watts
Lower-grade (Level 1)	5.1	1	D	1	Isup	9	I		
	5.2	2	VD	2	II	10	II		
	5.3	2+	HVD	3a	IIsup	11	III		
	5.4	3-	S	3b	III	12	IV		
	5.5	3	HS	4a	4	13	IV+		
	5.6	3+	VS	4b	5	14	V		0.00
	5.7	4	VS	4c	5	15	V+		0.25
	5.8	4+	HVS	5a	5sup	16	VI-	5.66	0.50
	5.9	5	E1	5b	6	17	VI	6	0.75
	5.10a	5+	E1	5b	6sup	18	VI+	6.33	1.00
Intermediate (Level 2)	5.10b	6a	E2	5c	6sup	19	VII-	6.66	1.25
	5.10c	6a+	E2	5c	6sup	20	VII	7	1.50
	5.10d	6b	E3	6a	6sup	21	VII	7	1.75
	5.11a	6b+	E3	6a	7a	22	VII+	7.33	2.00
	5.11b	6c	E4	6b	7b	23	VIII-	7.66	2.25
	5.11c	6c+	E4	6b	7b	23	VIII-	7.66	2.25
Advanced (Level 3)	5.11d	7a	E4	6b	7c	23	VIII	8	2.50
	5.12a	7a+	E5	6b	8a	24	VIII+	8.33	2.75
	5.12b	7b	E5	6c	8b	25	IX-	8.66	3.00
	5.12c	7b+	E6	6c	8c	26	IX-	8.66	3.25
	5.12d	7c	E6	6c	9a	27	IX	9	3.50
	5.13a	7c+	E7	7a	9b	28	IX+	9.33	3.75
Elite (Level 4)	5.13b	8a	E7	7a	9c	29	X-	9.66	4.00
	5.13c	8a+	E7	7a	10a	30	X-	9.66	4.25
	5.13d	8b	E8	7a	10b	31	X	10	4.50
	5.14a	8b+	E8	7a	10c	32	X+	10.33	4.75
	5.14b	8c	E9	7a	11a	33	XI-	10.66	5.00
	5.14c	8c+	E9	7b	11b	34	XI	11	5.25
Higher Elite (Level 5)	5.14d	9a	E10	7b	11c	35	XI+	11.33	5.50
	5.15a	9a+	E10	7b	12a	36	XI+	11.33	5.75
	5.15b	9b	E11	7b	12b	37	XII-	11.66	6.00
	5.15c	9b+	E11	7b	12c	38	XII	12	6.25

N.B. *USA system is the Yosemite Decimal System (YDS). The French/European system is also known as the 'Sport Grade System'. The Ewbank System is generally common to Australia, New Zealand and South Africa (with some minor differences). UIAA is applied to short bolted routes in Western Germany, Austria, Switzerland, Czech Republic, Slovakia and Hungary. BRZ is the Brazilian grading system which is similar to that of the French/sport system with the exception of the use of 'sup' grades to distinguish between lower grades. British Adj and Tech grades are used to classify Traditional style routes mainly in the United Kingdom, the Adj grade provides an indication of exposure and protection whilst the Tech grade denotes the technical difficulty of the climb. The Watts scale is an example of a grading scale conversion adapted to allow for ease of comparison and statistical analysis within rock climbing research and literature (Watts et al., 1993).*

3.2.3 Capillary sampling sites for rock climbing

Capillary blood sampling presents a varying challenge for exercise physiologists, and is often dependent on the nature of the sport. The different types of movements involved and environments in which sports are performed dictate that a variety of sampling sites and collection techniques be employed. Sports such as running, rowing, swimming and cycling have devised their own capillary blood sampling protocols (Dassonville et al., 1998; Forsyth and Farrally, 2000; Forsyth and Reilly, 2004; Garland and Atkinson, 2008; Ribeiro et al., 1990). More recently, as a result of disproportionate loading on the upper body when climbing, the almost constant requirement to use the hands for gripping, and the desire to collect pre and post-climb samples, researchers have also used the ear-lobe as an alternative sampling site to the finger (Bertuzzi et al., 2007; de Geus et al., 2006; Draper et al., 2006a; Heyman et al., 2009; Rodio et al., 2008). However, some problems have been encountered when sampling at the ear-lobe. The anatomical structure ear-lobes can present problems with sampling, especially when larger volumes of blood (over 100µL) are required for multiple assays; such as BLa and cortisol (Draper et al., 2006b; Godfrey et al., 2004; Hodgson et al., 2008).

In previous studies concerned with the activity of rowing, Forsyth and Farrally (2000) and Garland and Atkinson (2008) have both used the first (big) toe as a capillary sampling site for BLa. Their findings have indicated that the toe provides a valid and reliable alternative site for BLa concentration (Forsyth and Farrally, 2000; Garland and Atkinson, 2008). This site has not been used in rock climbing research and may not have been considered, as unlike rowing ergometry where the toe is relatively still, in rock climbing the foot is contained within a shoe and is required for movement when ascending a route.

Studies concerned with the measurement of cortisol in response to a stressor have generally utilised the sampling and assay of plasma cortisol or salivary cortisol (Bullock et al., 2009; King and Hegadoren, 2002; Levine et al., 2007; Sherk et al., 2011). Often the use of salivary cortisol is employed where the invasive methods associated with blood sampling (specifically venipuncture), are undesirable. This could be due to the nature of the study (movement or requiring multiple samples), or in minimizing inducement of stress and responses such as ‘white coat syndrome’ which may affect cortisol concentrations (Levine et al., 2007). However, assay sensitivity and standardization issues when measuring cortisol levels in saliva have been cited as areas of concern (Chiu et al., 2003; Raff et al., 2003). It should also be noted that many studies require the measurement of other analytes besides salivary steroids. In such instances blood sampling is preferable, i.e. BLa post-exercise.

Where venipuncture is inappropriate, plasma cortisol samples have been collected via capillary blood sampling, mirroring its widely accepted use as a sample site for determining BLa concentration (Bullock et al., 2009; Draper et al., 2008a; Fontani et al., 1998). Two known rock climbing studies concerned with measuring cortisol as a stress marker have done so using capillary fingertip (Hodgson et al., 2008) and venipuncture (Sherk et al., 2011) sampling. In a similar manner to sampling for BLa, the ear-lobe has been used for capillary plasma cortisol sampling in a small number of studies, typically where the fingertip is inaccessible. Interestingly, the use of a 'heel prick' to collect capillary blood samples for the determination of plasma cortisol concentration (alongside other hormones) in infants is commonplace (Anders et al., 1970; Grunau et al., 2005). However, there are no indications that the foot, or more specifically the first (big) toe site has been used to extract the volumes of blood needed to assess plasma cortisol concentrations in adults.

Whether used to collect samples for measurement of BLa or plasma cortisol concentration, the use of fingertip capillary sampling in conjunction with the activity of rock climbing could be regarded as problematic. This is with particular reference to the role of the upper body and the constant load placed on the fingertips when gripping holds (Giles et al., 2006; Sheel, 2004; Watts, 2004). Sometimes participants are required to complete multiple ascents, or bouts of rock climbing for research purposes. This activity, coupled with the potential need for repeated puncturing of the fingertip, may have a compromising effect on the climber's ability to perform at their best. It was therefore thought that the use of the toe as a capillary sampling site may provide an appropriate alternative for use in collecting blood samples for determining both BLa and plasma cortisol concentrations. To this end, differences in BLa and plasma cortisol concentrations obtained via capillary blood samples taken from the fingertip and from the toe during rock climbing were examined. This was done in order to validate the use of the toe as a sampling site for the main experimental studies contained within this thesis.

Participants

Ten (9 males, 1 female) university student climbers volunteered to take part in the study. The mean ± SD age, height, mass and body fat percentage (Inbody 230, Biospace, Korea) of the participants were 26 ± 7 years, 1.77 ± 0.08 m, 76.03 ± 11.30 kg and 13.3 ± 5.6% respectively. All participants were regular climbers (climbing at least twice a week) and had a mean redpoint grade of 21.5 ± 3.1(Ewbank) with a minimum of 3 years experience. Ethical approval was obtained from the University of Canterbury Human Ethics Committee and all participants completed a written informed consent after having the procedures fully explained. Medical and health history questionnaires were completed by each climber prior to testing.

Procedures

Each of the climbers completed their test during a single (morning) visit to the laboratory and all data were collected within a two week time period. Participants were asked to refrain from strenuous exercise the day before the test and to avoid eating within two hours of climbing. All participants completed a standardised warm-up prior to their climbing trial. This consisted of 5 min of light jogging at approximately 50% of their maximum 10 km running speed, 5 min of mobilisation and stretching, followed by 5 min of easy climbing and route familiarisation during which time the climbers were able to practice all moves on the designated test route. The climbing involved repeated ascents of a bouldering route set on a 4.03 m high by 2.44 m wide artificial wall, which for the purposes of the study was adjusted to three different angles (91°, 100° and 110°) as shown in Figure 3.3.

Figure 3.3 The angles of the climb (degrees from horizontal).

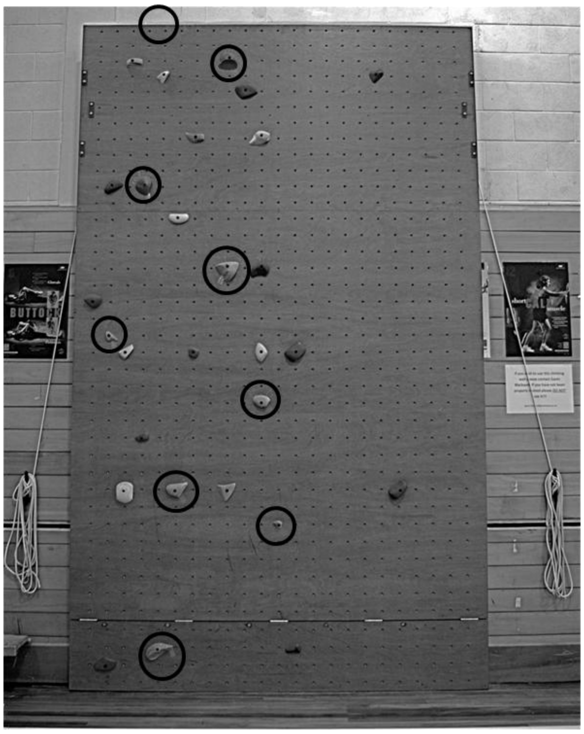

Figure 3.4 The designated climbing route used at each angle.

The route (see Figure 3.4) was designed using nine modular hand and foot holds (Uprising Ventures Ltd, Christchurch, New Zealand). The participants climbed the route at three different angles (91°, 100° and 110°) with grades set and confirmed at 16, 18 and 21 (Ewbank) respectively. This was in order to progressively increase the workload for each climbing bout. Each ascent began with a sitting start and participants were instructed to grasp the top of the wall before beginning their descent (down climb). In addition to these instructions the participants were reminded that the use of 'smearing' was not permitted. Participants were asked to ascend and descend (down climb) the route (without rest) three times at each angle. Climbers returned to a sit start after each descent, then immediately began the next ascent. Mean (± SD) climb time (total time for the three ascents) across the three angles was 63 ± 17 s, with non-significant time differences between the angles. A 5 min passive recovery period was observed between the ascents of the route at each different angle.

Blood analysis

Arterialised capillary blood samples were collected simultaneously from the fingertip and first toe before the first climb (prior to putting on climbing shoes) and immediately after the climbing shoe had been removed post-climb by trained and accredited technicians. Climbers were instructed to remove their climbing shoe as quickly as possible after the third descent of the route at each angle. Sample sites were prepared using a non-alcoholic medical wipe, (TYCO Healthcare, UK) Haemolance Plus lances were used to puncture (1.6 mm depth) the skin (Haemedic, Poland). Two samples were collected from each sample site, the first (50 µL) was collected using heparinised micro hematocrit capillary tubes (Oxford Labware, USA) and transferred to Eppendorf microtubes (Starsledt Akhengesellshaft & Co, Numbiecht, Germany) . The second sample (300 µL) was collected using lithium heparin CB300CH Microvettes® microtubes (Starsledt Akhengesellshaft & Co, Numbiecht, Germany). Post sampling, the first toe and fingertip were sealed with a waterproof plaster to minimise the possibility of infection or the transfer of blood to the climbing holds. The holds were cleaned using disinfectant liquid (Viraclean, Whiteley Medical, Australia) after each participant completed the trial.

All samples were stored on ice before being analysed within 15 min of collection. A YSI STAT PLUS 2300 glucose and lactate analyzer (Yellow Springs Instruments, Ohio, USA) calibrated and checked against a standard solution prior to analysis was used to assay the lactate concentration in each 50 µL sample. The YSI STAT PLUS 2300 used a 25 µL blood sample that was haemolysed (YSI1515 lysing agent) and stabilised (YSI2357 buffer). Test-retest reliability of the YSI STAT PLUS 2300 has been previously demonstrated by Draper et al. (2006a).

Plasma was collected from the 300 µL samples after the centrifugation (cr2000, Centurion Scientific, West Sussex, England) of the tubes (10,000 rpm for 10 min at ambient room temperature. The separated plasma was placed in Eppendorf microtubes (Starsledt Akhengesellshaft & Co, Numbiecht, Germany) and stored at -20^{o}C for later analysis. The plasma samples were analysed for cortisol using the Enzyme-Linked Immunosorbent (ELISA) method (Dept of Clinical Biochemistry, Christchurch Hospital, Christchurch, New Zealand) as described and validated by Lewis and Elder (1985). All standards and samples were analysed in duplicate, a single participants assays were analysed in entirety in an attempt to minimise within-subject variability. Intra assay coefficients of variation (CV %) were 5.91% and 7.94% for finger and toe respectively. Results of paired samples *t*-tests for finger and toe revealed there were no significant differences between duplicate assays. Cortisol values were expressed in nmol·L^{-1} when initially measured and are given together with the values converted to µg·dL and ng·mL. For this conversion nmol·L^{-1} values were divided by a factor of

27.59 (Volovitz et al., 1995) to give µg/dL values, these were then multiplied by 10 to give values in ng/mL.

Statistical analysis

Results of one-sample Kolomogorov-Smirnov goodness-of-fit tests indicated that all variables displayed a normal distribution. A limits of agreement plot, as proposed by Altman and Bland (1983), was compiled to assess repeatability between the sampling sites for both BLa and plasma cortisol. The limits of agreement between first toe and fingertip capillary BLa and plasma cortisol concentrations were determined using the 95% confidence interval. From this, the upper and lower limits of the population confidence interval were calculated. Regression analysis was subsequently employed to identify possible adjustments for comparison between the sample sites for both BLa and plasma cortisol concentration. The Bland and Altman limits of agreement plots were calculated using Microsoft Excel 2007 (Microsoft Corp. Redmond, WA) while all other analyses were conducted using the SPSS 19.0 for Windows (IBM Corp. Armonk, NY).

Results

Blood lactate

Mean ± SD BLa concentrations assayed for the samples taken from the first toe and finger pre-climb and post 91°, 100° and 110° angle climbs are detailed in Table 3.5. The pre-climb mean BLa concentration for the samples taken from the first toe was 0.3 mmol·L^{-1} higher than for that found at the fingertip. Immediately post each climb, mean BLa concentrations recorded for the fingertip were 0.04, 0.09 and 0.09 mmol·L^{-1} higher than the toe respectively.

Table 3.5 Mean ± SD blood lactate concentrations by sample site and angle of ascent.

Sample Site	BLa concentration			
	Pre-climb (mmol·L^{-1})	*Post 91° (mmol·L^{-1})*	*Post 100° (mmol·L^{-1})*	*Post 110° (mmol·L^{-1})*
Finger	1.80 ± 0.67	2.84 ± 0.72	3.66 ± 1.10	4.26 ± 1.03
Toe	2.10 ± 0.73	2.75 ± 0.65	3.62 ± 1.13	4.17 ± 1.21

Figure 3.5 shows the limit of agreement plot for 40 paired fingertip and toe capillary BLa concentrations. This plot reveals that 90% of the data points had a difference of less than 0.5mmol·L^{-1} between the finger and toe sampling sites. The distribution of the

data points also suggests that there appeared to be no bias in estimation between sampling sites.

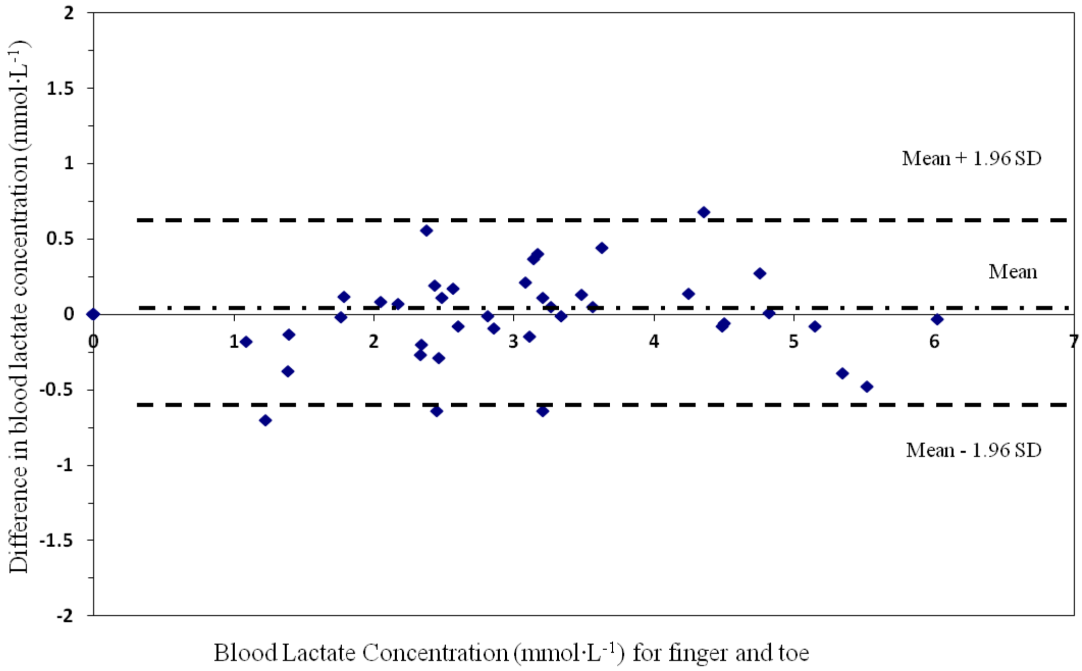

Figure 3.5 Limits of agreement for blood lactate concentration between fingertip and first (big) toe sample sites.

A regression analysis was performed to examine the relationship between the sample sites and to identify the adjustments necessary to predict fingertip capillary BLa concentrations from first (big) toe BLa concentration. The plot for the regression analysis is shown in Figure 3.6. The regression equation for which was R^2 = 0.94, y = 0.940x + 0.208.

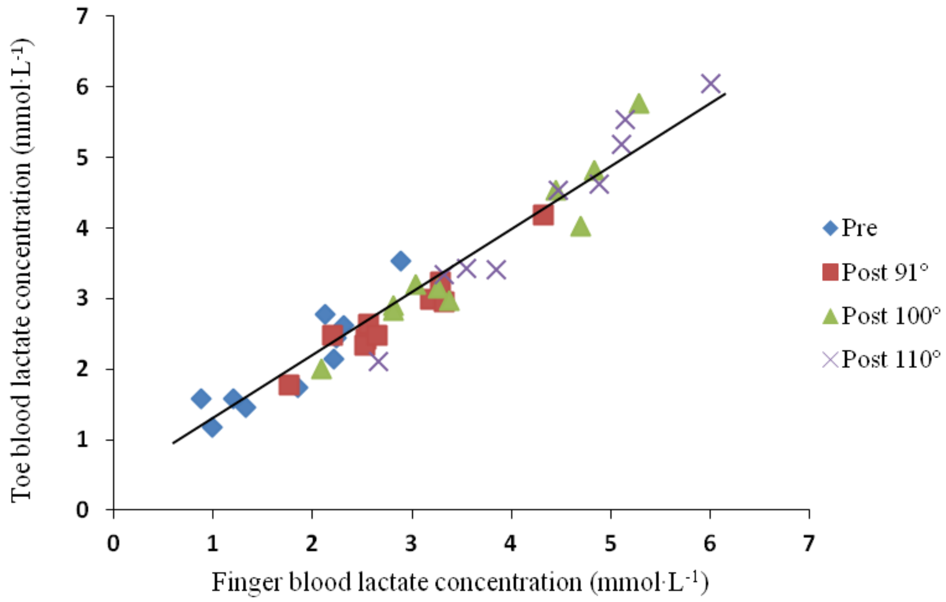

Figure 3.6 Regression model for toe and fingertip blood lactate concentration pre-climb and immediately post-climb at each angle.

Capillary BLa concentrations taken from the finger and toe were well within the upper and lower bounds of the 95% population confidence interval. In addition regression analysis revealed a strong relationship between mean BLa concentrations for finger and toe samples.

Plasma cortisol

Mean ± SD plasma cortisol concentrations assayed from capillary samples taken from the first toe and finger pre-climb and post-climb at each angle (91°, 100° and 110°) are reported in Table 3.6. Pre-climb and post-climb at 110° mean plasma cortisol concentrations for samples taken at the finger were higher than the toe by 3.78ng/mL and 4.09 ng/mL respectively. Immediately post-climb at 91° and 100° mean plasma cortisol concentrations recorded at the toe were 6.56 ng/mL and 10.68 ng/mL higher than the finger respectively. As indicated previously, results of paired samples *t*-tests for finger and toe indicated there were no significant differences between the assays.

Table 3.6 Mean ± SD plasma cortisol concentrations by sample site and angle of climb (Values given in nmol·L^{-1}, µg·dL and ng·mL for comparative purposes).

Sample	Plasma cortisol concentration		
	ng/mL	*nmol·L^{-1}*	*µg/dL*
Pre-climb			
Finger	339.0 ± 100.38	12.29 ± 3.64	122.87 ± 36.38
Toe	328.57 ± 103.96	11.91 ± 3.77	119.09 ± 37.38
Post 91°			
Finger	332.25 ± 94.30	12.04 ± 3.42	120.43 ± 34.18
Toe	350.38 ± 99.59	12.7 ± 3.61	126.99 ± 36.10
Post 100°			
Finger	311.78 ± 112.95	11.3 ± 4.09	113.0 ± 40.94
Toe	341.22 ± 150.23	12.37 ± 5.45	123.68 ± 54.45
Post 110°			
Finger	383.14 ± 64.07	13.88 ± 2.32	138.87 ± 23.22
Toe	371.86 ± 88.45	13.48 ± 3.21	134.78 ± 32.06

The limits of agreement plot for paired fingertip and first toe capillary plasma cortisol concentration is shown in Figure 3.7. The Altman Bland plot indicated relatively close agreement between the two sampling sites, with the standard deviation of differences being ± 16.9ng/ml.

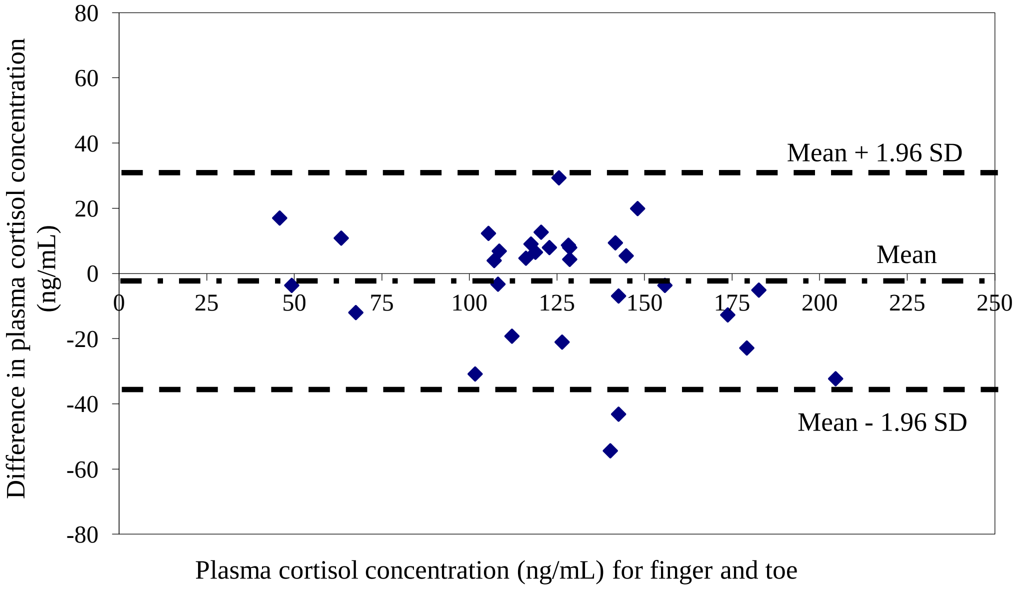

Figure 3.7 Limits of agreement for plasma cortisol concentration between fingertip and first (big) toe sample sites.

In order to examine the relationship between the sample sites and to identify adjustments necessary to predict fingertip plasma cortisol concentrations from first toe assay data, a regression analysis was performed. The plot for the regression analysis is shown in Figure 3.8. The regression equation for the model was R^2=0.78, y = 1.031x – 2.079.

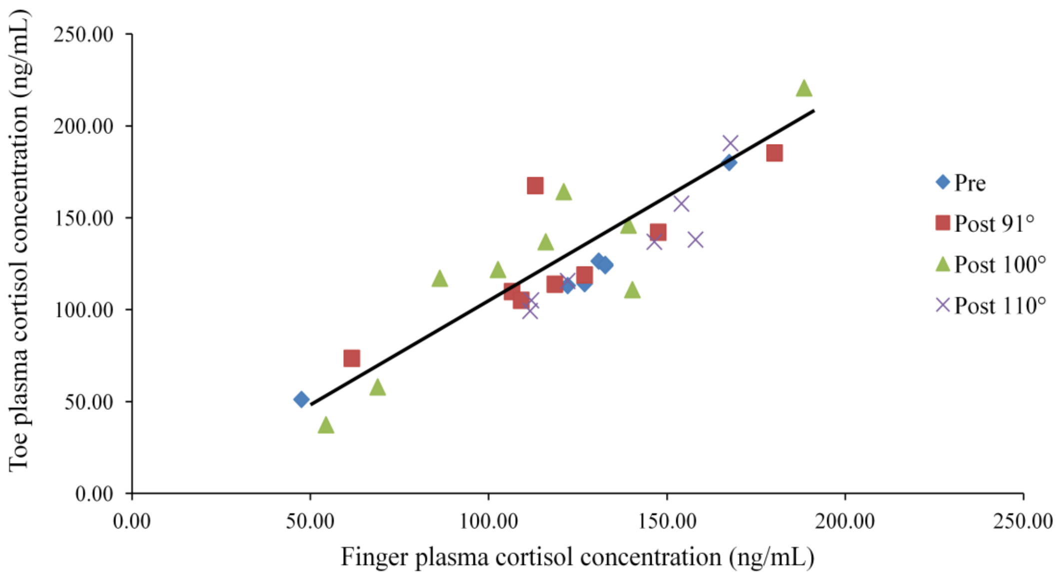

Figure 3.8 Regression model for first (big) toe and fingertip plasma cortisol concentration pre-climb, and immediately post 3 ascents at each angle.

Findings

The limits of agreement plot (Figure 3.7) revealed capillary plasma cortisol concentrations taken from the finger and first toe to be well within the upper and lower bounds of the 95% population confidence interval. Furthermore, a strong relationship (R^2 = 0.78) between mean plasma cortisol concentrations for the finger and first toe samples was revealed with subsequent regression analysis Figure 3.8. Similarly, the limits of agreement plot for capillary BLa concentrations (Figure 3.5) taken from the first toe and fingertip were within the upper and lower bounds of the 95% population confidence interval. Subsequent regression analysis revealed a strong relationship (r = 0.97, R^2 = 0.94) between mean lactate concentrations for the finger and toe samples (Figure 3.6). Based on these findings, the first toe appears to provide an alternative sampling site for plasma cortisol which avoids the compromise of grip during climbing, particularly with regard to the impact associated with sampling repetition and obtaining larger samples for multiple assays. It also demonstrates its appropriateness as a sampling site where multiple analytes, which require collection of blood, are being investigated. As such the use of the first toe as a sampling site to collect capillary blood samples to determine both BLa and plasma cortisol concentrations in the main studies was justified.

3.2.4 Summary

The preliminary studies presented in this thesis were conducted primarily for the purposes of justifying and validating methods used in the two main experimental chapters which follow. However, in doing so it is also hoped that the methods investigated may contribute to the number of climbing specific methods of assessment which can be repeated and replicated in future rock climbing studies. It is hoped that this would allow for greater ease of comparison between studies and their findings. The validation of self-reported ability grades and suggested grouping categories are of particular relevance here. Prior to the study conducted for the purposes of this thesis, no known research had validated the use of self-reported ability in rock climbing, despite its use being commonly accepted. It would appear that self-report provides a valid method of assessment, which when coupled with a systematic ability classification framework could serve as useful additions to future climbing research.

Until recently climbers and researchers have typically utilised training techniques and assessment tools originally designed for mainstream sports or laboratory based protocols. A growing appreciation for the development of novel or alternative assessment methods which take the specificity of rock climbing into account is evident. Reviews of rock climbing research have cited the development of such tools or methods as a requirement in order to build upon previous research (Giles et al., 2006; Sheel, 2004; Watts, 2004).. Sport specific assessment of strength, power, and flexibility which better replicate the movement demands of rock climbing have recently been developed (Brent et al., 2009; Draper et al., 2009; Draper et al., 2011a; Michailov et al., 2009; Schöffl et al., 2006). Similarly, authors have developed protocols to assess fitness and performance using climbing based field testing as opposed to laboratory based testing (Bertuzzi et al., 2012; Booth et al., 1999; España-Romero et al., 2009). Despite these advances, the development of methods of assessment which are tailored to the specific requirements of rock climbing is somewhat in its infancy. The validation of alternative methods such as the use of the big toe as a capillary sampling site for BLa and plasma cortisol presents another useful protocol which can be adopted in future rock climbing research.

3.3 Participants

3.3.1 Participant recruitment

The participants who took part in the experimental studies were recruited from climbing communities and development squads/clubs in the local area (Christchurch, New Zealand). Potential participants were informed of the study in person by members of the research team, with no information sought or recruitment conducted by third parties. All participants were engaged in regular physical activity, including rock climbing, and were accustomed to the equipment and procedures associated with the sport. In addition, all were familiar with The Roxx indoor climbing wall facility where climbing testing sessions were conducted. Upon recruitment, participants were asked to provide additional information regarding current rock climbing ability and activity level. To this end, participants gave information regarding their best indoor on-sight and redpoint lead ascent within the last 12 months (rated using the Ewbank grading system), number of years lead climbing and number of days climbing per week.

All participants were given a full written and verbal explanation of the procedures, risks and commitment required for each study prior to involvement in any experimental procedures. Following the completion of a medical questionnaire, participants provided written informed consent to participate. Where an under-age participant sought to take part in the study, the necessary information, and consent forms were given to the parent/guardian in attendance, or given to the participant to take to parents/guardians for reading and approval prior to any testing. Participants were informed that they could withdraw from the study at any time, or could withdraw their consent without having to provide a reason. In addition, it was stressed that all data would be treated as confidential and anonymity would be preserved if the results were published in a journal or other publication in addition to forming part of this thesis.

For all exercise tests, participants were asked to adhere to set guidelines prior. Participants were instructed to arrive for testing having observed a period of complete rest for at least 12 hours and having refrained from strenuous training in the 48 hours prior to testing. In addition, it was requested that the participants arrive having refrained from consuming alcohol for 24 hours and having consumed no food or caffeine in the 3 hours prior to each testing session. Adherences to these instructions were verified verbally before conducting each session.

3.3.2 Familiarisation, feedback and termination procedures

The participants recruited for the studies were actively involved in the sport of rock climbing with varying degrees of ability level. All participants had lead climbing experience and were accomplished climbers, and as such were familiar with the associated procedures and risks inherent within the sport. All participants used their personal climbing equipment when undertaking the testing and were instructed to climb in their own time at a pace which was comfortable, without weighting the safety rope. All participants were recruited at The Roxx indoor climbing wall and as such were familiar with the location used for experimental testing. However, due to the lack of familiarity with the laboratory equipment used during data collection, participants were given the opportunity to practice an example of the required exercise. This involved an ascent of an unrelated climbing route wearing all equipment necessary for testing procedures. This was to ensure that each participant was comfortable with their surroundings and the equipment used and to minimize any influence these factors might have on the results obtained. During experimental climbing testing, participants were not given any feedback or encouragement and could retire at any stage during the ascent. When participants fell, or weighted the safety rope the attempt was terminated and the participant was lowered to the ground to complete the post-climb protocol which is detailed within each experimental chapter.

3.4 Laboratory based testing

3.4.1 Descriptive data and anthropometric measures

Descriptive data and anthropometric measurements for each participant were taken before each testing session, including age, height, mass and percentage body fat. Height was measured using a stadiometer (University of Canterbury) measured to the nearest 0.01 m. Body mass and percentage body fat were measured using combined electronic scales and bioelectrical impedance analysis (InBody 230, Biospace, Korea) to an accuracy of 0.01 kg and 0.1% respectively. Both height and weight were recorded with the participant barefoot, clad in the attire they would wear during testing.

3.4.2 Incremental test to determine maximal oxygen uptake

As part of the experimental testing, participants were first required to complete an incremental treadmill test, using the Athlete Led Protocol (ALP) as described by Hamlin et al. (2012) in order to determine maximal oxygen uptake ($\dot{V}O_{2max}$). Due to the unfamiliar nature of laboratory based experimental exercise testing and its associated procedures, coupled with the requirement for maximal exhaustive effort, participants were given a full verbal explanation of the equipment and protocol upon arrival. In addition, participants were offered the opportunity to familiarize themselves with the equipment used, including use of the treadmill. During the laboratory based incremental exercise test, participants were given verbal encouragement to incite a maximal effort during the test and to maintain motivation. The point of exhaustion was defined as the point at which the athlete indicated they could not continue, or where the experimenter deemed it appropriate to terminate the test.

An incremental test to exhaustion was undertaken by each participant in order to obtain a measure of maximal oxygen uptake. The test was conducted on a treadmill (Woodway® Waukesha, WI, USA), participants started with an initial running speed of 8 kph and 0% gradient. The protocol involves two distinct phases; during the initial phase speed was increased by 1kph at the end of each minute and continued until the participant indicated (by pointing upwards) that they had reached the maximal cadence they were able to maintain. This signalled the start of the second phase, during which treadmill gradient was increased by 1 percent at the end of each minute. This increase continued until exhaustion, with the participant no longer able to continue, typically within 12-15 min. Pulmonary gas exchange was measured using on-line breath-by-breath (b^2) analysis throughout the test. Data were smoothed (5 steps) and $\dot{V}O_{2max}$ was determined as the highest 15 s average $\dot{V}O_2$ typically seen during the final 60 s of the test. In addition HR_{max} were noted during, taken as the highest peak HR observed during the test.

3.5 Pulmonary gas exchange and heart rate data

The studies contained within this thesis sought to examine the sport-specific physiological responses of rock climbers, and as such, experimental trials were conducted outside the laboratory in a field setting. In order to obtain measures of $\dot{V}O_2$, a portable gas analysis system, the Cosmed K4b^2 (Cosmed S.r.l., Rome, Italy) was used for all tests. The use of the Comsed K4b^2 has been widely accepted as a valid and reliable breath-by-breath gas analysis system for use in a non-laboratory setting (Ballard et al., 2000; Bertuzzi et al., 2012; Duffield et al., 2004; Koh et al., 2005; Parr et al., 2001; Pires et al., 2011; Sheel et al., 2003).

3.5.1 Cosmed K4b^2 specification

The Cosmed K4b^2 is a versatile gas exchange analysis system, designed specifically for field testing, yet can still be used via a serial (laboratory) station if required. The K4b^2 can be used in the field in two different configurations, namely using data recording and storage or telemetry data transmission. When used as a data recorder, breath-by-breath data is stored in the units built in memory (1MB). The storage facility can hold data for up to 16,000 breaths. Once a test is completed the data/results can be downloaded from the portable unit (PU) to a PC via an RS 232 port. When using telemetry data transmission the system uses a small transmitter and a receiver unit connected to a PC via a serial port so the information can be viewed in real time. The test data can be viewed and monitored on-line both in table and graphical format. The PU will also store the test (as in data recorder configuration) ensuring that should any interference occur, the data may still be downloaded manually.

The K4b^2 system employs a breath-by-breath analysis procedure. The PU contains O_2 and CO_2 analyzers, sampling pump, UHF transmitter, barometric sensors and electronics, all powered by a rechargeable battery unit. The system is worn by a participant during testing with an anatomical harness which can be adjusted for best positioning during a given activity or test. The K4b^2 system features rapid response (<150ms per 90% full scale) O_2 and CO_2 analyzers which are flow dependent, thermostated and compensated for variations in barometric pressure and temperature. The O_2 analyzer has a measurement range of 7-24% O_2 with accuracy to 0.02% O_2. The CO_2 analyzer has a measurement range of 0-8% CO_2 and accuracy to 0.01% CO_2. Prior to testing, relative humidity is ascertained and values are entered manually into the Cosmed K4b[2] PU. Respiratory flow is measured via a bi-directional turbine (diameter 28mm) with a flow range capacity of up to 20L/sec. The ventilation range is 0-300 litres per minute with accuracy to ± 2%. Flow resistance is stated at <0.7 cmH_2O s/L at 12 L/s with a resolution of 4 mL. The turbine is fixed to a soft facemask with a very low dead space, and which is available in varying sizes for optimal fit. A head-cap with adjustable straps is used to secure the face mask in place. During respiration a mobile, low-mass and inertia rotor blade in the turbine is set in motion. The rotation of the rotor blade is measured by an opto-electric system that counts the number of revolutions per second. The flowmeter measures the airflow rate, calculates the volume of expiratory air per minute (body temperature and pressure saturated (BTPS)) and counts the number of expiratory cycles per minute. Concentrations of expired Oxygen (F_EO_2) and Carbon Dioxide (F_ECO_2) are sampled through a removable sampling plug which is housed within the turbine unit that connects to the sample port of the portable unit via a Nafion (Permapure®) tube. The Nafion tube permits the equilibration of water vapour pressure (in the sample line with that of the surrounding environment) across its membrane, before the sample reaches the analyzers.

The breath-by-breath measures are determined by the detection of the beginning of the inspiratory cycle performed by the flowmeter, and is aligned with the change in O_2 and CO_2 fractions from end tidal to room air. Accuracy and reproducibility of the delay measurement is guaranteed to be within ± 20 ms using this procedure. The signals for O_2, CO_2 and volume are aligned, from which Oxygen uptake ($\dot{V}O_2$) and Carbon Dioxide production ($\dot{V}CO_2$) are calculated according to the Haldane transformation as follows:

$$\dot{V}O_2 = \dot{V}_I\,(F_IO_2) - \dot{V}_E\,(F_EO_2)$$

$$\dot{V}CO_2 = \dot{V}_E\,(F_ECO_2) - \dot{V}_I\,(F_ICO_2)$$

F_IO_2 is fixed, assuming a room air concentration of 20.93%

F_ICO_2 is fixed, assuming a room air concentration of 0.03%

(Cosmed, 1998)

3.5.2 Cosmed K4b^2 calibration

Prior to each test the K4b^2 portable measurement system was calibrated as specified in the K4b^2 user manual. Calibrations are necessary to assure the system acquires reliable measurements. This involves a series of flow/volume and analyzer calibrations conducted using the software provided and connection to a PC via an RS 232 port. Before any calibration procedures were undertaken it was ensured that the PU was turned on and the required warm-up (45 min) completed. In addition, the system was configured with the correct gas concentration values for room air (20.93% for O_2 and 0.03% for CO_2) using the mixture contained within the Alpha calibration gas cylinder (16.4 ± 0.1% for O_2 and 4.98 ± 0.03% for CO_2) and volume of the calibration syringe (3L).

Flows and volumes are measured using a bidirectional digital turbine housed in the flowmeter. Although stated within the user manual that the turbine flowmeter does not require daily calibration as it is unaffected by pressure, humidity and/or temperature, calibration was carried out prior to each test as standard procedure, partly to eliminate any discrepancies that may have existed between turbine units as the same turbine was not used for all tests. To calibrate the flow/volume a 3L syringe (Cosmed S.r.l., Rome, Italy) was connected to the flowmeter and turbine and ten inspiratory and expiratory strokes measured.

Analyzer calibrations are required to calibrate the zero, gain and delay of the K4b^2 gas sensors. The system allows three calibrations, all of which were conducted prior to testing for each participant. Room air calibration is conducted automatically by the system before each test and consists of sampling room air. This updates the baseline of the CO_2 analyzer in order to match the readings with the predicted atmospheric values (20.93% for O_2 and 0.03% for CO_2). Reference gas calibration consists of sampling a gas with a known composition from a calibration cylinder (BOC Gas Ltd), thus updating the baseline and the gain (span) of the analyzers in order to match the readings with the predicted values. Lastly, delay calibration was necessary to accurately measure the time needed for the gas sample to pass through the sampling line before being analyzed.

3.5.3 Cosmed K4b^2 setup

Participants were fitted with the K4b^2 using the anatomical chest harness supplied. The harness was arranged such that both the battery and analyzer unit (total weight 0.7 kg) were positioned on the back (see Figure 3.9 and Figure 3.10). This was done in order to minimize interference with movement and climbing equipment. In addition, all sample lines and connecting cables were secured to ensure that they did not compromise the climbers' movement. All tests were monitored via telemetry data transmission and stored tests were downloaded from the PU post-test for each participant.

Figure 3.9 Cosmed K4b^2 harness configuration anterior and posterior views.

Figure 3.10 Cosmed K4b^2 harness configuration lateral views.

3.5.4 Heart rate data

Heart rate data was measured and recorded in accordance with breath-by-breath intervals throughout all experimental tests. This was achieved using the heart rate probe supplied with the K4b^2 combined with a polar heart rate monitor belt worn by the participant (Polar FS1, Polar Electro, Oy, Kempele, Finland).

3.6 Capillary blood sampling and assay

3.6.1 Blood lactate concentration

Blood lactate sampling was implemented in order to determine the change in BLa concentration in response to exercise, with pre- and post-sampling intervals detailed within the experimental chapter for each study. All blood samples required for determining BLa concentration during the experimental studies contained within this thesis were collected via capillary blood sampling from the first (big) toe. The first (big) toe was prepared using a non-alcoholic medical wipe (TYCO Healthcare, UK) and allowed to dry naturally in room air to avoid contamination. Haemolance Plus lances (Haemedic, Poland) were used to puncture the skin to a depth of 1.6 mm. The first drop of blood was wiped away using a small lint free tissue before a free flowing sample was collected on a reagent strip. This was used to determine BLa concentration immediately using the Lactate Pro (Arkray Inc, Kyoto, Japan) portable analyser. The Lactate pro required a 5 µL sample to cover each reagent strip, with analysis carried out via amperometrical measurement and the result given in mmol·L^{-1}. The Lactate Pro was calibrated prior to each use using the calibration strips supplied.

3.6.2 Plasma cortisol concentration

All blood samples required for determining plasma cortisol concentration during the experimental studies contained within this thesis were collected via capillary blood sampling from the first (big) toe. The toe was prepared using a non-alcoholic medical wipe (TYCO Healthcare, UK) and allowed to dry naturally in room air to avoid contamination. Haemolance Plus (Haemedic, Poland) lances were used to puncture the skin to a depth of 1.6mm. Blood samples (300µl) were collected using lithium heparin CB300LH Microvettes (Starstedt Aktiengesellschaft & Co, Numbrecht, Germany). All blood samples were stored on ice until centrifugation (cr2000, Centurion Scientific, West Sussex England). Plasma samples were separated and placed in Eppendorf microtubes (Starstedt Aktiengesellschaft & Co, Numbrecht, Germany) and stored at -20ºC for later analysis.

3.6.3 Enzyme Linked Immunosorbent Assay (ELISA)

The plasma samples were analysed for cortisol using an Enzyme Linked Immunosorbent Assay (ELISA) method (Department of Clinical Biochemistry, Christchurch Hospital, Christchurch, New Zealand) as described in full and validated by Lewis and Elder (1985).

In order to complete the analysis 10 µL of plasma was required per assay. An odd appearance for any specimen was noted, which could indicate haemolysis. Coating solution was emptied from the previously prepared plates, blotted and put through a cycle of four washes with wash solution. Coating solution for each plate was made up by adding 5 µL of cortisol-thyroglobulin conjugate to 10 mL of guanidine hydrochloride (6mol·L^{-1}) in a glass beaker, ensuring to mix the solution well. Coating solution (100 µL) was added to all wells of a Falcon Plate (Microtest III 3912) using an Eppendorf multipippette. Coated plates were covered and refrigerated overnight at 4ºC.

The wells were emptied and blocked with 150 µL of Assay Buffer (Phosphate Buffered Saline (PBS); 0.05mol·L^{-1} PO_4^-) per well before being incubated at room temperature for 15-30 min before use. Blocking buffer was emptied and the plate blotted to remove any residue. Cortisol standard solutions were prepared as set out in Table 3.7.

Table 3.7 Cortisol standards and methods of preparation (Elder, 2010).

Standard	Preparation
Stock standard	1 mg/mL cortisol made up in ethanol biannually
Working standard	1µg/mL [50 ng/45 µL] Prepared by diluting 55.6 µL of stock standard to 50 mL with assay buffer containing bromocresol purple as an indicator (prepared in ethanol and a few drops added to assay buffer prior to use).
Top standard	5000 pg/45 µL (2800 $nmol \cdot L^{-1}$ final concentration) Prepared by adding 2 mL of working standard to 18mL assay buffer. Serial dilutions of the top standard are carried out to prepare 1400; 700; 350; 175 $nmol \cdot L^{-1}$ standards. Zero standards are assay buffer containing bromocresol purple.

Standards (0, 175, 350, 700, 1400, 2800 $nmol \cdot L^{-1}$) were dispensed (45 µL) in duplicate into the standard wells shown in Figure 3.11. To each of the standard wells 5 µL of human plasma stripped of cortisol was added. Assay buffer featuring Bromocresol purple indicator (45 µL) was added to each well for all samples (controls and unknowns; wells 1-40, see Figure 3.11). Using a P10 pipette 5 µL of undiluted controls (Biorad Lypochek 1, 2 and 3 reconstituted with 5ml distilled water) and unknown plasma were added in duplicate to each appropriate sample well. The Bromocresol purple indicator was used to show that a sample (control/unknown) had been added and demonstrates a shift in the blue spectrum. Monoclonal antibody A2 (1:25) 288 µL was added to 7.0 mL PBS assay buffer and 20 µL goat anti-mouse HRP (Chemicon). An electronic multipippette was used to add 50 µL to all wells and the plate was subsequently incubated at ambient temperature for 20-40 min, depending on the antibody batch. Once the appropriate incubation period had lapsed the plate was washed (four cycles) with a wash solution, blotted and 100 µL of 3,3',5'5'-tetramethylbenzidine (TMB) substrate was added to all wells. Once developed the plate exhibited a blue colouration and with the desired level reached was stopped using 100 µL 0.9 $mol \cdot L^{-1}$ hydrochloric acid stop solution, causing a colour change from blue to yellow. Finally, absorbance of plate wells was read at 450 nm (FLUOStar Galaxy).

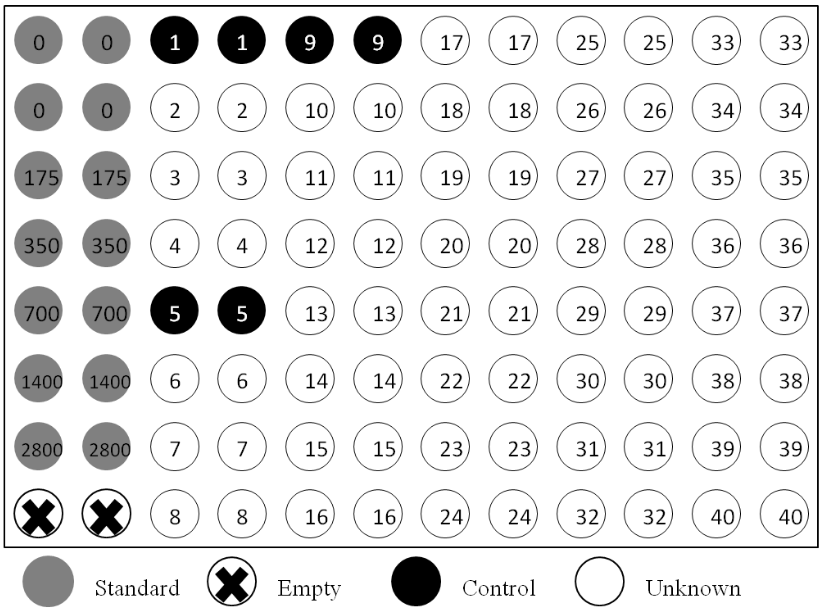

Figure 3.11 Pictorial representation of well plate setup used for ELISA plasma cortisol assay method.

All standards, controls and unknown samples were analysed in duplicate. Intra assay coefficients of variation were <10%. A single participants plasma samples were analysed in entirety in an attempt to minimise within-subject variability. Cortisol values were given in nmol·L^{-1} and subsequently converted to µg/dL and ng/mL with a factor of 27.59 (Volovitz et al., 1995).

3.7 Psychological assessment

A number of subjective psychological measures were obtained in order to aid in investigating the interaction between the psychological and physiological demands of rock climbing under the conditions described within each study. The three psychological inventories included were The Profile of Mood States (POMS) (McNair et al., 1971), the Revised Competitive State Anxiety Inventory-2 (CSAI-2R) (Cox et al., 2003), and the National Aeronautics and Space Administration Task Load Index (NASA-TLX) (Hart and Staveland, 1988).

3.7.1 Profile of Mood States (POMS)

The POMS questionnaire is a widely used measure of transient mood states. The inventory is designed to assess current 'right now' mood states and mood changes. It is most commonly employed within a clinical setting and has been administered in a variety of patient groups (Braslis et al., 2008; Guadagnoli and Mor, 1989; Salinsky et al., 2005; Schag et al., 1992; Smith et al., 1994; Ward, 1994), but has also been validated with respect to the general population with normative adult and geriatric data (Nyenhuis et al., 1999). The POMS has been shown to correlate with other measures of mood state such as the Visual Analog Mood Scales (VAMS), measures of depression using the Beck Depression Inventory (BDI), and anxiety assessment utilizing the State Trait Anxiety Inventory (STAI) therefore establishing its validity as a measure of mood state in its own right (Nyenhuis et al., 1999).

The Profile of Mood States (POMS) questionnaire (21 item shortened version) was administered immediately upon arrival to climbing test sessions in order to assess participants' mood states prior to their taking part. The questionnaire measures individuals' perception of tiredness and weariness (fatigue), readiness to partake in physical/mental work (vigour), aggression or hostility (anger), worthlessness (depression) and restlessness (tension). Each item was scored on a Likert scale of 0-4 (0; Not at all, 1; A little, 2; Moderately, 3; Quite a bit, 4; Extremely) and raw scores for each item were interpreted to give an average score for each of the subscales (fatigue, vigour, anger, depression and tension).

3.7.2 Competitive State Anxiety Inventory -2 Revised (CSAI-2R)

Whilst there are at least twenty-two published scales devoted to measuring anxiety, one of the most widely used sport-specific inventories in previous research has been the Competitive State Anxiety Inventory-2 (Martens et al., 1990). This has been used in research published in over thirty-five articles relating to anxiety exhibited in a sporting context (Ostrow, 1990). The CSAI-2 was developed from an earlier version (CSAI) taken from the State Trait Anxiety Inventory (Spielberger et al., 1970) to represent a sport-specific measure of anxiety. However, the original CSAI was found to be unidimensional, thus the CSAI-2 was developed as an instrument which measures both cognitive and somatic sport-specific anxiety. During validation a third construct emerged, namely self-confidence, The final version of the CSAI-2 contains three subscales: cognitive anxiety, somatic anxiety and self-confidence, each of which consist of nine items (Martens et al., 1990).

In a study by Cox et al. (2003) designed to assess the factor structure of the CSAI-2 via confirmatory factor analysis (CFA), the results indicated that the CSAI-2 model did not provide a satisfactory fit and was thought to have a psychometric weakness. This was also highlighted in previous studies (Andrew et al., 1999; Tsorbatzoudis et al., 1998). In response to this, CSAI-2 items that loaded on more than one factor were sequentially deleted and ten items were removed (Lagrange Multiplier Test). The resulting 17-item revised CSAI-2 was then subjected to a CFA using a validation data sample revealing a greatly improved model fit. The authors concluded that the revised version of the CSAI-2 instrument, the CSAI-2R possessed stronger psychometric responses in terms of factor structure whilst still maintaining the theoretical structure of the original instrument. As such, the use of the CSAI-2R is recommended in place of the original CSAI-2.

In each of the studies presented within the experimental chapters contained within this thesis the CSAI-2R was used to assess each individual's feelings of anxiety and self confidence prior to engaging in a climbing ascent. The CSAI-2R was completed by each participant (paper and pencil form) immediately pre-climb. Each item on the CSAI-2R inventory (17 in total), is scored on a Likert scale of 1-4 (1; not at all, 2; somewhat, 3; moderately so, 4; very much so). The three subscale scores are obtained by summing, dividing by number of items (somatic anxiety; 7-items, cognitive anxiety; 5-items and self confidence; 5-items), and multiplying by 10, with a score range of 10 to 40 for each subscale (Cox et al., 2003).

3.7.3 National Aeronautics and Space Administration Task Load Index (NASA-TLX)

The administration of the NASA-TLX is a popular technique for measuring subjective mental workload and relies on participants rating workload on six subscales; mental demand, physical demand, temporal demand, performance, effort and frustration (Table 3.8). The NASA-TLX is typically used to derive an overall workload score based on a weighted average of the six subscales. Three of the subscales relate to the demands imposed on the participant (mental, physical, and temporal) whereas the other subscales focus on interaction with the task (performance, effort, frustration).

Table 3.8 NASA-TLX rating scale descriptions (Cao et al., 2009).

Subscale	Description
Mental demand	How much mental demand and perceptual activity was required (thinking, deciding, calculating, remembering, looking, searching etc)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical demand	How much physical activity was required (pushing, pulling, turning, controlling, activating etc)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal demand	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	How successful do you think you were in accomplishing the goals of the task set by the experimenter? How satisfied were you with your performance in accomplishing these goals?
Effort	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration level	How insecure, discouraged, irritated, and annoyed or secure, gratified, content, relaxed, and complacent did you feel during the task?

The NASA-TLX (Hart and Staveland, 1988) is one of the most widely known tools for assessing subjective workload (Baulk et al., 2007; Greenwood-Ericksen et al., 2004; Hart, 2006; Kaber et al., 2000; Reilley et al., 2003; Turner et al., 2006). It has been extensively tested and frequently used in human performance studies (Jorgensen et al., 1999) and is considered a robust and valid measure of subjective workload (Battiste and Bortolussi, 1988; Hill et al., 1992; Moroney et al., 1995). This includes its application with respect to physiological function (cardiovascular, muscular, brain function etc) which is thought to index different aspects and workloads (Miyake, 2001). In addition, it has been reported that the NASA-TLX is often favoured by participants when compared with other subjective workload assessment techniques (e.g. Subjective Workload Assessment Technique; SWAT, the Cooper – Harper scale) and has also been shown to be highly correlated with other such measures (Hill et al., 1992).

The NASA-TLX was administered in paper and pencil form with the six subscales scored on a Likert scale of 0-20 (Low-High). All participants were asked to complete the inventory rating their feelings for the six components; mental demand, physical demand, temporal demand, performance, effort and frustration immediately after a climbing ascent attempt. Raw scores (un-weighted) for each of the six subscales were used as opposed to an overall workload score. This method of interpretation is often referred to as raw TLX (RTLX) with high correlations shown between weighted and unweighted scores (Byers et al., 1989; Moroney et al., 1992).

3.8 Procedures and data analysis

The methods detailed in this chapter are common to both studies contained within this thesis. Details of procedures, data analysis and statistical analysis employed with respect to each individual study, with any additional or exclusive protocols, are addressed in the subsequent chapters.

Chapter 4

Study One

4.1 Introduction

In one of the leading textbooks devoted to improving climbing performance Goddard and Neumann (1993) describe climbing as a multi-faceted sport, requiring both strength and technique whilst balancing anxiety and determination in order to succeed. The authors put forward six key aspects of climbing performance, each thought to influence another. These include co-ordination and technique, tactics, physical fitness, psychological aspects, background and external conditions. Despite this initial suggestion of an interaction of factors from a coaching perspective, scientific research during the early 1990’s was dominated by investigating which key physical characteristics alone were determinants of rock climbing success (Grant et al., 2001; Grant et al., 1996; Grant et al., 2003; Watts et al., 2003; Watts et al., 1993). These studies began by investigating anthropometry of elite climbers, which subsequently progressed to highlighting other physical and trainable determinants of performance, such as strength, power, power-endurance and flexibility (Draper and Hodgson, 2008; Giles et al., 2006; Sheel, 2004; Watts, 2004). However, in a systematic approach to investigating key determinants of success Mermier et al. (2000) concluded that physical attributes, characteristics, or components of fitness alone do not explain the variance in performance between climbers of differing abilities.

A shift to conducting field based rock climbing research ensued, and was directed primarily towards examining the physiological responses to climbing exclusive of any other factors (Billat et al., 1995; Booth et al., 1999; Draper et al., 2006a; Draper et al., 2006b; Schöffl et al., 2004b; Wall et al., 2004). This approach was possibly due to the assumption at the time that the psychological demand of climbing remained the same regardless of style of ascent (Mermier et al., 2000; Mermier et al., 1997; Sheel, 2004). This belief may have been influenced by the fact that much of the research was conducted on artificial surfaces, or climbing ergometers, with only two known studies conducted on natural rock (Booth et al., 1999; Williams et al., 1978). Similarly, studies which attempted to investigate lead climbing responses, particularly on-sight ascents are somewhat limited in number. Findings from studies which have investigated physiological responses to bouts of rock climbing have suggested that style of ascent, demands of the climb and environment all contribute to the overall physiological demand imposed by the climb, as initially put forward by Goddard and Neumann (1993). In two separate reviews of rock climbing research both Sheel (2004) and Watts (2004) have emphasised that a broader appreciation of such factors should be taken into account, both when investigating responses to rock climbing, and when interpreting the findings of any given study.

Initial studies investigating physiological responses to rock climbing were largely descriptive in nature. These studies measured HR, $\dot{V}O_2$ and BLa concentration during, and in response to bouts of rock climbing with the aim of reporting on relative aerobic and anaerobic contributions during the activity (Billat et al., 1995; Booth et al., 1999; Mermier et al., 1997). A study conducted by Billat et al. (1995) was one of the first to investigate $\dot{V}O_2$ and HR in response to rock climbing in order to examine the energy specificity of the sport, and characterise the responses of elite level climbers in a field based setting. Over the past two decades several studies have expanded upon the research of Billat et al. (1995) et al by investigating climbers physiological responses when ability level and task difficulty are manipulated. This has resulted in increased speculation, and often discordant findings as to the relative contributions of aerobic and anaerobic metabolism with respect to factors such as climb difficulty, route displacement and style of ascent. (Bertuzzi et al., 2007; Bertuzzi et al., 2012; de Geus et al., 2006; España-Romero et al., 2012; España-Romero et al., 2009; Pires et al., 2011). Further to this a number of specialised physiological responses have been suggested, such as the disproportionate rises in HR during climbing for a given $\dot{V}O_2$ suggesting a breakdown in the linear relationship between HR and $\dot{V}O_2$ during the activity (Bertuzzi et al., 2007; Billat et al., 1995; Booth et al., 1999; Mermier et al., 1997; Sheel et al., 2003; Watts and Drobish, 1998). Authors have also commented that physiological responses and extent of such adaptations may differ with respect to experience and ability level (Giles et al., 2006; Sheel, 2004; Watts, 2004).

A more recent approach to investigating determinants of successful climbing performance embraces a cross-disciplinary approach, investigating both physiological and psychological responses to climbing (Draper et al., 2008b; Draper et al., 2010; Hodgson et al., 2008; Sanchez et al., 2009). Whilst this approach to investigating the demands of rock climbing is somewhat in its infancy, previous research has suggested that there may be physiological and psychological differences between differing styles of ascent. A key psychological factor thought to be important to rock climbing performance is anxiety, particularly with respect to fear of falling, and the perception of perceived and actual risk (Boorman, 2008; Sanchez et al., 2009). A study conducted by Hodgson et al. (2008) revealed significant differences in plasma cortisol concentrations and anxiety among intermediate climbers in a comparison of lead climbing, second ascent, and top-roping. Draper et al. (2008b) reported significant differences in somatic and cognitive anxiety, coupled with elevated HR and $\dot{V}O_2$ among intermediate climbers during an on-sight lead climb, and a pre-practiced lead climb on the same route. These findings highlight both the differing psychological demand for ascent style, and the possible physiological manifestations of anxieties which contribute to the overall physiological responses to rock climbing. Given the limited number of studies which have investigated the demands of rock climbing in this manner, little is known about the relative impact of the psychological component of performance with respect to ability level. Anecdotally, coaches and experienced climbers report no differences in the mind set between lead and top-rope ascents, with attaining a balance between perceived and actual risk cited as a possible advantage (Binney and McClure, 2005; Boorman, 2008).

The purpose of this study was twofold, firstly to examine and explore psychological and physiological responses to difficult on-sight ascents with respect to ability level, and secondly to examine the effects of ascent style (lead and top-rope) on psychological and physiological responses to on-sight climbing.

4.2 Methods

This section provides details of the participants, experimental design, procedures and data analysis associated with study one only. Throughout this section reference is made to sections contained within the previous chapter *(General Methods*) and should be referred to where applicable.

4.2.1 Participants

Seventy-seven rock climbers volunteered to take part in the study. All climbers were actively involved in the sport, climbing at least once a week on artificial surfaces and natural rock. All climbers were proficient in the discipline of sport lead climbing. Participants were included and grouped based on self-reported on-sight and redpoint ability (within the last 6 months) given relative to the Ewbank grading system (see *2.4.6 Ewbank*). Climbers were categorised into lower-grade (n = 14), intermediate (n = 23), advanced (n = 23) and elite (n = 17) ability groups based on the criteria presented in Table 4.1 which was agreed upon and confirmed via the methods presented in previous chapter (see *3.2.2 Ability classification*).

Table 4.1 Ability classification and grouping categories based on self-reported grades (Ewbank).

Ability Group	Redpoint	On-sight
Lower-grade	≤19	≤17
Intermediate	20-24	18-20
Advanced	25-29	21-24
Elite	≥30	≥25

Within each ability group, participants were matched for age, sex and experience, and were randomly assigned to either a ‘lead’ or ‘top-rope’ group. Of the seventy-seven climbers who volunteered to take part in the study five participants; 3 intermediate (all lead group), 2 elite (one lead, one top-rope) had to withdraw from the study owing to other commitments, such as overseas travel or injury. Descriptive data for experience, anthropometric and fitness characteristics, with respect to the seventy-two participants who completed all testing requirements are presented in Table 4.2.

Table 4.2 Participants climbing experience, anthropometric, and fitness characteristics for males and females and total for each ability group (mean ± SD).

Ability group	n	Lead climbing experience	On-sight (Ewbank)	Redpoint (Ewbank)	Age (years)	Height (cm)	Mass (kg)	Body fat (%)	$\dot{V}O_{2max}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	HR_{max} ($bts \cdot min^{-1}$)
Lower-grade										
Male	4	0.4 ± 0.1	15.8 ± 1.0	16.5 ± 2.4	24.0 ± 1.8	184.4 ± 11.0	82.2 ± 11.6	10.7 ± 1.7	47.8 ± 3.0	190.3 ± 4.6
Female	10	2.6 ± 3.9	16.0 ± 1.1	17.3 ± 1.2	28.4 ± 8.7	162.6 ± 5.6	60.0 ± 6.4	24.3 ± 5.2	39.9 ± 5.8	186.1 ± 8.9
Total	14	2.0 ± 3.4	15.9 ± 1.0	17.1 ± 1.5	27.1 ± 7.6	168.5 ± 12.0	66.4 ± 13.0	20.4 ± 7.7	42.2 ± 6.3	187.4 ± 7.9
Intermediate										
Male	13	5.4 ± 6.6	18.4 ± 0.5	20.8 ± 1.1	27.2 ± 6.1	180.7 ± 5.0	82.0 ± 10.3	16.7 ± 4.3	54.2 ± 8.5	189.2 ± 10.2
Female	7	3.2 ± 3.2	18.4 ± 0.5	20.4 ± 0.8	24.7 ± 6.0	166.0 ± 5.8	59.9 ± 4.7	22.0 ± 3.5	43.9 ± 7.9	191.1 ± 12.7
Total	20	4.6 ± 5.7	18.4 ± 0.5	20.7 ± 1.0	26.3 ± 6.1	175.6 ± 8.9	74.3 ± 13.9	18.5 ± 4.7	50.6 ± 9.5	189.9 ± 10.8
Advanced										
Male	18	8.4 ± 9.7	23.1 ± 0.5	25.8 ± 1.2	28.2 ± 10.4	177.9 ± 5.8	71.4 ± 7.5	11.2 ± 4.3	58.0 ± 6.9	193.3 ± 10.7
Female	5	7.0 ± 4.1	22.8 ± 1.1	25.0 ± 2.0	26.0 ± 8.6	166.1 ± 6.6	58.7 ± 9.2	19.6 ± 3.7	41.0 ± 6.5	188.4 ± 4.2
Total	23	8.1 ± 8.9	23.0 ± 0.7	25.7 ± 1.4	27.7 ± 9.9	175.3 ± 7.6	68.6 ± 9.4	13.0 ± 5.4	54.3 ± 9.8	192.2 ± 9.8
Elite										
Male	14	7.6 ± 5.6	26.1 ± 0.9	28.8 ± 1.8	23.4 ± 5.2	175.9 ± 5.4	68.4 ± 6.7	10.1 ± 2.9	58.1 ± 4.1	192.5 ± 7.5
Female	1	4.0 ± 0.0	25.0 ± 0.0	28.0 ± 0.0	17.0 ± 0.0	165.5 ± 0.0	57.6 ± 0.0	16.9 ± 0.0	43.2 ± 0.0	184 ± 0.0
Total	15	7.3 ± 5.5	26.1 ± 0.9	28.7 ± 1.7	23.0 ± 5.3	175.2 ± 5.9	67.7 ± 7.1	10.1 ± 3.3	57.1 ± 5.5	191.9 ± 7.5

4.2.2 Experimental design

Study one comprised of three separate sessions, conducted on different days, with a minimum of two days separating each session. All participants were asked to adhere to pre-test guidelines detailed in *3.3.1Participant recruitment*. The first of the three sessions (LAB) took place in the exercise physiology laboratory at the University of Canterbury, (Christchurch, NZ), where anthropometric tests were conducted and $\dot{V}O_{2max}$ assessment was made. Details of the procedures involved are contained within section *3.4 Laboratory based testing*. Climbers then completed session two (BASE) and three (CT) at The Roxx artificial indoor climbing wall facility. These sessions were conducted at the same time of day to eliminate the possible impact of circadian variation on the measures being obtained, with particular regard to plasma cortisol concentration. Session two (BASE) was conducted in order to obtain baseline measures of mood state and plasma cortisol concentration. In addition, a hidden familiarisation was included in order allow the participants to become accustomed to wearing the Cosmed $K4b^2$ system. During the CT participants were required to attempt an on-sight ascent of a route set on an artificial indoor wall (The Roxx, Christchurch, NZ). As stated previously the style of ascent was split for each ability group such that participants attempted either a top-rope or lead ascent.

4.2.3 Climbing wall and route setting

Four independent test routes were set, allowing for one designated route for each ability group. The test route was set at a consistent grade of difficulty for the entire climb. The difficulty grading for each route was selected in order to provide an on-sight ascent at the upper limits of participants' self-reported ability, with failure to complete the climb a realistic possibility. Each route was set and confirmed by expert climbers with the difficulty grades 16, 18, 22 and 25 given to the lower-grade, intermediate, advanced and elite routes respectively. The test routes were set on a public climbing wall and remained in place over the course of testing. Due to the nature of the study whereby an on-sight attempt of the route was required, participants were instructed not to climb any routes which were identified as being associated with the College of Education. The routes in question were identified by a coloured plaque affixed to the wall, an example of which is displayed in Figure 4.1. Where possible, participants were also asked to refrain from watching other climbers attempting the routes, this was done in order to limit the amount of information (beta) gathered about the route prior to their own on-sight ascent.

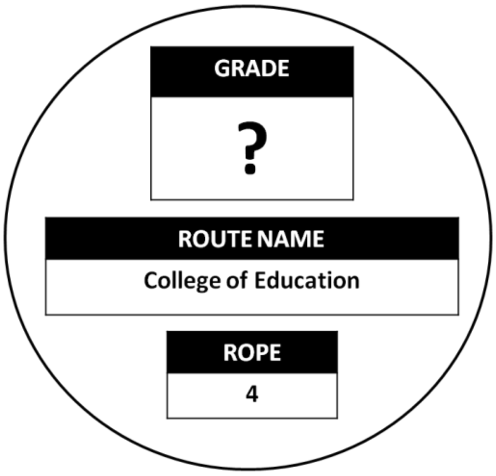

Figure 4.1 Illustration of the plaques used during the study to identify test routes.

All four routes were set on the same section of artificial wall (Sheer adventure) and followed the same line of pre-placed protection (Figure 4.2) The routes were featured on a 12.13 m high section of wall, and were set with the use of modular holds (Uprising ventures, Christchurch, New Zealand). Routes were distinguished by coloured bolt-on holds, with the use of natural features (smearing) for feet also permitted. The routes were protected with 7 bolts and a lower off point. Pre-placed quick draws were used during the lead climb ascents. Distance to the first bolt/clip was 2.85 m with a mean distance between bolts of 1.33 ± 0.31 m thereafter.

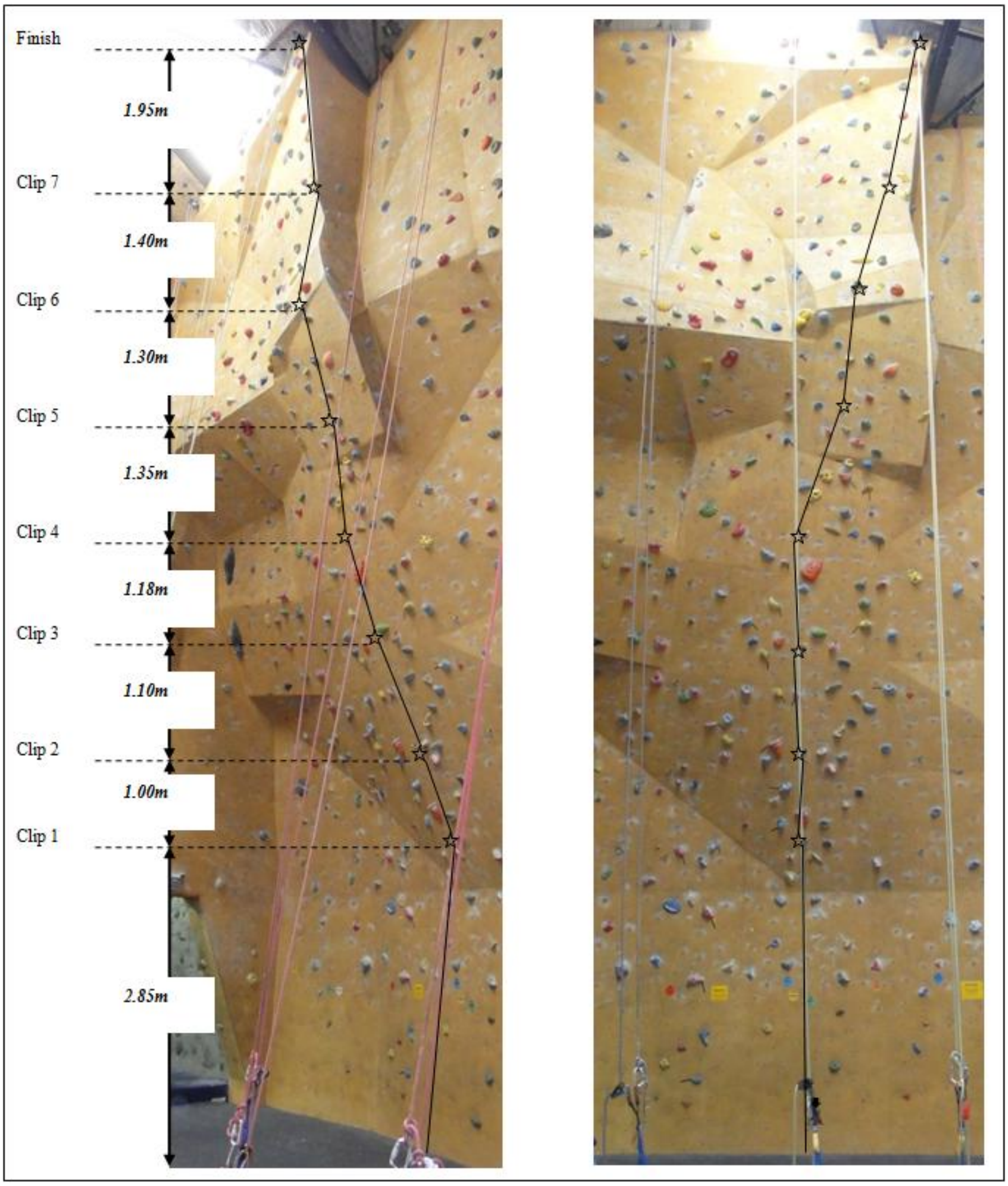

Figure 4.2 The profile of wall section used for setting all routes, including distance between clips (bolts).

4.2.4 Procedure

A diagrammatical representation of the procedural timelines for the BASE and CT sessions is presented in Figure 4.3**.** Upon arrival at the BASE session participants were first required to complete the POMS inventory (see *3.7.1 Profile of Mood States (POMS)*). During the initial hour of the baseline session, participants remained inactive (sitting), and three capillary blood samples for the determination of plasma cortisol concentration were collected as follows; immediately upon arrival, 30 min, and 60 min post-arrival, according to the sampling methods set out in *3.6.2 Plasma cortisol concentration*. Once all baseline measures were complete participants were then informed of the opportunity to climb two routes on a top-rope wearing the $K4b^2$ as detailed in *3.5.3 Cosmed K4b2 setup*. It should be noted that the participants were unaware they would be asked to climb at the end of the baseline session. This was arranged as such in order to eliminate the effects of any anxieties they may have experienced in anticipation of climbing, which may have influenced baseline values.

The CT session in which the climbers completed an on-sight attempt of a route set at the upper limits of their self-reported ability was conducted as follows. Upon arrival, climbers were asked to complete the POMS inventory and a capillary blood sample was collected for the determination of plasma cortisol concentration. Once the first blood sample had been collected and the questionnaire completed, participants were informed of their style of ascent (lead or top-rope). The grade (Ewbank) of the test route was not disclosed in order to maintain the on-sight conditions under which the route was to be attempted. However, participants were informed that the difficulty of the route would be at the upper limit of their self-reported on-sight ability. This was done in order to elicit an appropriate response to the task they were presented with. Climbers then completed a prescribed warm up consisting of three distinct phases; 5 min light jogging, mobilising/stretching exercises and one ascent of a route of their choice on a top-rope (typically at least two difficulty grades below their designated test route). Immediately post warm-up climbers were seated and a second capillary blood sample was collected (15 min post-arrival).

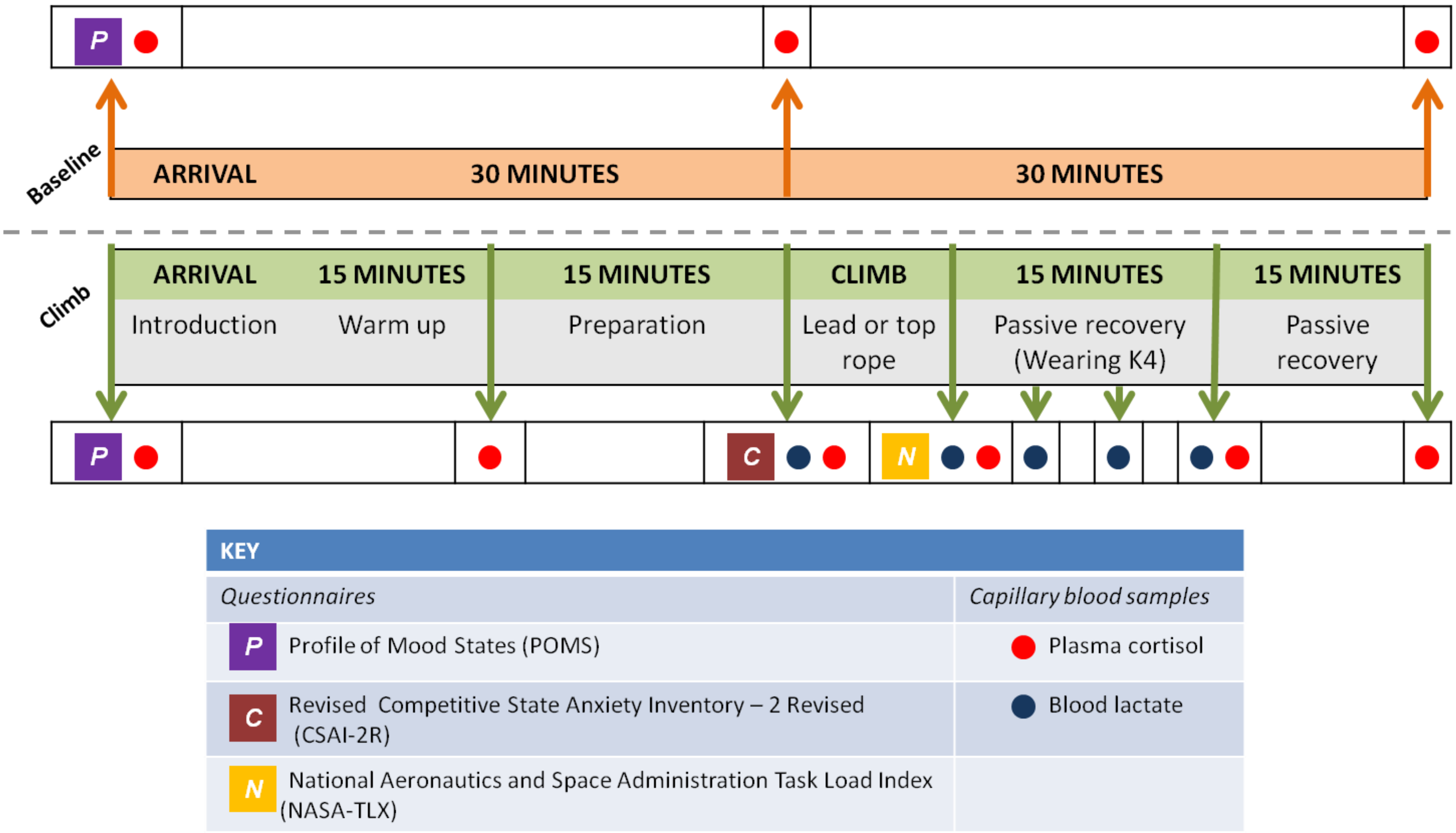

Figure 4.3 Timeline for baseline (BASE) and climbing trial (CT)

Climbers were then fitted with a polar FS1 (Polar Electro, Oy, Kempele, Finland) heart rate monitor and Cosmed K4b^2 as per the setup described in section *3.5.3 Cosmed K4b2 setup*, and were also instructed to fit their climbing harness before pre-climb blood sampling was completed. Pre-climb BLa concentration was determined using the lactate pro portable analyser via the methods set out in section *3.6 Capillary blood sampling and assay*, and a capillary blood sample for determining plasma cortisol concentration was collected (where possible pre-climb sampling was conducted 30 min post-arrival). Once complete, climbers prepared themselves to climb (shoes, chalk) and attached themselves to the rope, after which they were asked to complete the CSAI-2R immediately prior to ascent (see section *3.7.2 Competitive State Anxiety Inventory -2 Revised (CSAI-2R)*).

Climbers were instructed to begin the climb in their own time, with ascent time recorded as the moment they made contact with the wall, to clipping or touching the lower off, or the point at which they fell from the route. A successful ascent was given when the climber reached the top of the route, unsuccessful ascents (fall) were also recorded. Throughout the climb HR and breath-by-breath gas analysis data were recorded. In addition, all ascents were captured on video to aid in any further analysis, or for identifying possible causes of inconsistencies in data. Once their attempt was complete, climbers were lowered to the floor upon which a 15 min passive (seated) recovery period was observed with the Cosmed K4b^2 remaining in situ. Immediately upon being lowered to the floor, climbers were instructed to be seated and remove their climbing shoe in order for BLa concentration to be measured and a capillary blood sample collected (post-climb). During this initial phase post-climb, the climbers also completed the NASA-TLX inventory (see *3.7.3 National Aeronautics and Space Administration Task Load Index (NASA-TLX)*). During the 15 min post-climb recovery BLa concentration was measured at 5, 10 and 15 min post-climb. Two further capillary blood samples were collected for the determination of plasma cortisol concentration at the end of the 15 min recovery period (15 min post-climb) and at 30 min post-climb.

During the climb, participants' breath-by-breath data were monitored via telemetry and later downloaded from the K4b^2 PU post-test. Capillary blood samples for the determination of plasma cortisol concentration were handled as per the methods set out in section *3.6.2 Plasma cortisol concentration*. Cortisol assays were carried out using the ELISA method (Lewis and Elder, 1985) set out in *3.6.3 Enzyme Linked Immunosorbent Assay (ELISA).*

4.2.5 Data analysis

A number of dependent variables were calculated based on the measures obtained during BASE and CT responses for the purposes of investigating pre, during and post-climb responses. The following section provides details of data treatment and the calculations or methods used in compiling data for key variables for the purposes of statistical analysis. Details of treatment of data with respect to laboratory based testing, and in particular determining $\dot{V}O_{2max}$ and HR_{max} have already been presented in *3.4.2 Incremental test to determine maximal oxygen uptake* and should be referred to where necessary.

Delta pre-climb cortisol

Delta (Δ) plasma cortisol concentrations pre-climb were calculated for each ascent by subtracting baseline 60 min values from pre-climb values.

Heart rate and oxygen consumption pre-climb

In order to provide measures of $\dot{V}O_2$ and HR immediately pre-climb, individuals recorded breath-by breath data were used. All invalid steps were discarded, and the data set was smoothed (5 steps). Pre-climb $\dot{V}O_2$ (mL·kg^{-1}·min^{-1}) and pre-climb HR (bts·min^{-1}) were measured as the 15 s average for each variable immediately prior to the commencement of the climbers' ascent.

Ascent time

Ascent time (s) was recorded for each attempted ascent. Where a climber successfully completed the test route, ascent time was recorded from the moment the climber made contact with the wall, to the climber either touching the 'lower-off' point (for top-rope ascents) or upon successfully clipping the lead rope at the 'lower-off' (for lead ascents). Where a climber was unsuccessful (fall), ascent time was recorded from first contact with the wall to the point at which the climber fell, (and were not permitted to continue).

Heart rate and oxygen consumption during ascent

In this instance the terms average $\dot{V}O_2$ and average HR were used to define $\dot{V}O_2$ and HR responses averaged across the entire ascent. These were calculated from breath-by-breath data where firstly all invalid steps were discarded and data were smoothed

(5steps) before calculating the averages for $\dot{V}O_2$ and HR based on values and number of steps recorded during the ascent.

Climb phases

Climb phases are referred to as either ‘to clip’ or ‘clipping’ and were established in order to investigate $\dot{V}O_2$ and HR responses during ascent. To this end, climb phase timing points obtained by video analysis were matched with breath-by-breath data. Individuals’ breath-by-breath data were treated in the following respect; invalid steps were discarded and all data were smoothed (5 steps) before being exported to Excel for subsequent analysis. Timing points for climb phases obtained via video analysis were marked accordingly, and average ‘to clip’ and ‘clipping’ for $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$) and HR ($bts \cdot min^{-1}$) were calculated based on number of steps within each given phase. The definition of climb phases and their measurement were based the following criteria.

Top-rope

In the top-rope ascents ‘to clip’ phases were defined as the points at which the climbers’ hips were level with route bolts. For example ‘to clip 1’ refers to the section of climb from first contact with the wall to the point at which the climbers hips were parallel with the first bolt, ‘to clip 2’ refers to the section of climb from the first bolt to the second bolt and so forth.

Lead

For the lead climbing ascents climb phases were defined slightly differently. The ‘to clip’ phases were taken as the moment the climber reached for the rope in order to clip the quickdraw at the bolt and ‘clipping’ phases were taken from this point until the point at which the climber resumed all four points of contact with the wall after clipping at the bolt was complete; simultaneously signalling the start of the next ‘to clip’ phase. For example ‘to clip 1’ refers to the section of climb from first contact with the wall to the point at which the climber reached for the rope to clip the first bolt, this also signalled the start of the ‘clipping 1’ phase which was concluded when the climber resumed contact with the wall, and thus also starting the ‘to clip 2’ phase and so forth.

Delta post-climb cortisol

Delta plasma cortisol concentrations post-climb were calculated for each ascent by subtracting pre-climb values from those obtained at 15 min post-climb as this is where peak plasma cortisol concentrations were evidenced.

Delta peak blood lactate

Delta peak BLa in response to the on-sight climb was calculated by subtracting pre-climb BLa values from individuals peak BLa post-climb. Delta peak BLa is given in $mmol \cdot L^{-1}$.

4.2.6 Statistical analysis

All analyses were performed using the SPSS program (version 19.0 Chicago IL) and Microsoft Excel (Microsoft 2007, Redmond WA) software packages. All unsuccessful ascents were excluded from analysis, with data reported as means ± SD unless otherwise indicated. The α-level was set at 0.05 (2-tailed) for all analyses with Bonferroni correction applied for multiple tests where appropriate. Variables were assessed for normality of distribution using the one-sample Kolomogorov-Smirnov goodness of fit test, 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).

Table 4.3 Dependent variable grouping for MANOVA

Group	Dependent variables	Independent variables
Pre-Climb	Δ pre-climb cortisol ($ng \cdot mL^{-1}$) Pre-climb $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$) Pre-climb HR ($bts \cdot min^{-1}$) CSAI-2R *Somatic anxiety* *Cognitive anxiety* *Self-confidence*	Ability group Ascent style
Climb	Average $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$) Average HR ($bts \cdot min^{-1}$)	Ability group Ascent style
Post-climb	Δ post-climb cortisol ($ng \cdot mL^{-1}$) Δ peak BLa ($mmol \cdot L^{-1}$) NASA-TLX *Mental demand* *Physical demand* *Temporal demand* *Performance* *Effort* *Frustration*	Ability group Ascent style

A series of tests were used to investigate differences between ability group (lower-grade, intermediate, advanced and elite) and ascent style (top-rope and lead) for a number of variables. To this end dependent variables were grouped and considered together for the purpose of conducting multivariate analysis of variance (MANOVA). As can be seen in Table 4.3 three separate MANOVA were carried out for grouped pre-climb, climb and post-climb variables as described below. Ascent time was analysed separately using a two-way between-groups analysis of variance (ANOVA) as outlined below. The decision to exclude ascent time from the MANOVA was taken due to the potential differences in climb time owing to technical ability and tactical decisions which would likely influence overall ascent time. More specifically static time versus movement time differed between ability groups, with more experienced climbers often having chosen to take advantage of strategic rests at key times which resulted in longer ascent time relative to climbers of different ability levels. In contrast at the lower end of ability static time may have been increased due to hesitation or inability to perform the required move to progress on the route.

A two-way between-groups MANOVA was implemented to investigate the main effects ‘ability group’ and ‘ascent style’, which also investigates an interaction effect (ability group by ascent style). Where a significant effect was indicated by the MANOVA the dependent variables were considered separately. Analysis was first conducted by means of analysis of covariance (ANCOVA) to determine any significant covariate effects due to sex, age, anthropometrical characteristics (height, mass and body fat percentage) or baseline fitness ($\dot{V}O_{2max}$ and HR_{max}). Where significant covariates were identified, the results of the ANCOVA were presented (including adjusted means (SE) for the dependent variable). If no significant covariate effect were observed, ANOVA was performed with subsequent Post-Hoc LSD where appropriate and the results of the ANOVA reported. A Bonferroni correction was applied to ANCOVA and ANOVA results in order to correct for multiple tests. For this the *p* value obtained was multiplied by the number of dependent variables included in the initial MANOVA analysis.

4.3 Results

A series of one-way repeated measures ANOVA tests were used to investigate differences in POMS responses. Results indicated that there were no significant differences between the baseline and climbing trial for any of the components (anger, tension, depression, vigour, fatigue). This suggests that prior mood state of the participants did not affect performance during the climbing trial.

As stated previously, data for unsuccessful ascents (where climbers fell during their ascent) were discarded and all analysis was carried out on data for successful ascents only. Of the 72 climbers who attempted an on-sight ascent of a route at the upper limit of their ability, 52 were successful (top-rope; n = 31, lead; n = 21). Table 4.4 provides a breakdown of the number of successful top-rope and lead ascents within each ability group and totals for each ability group. Descriptives (mean ± SD) for successful with respect to age, climbing experience and self-reported ability is provided in Table 4.5.

Table 4.4 Number of successful and unsuccessful ascents with respect to ability group and ascent style.

Ability group	Successful ascents (n)	Unsuccessful ascents (n)
Lower-grade		
Top-rope	7	0
Lead	3	4
Total	10	4
Intermediate		
Top-rope	7	5
Lead	5	3
Total	12	8
Advanced		
Top-rope	10	1
Lead	9	3
Total	19	4
Elite		
Top-rope	7	1
Lead	4	3
Total	11	4

Table 4.5 Participants climbing experience and ability level for successful ascents only (mean ± SD).

Ability group	*n*	Age (years)	Lead climbing experience (years)	On-sight (Ewbank)	Redpoint (Ewbank)
Lower-grade	10	25.8 ± 4.3	1.6 ± 3.0	16.2 ± 0.9	17.5 ± 1.6
Intermediate	12	27.4 ± 6.5	6.4 ± 6.8	18.5 ± 0.5	20.8 ± 0.9
Advanced	19	27.6 ± 10.4	8.5 ± 9.4	23.2 ± 0.6	25.9 ± 1.2
Elite	11	23.1 ± 4.4	6.9 ± 5.1	26.3 ± 0.9	29.3 ± 1.5

The following sections present the results for study one. Results have been grouped into the following subsets; anthropometric characteristics and aerobic fitness, pre-climb, ascent time, HR and O_2 consumption during ascent, and post-climb.

4.3.1 Anthropometric characteristics and aerobic fitness

Anthropometric and fitness characteristic data (mean ± SD) for successful climbers is presented in Table 4.6. Data for males and females within each group are presented separately. This highlights the discrepancy in male and female breakdown of each ability group and as such caution was extended in interpreting group differences. As stated previously, ANCOVA was employed when investigating dependent variables individually which aims to account for variance attributed to sex differences.

Table 4.6 Successful participants anthropometric and fitness characteristics (mean ± SD).

Ability group	*n*	Height (cm)	Mass (kg)	Body fat (%)	$\dot{V}O_{2max}$ (mL·kg^{-1}·min^{-1})	HR_{max} (bts·min^{-1})
Lower-grade						
Male	3	178.7 ± 7.1	77.0 ± 6.5	11.5 ± 0.7	48.5 ± 3.2	188.3 ± 3.1
Female	7	162.0 ± 6.3	60.2 ± 7.2	24.1 ± 5.7	39.7 ± 5.4	188.0 ± 4.8
Total	10	167.0 ± 10.1	65.2 ± 10.5	20.3 ± 7.7	42.4 ± 6.3	188.1 ± 4.1
Intermediate						
Male	9	179.3 ± 4.7	81.4 ± 11.9	16.5 ± 5.0	56.0 ± 9.3	189.3 ± 12.0
Female	3	170 ± 2.0	62.2 ± 2.0	19.7 ± 1.9	45.3 ± 10.4	190.0 ± 12.5
Total	12	177.0 ± 5.8	76.6 ± 13.4	17.3 ± 4.5	53.3 ± 10.3	189.5 ± 11.6
Advanced						
Male	16	177.4 ± 5.6	70.5 ± 7.3	11.4 ± 4.6	58.5 ± 6.8	192.9 ± 11.0
Female	3	166.0 ± 9.3	53.4 ± 6.4	18.0 ± 2.4	41.6 ± 8.5	188.3 ± 3.8
Total	19	175.6 ± 7.4	67.8 ± 9.5	12.4 ± 4.9	55.9 ± 9.4	192.2 ± 10.3
Elite						
Male	11	175.4 ± 5.4	68.9 ± 5.4	9.9 ± 3.0	57.9 ± 4.4	192.4 ± 8.3
Female	-	-	-	-	-	-
Total	11	175.4 ± 5.4	68.9 ± 5.4	9.9 ± 3.0	57.9 ± 4.4	192.4 ± 8.3

4.3.2 Pre-climb

A two-way between-groups MANOVA was performed to investigate differences in pre-climb state for the main effects 'ability group' and 'ascent style' as well as the interaction effect (group*ascent style). Six dependent variables were used: Δ pre-climb cortisol, pre-climb HR, pre-climb $\dot{V}O_2$, somatic anxiety, cognitive anxiety and self-confidence. The independent variables were ability group (lower-grade, intermediate, advanced and elite) and ascent style (lead and top-rope). There was a significant difference between ability groups in the combined dependent variables for pre-climb ($F_{(18,120)}$ = 2.183, p = 0.007; Pillai's Trace 0.74, partial Eta^2 = 0.247). After the two-way MANOVA revealed a significant difference for the main effect 'ability group' the dependent variables were considered separately.

Delta pre-climb cortisol

Mean ± SD values for Δ pre-climb cortisol are presented in Table 4.7. The large SD should be taken into consideration when reviewing these values, and as such makes it difficult to comment upon the responses obtained. Aside from the lower-grade group, Δ pre-climb cortisol responses appeared to be slightly higher prior to the top-rope ascents in each ability group. A one-way between-groups ANOVA indicated that there was no significant difference in Δ pre-climb cortisol values between ability groups ($F_{(3,48)}$ = 1.606, p = > 1.0, partial Eta^2 = 0.091).

Table 4.7 Mean ± SD Δ pre-climb cortisol for groups presented with respect to ascent style (lead and top-rope) and group total.

Ability group	*n*	Δ pre-climb cortisol (ng/mL)
Lower-grade		
Top-rope	7	32.2 ± 35.0
Lead	3	49.5 ± 54.5
Total	10	37.4 ± 39.3
Intermediate		
Top-rope	7	54.8 ± 60.8
Lead	5	33.6 ± 15.7
Total	12	46.0 ± 47.1
Advanced		
Top-rope	10	23.6 ± 48.9
Lead	9	4.1 ± 34.3
Total	19	14.4 ± 42.6
Elite		
Top-rope	7	54.7 ± 63.1
Lead	4	36.9 ± 27.1
Total	11	42.5 ± 51.2

Heart rate and oxygen consumption pre-climb

Heart rate

A one-way between-groups ANCOVA was conducted to compare pre-climb HR between ability groups. The independent variable was 'ability group' (lower-grade, intermediate, advanced and elite), and the dependent variable consisted of HR measured prior to attempting an on-sight ascent on top-rope or lead. Participants age, sex, height, mass, percentage body fat, HR_{max} and $\dot{V}O_{2max}$ were used as covariates in this analysis. Age was found to be a significant covariate (p = 0.014), with a partial Eta^2 value of 0.122. After adjusting for age, there was a significant difference between groups for pre-climb HR ($F_{(3,47)}$ = 3.108, p = 0.035, partial Eta^2 = 0.166). However, when a Bonferroni correction was applied for multiple tests the difference was considered non-significant (p = 0.21). The adjusted group total **means (SE)** are presented in Table 4.8 alongside unadjusted means (± SD).

Table 4.8 Pre –climb HR responses for ability groups presented as mean ± SD for lead, top-rope and total for each group alongside mean (SE) adjusted totals.

Ability group	Pre-climb HR ($bts \cdot min^{-1}$)			
	Top-rope	*Lead*	*Total*	***Adjusted total***$^{\alpha}$
Lower-grade	98.2 ± 10.0	106.6 ± 11.4	100.8 ± 10.6	**100.4 (4.8)**
Intermediate	105.0 ± 4.6	107.7 ± 19.9	105.9 ± 12.5	**106.7 (4.4)**
Advanced	110.7 ± 16.8	117.3 ± 20.5	114.0 ± 18.5	**114.4 (3.5)**
Elite	123.3 ± 14.2	115.8 ± 27.3	120.6 ± 18.9	**118.3 (4.6)**

$^{\alpha}$Adjusted for age

Oxygen consumption

A one-way between-groups ANCOVA was conducted to compare pre-climb $\dot{V}O_2$ between ability groups. The independent variable was 'ability group' (lower-grade, intermediate, advanced and elite), and the dependent variable consisted of $\dot{V}O_2$ measured prior to attempting an on-sight ascent on top-rope or lead. Participants age, sex, height, mass, percentage body fat, HR_{max} and $\dot{V}O_{2max}$ were used as covariates in this analysis. Percentage body fat was found to be a significant covariate (p = 0.016), with a partial Eta^2 value of 0.119). After adjusting for percentage body fat, there was a significant difference between groups for pre-climb $\dot{V}O_2$ ($F_{(3,46)}$ = 3.132, p = 0.034, partial Eta^2 = 0.170). However, when a Bonferroni correction was applied for multiple tests, the difference was considered non-significant (p = 0.21). The adjusted group total **means (SE)** are presented in Table 4.9 alongside unadjusted means (± SD).

Table 4.9 Pre –climb $\dot{V}O_2$ for ability groups presented as mean ± SD for lead, top-rope and total for each group alongside mean (SE) adjusted totals.

Ability group	Pre-climb $\dot{V}O_2$ (mL·kg^{-1}·min^{-1})			
	Top-rope	*Lead*	*Total*	***Adjusted total***$^{\alpha}$
Lower-grade	8.3 ± 2.3	9.3 ± 0.6	8.6 ± 2.0	**9.6 (0.8)**
Intermediate	10.2 ± 1.7	11.4 ± 1.7	10.7 ± 1.7	**11.1 (0.7)**
Advanced	12.4 ± 2.3	10.9 ± 1.4	11.6 ± 2.0	**11.3 (0.6)**
Elite	14.8 ± 4.4	13.5 ± 4.6	14.3 ± 4.3	**13.5 (0.8)**

$^{\alpha}$Adjusted for percentage body fat

Competitive state anxiety inventory – 2 revised

Differences in respondents CSAI-2R scores for somatic anxiety, cognitive anxiety and self-confidence are presented in Table 4.10. A one-way between-groups ANOVA was performed for each construct, which indicated that there was no significant difference between ability groups (lower-grade, intermediate, advanced and elite) for the dependent variables somatic anxiety ($F_{(3,48)}$ = 2.051, p > 1.0, partial Eta^2 = 0.076), cognitive anxiety ($F_{(3,48)}$ = 0.729, p > 1.0, partial Eta^2 = 0.44), and self-confidence ($F_{(3,48)}$ = 1.323, p < 1.0, partial Eta^2 = 0.076).

Table 4.10 Mean ± SD scores for somatic anxiety, cognitive anxiety, and self-confidence presented for each ability group with respect to ascent style (lead and top-rope) and as group total.

Ability group	*n*	Somatic anxiety	Cognitive anxiety	Self-confidence
Lower-grade				
Top-rope	7	15.7 ± 4.6	19.4 ± 6.9	26.9 ± 7.0
Lead	3	14.3 ± 2.5	16.0 ± 5.3	27.3 ± 11.4
Total	10	15.3 ± 4.0	18.4 ± 6.4	27.0 ± 7.9
Intermediate				
Top-rope	7	20.4 ± 5.2	18.3 ± 10.2	30.6 ± 7.2
Lead	5	16.6 ± 2.8	16.8 ± 5.4	30.4 ± 5.0
Total	12	18.8 ± 4.6	17.7 ± 8.2	30.5 ± 6.1
Advanced				
Top-rope	10	16.4 ± 3.0	15.8 ± 3.1	25.8 ± 6.9
Lead	9	16.2 ± 4.0	17.6 ± 5.6	25.8 ± 4.5
Total	19	16.3 ± 3.4	16.6 ± 4.4	25.8 ± 5.7
Elite				
Top-rope	7	15.1 ± 4.9	15.1 ± 4.9	29.7 ± 7.4
Lead	4	15.0 ± 4.7	14.5 ± 3.4	25.5 ± 6.6
Total	11	15.1 ± 4.6	14.9 ± 4.2	28.2 ± 7.1

4.3.3 Ascent time

Mean ± SD ascent times for ability groups and style of ascent are presented in Table 4.11. A two-way between-groups ANOVA indicated there was no significant difference in ascent times between ability groups ($F_{(3,44)}$ = 0.932, p = 0.434, Partial Eta^2 = 0.060). Furthermore, the two-way between-groups ANOVA revealed a non-significant interaction effect for 'ability group*ascent style' ($F_{(3,44)}$ = 0.562, p = 0.643). However, a significant difference for the main effect 'ascent style' was indicated ($F_{(1,44)}$ = 28.338, $p < 0.0005$; Partial Eta^2 = 0.39), suggesting that lead on-sight ascents took significantly longer than top-rope ascents.

Table 4.11 Mean ± SD ascent time (s) for top-rope and lead ascents within each ability group.

Ability group	*n*	Ascent time (s)
Lower-grade *		
Top-rope	7	129.7 ± 27.7
Lead	3	191.0 ± 10.6
Intermediate *		
Top-rope	7	117.7 ± 16.0
Lead	5	183.0 ± 37.1
Advanced *		
Top-rope	10	114.5 ± 20.1
Lead	9	163.7 ± 49.2
Elite		
Top-rope	7	135.7 ± 43.9
Lead	4	167.3 ± 11.5

*Indicates significant difference (p < 0.05 after Bonferroni correction) between lead and top-rope ascents within the group.

After a significant effect for 'ascent style' was revealed, a series of independent sample *t*-tests were performed to investigate differences within each ability group between top-rope and lead on-sight ascents. Top-rope on-sight ascents were completed significantly faster than lead ascents in the lower-grade ($t_{(8)}$ = 3.609, p = 0.028, mean difference = 61.3, CI 100.4 - 22.1), intermediate ($t_{(10)}$ = 4.202, p = 0.008, mean difference = 65.3, CI 99.9 - 30.7) and advanced ($t_{(17)}$ = 2.907, p = 0.04, mean difference = 49.2, CI 84.8 - 13.5) but not in the elite ($t_{(9)}$ = 1.380, p = 0.201, mean difference = 31.5, CI 83.2 - 20.2) group.

4.3.4 Heart rate and oxygen consumption during ascent

A two-way between-groups MANOVA was performed to investigate differences in average HR and $\dot{V}O_2$ for the main effects 'ability group' and 'ascent style' as well as the interaction effect (group*ascent style). Two dependent variables were used; average HR and average $\dot{V}O_2$. The independent variables were 'ability group' and 'ascent style'. A significant effect was indicated for 'ability group' on the combined dependent variables ($F_{(6,80)}$ = 3.507, p = 0.004; Pillai's Trace 0.417, partial Eta^2 = 0.208). After a significant difference for the main effect 'ability group' was indicated by the two-way MANOVA the two dependent variables were considered separately.

Heart rate

A one-way between-groups ANCOVA was conducted to compare average HR between ability groups. The independent variable was 'ability group' (lower-grade, intermediate, advanced and elite), and the dependent variable consisted of HR averaged over the entire ascent time (lead and top-rope combined). Participants age, sex, height, mass, percentage body fat, HR_{max} and $\dot{V}O_{2max}$ were used as covariates in this analysis. Age and HR_{max} were found to be significant covariates (age p = 0.017, HR_{max} p = 0.032), with partial Eta^2 values of 0.126 and 0.103 respectively. After adjusting for age and HR_{max}, there was no significant difference between ability groups for average HR ($F_{(3,43)}$ = 1.955, p = 0.135, partial Eta^2 = 0.120). The adjusted group total **means (SE)** are presented in Table 4.12 alongside unadjusted means (± SD).

Table 4.12 Average HR responses for ability groups presented as mean ± SD for lead, top-rope and total for each group alongside mean (SE) adjusted totals.

Ability group	Average HR (bts·min^{-1})			
	Top-rope	*Lead*	*Total*	***Adjusted total***$^{\alpha}$
Lower-grade	160.0 ± 8.6	148.7 ± 10.6	156.6 ± 10.2	**157.5 (3.5)**
Intermediate	162.7 ± 7.9	161.6 ± 20.4	162.2 ± 13.6	**163.5 (3.0)**
Advanced	162.1 ± 14.2	170.1 ± 12.4	166.1 ± 13.5	**166.7 (2.5)**
Elite	171.8 ± 9.4	167.9 ± 13.1	170.6 ± 10.0	**167.8 (3.4)**

$^{\alpha}$Adjusted for age and HR_{max}

Further to this, mean HR averaged for each climb phase (average ‘to clip’ and ‘clipping’) for each ability group were plotted in order to provide a descriptive account of HR over the entire route for top-rope (Figure 4.4) and lead (Figure 4.5) ascents. Mean HR for the climb phases during the top-rope ascent (Figure 4.4) was similar across ability groups. However, mean HR responses for elite climbers were marginally higher than the other three ability groups. In the reviewing HR during lead ascents (Figure 4.5) HR to clip/clipping appeared to be marginally lower for the lower-grade and intermediate climbers when compared to the advanced and elite groups.

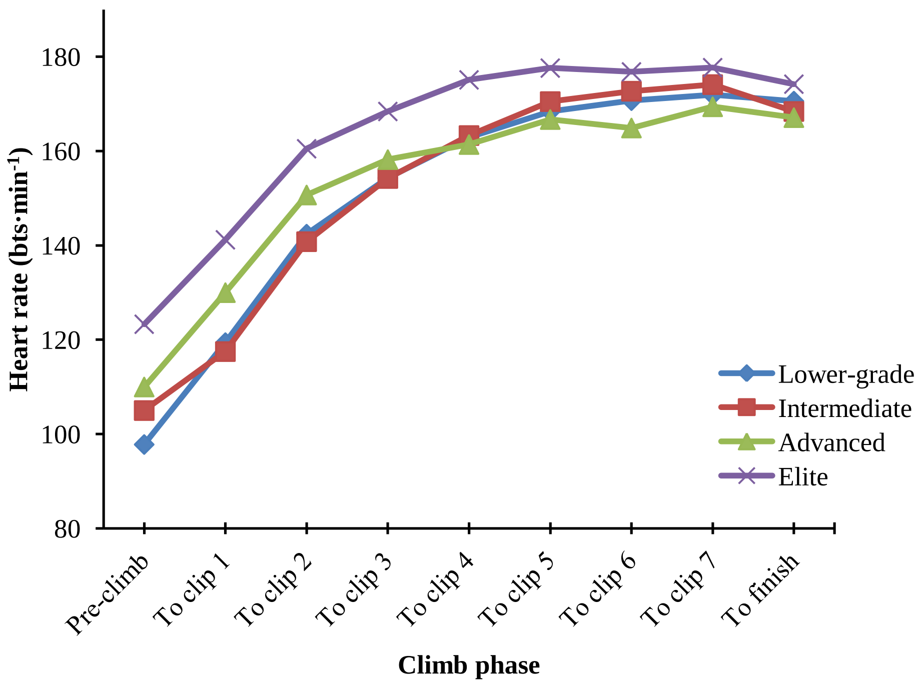

Figure 4.4 Mean HR averaged to each clip for top-rope ascents only, presented with respect to ability group (lower-grade, intermediate, advanced, elite).

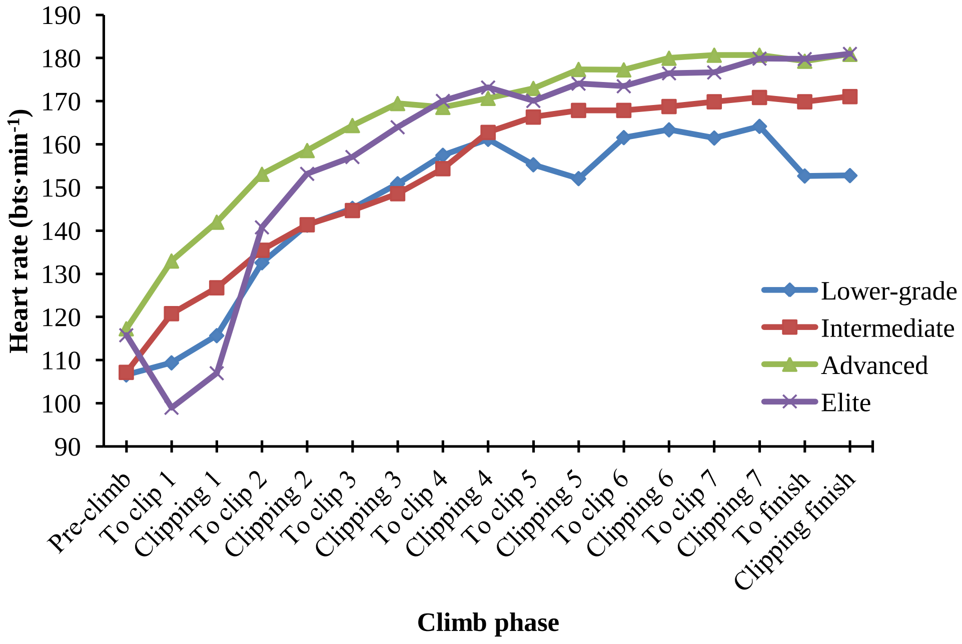

Figure 4.5 Mean HR averaged to each clip, and during lead rope clipping for lead climbing ascents only, presented with respect to ability group (lower-grade, intermediate, advanced, elite).

Oxygen consumption

A one-way between-groups ANCOVA was conducted to compare average $\dot{V}O_2$ between ability groups. The independent variable was 'ability group' (lower-grade, intermediate, advanced and elite), and the dependent variable consisted of average $\dot{V}O_2$ during an on-sight ascent on top-rope or lead. Participants age, sex, height, mass, percentage body fat, HR_{max} and $\dot{V}O_{2max}$ were used as covariates in this analysis. $\dot{V}O_{2max}$ was found to be a significant covariate (p = 0.001), with a partial Eta^2 value of 0.238. After adjusting for $\dot{V}O_{2max}$, there was a significant difference between groups for average $\dot{V}O_2$ ($F_{(3,44)}$ = 4.991, p = 0.005, partial Eta^2 = 0.254). When a Bonferroni correction was applied for multiple tests the difference was still considered significant (p = 0.01). The adjusted group total **means (SE)** are presented in Table 4.13 alongside unadjusted means (± SD). Comparisons of adjusted means (with Bonferroni correction applied) indicated that average $\dot{V}O_2$ was significantly higher in the elite group compared to lower-grade (mean difference = 6.61, CI 1.54 – 11.68) and advanced (mean difference = 4.08, CI 0.20 – 7.95) groups, but not when compared to the intermediate group (mean difference = 2.67, CI -1.51 – 6.84).

Table 4.13 Average $\dot{V}O_2$ during ascent for ability groups presented as mean ± SD for lead, top-rope and total for each group alongside mean (SE) adjusted totals.

Ability group	Average $\dot{V}O_2$ (mL·kg^{-1}·min^{-1})			
	Top-rope	*Lead*	*Total*	***Adjusted total***$^{\alpha}$
Lower-grade	26.4 ± 3.6	26.8 ± 2.9	26.5 ± 3.2	**28.9 (1.3)**
Intermediate	33.5 ± 4.9	32.3 ± 2.4	33.0 ± 4.0	**32.9 (1.0)**
Advanced	32.8 ± 5.5	31.3 ± 4.2	32.0 ± 4.8	**31.5 (0.9)**
Elite	37.7 ± 3.5	34.7 ± 3.4	36.8 ± 3.6	**35.5 (1.1)**

$^{\alpha}$Adjusted for $\dot{V}O_{2max}$

To further investigate the $\dot{V}O_2$ responses to on-sight lead and top-rope climbing with respect to ability average $\dot{V}O_2$ values for each phase of the climb (to clip/clipping) were calculated. Mean $\dot{V}O_2$ averaged at each phase of the route for all groups was plotted to provide a descriptive account of $\dot{V}O_2$ responses over the entire route for lead (Figure 4.6) and top-rope (Figure 4.7) ascents.

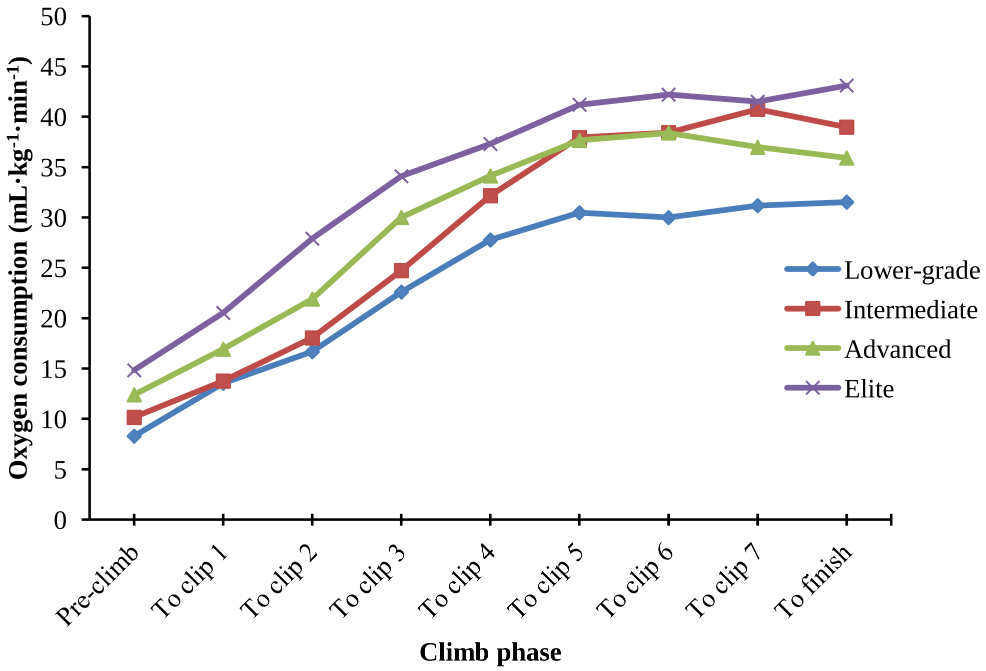

Figure 4.6 Mean $\dot{V}O_2$ averaged to each clip during top-rope ascents only, presented with respect to ability group (lower-grade, intermediate, advanced, elite).

Mean average $\dot{V}O_2$ throughout the climb phases for lead and top-rope ascents displayed similar trends with $\dot{V}O_2$ levelling off throughout the latter half of the ascent. It can be seen from Figure 4.6 and Figure 4.7 that during both styles of ascent $\dot{V}O_2$ responses throughout the climb were similar for the intermediate and advanced ability groups, whilst the elite and lower-grade groups were shown to have comparatively higher and lower oxygen consumption respectively

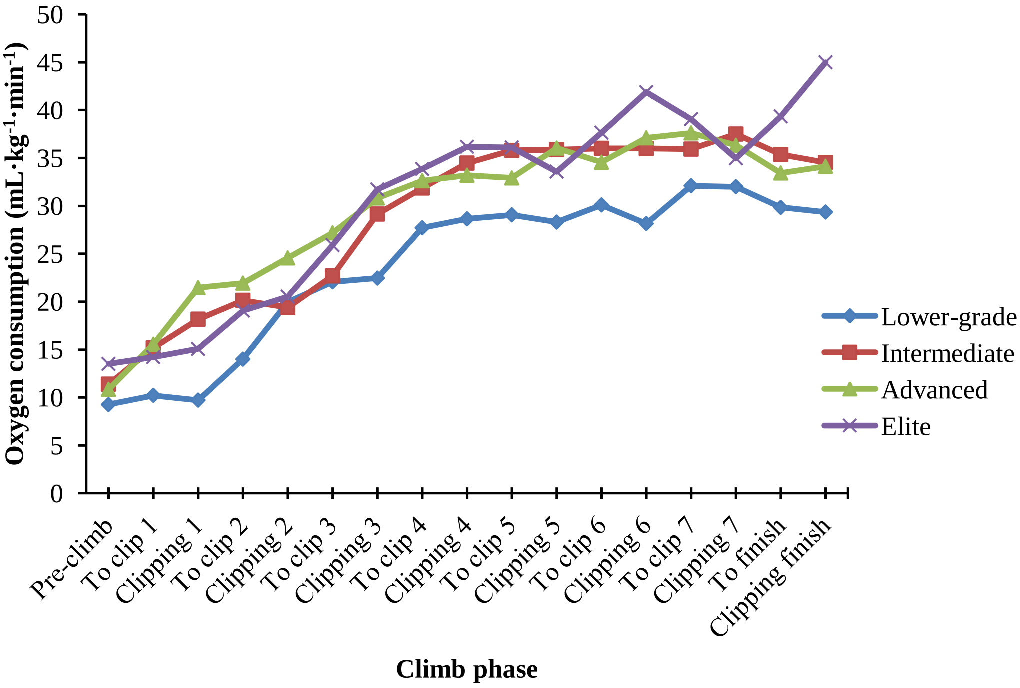

Figure 4.7 Mean $\dot{V}O_2$ averaged to each clip and during lead rope clipping for lead ascents only, presented with respect to ability group (lower-grade, intermediate, advanced, elite).

4.3.5 Post-climb

A two-way between-groups MANOVA was performed to investigate ability and ascent style differences in post-climb responses for the main effects 'ability group' and 'ascent style' as well as the interaction effect (group*ascent style). Eight dependent variables were used: Δ post-climb cortisol, Δ peak BLa, and ratings of task demand for mental, physical, temporal, performance, effort and frustration sub-scales. The two-way between-groups MANOVA indicated non-significant differences for the main effects 'ability group' (p = 0.176) and 'ascent style' (p = 0.070). This was also the case with respect to interaction effect (p = 0.820). After the two-way MANOVA revealed non-significant differences for the main effects and interaction effect no further analyses were carried out. However, mean ± SD values for post-climb responses are presented separately for descriptive purposes.

Post-climb cortisol

An overview of mean plasma cortisol concentrations measured throughout the BASE and CT for each ability group is presented in Figure 4.8.

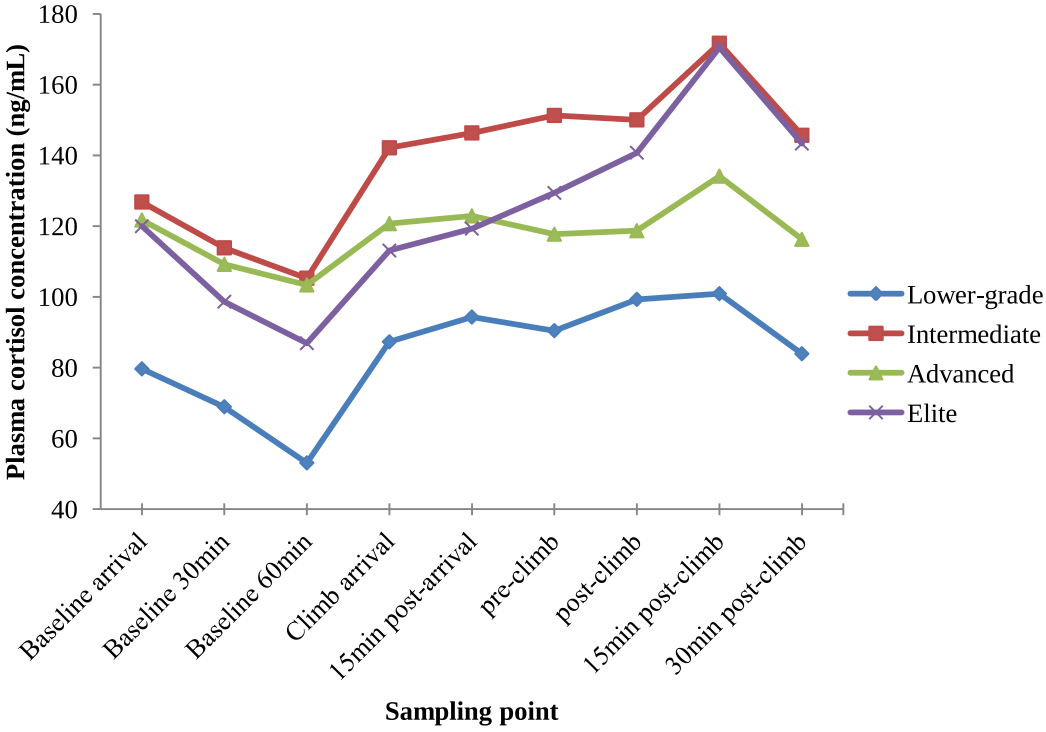

Figure 4.8 Mean plasma cortisol concentrations at various sampling points throughout the BASE and CT for lower-grade, intermediate, advanced and elite groups.

Mean plasma cortisol concentrations displayed similar trends across the BASE and CT in all ability groups. Peak concentrations were observed at 15 min post-climb for all ability groups. Mean values for the lower-grade ability group were lower than intermediate, advanced and elite groups. In order to examine the relative cortisol response post-climb in isolation, Δ post-climb cortisol concentrations were calculated by subtracting climbers pre-climb values from those obtained 15 min post-climb. Mean

± SD Δ post-climb cortisol concentrations are presented in Table 4.14. Data presented suggest that responses were greater for lead ascents compared to top-rope in all four ability groups. Group total mean Δ post-climb cortisol concentrations were lowest in the lower-grade group and highest for elite climbers. However, due to large differences in individual responses large SD values were observed.

Table 4.14 Mean ± SD Δ Post-climb cortisol for ability groups presented with respect to ascent style (lead and top-rope) and group total.

Ability group	*n*	Δ Post-climb cortisol (ng/mL)
Lower-grade		
Top-rope	7	-3.3 ± 23.1
Lead	3	42.5 ± 27.0
Total	10	10.4 ± 31.7
Intermediate		
Top-rope	7	0.8 ± 24.2
Lead	5	47.8 ± 66.2
Total	12	20.4 ± 50.0
Advanced		
Top-rope	10	4.5 ± 31.5
Lead	9	29.7 ±37.8
Total	19	16.4 ± 36.0
Elite		
Top-rope	7	31.3 ± 30.4
Lead	4	58.2 ± 24.0
Total	11	41.1 ± 30.2

Figure 4.9 provides an overview of mean plasma cortisol concentrations for ascent style totals (top-rope and lead). Plasma cortisol concentrations were similar for top-rope and lead ascents throughout the CT until 15 min and 30 min post-climb. Although peak plasma cortisol concentrations were observed at 15 min post-climb in response to both styles of ascent, mean values 15 min and 30 min post-climb in response lead climbing were higher than top-rope ascents.

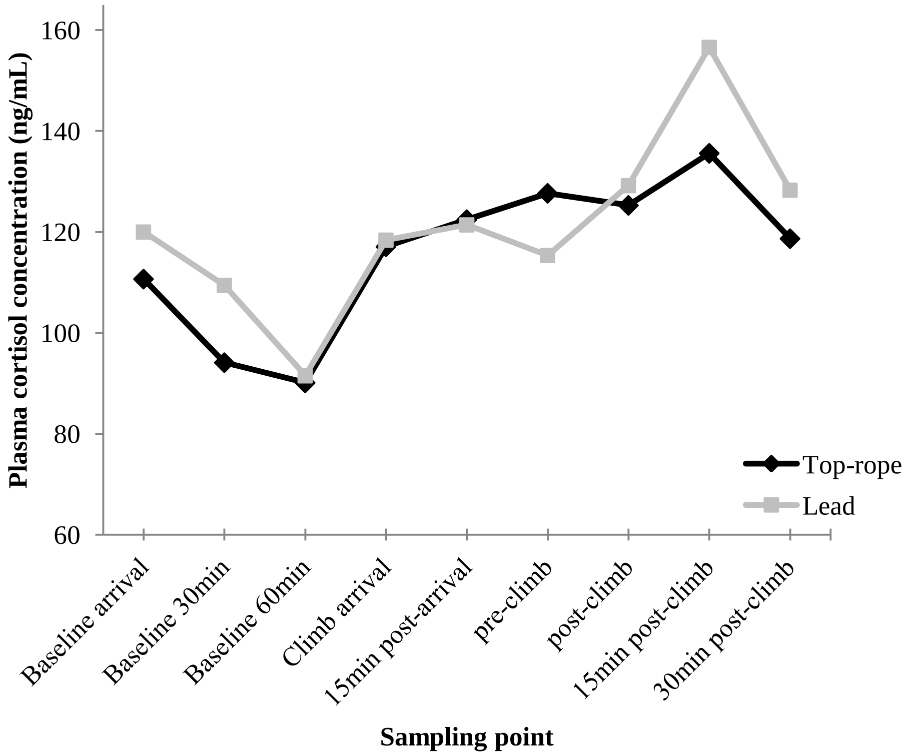

Figure 4.9 Mean plasma cortisol concentrations at various sampling points throughout the BASE and CT for total top-rope and lead ascents.

Blood lactate

Mean BLa measured pre and post-climb, (sampled over a 15 min passive recovery period) for each ability group are presented in Figure 4.10. Mean BLa pre-climb was similar for all ability groups, suggesting climbers started their ascents in a similar preparatory state. Blood lactate concentrations immediately post-climb were similar for intermediate, advanced, and elite groups rising above 4.0 mmol·L^{-1}. However, this was not replicated in the lower-grade group. In all ability groups mean peak BLa was observed immediately post-climb. As can be seen in Figure 4.10 mean BLa was attenuated over the 15 min recovery period, yet was not returned to pre-climb levels. Responses over the 15 min passive recovery were similar for the advanced and elite groups, however the mean BLa for the intermediate group remained considerably elevated.

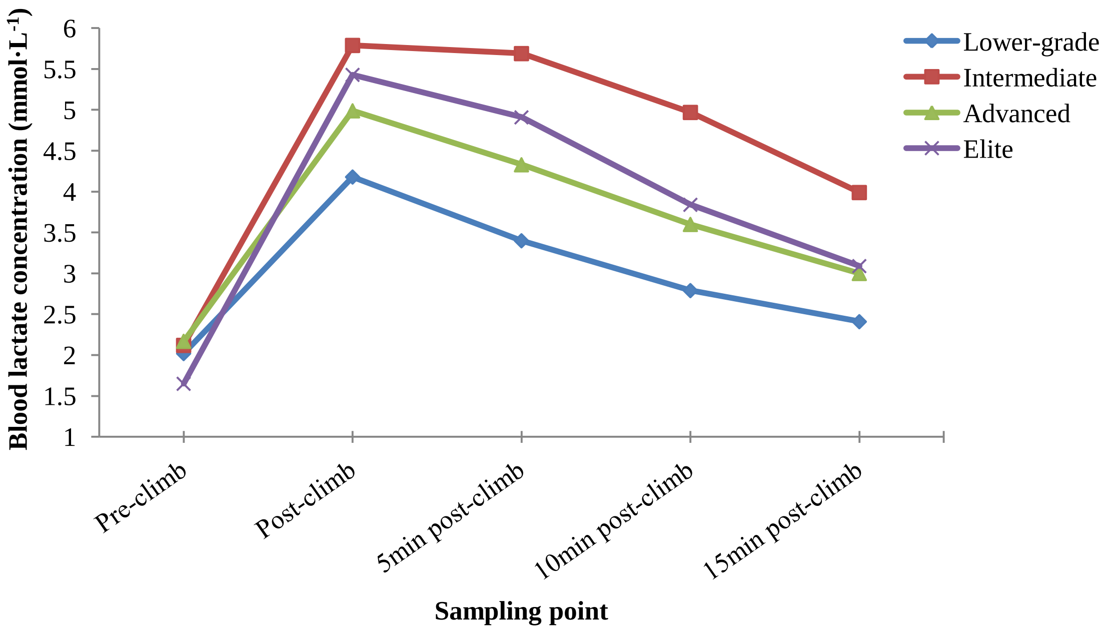

Figure 4.10 Mean BLa concentration at pre-climb and various post-climb sampling points for lower-grade, intermediate, advanced and elite groups.

In order to examine the relative increase in BLa post-climb Δ Peak BLa concentrations were calculated by subtracting individuals pre-climb BLa values from their peak BLa measured post-climb. Mean ± SD Δ Peak BLa for top-rope and lead ascents as well as ability group totals are presented in Table 4.15. In both the intermediate and advanced groups Δ Peak BLa was slightly higher in response to lead climbing ascents when compared to top-rope ascents. With the exception of the lower-grade group the difference between lead and top-rope ascents within the intermediate, advanced and elite groups decreased slightly with increasing ability (intermediate 0.9mmol·L^{-1}, advanced 0.7mmol·L^{-1} and elite 0.1mmol·L^{-1}).

Table 4.15 Mean ± SD Δ Peak BLA for ability groups presented with respect to ascent style (lead and top-rope) and group total.

Ability group	*n*	Δ Peak BLa ($mmol \cdot L^{-1}$)
Lower-grade		
Top-rope	7	2.4 ± 0.9
Lead	3	1.6 ± 0.5
Total	10	2.2 ± 0.9
Intermediate		
Top-rope	7	3.5 ± 1.0
Lead	5	4.4 ± 2.6
Total	12	3.9 ± 1.3
Advanced		
Top-rope	10	2.5 ± 0.7
Lead	9	3.2 ± 1.1
Total	19	2.8 ± 0.9
Elite		
Top-rope	7	3.8 ± 1.4
Lead	4	3.9 ± 1.2
Total	11	3.8 ± 1.3

National Aeronautics and Space Administration Task Load Index

Mean ± SD values reported for the ratings given for each of the six sub-scales of the NASA-TLX questionnaire which was completed immediately post-climb are presented in Table 4.16.

Table 4.16 Mean ± SD scores for NASA-TLX subscales for ability groups and ascent styles

Ability group	*n*	Mental	Physical	Temporal	Performance	Effort	Frustration
Lower-grade							
Top-rope	7	7.4 ± 4.5	10.3 ± 3.6	6.6 ± 4.5	13.9 ± 2.9	11.4 ± 3.4	4.1 ± 2.7
Lead	3	3.3 ± 2.1	10.7 ± 3.1	2.3 ± 2.5	17.7 ± 2.5	12.3 ± 0.6	6.3 ± 4.7
Total	10	6.2 ± 4.3	10.4 ± 3.3	5.3 ± 4.4	15.0 ± 3.2	11.7 ± 2.8	4.8 ± 3.3
Intermediate							
Top-rope	7	9.4 ± 3.6	12.1 ± 3.9	8.1 ± 4.7	13.3 ± 3.2	12.9 ± 4.5	9.1 ± 5.4
Lead	5	13.6 ± 2.2	13.8 ± 3.7	8.6 ± 5.1	15.8 ± 2.2	14.8 ± 1.6	10.6 ± 3.9
Total	12	11.2 ± 3.6	12.8 ± 3.8	8.3 ± 4.6	14.3 ± 3.0	13.7 ± 3.6	9.8 ± 4.7
Advanced							
Top-rope	10	7.5 ± 3.7	10.9 ± 3.8	4.5 ± 3.4	14.8 ± 3.8	12.3 ± 3.4	3.7 ± 3.5
Lead	9	7.1 ± 5.0	10.0 ± 5.6	5.6 ± 6.1	14.3 ± 2.6	10.7 ± 4.6	8.6 ± 7.9
Total	19	7.3 ± 4.2	10.5 ± 4.6	5.0 ± 4.7	14.6 ± 3.2	11.5 ± 4.0	6.0 ± 6.3
Elite							
Top-rope	7	8.6 ± 5.4	12.9 ± 3.4	8.6 ± 5.2	15.1 ± 2.6	12.4 ± 4.9	4.6 ± 3.6
Lead	4	7.5 ± 4.2	10.5 ± 5.2	7.0 ± 4.6	13.8 ± 4.6	10.3 ± 5.4	8.5 ± 2.9
Total	11	8.2 ± 4.8	12.0 ± 4.1	8.0 ± 4.8	14.6 ± 3.3	11.6 ± 4.9	6.0 ± 3.8

In the lower-grade and intermediate groups the top-rope ascent was considered less mentally demanding than the lead ascent, whilst in the advanced and elite groups mean scores for mental demand were marginally higher for top-rope (<1.0). Physical demand was reported as being similar between lead and top-rope ascents within groups, and did not differ greatly between ability levels. Rating of performance post-climb between groups was also similar, with mean values for the subscale ranging from 14.3 – 15.0. There were notable differences in ratings of frustration with respect to top-rope and lead ascents within ability groups, with all showing greater levels of frustration in response to the lead ascent compared with top-rope.

4.4 Discussion

The aim of the current study was to investigate differences in psychological and physiological responses to on-sight indoor rock climbing with respect to ability level and ascent style. To this end 72 climbers were split into the following ability groups; lower-grade (n = 14), intermediate (n = 20), advanced (n = 23) and elite (n = 15) based on respective best self-reported on-sight grades of ≤17, 18-20, 21-24 and ≥25. Each climber attempted an on-sight ascent of a designated test route set on an indoor artificial climbing wall. A separate test route was set for each ability group which targeted their self-reported ability with respect to best on-sight. This was done in order to ensure that all participants were subjected to difficult climbing coupled with an added element of uncertainty, with a fall from the route a realistic possibility. Participants were matched for age, sex and experience, and randomly assigned to either lead or top-rope ascent. Climbers were not informed of their ascent style until 15 min prior to climbing. Responses to the climbing task were measured pre, during, and post-climb using a number of psychological and physiological markers in order to assess the demands of difficult on-sight ascents.

The large number of participants and the use of four distinct ability groups in the current study are unique with respect to current literature. To my knowledge this appears to be the only known study to systematically explore the psychological and physiological responses of climbers ranging in ability from lower-grade to elite, during difficult indoor sport climbing on-sight ascents on both lead and top-rope. Only a small number of studies currently exist in this specific area of research (Draper et al., 2008b; Draper et al., 2010; Hodgson et al., 2008). As well as the large scale of the study, the novel methodological approach, and conditions of the study are of importance. In previous research there has been a large degree of ambiguity in defining ability level and resultant groups based on self-reported ability. Mean ability level is often presented with respect to a grading system, however ability within a group ranges greatly (refer to Table 3.2 *Summary of ability grades and grouping categories reported in rock climbing studies between the years 2000 and 2010.*). In contrast to this, climbers in the current study were recruited and included based on a narrow grade range, with test routes set relative to best previous on-sight ascent. This resulted in extremely homogenous groups with respect to on-sight ability, where the SD for each group were ~1 grade (Table 4.2). In the current study, four distinct ability categories were strictly defined (3.2.2 *Ability classification*). This was done with the aim of presenting a systematic breakdown of where differences in responses may be observed across a more comprehensive range of abilities. Finally, the on-sight ascent conditions in the current study serve to better reflect the true nature of difficult climbing, taking into account both psychological and physiological responses with respect to top-end performance. As such, it is hoped that the findings may hold better implications for high-level climbing and provide a more accurate reflection of the demands of difficult rock climbing.

In the current study it was appreciated that variances between group totals for anthropometric measures may have largely been due to gender differences given the male:female ratio within each ability group. This is with particular regard to the lower-grade group where female participants were in the majority. Observations with regard to height, mass and percentage body fat differences between groups, and in relation to previous studies are discussed separately for males and females where appropriate. The trends observed for height, mass and percentage body fat with respect to high level climbers in the current study was in support of those stipulated in previous studies. More specifically, where elite climbers have been described as being short in stature, with low body mass, and low percentage body fat when compared to less experienced, or non-climbers (Cheung et al., 2011; Macdonald and Callender, 2011; Michailov et al., 2009; Watts et al., 2003; Watts et al., 1993).

Although differences in anthropometric and fitness characteristics between ability groups were not examined for statistical significance in the current study, some trends were observed. Differences between lower-grade, intermediate, advanced and elite climbers for height were minimal for males and females. However, higher level male climbers were reported to be slightly shorter in stature when comparing the two lower ability groups with the advanced and elite groups (Table 4.6). At the upper end of the ability range height differentiation between advanced and elite male climbers was minimal; differences were most prominent when lower ability climbers were compared with elite climbers. This was also true with respect to female climbers yet in the opposite regard, as mean height reported for lower-grade climbers was less than both the intermediate and advanced groups. As was seen with respect to height, the advanced and elite groups showed similar mean values for mass which were lower than that of the two lower ability groups, supporting previous suggestions that higher-level climbers have a lower mass than less experienced climbers (Giles et al., 2006; Grant et al., 2001; Grant et al., 1996; Sheel, 2004; Watts, 2004; Watts et al., 1993). This attribute has been discussed as advantageous to climbers due to the requirement to continuously support the bodyweight, predominantly with the use of the upper body muscles (Cheung et al., 2011; Giles et al., 2006; Grant et al., 2001; Grant et al., 1996; Michailov et al., 2009; Sheel, 2004; Watts, 2004).

Finally, mean percentage body fat values in the current study showed that higher level male climbers possessed a comparatively lower percentage body fat when compared with climbers of lower ability. Percentage body fat for successful elite male climbers was found to be < 10% in the current study, which is comparable to the measures obtained with respect to high level climbers in the studies by Macdonald and Callender (2011); Watts et al. (2003) and Cheung et al. (2011). However, this was higher than reported for competitive climbers of world standard for bouldering and sport climbing in the respective conducted by Michailov et al. (2009) and Watts et al. (1993). Similarly, percentage body fat among female climbers showed a concurrent decrease with increase in ability, although it should be noted that there were no female climbers included in the successful elite group. Mean percentage body fat with respect to the advanced female climbers in the current study was not too dissimilar to values reported for competitive boulderers by Michailov et al. (2009). This physical characteristic is often highlighted and discussed as a discerning feature between high level climbers and those of lower ability, particularly among female climbers (Grant et al., 2001). My study appears to support this, with elite climbers, (or advanced with respect to females in the study) showing lower measures of body fat when compared with other ability groups.

In addition to anthropometric characteristics, measures of aerobic fitness based on $\dot{V}O_{2max}$ and HR_{max} determined by running to exhaustion were evaluated for each group.

As stated previously $\dot{V}O_{2max}$ and HR_{max} were assessed in order to calculate relative workload intensity during ascent. Running to exhaustion was used to asses $\dot{V}O_{2max}$ in the current study, all climbers appear to have higher $\dot{V}O_{2max}$ than climbers of varied abilities in other studies such as Billat et al. (1995); de Geus et al. (2006); Nicholson et al. (2007); Watts and Drobish (1998) and Magalhaes et al. (2007); yet values were comparable to the intermediate climbers in the two psychophysiological studies conducted by Draper et al. (2008b) and Draper et al. (2010). Mean ± SD $\dot{V}O_{2max}$ values for each group showed a marginal increase with increases in ability. The lowest $\dot{V}O_{2max}$ was observed in the lower-grade group, and was highest for elite climbers, whereas HR_{max} did not appear to differ greatly between groups. The $\dot{V}O_{2max}$ values presented in the current study appear to corroborate the previous suggestions that climbing training at an intermediate level upward may provide the work intensity necessary to increase aerobic fitness levels, with $\dot{V}O_{2max}$ values for ability groups representative of those reported in 'trained' individuals (Pires et al., 2011; Rodio et al., 2008; Sheel et al., 2003).

Of the 52 successful ascents completed by participants in this study a greater number were completed on top-rope (top-rope = 31, lead = 21). In all ability groups the number of successful top-rope ascents was greater than lead ascents (Table 4.4). This is potentially due to the proposed greater physical and technical demands of lead climbing. Top-roping often serves as a less demanding mode of attempting routes prior to lead ascents, as the climber can focus primarily on the movement sequence of the climb and disregard the need to take up stances and clip the bolts on route. The greater number of successful top-rope ascents may be explained relative to the greater ability of climbers with respect to redpoint grade (Table 4.5), which indicates their capacity to succeed on more difficult routes under less demanding conditions.

In the current study, pre-climb variables (somatic anxiety, cognitive anxiety, self-confidence, Δ pre-climb cortisol, pre-climb HR and pre-climb $\dot{V}O_2$) were considered together in order to investigate pre-climb state, more specifically levels of anxiety, prior to an on-sight ascent on lead or top-rope. Although a significant effect was indicated for 'ability group' when the pre-climb variables were considered together, surprisingly there was no significant effect for ascent style. Therefore it would appear that climbers exhibited similar psychological and physiological responses pre-climb whether they were to attempt an on-sight ascent on lead or top-rope. Furthermore, this lack of significant difference between ascent styles in levels of pre-climb anxiety during difficult on-sight ascents appears to be replicated across all levels of ability. This finding is somewhat surprising, as it appears to contradict previous research conducted by authors such as Draper et al. (2008a) and Hodgson et al. (2008) who have both noted significant differences in anxiety response in differing ascent protocols where participants completed multiple ascents of the same route. Taking into consideration the findings of previous studies, the results of the current study appear to emphasize the influence of condition of ascent (on-sight) as well as style of ascent upon subjective and objective measures of anxiety.

In the previous studies conducted by both Draper et al. (2008b) and Hodgson et al. (2008) participants completed multiple ascents of the same route with ascent style manipulated between consecutive ascents. Draper et al. (2008b) examined the psychological and physiological responses of intermediate climbers prior to and during an on-sight lead ascent and a subsequent lead ascent of the same route, noting significant differences in levels of somatic and cognitive anxiety pre-climb between ascents. Hodgson et al. (2008) examined climbers' cortisol and subjective emotional responses to three differing conditions of ascent designed to provide combinations of higher and lower levels of mental and physical stress. Three ascents were completed in a randomised order under 'lead' (most stressful), 'top-rope' (least stressful) and 'lead and top-rope' conditions. Furthermore climbers were required to attempt the test route as a familiarisation which also acted as a vetting process to ensure required standard of ability was met before the experimental trial. Finally, Draper et al. (2010) examined differences in physiological and psychological responses to pre-practiced lead and top-rope ascents, finding no significant differences in levels of somatic and cognitive anxiety between ascents. Based on their findings and the previous findings of Hodgson et al. (2008) and Draper et al. (2008b) the authors concluded that for intermediate climbers the most anxiety-provoking situation was an on-sight lead climb. Hardy and Hutchinson (2007) also observed that climbers exhibited greater levels of anxiety when lead climbing as opposed to top-roping, and this was also the case when lead climbing at their ability limit compared to lead climbing two grades below their reported maximum. However, a third experiment revealed what was described by the authors as an 'unexpected finding', stating that when attempting an unknown route, climbers in their study reported similar levels of anxiety prior to ascent, regardless of whether they were on lead or top-rope. It would appear that the findings of the current study support the latter of the three findings reported by Hardy and Hutchinson (2007) in that an unknown route, represented in this instance by an on-sight ascent, elicits a similar anxiety response regardless of ascent style. Furthermore this response does not appear to be altered based on experience or ability level.

In the current study were no significant differences between ability groups for levels of perceived somatic anxiety and cognitive anxiety. However in the two higher ability groups (advanced, elite) levels of somatic and cognitive anxiety were similar regardless of ascent style, this was particularly prominent amongst the elite climbers with a narrow mean score range of 14.5 – 15.1 for somatic and cognitive anxiety (when reviewing lead and top-rope ascents together). Although non-significant, small concurrent decreases in cognitive anxiety with an increase in ability level were observed across groups, and as such subjective ratings of anxiety were greatest in the lower-grade group and lowest for elite group (mean difference 3.49 CI 1.8 – 8.8). This trend was not replicated for somatic anxiety. The lack of significant difference in anxiety levels between climbers of differing ability in the current study was unexpected; particularly with respect to the elite versus the lower-grade climbers where experience and exposure to lead climbing was considerably lower (Table 4.5). Further to this, levels of perceived anxiety in the current study were found to be comparable to those reported for intermediate climbers in the previous studies of (Hodgson et al., 2008) and (Draper et al., 2010). Particularly with respect to levels of cognitive anxiety which appear to sit within a comparatively narrow range of 15 and 20 points regardless of ascent style and ability.

Skill level is considered to be a mediating variable in symptom interpretations of anxiety, with greater levels of perceived control thought to contribute to habituation of subjective anxiety responses in more experienced individuals (Hare et al., 2013; Lundqvist et al., 2011). However in the current study there were no significant differences between ability groups in subjective scores for somatic and cognitive anxiety, nor was an interaction effect indicated for ascent style and ability group for grouped pre-climb variables. The use of the CSAI-2R in order to provide an appropriate rating of perceived anxiety in response to a single ascent should perhaps be considered here. Whether the CSAI-2R provides an accurate measure of anxiety under these circumstances where no previous measure has been obtained may be questionable. As discussed previously when introducing the studies of Draper et al. (2008b), Hodgson et al. (2008) Draper et al. (2010) and Hardy and Hutchinson (2007), all utilised a repeated measures design, whereby participants provided ratings of subjective anxiety in response to a multiple ascents varying in style. In the current study a repeated measures design whereby each participant would ascend the route on both lead and top-rope on separate occasions was not viable as it would breach the on-sight conditions of ascent. Whether the CSAI-2R provides a measure of subjective anxiety sensitive to a single on-sight ascent where no comparison between other conditions or past performance can be made may warrant further investigation, and may account for the lack of significant difference in perception of anxiety between ascent styles and ability groups in this instance.

An alternative explanation for the lack of significant difference in subjective anxiety responses across studies and with respect to experience level in the current study is that wording of anxiety items in the CSAI-2R may be too neutral or ambiguous, easily resulting in the interpretation of items as threat-related or associated with a challenge instead eliciting positive emotions (Lundqvist et al., 2011). As such, a measure of intensity of anxiety alone may not be adequate when attempting to investigate possible differences between athletes responses (Jones et al., 1993; Lundqvist et al., 2011; Mellalieu et al., 2006). Increasingly a number of studies have utilised the measurement of a directional dimension of emotions such as anxiety in addition to intensity.

The measurement of intensity of anxiety alone is commonly upheld within sport psychology. Anxiety is viewed as having a weak and negative relationship to performance (Craft et al., 2003; Woodman and Hardy, 2003). Furthermore, for optimal athletic performance athletes must be able to control anxiety in order to avoid hyperarousal which is thought to be detrimental to performance (Jensen, 2010; Woodman and Hardy, 2001; Zaichkowsky and Baltzell, 2001). However, it has been found that this is not always the case, with a number of authors commenting upon the positive effects of performance anxiety (Jones et al., 1993; Jones and Cale, 1989; Parfitt and Hardy, 1993). It is therefore suggested that the way an athlete interprets their symptoms of anxiety may result in a situation being judged as either: (a) positive and challenging or (b) negative and overwhelming (Mellalieu et al., 2006; Nicholls et al., 2010).

The importance of evaluating directional anxiety as well as intensity was first discussed in detail by Jones et al. (1993) who stated that the CSAI-2R measures the intensity of symptoms which are thought to signify the presence of anxiety, yet fails to distinguish between the directional perceptions of symptoms. This refers to an individuals' interpretation of the symptoms in terms and how an individual relates them to upcoming performance. This has been further supported by Hanin's Individual Zones of Optimal Functioning (IZOF) approach which posits that the emotional response of athletes is individual and complex and therefore assessment of anxiety as a single emotion may be oversimplified (Hanin, 2007; Lazarus, 2000). A central tenet of the IZOF model is that each performer has a specific optimal performance zone of idiosyncratic emotion intensities in which best performances will most likely occur. If a performer's affect level lies outside their own optimal zone, performance will be impaired. The IZOF model conceives of emotion in a multidimensional manner as manifested through a number of pleasant or unpleasant interactive components. As such, the IZOF model considers unpleasant emotional states such as anxiety not only as debilitative, but also facilitative depending on their meaning and intensity. This concurs with the more complex conceptualization of anxiety put forward by Jones et al. (1993) which stipulates that ratings of emotional intensity alone may be inadequate in predicting athletic performance if functional or directional effect is not defined. In both of these instances it is suggested that favourable or unfavourable expectancies would lead a performer to perceive unpleasant emotional states as having respectively facilitative or debilitative consequences for performance.

Jones et al. (1994) showed that there was no difference between elite and non-elite performers (competitive swimmers distinguished on the basis of qualifying times) in ratings of intensity of cognitive and somatic anxiety symptoms. However, elite performers interpreted both anxiety states as being more facilitative to performance than non-elite performers. Furthermore, subjects were classified as 'debilitated' or 'facilitated' based on skill level and how they reported anxiety symptoms. Interestingly 52.6% of the non-elite group reported anxiety symptoms as debilitating, which was a stark contrast to the respective 14.7% of the elite group. As such, the authors emphasied the importance of skill level as an individual difference variable in the examination of the nature of the (competitive) anxiety response. Currently there is no known accepted single measure which is thought to successfully integrate the intensity and directional components of anxiety (Burton and Naylor, 1997; Lundqvist et al., 2011). In most studies which simultaneously assess intensity and directional perceptions of anxiety a modified version of the CSAI-2R is used, or alternative questionnaires are used and a directional scale for each item is also included. Total scores for direction and intensity of anxiety response are obtained by summarizing the scores on each scale separately. Analysis of results in this manner has produced similar results to those obtained by Jones et al. (1994), supporting the suggestion that athletes can differ in their ratings of anxiety symptoms as facilitative or debilitative (Fletcher and Hanton, 2001; Hanton and Jones, 1997; Hanton et al., 2000; Jones and Hanton, 2001; Mellalieu et al., 2004). Interestingly, and of particular relevance to the results of the current study, significant differences in total scores of the directional dimension of perceived anxiety have been reported despite a lack of significant differences in total anxiety intensity scores (Hanton et al., 2000; Hanton et al., 2008). In addition athletes which were considered as skilled or possessing elite status have been found to be more likely to rate intensity of anxiety symptoms as more facilitative than less skilled or experienced counterparts (Jones et al., 1994; Jones et al., 1993; Mellalieu et al., 2006; Perry and Williams, 1998).

Typically direction and intensity scores for perceived anxiety have been considered as two entirely separate variables. In a more recent study Lundqvist et al. (2011) identified the need to combine these scores to further investigate the relationship between the two measures and performance outcome. To this end ratings of intensity and direction (facilitative or debilitative) were merged to provide a frequency of items rated as either (1) moderate to high anxiety intensity and rated as debilitative, (2) moderate to high in anxiety intensity and rated as facilitative, (3) low in anxiety intensity and rated as debilitative and (4) low in anxiety intensity and rated as facilitative. This was in order to evaluate differences in responses and frequency of items in elite and sub-elite athletes (swimmers) alongside performance scores. Using this approach, findings suggested that facilitative directional scores were a consequence of low anxiety intensity, possibly combined with high self-confidence. The authors also raised concerns regarding the number of items on the CSAI-2R which were rated as neither facilitative nor debilitative, coupled with low levels of intensity. This was unexpected as perceptions of athletes and coaches demonstrated pre-competition stressors such as high importance of the event and uncertainty of outcome which should have led to elevated anxiety.

Lundqvist et al. (2011) suggested that many of the specific anxiety items included in the inventory were not perceived by the athletes as relevant for performance. These findings provide further support to the previous argument that some items included in the CSAI-2R are too ambiguous and may not be the most effective rating scale in all instances. Further research which seeks to investigate perceptions of anxiety in a directional manner in response to rock climbing using similar approaches to that of Lundqvist may be beneficial in understanding anxiety response, and the appropriateness of the CSAI-2R in this context. Given the highly individual and specific nature of rock climbing it may be that the items included do not register as relevant for performance, and could account for the lack of difference with respect to skill or experience resulting in similar intensity ratings. Alternatively, other emotions which contribute to an individual's affective state prior to climbing may have a greater role in determining performance. Further consideration of positive emotions and their impact on performance as opposed to unpleasant emotions and their detrimental impact may be of interest in underpinning the psychological demands of the sport.

A wider range of performance-related emotions are considered to account for positive as well as negative consequences upon performance. This was demonstrated in the findings of a study conducted by Sanchez et al. (2009) investigating psychological states during an elite climbing competition. As well as assessing levels of perceived anxiety using the CSAI-2 participants also completed the Positive and Negative Affect Schedule (PANAS) prior to competition. This questionnaire encompasses a bi-dimensional theory of emotions which postulates that individuals can experience a mixture of positive and negative emotions during a specific time period. Participants are required to rate the extent to which they are experiencing each emotion moments before performing. Sanchez et al. (2009) found that high levels of somatic anxiety were positively correlated with positive affect. Furthermore, somatic anxiety and positive affect were positively correlated with output performance. These findings demonstrated that an individual may experience both positive and negative emotions during a stressful encounter, with more successful athletes able to maintain more positive affective state. These findings were thought to highlight the beneficial role of positive emotions as opposed to the detrimental impact of negative emotions. In contrast to the directional approach suggested by Jones et al. (1993) this study highlighted the co-existence of positive and negative emotions, with different emotions experienced simultaneously as opposed the interpretation of a single emotion. The evaluation of positive emotions not directly explored in the current study may serve to provide a better understanding of the effect of pre-performance psychological state upon performance with respect to ability level. Assessing pre-climb emotional states and how these deviate from optimal performance levels between ability groups and in response to differing conditions of ascent may be a beneficial avenue of research. It should be noted that the results of the current study are restricted to successful climbers (those who completed the route) only. Whether successful climbers are homogonous in their response regardless of ability, yet differ to those who are unsuccessful has not been established and may be of further interest.

In the current study a Δ pre-climb cortisol (plasma) concentration were calculated in order to provide an objective marker of stress prior to difficult on-sight lead and top-rope ascents. Cortisol is the primary hormonal endpoint resulting from the activation of the HPA axis. This is a slower acting mechanism compared to activation of the sympathetic-adrenal-medullary (SAM) axis which results in the fight or flight response owing to the hormonal endpoints adrenaline and noradrenalin. Whilst activation of the SAM axis is associated with short-term physiological responses (i.e. increased heart rate, sweating, shortness of breath) the activation of the HPA axis is a slower acting mechanism which enables further mobilisation of physiological resources in order to respond appropriately to a stressful stimulus. Athletic events are naturalistic stressors that have been recognized to elicit changes in cortisol secretion, particularly where situational features of a performance or competition are manipulated (Filaire et al., 2001; Quested et al., 2011; Rohleder et al., 2007). Previous observations that cortisol reactivity becomes habituated with repeated exposure to laboratory stressors have been reported (Kirschbaum et al., 1995). Coupled with the anecdotal view that experienced or elite climbers report no difference in mind set, and are thought to possess a diminished fear of falling, a lower pre-climb cortisol reactivity could be anticipated in the advanced and elite climbers. Delta pre-climb cortisol concentrations in the current study, although elevated above baseline values, were not significantly different between ability groups or ascent styles. This finding suggests that the physiological stress response prior to difficult on-sight climbing was similar regardless of skill level or experience. Hare et al. (2013) reported similar findings based on experience level in response to a single sky dive in novice and experienced participants. In their study, the authors investigated state anxiety and cortisol reactivity to skydiving. This was in order to determine whether stress reactivity is altered in response to a naturalistic stressor as a function of repeated exposure. Interestingly, Hare et al. (2013) found that there were no significant differences in pre-jump levels of cortisol (salivary) between novice and experienced sky divers prior to a single jump, despite lower subjective ratings of anxiety in the more experienced group.

A meta-analysis of tasks which are designed to induce stress suggested that cortisol reactivity is most amenable to tasks with either (1) high socio-evaluative threat or (2) low perceived situational control (Dickerson and Kemeny, 2004). Given the conditions of ascent and difficulty of the route, coupled with the ascent being performed under test conditions pre-climb state in the current study appears to reflect both of these factors. Ascents were recorded for data collection purposes, and all ascents were attempted on a climbing wall which was accessible to the public, with an audience of peers and other climbers likely. Furthermore, whilst participants were aware of the on-sight nature of ascent they were not informed of their style of ascent (lead or top-rope) until 15 min prior to ascent. These factors foster a high degree of uncertainty in relation to the task, irrespective of ability level. In addition the consequences and risks do not reduce with each climb, and the potential for physical harm remains regardless of experience. However caution should be extended in interpreting the findings of the current study owing to intra-individual biological differences and study design. In reviewing the mean ± SD values for Δ pre-climb cortisol levels it is unsurprising that no significant effects were evidenced owing to large SD values. This highlights the large range of individual responses observed in measuring plasma cortisol concentration, and as such makes it difficult to comment on any trends observed across groups. Whilst attempts were made to limit variation in responses by matching BASE and CT sessions to account for diurnal variation and awakening response, this could not account for individual responses. Cortisol reactivity habituation in response naturalistic stressors is currently not well understood. Further investigation exploring intra-individual cortisol reactivity habituation in rock climbing across multiple on-sight ascents using a repeated measures design may provide a better insight into how this response may differ between ability levels.

Table 4.17 Mean ± SD pre-climb HR and $\dot{V}O_2$ responses expressed as percentage of maximal values obtained during running to exhaustion.

Ability group	Pre-climb HR (% HR_{max})	Pre-climb $\dot{V}O_2$ (% $\dot{V}O_{2max}$)
Lower-grade	53.6 ± 6.2	20.1 ± 2.9
Intermediate	55.9 ± 5.9	20.4 ± 3.4
Advanced	59.2 ± 8.8	21.6 ± 5.5
Elite	62.7 ± 9.5	24.7 ± 6.7

Heart rate responses prior to ascent were notably elevated beyond resting levels (> 100bts·min^{-1}) for all ability groups (Table 4.17) suggesting that prior to ascent climbers exhibited high levels of physiological arousal. Pre-climb BLa concentration (mean ± SD) were similar for lower-grade (2.02 ± 0.37 mmol·L^{-1}), intermediate (2.12 ± 0.53 mmol·L^{-1}), advanced (2.17 ± 0.62 mmol·L^{-1}) and elite (1.65 ± 0.41 mmol·L^{-1}) groups, indicating that participants were in a similar state of physical preparation before attempting their ascent. Taken together, these responses suggest that HR was elevated pre-climb despite the absence of a physical stressor. Significant differences between ability groups were indicated for both pre-climb HR and pre-climb $\dot{V}O_2$. However, when corrected for multiple tests these differences in HR and $\dot{V}O_2$ were considered non-significant. Although not statistically significant mean ± SD pre-climb HR and pre-climb $\dot{V}O_2$ (presented in Table 4.8 and Table 4.9 respectively) demonstrated a concurrent increase with increase in ability level. This trend was still evident when pre-climb HR and pre-climb $\dot{V}O_2$ were expressed as fractions of HR_{max} and $\dot{V}O_{2max}$, and could be an indication of increased physiological arousal prior to ascent.

Ascent times did not differ significantly between ability groups. However, there was a significant effect for ascent style, with top-rope ascents completed significantly faster than lead ascents in all but the elite group. The greatest difference in ascent time between lead and top-rope ascents were observed in the lower-grade and intermediate groups in this study (Table 4.11). Although a difference in ascent time was anticipated given the additional demand imposed by the clipping requirement during lead ascents, a novel finding of the current study was that differences in ascent times for lead and top-rope were diminished in the advanced and elite groups, with no significant difference between ascent styles in the elite group. The difference between lead and top-rope ascent times in the elite group was only 31 s, approximately half that of the lower-grade and intermediate group. This suggests that the elite climbers in the current study climbed the route in a similar manner, regardless of safety rope protocol, and may be indicative of style of climbing and greater route planning ability prior to ascent. This supports the previous findings of Pijpers et al. (2003) who investigated movement behaviour during climbing tasks in high and low demand conditions, noting slower climbing times, and movements during ascent which were described as ‘rigid’ or ‘jerky’ under greater demand. The authors reinforced the suggestion that repeated exposure to anxiety-provoking situations would result in a decrease in effects on performance. It may be that given the overall experience of the higher-level climbers (Table 4.5) the discrepancy between perceived and actual risk associated with the on-sight condition was diminished. As such, participants may have been afforded the opportunity to ascend the route in a more autonomous manner, irrespective of ascent style, resulting in similar ascent times.

In rock climbing, and lead climbing in particular, fear of falling is often referred to as a key performance factor which should be addressed in order to progress performance. In order to overcome 'fear of falling', repeated exposure and desensitisation has been suggested as beneficial, with the belief that in doing so a climber is able to focus on the task of climbing alone, eliminating inhibiting thoughts and tasks, observing important information only. Boorman (2008) presented findings which showed a decrease in participants cognitive state anxiety in response to lead climbing after completing a falling training course. In doing so it was suggested that training for falling had a positive influence on participants' performance levels, with more confidence in the equipment, belay system and belayer. In the current study the level of lead climbing experience was greater amongst the advanced and elite climbers when compared to lower-grade and intermediate groups (Table 4.5). This difference, taken together with the increased on-sight lead climbing ability, may account for the lack of significant difference in ascent time between lead and top-rope ascents for elite climbers in this study.

Previous studies have reported average $\dot{V}O_2$ during a single bout of rock climbing to be between 20 and 30 $mL \cdot kg^{-1} \cdot min^{-1}$ (refer to Table 2.9). The values reported in the current study appear to be at the upper end of this range, with only the lower-grade ability group having an average $\dot{V}O_2$ below 30 $mL \cdot kg^{-1} \cdot min^{-1}$. Given the nature of the route with respect to relative difficulty and on-sight condition, this is not surprising. A number of studies have reported higher $\dot{V}O_2$ during more difficult ascents (de Geus et al., 2006; Mermier et al., 1997; Watts and Drobish, 1998). Mean ± SD average $\dot{V}O_2$ presented in Table 4.13 show a difference between elite and lower-grade groups, whilst the responses of the intermediate and advanced groups are seemingly comparable. Significant differences were indicated for average $\dot{V}O_2$ during ascent, even when adjusted for the significant covariate $\dot{V}O_{2max}$. Based on comparisons of the adjusted means (Table 4.13) the elite group were shown to have a significantly higher average

$\dot{V}O_2$ compared to both the advanced and lower-grade climbers. Given the higher $\dot{V}O_{2max}$ values discussed earlier, and greater average $\dot{V}O_2$ during ascents for elite climbers in the current study, it would appear that the possession of a greater aerobic capacity may be advantageous to rock climbing performance. When average HR and $\dot{V}O_2$ during ascent are expressed as percentage of HR_{max} and $\dot{V}O_{2max}$ respectively (Table 4.18), it can be seen that all groups utilised similar fractions of maximal capacity during ascent. These results demonstrate that despite a significantly higher average $\dot{V}O_2$ during ascent for elite climbers in absolute terms, when these values are considered relative to $\dot{V}O_{2max}$ participants were found to be working at the same intensity regardless of ability level. This highlights that in the current study 'difficult' climbing relative to best on-sight ability required a similar contribution from aerobic metabolism irrespective of ability level. One possibility is that in each instance a $\dot{V}O_2$ limitation may have been demonstrated, owing to the relative difficulty of each route. In further support of this point, ratings of physical demand, performance and effort obtained from NASA-TLX responses were similar for all ability groups (Table 4.16). These findings suggest that oxygen uptake may not be directly related to grade or personal ability when climbing routes set relative to best performance. As such other factors may contribute to climb demand such as technical and tactical decisions and personal climbing style, resulting in more strategic ascents which allow an individual to succeed on higher graded routes at the same relative workload.

Table 4.18 Mean ± SD Average HR and $\dot{V}O_2$ responses expressed as percentage of maximal values obtained during running to exhaustion.

Ability group	Average HR (% HR_{max})	Average $\dot{V}O_2$ (% $\dot{V}O_{2max}$)
Lower-grade	83.0 ± 5.0	63.3 ± 8.4
Intermediate	85.8 ± 6.9	63.2 ± 8.7
Advanced	86.8 ± 6.1	59.4 ± 11.7
Elite	88.5 ± 4.1	63.7 ± 6.8

The on-sight ascents in the current study appeared to require a large contribution from aerobic metabolism (~60%) irrespective of ability level and difficulty.. This finding is in agreement with previous research which suggests that although rock climbing is viewed as being reliant on anaerobic muscular power and endurance, climbing involves a significant contribution from aerobic metabolism (Sheel et al., 2003; Watts et al., 2000). Interestingly, the fractions of maximal workload seen in my study with respect to $\dot{V}O_2$ were comparable to those reported in a study by Magalhaes et al. (2007), who found that subjects achieved approximately 61% of maximal treadmill running $\dot{V}O_2$ whilst climbing continuously until an exhaustion related fall occurred. These values are among some of the highest $\dot{V}O_2$ values reported in literature during indoor climbing exercise (see Table 2.9). Given that all participants were climbing relative to their maximum ability level in the current study, the greater contributions from aerobic metabolism may be in order to meet the energy demands imposed given the nature of rock climbing. It is well known that climbers often choose to 'rest' during ascents in order to reduce the fatiguing process, particularly in the smaller muscle groups responsible for finger flexion. As such it is thought that these non-systemized rest periods may aid in the partial re-synthesis of high-energy phosphate stores in muscles, demonstrating the interdependence between the aerobic and anaerobic alactic energy systems in rock climbing, as suggested by Bertuzzi et al. (2007). This appears to be a plausible explanation given the relative difficulty of each route and the large fraction of $\dot{V}O_{2max}$ utilised during ascents, and the accumulation of BLa post-climb (Figure 4.10) seen in the current study. Furthermore, this relationship, or interdependence as it has been previously described appears to be the same, regardless of training status or skill level of the climbers, and is in line with the previous findings of a Bertuzzi et al. (2007)

In reviewing Figure 4.6 and Figure 4.7 which depict $\dot{V}O_2$ averaged for each phase of the climb for top-rope and lead ascents respectively, all ability groups appeared to reach a plateau in $\dot{V}O_2$ response at similar points during the ascent, typically around the 4^{th} or 5^{th} clip. Watts et al. (2000) also evidenced a levelling off of $\dot{V}O_2$ during ascent, stating that $\dot{V}O_2$ increased over the initial 100s of subjects ascents and then appeared to plateau for the remainder of ascent. Whether this plateau is representative of an attainment of a steady-state, or a climbing specific maximum $\dot{V}O_2$ limitation is difficult to determine. However, the former of these suggestions is more widely accepted (Sheel, 2004; Watts et al., 2000; Watts and Drobish, 1998). Given the large proportion of isometric workload imposed on the active muscles during rock climbing, the observed leveling off in $\dot{V}O_2$ may also be indicative of occlusion in blood flow during contractions, limiting the transport of O_2 to the working muscles (Asmussen, 1981).

In the current study the trend for average HR during ascent when expressed as percentage of HR_{max} shows a slight concurrent increase with increase in ability level. The use of a greater fraction of maximal values could be indicative of an increased HR response owing to the increased technical difficulty of climb. In the current study the same section, and therefore profile of wall was used for each route and difficulty was manipulated by the number and size of holds. This factor may have impacted upon the type and extent of muscle recruitment required to maintain contact with the wall. This is in agreement with Billat et al. (1995) who found that when climbers ascended two routes of the same grade which differed in technical and physical demand, a route which was considered more demanding, owing to technical moves and smaller holds elicited a greater HR and $\dot{V}O_2$ response. This was compared to a route where difficulty was increased by manipulation of wall angle (overhanging nature). In the current study the activation of more muscle fibres for the recruitment required, in particular fast twitch muscle fibres may have resulted in an increased build up of metabolites (Gollnick et al., 1974a; Gollnick et al., 1974b), resulting in activation of the metaboreflex characterised by an increased disproportionate rise in HR for a given $\dot{V}O_2$ (O'Leary et al., 1999).

A disproportionate HR over a given $\dot{V}O_2$ was evident in all groups in the current study (Table 4.18), supporting the findings of previous studies (Billat et al., 1995; Booth et al., 1999; de Geus et al., 2006; Mermier et al., 1997) which have commented upon this relationship. The higher HR response for a given $\dot{V}O_2$ during rock climbing has previously been attributed to a number of factors. Authors have speculated that HR rises may be due to increased anxiety, continued elevation of the arms, the attainment of an arm specific peak $\dot{V}O_2$ or the presence of the metaboreflex (Billat et al., 1995; Draper et al., 2010; Giles et al., 2006; Watts and Drobish, 1998). Rock climbing is characterized by a large amount of time spent in isometric contraction in order to maintain contact with the wall (Sheel et al., 2003). The metaboreflex has been suggested to occur during such periods of sustained isometric contraction (Kaufman and Forster, 1996). Triggered by the accumulation of metabolites within working tissue and resulting muscle ischaemia (a lack of O_2 being delivered to the active muscle), the metaboreflex is thought to elicit a powerful sympathetically mediated pressor response.

This response, thought to consist of increased HR, ventricular performance, central blood volume mobilization and cardiac output, results in preferential redistribution of blood flow to working skeletal muscle (Kaufman and Forster, 1996; O'Leary et al., 1999; Rowell, 1993).

Sheel et al. (2003) proposed that muscle metaboreflex may be enhanced by climbing specific training, presenting an adaptive response to climbing technically demanding routes which require greater recruitment of forearm/upper body musculature. In support of this suggestion MacLeod et al. (2007) found that climbers were able to perfuse O_2 from the forearm flexors to a greater extent than non-climbers. Furthermore, climbers had a significantly greater rate of re-oxygenation during the recovery periods of intermittent contractions of within the forearm. A number of studies have suggested that training with ischemic muscle actions result in certain adaptations. Such adaptations are thought to be due to changes in the sensitivity of the peripheral chemoreceptors and mechanoreceptors and the central command component of the cardiovascular response (Ferguson and Brown, 1997; Kahn et al., 2000; MacDougall et al., 1992). The magnitude of such responses is thought to be directly related to the effort produced by an individual and by a peripheral component related to the build-up of metabolites in the exercising muscles . It would therefore appear plausible that given the elite climbers in the study were more accustomed to producing a maximal effort, they were able to produce a greater effort during ascent. This would have resulted in a larger central command mediated response via a peripheral response to greater activation of chemoreceptors and mechanoreceptors within the exercising muscle, accounting for the greater HR response during ascent in the current study. Further research investigating the breakdown of the HR-$\dot{V}O_2$ relationship with respect to investigating markers of muscular metaboreflex based on situational demand and ability level is of further interest.

Physical demand during ascent as indicated by post-climb responses was not significantly different between ability groups, or with respect to ascent style when post-climb variables (Δ post-climb cortisol, Δ peak BLa, mental demand, physical demand, temporal demand, performance, effort and frustration) were considered together. This finding is unsurprising given the similarity between groups for the HR and $\dot{V}O_2$ responses measured during ascent when expressed as percentages of maximum. This finding further supports the suggestion that all ability groups were working at the same relative intensity during their respective ascents. Blood lactate responses over a 15 min passive recovery period post-climb were similar for ability groups, with mean peak BLa observed immediately post-climb in all instances (Figure 4.10). Peak BLa values observed post-climb in the current study were comparable to those reported previously in response to a single bout of rock climbing (Billat et al., 1995; de Geus et al., 2006; Watts and Drobish, 1998). Although no significant differences for peak BLa concentrations were observed post-climb across ability groups in the current study, the rise in BLa concentration for lower-grade climbers appeared to be lower than the intermediate, advanced and elite groups, even when expressed as Δ peak BLa. This may be indicative of the lower technical and physical demand imposed by the easier route. As stated previously, given the routes were set on the same profile of wall difficulty was manipulated with size and number of holds. As such, the holds featured on the lower-grade route were bigger, affording a more positive grip or 'jugged' handholds. It is likely that this would have resulted in decreased muscle recruitment of the upper body and the forces produced by climbers, coupled with the potential for greater distribution of weight (loading) of larger muscle groups of the lower limbs. The opportunity for systemized rest periods may also have been better facilitated on the easier route. Consequently, the constriction of the blood vessels may have been diminished in the lower-grade climbers. This may have better facilitated the diffusion of BLa out of the working muscles to be taken up by non-exercising muscles as previously demonstrated (Ament and Verkerke, 2009; Gladden, 2004; Oyono-Enguelle et al., 1989; Westerblad et al., 2002).

Lactate concentration in blood and extracellular fluids shows a rapid accumulation above a certain workload, this is defined as the 'lactate threshold' (Brooks, 1985). More specifically, lactate threshold is described as the workload at which lactate production is exactly in equilibrium with tissue lactate consumption (Ament and Verkerke, 2009). Based on a fixed anaerobic threshold of 4.0 $mmol \cdot L^{-1}$ the levels of BLa accumulation in the current study are suggestive of activity which takes place above the lactate threshold and is indicative of anaerobisis in the muscle (Heck et al., 1985), therefore signalling a degree of anaerobic energy production. The dominating anaerobic pathways to regenerate ATP are degradation of phosphocreatine (PCr) and breakdown of muscle glycogen to lactate and hydrogen ions. Whilst lactate ions are thought to have little effect on muscle contraction the H^+ (protons) result in a reduced pH (~ 0.5 pH units)(Fitts, 1994). It has previously been demonstrated that declined muscle force generation has been shown to be correlated with decrease in muscle pH (Pate et al., 1995). As such the reduction in pH (acidosis) has classically been considered to be the cause of muscle fatigue and tissue damage during exercise (Fitts, 1994; Hermansen, 1981; Sahlin, 1992). Increasingly the role of H^+ in depressing muscle function by acidosis has been challenged (Bruton et al., 1998; Pate et al., 1995; Westerblad et al., 1997; Wiseman et al., 1996). Instead an increased level of inorganic phosphate (Pi) as a result of the hydrolysis of PCr has been linked to several mechanisms which may depress contractile function (Dahlstedt et al., 2001; Dahlstedt et al., 2000; Dahlstedt and Westerblad, 2001). More recently studies such as those conducted by Kabbara and Allen (2001) Dahlstedt and Westerblad (2001) and Dahlstedt et al. (2001) suggest that increased P_i as opposed to acidosis is the most prominent cause of fatigue during bouts of high intensity exercise. More specifically these arguments are based on studies reporting no reduction in muscle force owing to decreased pH when experiments are performed at temperatures encountered physiologically (Pate et al., 1995; Westerblad et al., 1997). In addition to this it has been shown that force sometimes recovers more rapidly than pH demonstrating a lack of causal effect between acidosis and fatigue (Sahlin and Ren, 1989).

It is still appreciated that exercise-associated fatigue sensations tend to increase in parallel with the accumulation of exercise associated metabolites (i.e. lactate), yet a direct causal relationship with fatigue has been questioned. As such it has been suggested that increased lactate concentration may result in indirect effects of fatigue. One suggestion is that cellular acidosis may activate group III-IV nerve afferents in muscle and hence whilst not directly involved in fatigue, results in the sensation of discomfort associated with fatigue (Westerblad et al., 2002). With this in mind 'lactic acid training' involving repeated activity which induces high plasma lactic acid levels may result in learning to cope with acidosis-induced discomfort without losing pace and technique. This would lead to being able to get the maximum effect out of muscles, which themselves are not thought to be directly inhibited by acidosis. The comparable peak BLa concentration across ability groups in the current study suggest exercise intensity was similar regardless of route difficulty and therefore participants were performing at a relative workload. Given that peak BLa was above the fixed anaerobic threshold of 4.0 $mmol \cdot L^{-1}$ in all instances, it may be that more experienced climbers possessed an increased tolerance to the fatiguing sensation associated with muscle acidosis. This may have afforded them the capacity to maintain greater force and technique in executing more difficult movements, particularly given that the difficulty ratings for the routes were manipulated by size, shape, and number of handholds.

Sheel et al. (2003) suggested that as well as an increased BLa tolerance, the ability to recover quickly after a bout of climbing may be advantageous to competitive climbers, particularly as competitions require the ascent of multiple climbing routes over the course of several hours. During the 15 min of passive recovery observed post-climb in the current study BLa was shown to decrease, yet did not return to pre-climb levels in any of the ability groups. This is consistent with previous research which has shown BLa accumulates during ascent and can remain elevated for up to 20 min post-climb (Sheel, 2004). Data presented in Figure 4.10 suggests that the BLa recovery profiles of elite and advanced climbers were similar, whilst mean group data for the intermediate climbers suggests a comparatively slower rate of decline, particularly across the initial 5 min post-climb. Although not examined directly in this study the trend in differences for mean peak BLa, and BLa removal rate during recovery between ability groups in could be indicative of concomitant respiratory, cardiovascular and biochemical adaptations in the higher ability climbers. These responses may have been induced by training i.e. greater volumes of successive bouts of climbing on difficult routes with increasing ability level in this study (Table 4.6). Training adaptations such as increases in myoglobin, capillary density, transit time, and enhanced O_2 extraction are all thought to result in an enhanced ability of the trained muscles to utilise O_2 and remove H^+ ions during intermittent exercise (Gollnick et al., 1974a; Hermansen and Wachtlova, 1971). As such, more efficient BLa removal in response to higher endurance training have been observed previously in a number of studies (Donovan and Brooks, 1983; Thomas et al., 2004). One of the main adaptations of skeletal muscle in response to endurance training is improved oxidative capacity (Donovan and Brooks, 1983; Dubouchaud et al., 2000). Oxidation is the main metabolic pathway for lactate disposal during periods of rest at sustained and submaximal exercises, and during recovery (Brooks et al., 1973; Depocas et al., 1969; Searle and Cavalieri, 1972). Pilegaard et al. (1994) observed that subjects exhibiting the highest lactate transport capacity were also those who displayed the highest $\dot{V}O_{2max}$. This appears to be reflected in both the higher $\dot{V}O_{2max}$ and $\dot{V}O_2$ during ascent seen with increase in ability across groups.

The time course of cortisol response post-climb was similar for all ability groups (Figure 4.8) and with respect to ascent style (Figure 4.9) in the current study. Peak plasma cortisol concentration values were observed at 15 min post-climb, supporting previous research which indicates that cortisol peak responses are typically observed 15-20 min post-stressor (Draper et al., 2008a; Levine et al., 2007; Pollard, 1995). When post-climb cortisol response was expressed as a Δ post-climb cortisol concentration by subtracting pre-climb values from those obtained 15 min post-climb mean ± SD concentrations within groups were greater for lead ascents compared to top-rope ascents (Table 4.14). However it should be noted that these differences were not statistically significant, possibly owing to large individual variability as demonstrated by SD values.

Cortisol secretion is known to increase in response to the physical exertion (Beaven et al., 2008; McGuigan et al., 2004; Roy et al., 2001; Sherk et al., 2011) and as such the observed trend demonstrating greater cortisol concentrations measured post-climb for lead ascents may in part be due to the increased physical loading and longer ascent times. This is particularly with respect to the lower ability groups where discrepancies in ascent times were greatest (Table 4.11). However given the given the moderate intensity (~ 60% $\dot{V}O_{2max}$) and short duration of the climbing task in the current study it would appear unlikely that cortisol concentration increased as a result of physical demand alone. Previous research has shown that exercise must be intense (>70% $\dot{V}O_{2max}$) and exceed 40 min in duration to result in any large increases in cortisol secretion (Hill et al., 2008; Jacks et al., 2002). As such the cortisol responses post-climb in this instance are most likely attributed to psychological stress as opposed to physiological stress alone.

Previous research has demonstrated that appraisal processes, and whether a given task is appraised as a threat or challenge may influence rate of cortisol secretion (Gaab et al., 2005; Jones et al., 2009; Quested et al., 2011). Threat appraisals represent the idea that the forthcoming event presents danger to individuals’ well being or self-esteem. On the contrary when one appraises the event with a specific focus on the opportunity for success, growth, learning and mastery these reflect challenge orientated appraisals (Lazarus and Folkman, 1984). In a study conducted by Gaab et al. (2005) it was found that threat appraisals predict 29% of variance in cortisol response. Similarly Jones et al. (2009) noted that HPA axis activity is understood to be triggered by perceptions of threat but unstimulated by challenge states, in fact challenge appraisals are thought to be negatively associated with cortisol secretion. In further support of this suggestion a meta analysis conducted by Dickerson and Kemeny (2004) has indicated that cortisol responses are strongest in situations that pose an evaluative threat. In the current study participants may have approached the top-rope ascents feeling a greater degree of control with the perception that they had the resources and capacity to tackle the specific demands of the task in question. In contrast lead ascents could have been perceived as more daunting, with a greater threat to social or physical harm with increased exposure. Although appraisal processes were not evaluated directly in the current study, ratings of frustration in relation to ascents were found to be greatest in response to lead ascents in all groups. This finding may serve to provide some indication as to how comfortable participants were with the task and their performance. It should however be noted that there remains a large degree of between person variability in such appraisals, predictors of which remain relatively unexplored.

4.5 Perspectives

Indoor on-sight sport climbing set at a difficulty level relative to self-reported best on-sight lead performance appears to elicit a similar psychological and physiological response pre-climb, irrespective of ascent style. This finding was consistent for lower-grade, intermediate, advanced and elite climbers. The lack of difference in Pre-climb responses between ascent styles within each group in the current study may be due to demands imposed by the on-sight condition and difficulty rating of ascent. In this respect, intensity of anxiety in relation to the on-sight condition and grade of route may outweigh the influence of ascent style as commented upon in previous studies. There were no significant differences between ability groups in levels of perceived somatic and cognitive anxiety pre-climb. Elite climbers reported similar levels of somatic anxiety in response to on-sight ascents as those of lower ability. In addition Δ pre-climb cortisol concentration was not significantly different between ability levels for on-sight ascents, suggesting that the physiological response to stress remained similar regardless of experience with no evidence of habituation. However a slight decrease in perception of cognitive anxiety in relation to the climbing task was shown with concurrent increase in ability level. My findings suggest that higher ability climbers may maintain a greater level of physiological arousal, whilst controlling for cognitive anxiety, possibly due greater experience and exposure to lead climbing at the upper limits of ability. An alternative explanation for the lack of significant difference in levels of perceived anxiety overall in the my study could be due to the measurement of intensity of anxiety alone. These findings may further highlight the somewhat ambiguous nature of the CSAI-2R, particularly in evaluating responses to a single ascent in a non-competitive setting. The potential influence of directional interpretations of anxiety symptoms and positive emotion not explored in the current study could provide important avenues of future research which may aid in identifying and better understanding of the psychological components of rock climbing performance.

When performing on-sight ascents relative to best self-reported ability, successful climbers in the current study utilised similar fractions of maximal HR and $\dot{V}O_2$ during ascent. Elite climbers completed successful ascents at much higher grades of difficulty whilst utilising similar fractions of HR and $\dot{V}O_2$ as lower ability groups on their respective ascents. In addition BLa concentrations measured immediately and at 5, 10 and 15 min post-climb for advanced and elite climbers indicated the possibility of an enhanced rate of recovery. Based on these findings one possibility is that training adaptations induced by successive bouts of difficult climbing in higher level climbers may have resulted in an enhanced ability to recover during rest periods of intermittent exercise. I speculate that a technical advantage, coupled with possible physiological adaptations gained with increased experience and training, may have led to more strategic and therefore efficient ascents at higher grades of difficulty.

Chapter 5

Study Two

5.1 Introduction

The main aim in rock climbing is to reach the top of any given route, whether this is a boulder only a few metres from the floor, or a sustained multi-pitch ascent, the desired outcome remains the same. Whether by means of a top-rope ascent, lead ascent, on-sight, flash or redpoint, in each instance success is denoted by the ability to reach the end point of the route. In a recreational context routes climbed are generally of a consistent and continuous grade. However, a route may still present a difficult move or 'crux', particularly on outdoor routes which are dependent on the natural features present. In contrast, indoor routes are generally set with the aim of promoting difficulty at a particular grade, with placement of modular holds manipulated to achieve the desired difficulty. This is not to say that indoor routes do not feature a 'crux' section, moreover in order to better replicate outdoor routes a setter my include a key movement sequence or hold somewhere within the route.

In competitive sport climbing the aim is consistent with other forms of rock climbing; to reach the top of the route, however the style of route and conditions of ascent are strictly enforced. For competitive ascents climbers must attempt a route under lead on-sight conditions. The main point of difference during competition is the route setting. Competition routes are set to increase in difficulty as the climber ascends, as such the route will often have multiple cruxes. Routes are set to ensure minimum resting points, and a sequence of moves which vary as not to give an advantage to any given climber. Emphasis is placed on distance achieved on the route, with a fall dictating the end of a climber's competitive performance (Gajewski et al., 2009). Performance is usually expressed with an overall score based on a pre-defined points system. Mermier et al. (2000) describes one such system whereby each successive handhold on the route increases in point value by one. Competitors are given a point value for the highest handhold reached and an additional subjective point value is added based on how well they used their last hold. If the competitor touched but did not grab the last hold before falling, a 0.1 point value is given. If the competitor grabbed the hold but was unable to move from the hold then 0.5 points were awarded. If the competitor grabbed the last hold and tried to move off it an additional 0.9 point value were added. This style of ascent demands an exhaustive ascent, often both physically and technically.

The majority of rock climbing research appears to report on the physiological and/or psychological responses of successful climbers only, with data for unsuccessful ascents discounted. As such the style of ascent and style of route employed for testing purposes are designed to promote a successful ascent. Previous studies have attempted to diminish the possibility of a fall by using methods such as pre-practised ascents, ascents of routes below top-end ability, and top-roped ascents as opposed to lead (Bertuzzi et al., 2007; Billat et al., 1995; de Geus et al., 2006; España-Romero et al., 2009; Sheel et al., 2003; Watts, 2004; Watts et al., 2000). A small number of studies have used competition-style routes to induce maximal efforts relative to ability for measurement of post-climb responses, or as a method of assessing ability level in climbers (Gajewski et al., 2009; Mermier et al., 2000; Watts et al., 2000; Watts et al., 1996). Yet research which investigates psychological or physiological responses during climbing which better simulates the demands of competitive ascents are limited (Gajewski et al., 2009; Heyman et al., 2009; Magalhaes et al., 2007; Sanchez et al., 2009; Watts et al., 2000).

Competitive climbing typically involves an effort to the point of failure and the realistic possibility of a fall. These types of ascent may invoke differing responses compared to those which are continuous in difficulty. Characterising the psychological and physiological responses to simulated competition climbing may be advantageous in identifying limitations to performance. In addition, whether ascents increasing in difficulty represent a greater demand either mentally or physically is currently unknown. As such the aim of this study was firstly to investigate the psychological and physiological responses during an on-sight competition-style ascent with respect to ability level (phase 1). Furthermore, no known study to date has reported data identifying performance differences between climbers who successfully complete a route and those who fall either when performing at a difficult grade relative to ability, or in a competitive context. In light of this, a secondary aim of the study was to investigate performance differences in relation to route style and outcome (Phase 2).

5.2 Phase 1

5.2.1 Methods

This section provides details of the participants, experimental design and procedures associated with phase 1 of study two. Throughout this section reference is made to Chapter 3 (*General Methods*) which presents methods and procedures which are common to both of the studies conducted in this thesis, and should be referred to where applicable.

Participants

Twenty-two rock climbers volunteered to take part in the study. These climbers were independent from those who took part in the experimental trials in study one, however recruitment criteria were identical. All climbers were actively involved in the sport, climbing at least once a week on both artificial surfaces and natural rock. All climbers were proficient in lead climbing techniques. Participants were recruited based on their self-reported on-sight ability (within the last 6 months) which was evaluated with respect to the Ewbank grading system. Climbers were categorised into intermediate, advanced and elite ability groups based on the criteria in Table 5.2. This was previously agreed upon and confirmed via the methods stipulated in section *3.2.2 Ability classification*. Lower-grade climbers were excluded owing to the demands and nature of ascent required for this experiment (to be detailed further in following sections). Descriptive data providing participants experience, anthropometric and fitness data are presented in Table 5.2.

Table 5.1 Ability classification and grouping categories based on self-reported grades (Ewbank).

Ability Group	Redpoint	On-sight
Lower-grade	≤19	≤17
Intermediate	20-24	18-20
Advanced	25-29	21-24
Elite	≥30	≥25

Table 5.2 Participants climbing experience, anthropometric, and fitness characteristics for males, females and group total presented with respect to ability level.

Ability group	*n*	Lead climbing experience	On-sight (Ewbank)	Redpoint (Ewbank)	Age (years)	Height (cm)	Mass (kg)	Body fat (%)	$\dot{V}O_{2max}$ (mL·kg^{-1}·min^{-1})	HR_{max} (bts·min^{-1})
Intermediate										
Male	4	1.3 ± 0.5	19.5 ± 0.8	21.0 ± 1.2	25.3 ± 9.4	180.4 ± 10.5	73.5 ± 10.5	12.6 ± 0.2	48.6 ± 6.8	192.0 ± 7.9
Female	3	2.7 ± 1.5	19.0 ± 1.0	21.7 ± 3.2	26.7 ± 9.5	64.8 ± 4.0	60.0 ± 9.4	18.6 ± 2.4	42.3 ± 1.0	188.3 ± 7.5
Total	7	1.9 ± 1.2	19.3 ± 0.8	21.3 ± 2.1	25.9 ± 8.6	173.7 ± 11.4	67.7 ± 11.7	15.2 ± 3.5	45.9 ± 5.9	190.4 ± 7.3
Advanced										
Male	7	3.2 ± 1.7	22.7 ± 1.3	24.7 ± 1.8	21.3 ± 6.3	176.6 ± 6.1	66.0 ± 11.4	9.5 ± 3.2	52.1 ± 4.1	189.1 ± 3.0
Female	3	4.3 ± 3.2	22.0 ± 1.0	24.3 ± 1.5	25.0 ± 7.0	167.0 ± 5.0	62.2 ± 4.4	18.0 ± 1.2	37.9 ± 4.8	186.3 ± 10.5
Total	10	3.6 ± 2.1	22.5 ± 1.2	24.6 ± 1.6	22.4 ± 6.3	173.7 ± 7.2	64.9 ± 9.7	12.0 ± 4.9	47.8 ± 8.0	188.3 ± 5.7
Elite										
Male	4	6.8 ± 3.8	25.3 ± 0.5	27.5 ± 1.9	28.3 ± 8.5	179.6 ± 14.0	76.0 ± 7.0	11.1 ± 7.0	53.3 ± 7.9	189.3 ± 10.2
Female	1	5.0 ± 0.0	25.0 ± 0.0	26.0 ± 0.0	19.0 ± 0.0	167.5 ± 0.0	65.7 ± 0.0	22.7 ± 0.0	35.9 ± 0.0	197.0 ± 0.0
Total	5	6.4 ± 3.4	25.2 ± 0.4	27.2 ± 1.8	26.4 ± 8.4	177.2 ± 13.3	74.0 ± 7.6	13.4 ± 8.0	49.8 ± 10.3	190.8 ± 9.5

Experimental design

The design of this experiment was similar to study one, with the main differences being style and demand of the climbing route, and conditions of ascent. Participants attended three sessions for the purposes of this study, one of which was laboratory based, and two visits to The Roxx indoor climbing wall facility (Christchurch, NZ). Each of these sessions took place on separate days with a minimum of one-week separation. All were asked adhere to pre-test guidelines detailed within section *3.3.1 Participant recruitment.* The first session took place at the exercise physiology laboratory at the University of Canterbury (Christchurch, New Zealand) where anthropometric data were recorded, and a $\dot{V}O_{2max}$ assessment was carried out. Details of the procedures used for the fitness assessment are presented in section *3.4 Laboratory based testing.* On a separate occasion participants then visited The Roxx climbing wall for the purpose of completing a familiarisation. Here they were given the opportunity to become accustomed to climbing wearing the $K4b^2$ portable system. This involved the completion of one lead ascent of a route of their choice, typically at least two grades below their self-reported best on-sight grade, whilst wearing the $K4b^2$. Upon arrival to this session (prior to undertaking their familiarisation ascent) climbers completed the POMS questionnaire to assess mood states which would be compared to those reported at the final testing session. The aim of this visit was to reduce any anxieties climbers may have had in wearing the portable analysis system for the first time in a climbing context, which may have otherwise impacted on measures obtained during the climbing trial. Finally, climbers attended a second session at The Roxx climbing centre. During this visit, participants completed an on-sight ascent of a designated test route set on an artificial indoor wall. The style of ascent remained the same for all participants, with all ascents attempted on lead.

The test climb in this experiment was completed in a competitive context resulting in some restrictions and logistical considerations. All ascents were conducted over the course of two days, and participants were allocated a specific time slot to begin their test. Participant arrival times were separated by 30 min intervals with some degree of overlap. Visual inspection and climbing of the test route was strictly prohibited, it was also ensured that participants who had not yet attempted the route were isolated from those who had, and were also unable to view the route prior to the allocated route inspection pre-climb. All participants were informed of the competitive nature of the ascent; ascents were timed and terminated where a fall from the route occurred. It was also explained that the individual who ascended highest on the route would be deemed the winner, with a prize incentive offered. Given that all ability groups were attempting the same route, a secondary prize was offered to the climber who best outperformed their self-reported ability level. This was done in order to promote a best performance among all groups. The same belayer was used for all ascents, and was familiar to the participants involved in the study; the route setter was present for route inspection purposes.

Climbing wall and route setting

A single test route was set for the purposes of this experiment. The difficulty grading of the route increased with height gained during ascent, starting at ~18 Ewbank and finishing at ~26 Ewbank at the top of the climb. The route was set in this manner to offer a similar style of route and ascent to that seen in competitive climbing, where routes increase in difficulty and success is determined by how far the climber can progress on the route. In this instance the route was designed and set such that the finishing grade was beyond the self-reported on-sight ability of the elite climbers participating in the study. As such, it was anticipated that the difficulty of the route would surpass the ability level of all participants, with a fall from the route highly likely. The route was set by an experienced competition route setter and confirmed by expert climbers (grade range 18-26 Ewbank). Due to the nature of the study, whereby an on-sight attempt under competitive conditions was required, setting of the route was withheld until the day prior to testing and was not identified by any form of signage. In addition, participants were instructed not to climb any unidentified routes, and where possible they were asked to refrain from watching other climbers attempting the route. This was done in order to limit the amount of information (beta) gathered about the route.

The route was set on the same section of artificial wall as those detailed in study one, yet followed a slightly different line of pre-placed protection in order to provide a route which could incur the desired level of difficulty at both the start and the end point of the ascent (Figure 5.1). The route was featured on a 12.13 m high section of wall, set with the use of modular holds (Uprising Ventures, Christchurch, NZ). The route was set alongside public routes, and was distinguished by coloured (blue) bolt on holds. The use of natural features (smearing) for foot placement was permitted, however participants were not allowed to use wall features (such as corners or 'aretes') for hand placements and were instructed to use modular holds only for hand placements. The route was protected with seven bolts and a lower-off point. Pre-placed quick draws were used during each ascent.

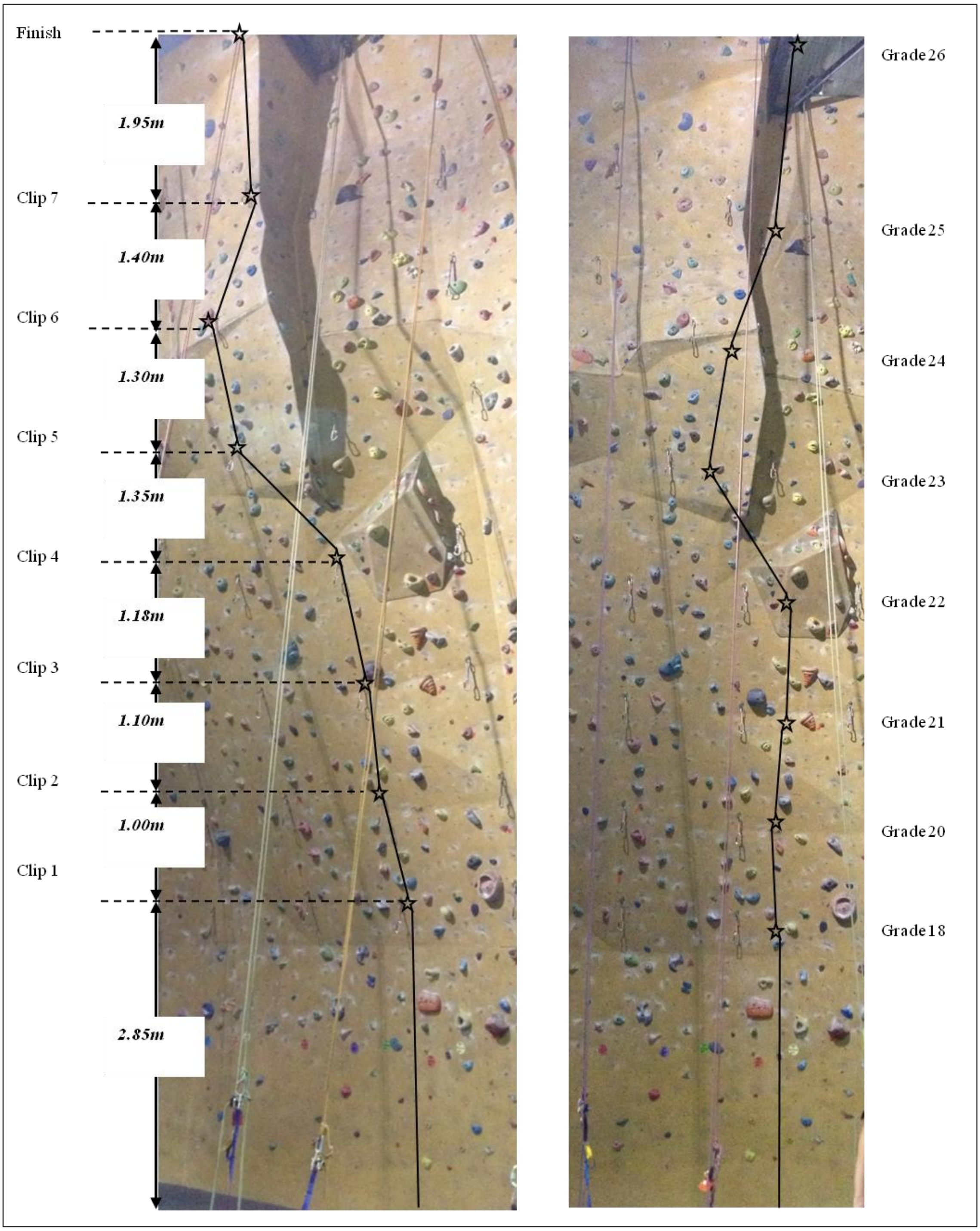

Figure 5.1 The profile of wall section, line of protection, distance between clips (bolts), and grade of difficulty (Ewbank) for the competition test route.

Procedure

Upon arrival at The Roxx climbing wall facility climbers were first asked to complete the POMS inventory, climbers were then asked to complete a prescribed warm-up consisting of three distinct phases; 5 min light jogging, mobilising/stretching exercises, and one ascent on a route of their choice on a top-rope (typically at least two difficulty grades below that of their best on-sight ability). Participants were then fitted with a polar FS1 (Polar Electro, Oy, Kempele, Finland) heart rate monitor and Cosmed K4b^2 as per the setup described in section *3.5.3 Cosmed K4b2 setup*, before being shown the test route. Climbers were shown the route by the route setter, who identified the line of protection (pre-placed quickdraws) that should be adhered to. During the route inspection climbers were permitted to question the route setter with regard to inclusion of holds, which were highlighted with the use of a laser pointer. However, participants were not permitted to question the nature of particular features, or grades of sections of the route.

Once the climber was satisfied with route inspection and had no more questions they were seated and pre-climb blood sampling was completed. Pre-climb BLa was determined using the Lactate Pro portable analyzer via the methods set out in section *3.6.1 (Blood lactate concentration*) and a capillary blood sample for determining plasma cortisol concentration was collected (see section *3.6.2 Plasma cortisol concentration*). Once complete, climbers prepared themselves to climb (shoes, chalk) and attached themselves to the lead rope. When ready, an experimenter then fitted the K4b^2 mask, and the participant was asked to complete the CSAI-2R immediately pre-climb.

Climbers were instructed to begin the climb in their own time, but that their ascent would be timed starting from the moment they made contact with the wall until they reached the lower-off or fell from the route. Throughout the climb HR and breath-by-breath gas analysis data were recorded. In addition all ascents were captured on video to aid in further analysis with respect to determining the height reached on the route, and to help in indentifying possible causes should inconsistencies in data arise. Once their ascent was completed (either through being subjected to a fall, or reaching the top) the climber was lowered to the floor, upon which a 15 min passive (seated) recovery period was observed. Immediately upon reaching the floor climbers were instructed to remove their climbing shoes and be seated for the purposes of post-climb blood sampling, and completion the NASA-TLX questionnaire. Blood lactate was measured via the methods described previously immediately post-climb and at 5, 10 and 15 min thereafter.

Capillary blood samples were collected for the purposes of determining plasma cortisol concentration both immediately post-climb and 15 min post-climb.

During the climb participants' breath-by-breath data were monitored via telemetry and later downloaded from the $K4b^2$ PU post-test. Capillary blood samples collected pre- and post-climb were handled as per the methods set out in *3.6.2.* Cortisol assays were carried out using the ELISA method set out in section *3.6.3* (*Enzyme Linked Immunosorbent Assay (ELISA))*

Data analysis

As in study one a number of dependent variables were calculated based on the measures obtained during the competition climb for the purposes of investigating pre, during and post-climb responses. The following section provides details of data treatment and the calculations or methods used in compiling data for key variables for the purposes of statistical analysis. Details of treatment of data with respect to laboratory based testing, and in particular determining $\dot{V}O_{2max}$ and HR_{max} have already been presented in *3.4.2 (Incremental test to determine maximal oxygen uptake*) and should be referred to where necessary.

Heart rate and oxygen consumption pre-climb

In order to provide measures of $\dot{V}O_2$ and HR immediately pre-climb, individuals' recorded breath-by-breath data were used. All invalid steps were discarded, and the data set were smoothed (5 steps). Pre-climb $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$) and Pre-climb HR ($bts \cdot min^{-1}$) were measured as the 15 s average for each variable immediately prior to the commencement of the climbers' ascent.

Ascent time

Ascent time (s) was recorded for each climb. Where a climber successfully completed the test route, ascent time was recorded from the moment the climber made contact with the wall to successfully clipping the lead rope at the 'lower-off'. Where a fall occurred ascent times were recorded from first contact with the wall, to the point of failure (and climbers were not permitted to continue).

Heart rate and oxygen consumption during ascent

In this instance the terms 'average $\dot{V}O_2$' and 'average HR' were used to define $\dot{V}O_2$ and HR responses across the entire ascent. These were calculated from breath-by-breath data where firstly all invalid steps were discarded and data were smoothed (5 steps) before calculating the averages for $\dot{V}O_2$ and HR based on values and number of steps recorded during the ascent.

Climb phases

Climb phases are referred to as either 'to clip' or 'clipping' and were established in order to investigate $\dot{V}O_2$ and HR responses during ascent. To this end, climb phase timing points obtained by video analysis were matched with breath-by-breath data. Individuals' breath-by-breath data were treated in the following respect; invalid steps were discarded and all data were smoothed (5 steps) before being exported to Excel for subsequent analysis. Timing points for climb phases obtained via video analysis were marked accordingly, and average 'to clip' and 'clipping' for $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$) and HR ($bts \cdot min^{-1}$) were calculated based on number of steps within each given phase.

The 'to clip' phases were taken as the moment the climber reached for the rope in order to clip the quickdraw at the bolt and 'clipping' phases were taken from this point until the point at which the climber resumed all four points of contact with the wall after clipping at the bolt was complete; simultaneously signalling the start of the next 'to clip' phase. For example 'to clip 1' refers to the section of climb from first contact with the wall to the point at which the climber reached for the rope to clip the first bolt, this also signalled the start of the 'clipping 1' phase which was concluded when the climber resumed contact with the wall, and thus also starting the 'to clip 2' phase, and so forth.

Delta post-climb cortisol

Delta plasma cortisol concentrations post-climb were calculated for each ascent by subtracting pre-climb values from those obtained at 15 min post-climb as this is where peak plasma cortisol concentrations were evidenced.

Delta peak blood lactate

Delta peak BLa in response to the on-sight climb was calculated by subtracting pre-climb BLa from an individual's peak BLa post-climb concentration. Delta peak BLa is given in $mmol \cdot L^{-1}$

Statistical analysis

All analyses were performed using the SPSS program (version 19.0 Chicago IL) and Microsoft Excel (Microsoft 2007, Redmond WA) software packages. Data are reported in means ± SD unless otherwise indicated. The α-level was set at 0.05 (2-tailed) with Bonferroni correction applied where appropriate. Variables were assessed for normality of distribution using the one-sample Kolomogorov-Smirnov goodness of fit test, 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).

A number of the dependent variables were grouped into three subsets for the purpose of conducting MANOVA, these were: pre-climb (pre-climb HR, pre-climb $\dot{V}O_2$, and CSAI-2R responses), during ascent (average HR and average $\dot{V}O_2$) and post-climb (Δ peak BLa, Δ post-climb cortisol, and NASA-TLX responses). For each set of grouped dependent variables a one-way between-groups MANOVA was performed to investigate the main effect 'ability group'. In order to investigate differences in ascent time between ability groups a one-way between-groups ANOVA was performed, with subsequent Post-Hoc LSD where significant. The decision to exclude ascent time from the MANOVA was taken due to the potential differences in climb time owing to technical ability and tactical decisions which would likely influence overall ascent time. More specifically static time versus movement time differed between ability groups, with more experienced climbers often having chosen to take advantage of strategic rests at key times which resulted in longer ascent time relative to climbers of different ability levels. In contrast at the lower end of ability static time may have been increased due to hesitation or inability to perform the required move to progress on the route.

5.2.2 Results

A series of one-way repeated measures ANOVA tests were used to investigate differences in POMS responses. Results indicated that there were no significant differences between the familiarisation and climbing trial for any of the components (anger, tension, depression, vigour, fatigue). This suggests that prior mood state of the participants did not affect performance during the climbing trial.

Pre-climb

In the current experiment pre-climb HR and pre-climb $\dot{V}O_2$ coupled with scores obtained from the CSAI-2R questionnaire were considered together. This was in order to investigate the psychophysiological responses of climbers to the climbing task with respect to ability level. A one-way between-groups MANOVA was performed to investigate ability group differences in pre-climb state for the main effect ‘ability group’. Five dependent variables were included in this analysis: pre-climb HR, pre-climb $\dot{V}O_2$, somatic anxiety, cognitive anxiety and self-confidence. The independent variable in this analysis was ‘ability group’. The one-way between-groups MANOVA indicated that there was no significant effect for ability group on grouped pre-climb variables ($F_{(10,32)} = 0.394$, $p = 0.940$; Pillai’s Trace 0.219, partial Eta^2 = 0.110), and as such no further analyses were carried out. Mean ± SD data for each of the pre-climb dependent variables are presented separately for descriptive purposes.

Heart rate and oxygen consumption pre-climb

Mean ± SD values for pre-climb HR and $\dot{V}O_2$ for each ability group are presented in Table 5.3. It can be seen that responses were marginally lower for the intermediate group when compared to advanced and elite groups. Furthermore, responses for the advanced and elite groups were similar.

Table 5.3 Pre-climb HR and pre-climb $\dot{V}O_2$ responses for ability groups (mean ± SD).

Ability group	*n*	Pre-climb HR (bts·min^{-1})	Pre-climb $\dot{V}O_2$ (mL·kg^{-1}·min^{-1})
Intermediate	7	110.3 ± 17.6	9.4 ± 2.9
Advanced	10	114.9 ± 18.0	9.9 ± 2.2
Elite	5	114.5 ± 9.7	9.9 ± 1.7

Competitive state anxiety inventory – 2 revised

Table 5.4 suggests that scores for somatic anxiety, cognitive anxiety and self-confidence did not vary greatly between ability groups. Somatic anxiety was found to be highest in the elite group; however, levels of cognitive anxiety in the elite group were the lowest of the three groups. Self-confidence was highest with respect to the advanced group. The scores for self-confidence were similar for elite and intermediate climbers (< 1 point difference).

Table 5.4 Mean ± SD scores for somatic anxiety, cognitive anxiety and self-confidence for each ability group.

Group	*n*	Somatic anxiety	Cognitive anxiety	Self-confidence
Intermediate	7	18.8 ± 3.7	16.9 ± 6.0	22.9 ± 5.3
Advanced	10	17.6 ± 5.3	16.0 ± 5.7	27.0 ± 7.1
Elite	5	19.7 ± 5.2	15.2 ± 4.8	23.6 ± 6.8

Ascent time

Ascent times and distance achieved (defined as number of clips reached) for each ability group are presented in Table 5.6. As anticipated the distance achieved during ascent shows a marginal increase with an increase in ability level, this trend was matched with respect to ascent time. The greatest difference in ascent times can be observed between the elite and intermediate groups. A one-way between-groups ANOVA indicated there was a significant difference for the main effect 'ability group' ($F_{(2,19)} = 4.880$, $p = 0.019$, partial $Eta^2 = 0.339$). Post-Hoc LSD indicated that ascent time was significantly greater for the elite group compared to both the intermediate group (mean difference = 85.6, CI 27.9 – 143.2) and the advanced group (mean difference = 56.4, CI 2.5 – 110.3). However, the difference is ascent time between intermediate and advanced was not significant (mean difference = 29.2, CI 29.7 – 88.1).

Table 5.5 Mean ± SD ascent time and distance (with respect to number of clips reached) for each ability group.

Ability group	*n*	Distance (clips)	Ascent time (s)
Intermediate	7	4.5 ± 1.0	103.4 ± 32.4
Advanced	10	4.9 ± 1.0	132.6 ± 39.1
Elite	5	5.4 ± 0.5	189.0 ± 74.1

Heart rate and oxygen consumption during ascent

A one-way between-groups MANOVA was performed to investigate ability group differences in average HR and average $\dot{V}O_2$ during an on-sight ascent of increasing difficulty. As such the two dependent variables average HR and average $\dot{V}O_2$ were used. The independent variable used in this analysis was 'ability group'. The one-way between-groups MANOVA indicated that there was no significant effect for 'ability group' on grouped average HR and $\dot{V}O_2$ ($F_{(4,38)} = 0.350$, $p = 0.843$; Pillai's Trace 0.071, partial $Eta^2 = 0.036$), and as such no further analyses were carried out. Mean ± SD data for average HR and average $\dot{V}O_2$ during ascent are presented in Table 5.6 for descriptive purposes.

Table 5.6 Average HR and $\dot{V}O_2$ during ascent presented as mean ± SD for each ability group.

Ability group	*n*	Average HR (bts·min^{-1})	Average $\dot{V}O_2$ (mL·kg^{-1}·min^{-1})
Intermediate	7	165.5 ± 6.8	25.4 ± 3.6
Advanced	10	164.0 ± 12.4	25.0 ± 2.5
Elite	5	162.7 ± 15.1	26.9 ± 3.4

The average HR and $\dot{V}O_2$ responses during ascents for each ability group presented in Table 5.6 appear to be similar. However, it should be recognised that the end point of each ascent was not consistent between groups or participants. A breakdown of the number of participants to reach each phase of the climb is given in Table 5.7. Heart rate and $\dot{V}O_2$ throughout the ascents, when averaged for each climb phase, are presented in Figure 5.2 and Figure 5.3 respectively.

Table 5.7 The breakdown of number of participants to each clip (climb phase) with respect to ability group.

Phase	Intermediate (*n*)	Advanced (*n*)	Elite (*n*)
To clip 1	7	10	5
Clipping 1	7	10	5
To clip 2	7	10	5
Clipping 2	7	10	5
To clip 3	7	10	5
Clipping 3	7	10	5
To clip 4	5	8	5
Clipping 4	4	8	5
To clip 5	3	6	5
Clipping 5	3	6	5
To clip 6	1	2	2
Clipping 6	1	2	2
To clip 7	0	0	0
Clipping 7	0	0	0
To finish	0	0	0
Clipping finish	0	0	0

As can be seen in Figure 5.2 HR during the ascents were similar between ability groups until the ‘to clip 3’ climb phase, at which point responses between the groups begin to show a small difference. Here both the intermediate and advanced groups HR were greater than the elite group. In addition the intermediate group showed a slightly higher HR response compared to the advanced group through the latter part of the ascent.

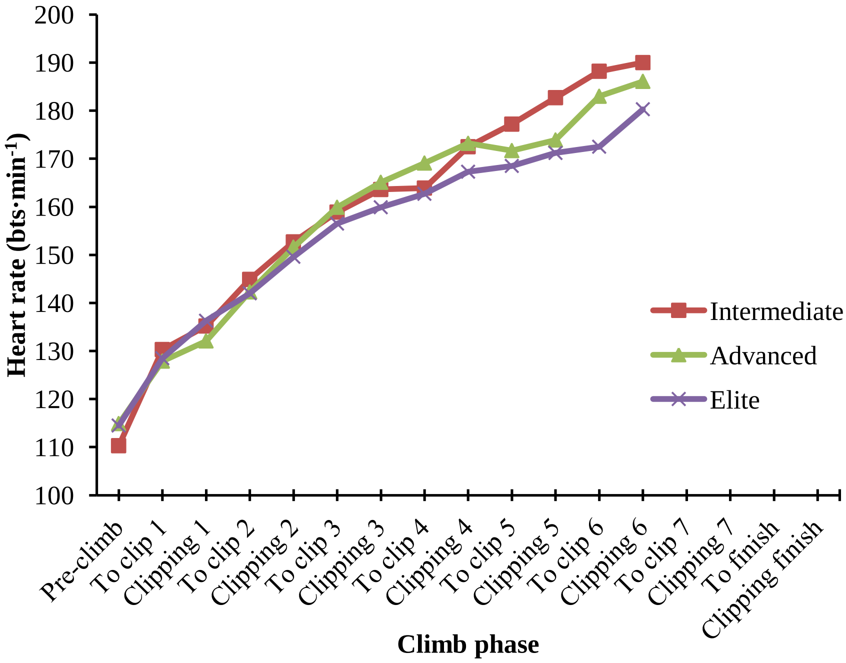

Figure 5.2 Mean HR averaged for each successful climb phase during ascent, presented with respect to ability group.

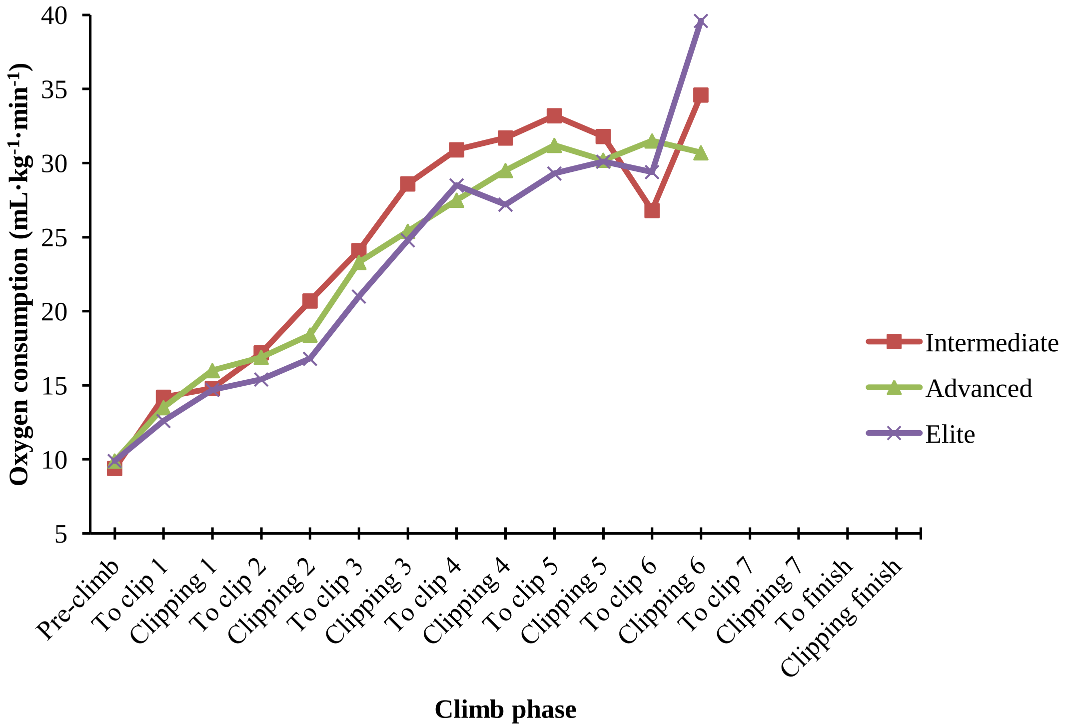

Figure 5.3 Mean $\dot{V}O_2$ averaged for each successful climb phase during ascent, presented with respect to ability group.

Post-climb

A one-way between-groups MANOVA was performed to investigate ability differences in post-climb state for the main effect 'ability group'. Eight dependent variables were included in this analysis: Δ post-climb cortisol concentration, Δ peak BLa concentration, and ratings of mental demand, physical demand, temporal demand, performance, effort and frustration determined by participants responses to the NASA-TLX questionnaire. The independent variable in this analysis was 'ability group'. The one-way between-groups MANOVA indicated that there was no significant effect for ability group on grouped post-climb variables ($F_{(16,22)} = 0.841$, $p = 0.492$; Pillai's Trace 0.219, partial Eta^2 = 0.421), and as such no further analyses were carried out. Data for each of the pre-climb dependent variables are presented separately for descriptive purposes.

Post-climb cortisol

Mean ± SD plasma cortisol values measured pre, post and 15 min post-climb are presented in Table 5.8. In all instances the concentrations were greatest for the intermediate group. Peak plasma cortisol concentrations were observed 15 min post-climb with respect to all ability groups. When expressed as Δ value, plasma cortisol concentration in response to the climbing task was greatest in the intermediate group. In reviewing mean ± SD values for Δ post-climb cortisol (Table 5.8) response it can be seen that large SD values were observed in each group.

Table 5.8 Mean ± SD values for plasma cortisol concentration measured pre, post and 15 min post-climb and when expressed as Δ post-climb (post-climb – pre-climb) for each ability group.

		Plasma cortisol concentration (ng/mL)			
Ability group	*n*	Pre-climb	Post-climb	15min post-climb	Δ post-climb
Intermediate	7	146.1 ± 43.0	142.4 ± 42.6	179.7 ± 58.6	37.6 ± 78.2
Advanced	10	114.5 ± 40.1	120.7 ± 41.0	127.2 ± 40.1	7.5 ± 47.5
Elite	5	140.2 ± 30.8	137.3 ± 28.5	152.6 ± 26.9	12.4 ± 23.9

Blood lactate

An overview of mean BLa measured pre-climb, and at 5 min intervals over a 15 min recovery period for each ability group are presented in Figure 5.4. Pre-climb values were similar for all ability groups. Mean peak BLa was observed immediately post-climb with respect to all ability groups, and was above 4.0 mmol·L in all instances. Blood lactate remained elevated above pre-climb values for the duration of the 15 min passive recovery period. Post-climb BLa measured over the 15 min recovery period was considerably higher for the elite group when compared to both the advanced and intermediate groups.

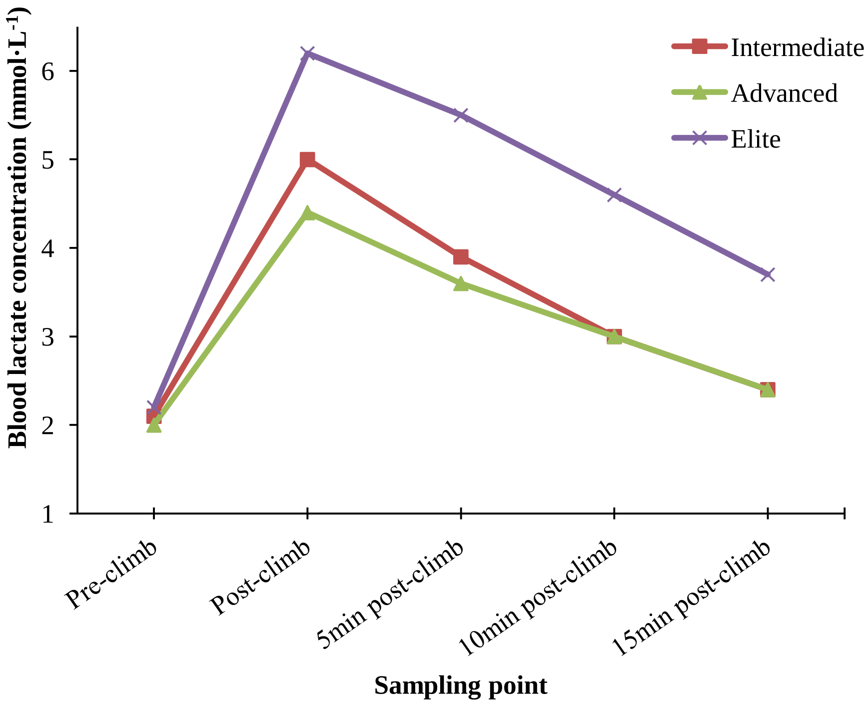

Figure 5.4 Mean BLa at pre-climb and post-climb sampling points for intermediate, advanced and elite groups.

Blood lactate responses post-climb for each ability group expressed as Δ values are presented in Table 5.9. In comparison to the intermediate and advanced groups, where Δ peak BLa was similar, the elite group Δ BLa post-climb was considerably higher.

Table 5.9 Mean ± SD Δ peak BLa for each ability group.

Ability group	*n*	Δ Peak BLa ($mmol \cdot L^{-1}$)
Intermediate	7	2.4 ± 0.6
Advanced	10	2.2 ± 1.3
Elite	5	4.0 ± 1.7

National Aeronautics and Space Administration Task Load Index

Ratings of task demand with respect to the six NASA-TLX subscales are presented for each ability group in Table 5.10. Ratings of temporal demand and frustration did not differ greatly between ability groups. Mental demand and physical demand were rated similarly by the intermediate and advanced groups, but were greater for the elite group. This trend was also apparent with respect to ratings of performance and effort in relation to the climbing task.

Table 5.10 Mean ± SD scores for the six NASA-TLX subscales, presented for each ability group.

Ability group	*n*	Mental	Physical	Temporal	Performance	Effort	Frustration
Intermediate	7	8.5 ± 5.0	9.0 ± 6.9	5.3 ± 5.9	9.2 ± 5.6	11.3 ± 7.0	9.7 ± 4.4
Advanced	10	8.2 ± 3.9	8.7 ± 4.9	7.7 ± 4.1	7.2 ± 5.7	12.1 ± 5.5	11.9 ± 3.7
Elite	5	10.0 ± 5.7	16.2 ± 2.2	5.8 ± 6.8	12.6 ± 2.9	15.0 ± 3.9	10.6 ± 6.6

5.3 Phase 2

5.3.1 Methods

For the second phase of study two, data for lead climbing ascents in study one were pooled with data obtained in phase 1 of study two. More specifically all data for lead ascents with respect to the intermediate, advanced and elite groups from study 1 were combined with data obtained for responses to competition ascents in phase 1 of this study. With respect to lead ascent data from study one, this included both successful and unsuccessful (where a fall occurred) ascents. Details of participants, a brief overview of experimental design, data analysis and statistical analysis are presented in this section.

Participants

Methods of recruitment, criteria for inclusion and grouping of participants with respect to ability level are provided in section *3.3.1 (Participant recruitment*).

In pooling all data from study one and phase 1 of this study categorisation with respect to ability group was maintained. However, a second grouping variable defined as ‘ascent category’ was also used to distinguish between the type of route climbed, and the outcome achieved. This resulted in three categories: successful, unsuccessful and competition. The successful and unsuccessful groups were comprised of participant data from study one for those who had attempted a lead on-sight ascent of a consistently graded route at the top end of self-reported ability. The competition group consisted of participant data for those who had attempted an on-sight ascent of a competition-style route which increased in difficulty as the climber progressed. Descriptive data (mean ± SD) for experience, anthropometric, and baseline fitness for participants included in phase 2 are presented in Table 5.11 (with respect to ability group and ascent category).

Table 5.11 Participants climbing experience, anthropometric characteristics, and fitness measures presented with respect to ability group and successful, unsuccessful or competition ascent.

Group	*n*	Lead climbing experience	On-sight (Ewbank)	Redpoint (Ewbank)	Age (years)	Height (cm)	Mass (kg)	Body fat (%)	$\dot{V}O_{2max}$ (mL·kg^{-1}·min^{-1})	HR_{max} (bts·min^{-1})
Intermediate										
Successful	5	9.0 ± 9.5	18.8 ± 0.4	21.4 ± 1.1	32.0 ± 7.2	178.4 ± 4.3	81.5 ± 13.8	17.7 ± 5.6	51.7 ± 7.8	185.4 ± 14.0
Unsuccessful	3	1.8 ± 1.0	18.3± 0.6	21.3 ± 1.5	29.7 ± 2.5	169.2 ± 16.5	66.3 ± 20.7	18.8 ± 4.1	44.4 ± 3.5	184.7 ± 10.1
Competition	7	1.9 ± 1.2	19.3 ± 0.8	21.3 ± 2.1	25.9 ± 8.6	173.7 ± 11.4	67.7 ± 11.7	15.2 ± 3.5	46.0 ± 5.9	190.4 ± 7.3
Total	**15**	**4.2 ± 6.2**	**18.9 ± 0.7**	**21.3 ± 1.6**	**28.7 ± 7.5**	**174.4 ± 10.6**	**72.0 ± 14.9**	**16.8 ± 4.4**	**47.6 ± 6.6**	**187.6 ± 10.1**
Advanced										
Successful	9	8.0 ± 8.1	23.4 ± 0.7	26.1 ± 1.3	25.3 ± 9.1	175.2 ± 8.9	67.8 ± 10.4	12.9 ± 4.1	51.4 ± 9.0	193.9 ± 10.7
Unsuccessful	3	6.0 ± 5.0	22.3 ± 0.6	24.7 ± 1.2	25.3 ± 7.1	176.0 ± 11.0	72.8 ± 10.8	12.5 ± 5.3	48.3 ± 11.2	192.3 ± 10.4
Competition	10	3.6 ± 2.1	22.5 ± 1.2	24.6 ± 1.6	22.4 ± 6.3	173.7 ± 7.2	64.9 ± 9.7	12.0 ± 4.9	47.8 ± 8.0	188.3 ± 5.7
Total	**22**	**5.7 ± 5.8**	**22.9 ± 1.0**	**25.2 ± 1.6**	**24.0 ± 7.5**	**174.6 ± 8.0**	**67.1 ± 10.0**	**12.5 ± 4.4**	**49.4 ± 8.6**	**191.1 ± 8.6**
Elite										
Successful	4	7.1 ± 3.3	26.8 ± 1.0	30.3 ± 1.5	24.3 ± 2.8	174.8 ± 6.8	70.6 ± 4.3	11.2 ± 3.2	59.1 ± 6.7	189.3 ± 8.7
Unsuccessful	3	9.0 ± 8.7	25.7 ± 0.6	27.7 ± 1.5	21.3 ± 9.3	173.7 ± 9.4	61.5 ± 11.1	13.5 ± 3.2	54.9 ± 10.2	189.3 ± 6.1
Competition	5	6.4 ± 3.4	25.2 ± 0.4	27.2 ± 1.8	26.4 ± 8.4	177.2 ± 13.3	74.0 ± 7.6	13.4 ± 8.0	49.8 ± 10.3	190.8 ± 9.5
Total	**12**	**7.3 ± 4.7**	**25.8 ± 0.9**	**28.3 ± 2.1**	**24.4 ± 6.9**	**175.5 ± 9.8**	**69.7 ± 8.7**	**12.7 ± 5.4**	**54.2 ± 9.4**	**190.0 ± 7.8**

Experimental overview

Full details of the experimental design and procedures can be referred to in sections 4.2 for data obtained in relation to the successful and unsuccessful lead ascents, and 5.2.1 with respect to competition ascents. The following measures were taken during the climbing test sessions: pre-climb HR, pre-climb $\dot{V}O_2$, anxiety (CSAI-2R), average HR, average $\dot{V}O_2$, BLa concentration (pre, post, 5, 10 and 15 min post-climb), plasma cortisol concentration (pre-climb, post-climb and 15 min post-climb) and ratings of task demand (NASA-TLX), were matched in order to facilitate comparisons between ability groups (intermediate, advanced and elite), and the three categories of ascent (successful, unsuccessful, competition).

Data analysis

The dependent variables used were identified and calculated in the same way as phase 1 (refer to *5.2 Phase 1, Data analysis*).

Statistical analysis

All analyses were performed using the SPSS program (version 19.0. Chicago IL) and Microsoft Excel (Microsoft 2007, Redmond WA) software packages. Data is reported in means ± SD unless otherwise indicated. The α-level was set at 0.05 (2-tailed) for all analyses with Bonferroni correction applied for multiple tests where appropriate.

Table 5.12 Dependent variable grouping for MANOVA (study two, phase 2).

Group	Dependent variables	Independent variables
Pre-Climb	Pre-climb $\dot{V}O_2$ (mL·kg^{-1}·min^{-1}) Pre-climb HR (bts·min^{-1}) CSAI-2R *Somatic anxiety* *Cognitive anxiety* *Self-confidence*	Ability group Ascent category
Climb	Average $\dot{V}O_2$ (mL·kg^{-1}·min^{-1}) Average HR (bts·min^{-1})	Ability group Ascent category
Post-climb	Δ post-climb cortisol (ng/mL) Δ peak BLa (mmol·L^{-1}) NASA-TLX *Mental demand* *Physical demand* *Temporal demand* *Performance* *Effort* *Frustration*	Ability group Ascent category

Variables were assessed for normality of distribution using the one-sample Kolomogorov-Smirnov goodness of fit test, 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). A series of tests were used to investigate differences between ability groups (intermediate, advanced and elite) and ascent category (successful, unsuccessful and competition) for a number of variables. To this end dependent variables were grouped and considered together for the purpose of first conducting MANOVA. Table 5.12 provides an overview of the dependent variables and independent variables used in each analysis. Ascent time was analysed separately using a two-way between-groups ANOVA as outlined below. The decision to exclude ascent time from the MANOVA was taken due to the potential differences in climb time owing to technical ability and tactical decisions which would likely influence overall ascent time. More specifically static time versus movement time differed between ability groups, with more experienced climbers often having chosen to take advantage of strategic rests at key times which resulted in longer ascent time relative to climbers of different ability levels. In contrast at the lower end of ability static time may have been increased due to hesitation or inability to perform the required move to progress on the route.

A two-way between-groups MANOVA was performed to investigate the main effects 'ability group' and 'ascent category', which also investigated an interaction effect (ability group by ascent category). Where a significant effect was indicated by the MANOVA, the dependent variables were considered separately. Analysis was then conducted by means of ANCOVA to determine any significant covariate effects due to: sex, age, anthropometric characteristics (height, mass and body fat percentage) or baseline fitness ($\dot{V}O_{2max}$ and HR_{max}). Where significant covariates were identified, the results of the ANCOVA were presented (including adjusted means (SE) for the dependent variable). If no significant covariate effect were observed, ANOVA was performed with subsequent Post-Hoc LSD where appropriate, and the results of the ANOVA reported. A Bonferroni correction was applied to ANCOVA and ANOVA results in order to correct for multiple tests. For this the *p* value obtained was multiplied by the number of dependent variables included in the initial MANOVA analysis.

5.3.2 Results

A series of one-way repeated measures ANOVA tests were used to investigate differences in POMS responses. Results indicated that there were no significant differences between the baseline and climbing trial for any of the components (anger, tension, depression, vigour, fatigue). This suggests that prior mood state of the participants did not affect performance during the climbing trial.

Pre-climb

A number of measures were used to investigate pre-climb state, data for these variables were considered together in order to determine whether there were any differences in pre-climb responses between ability group and ascent category. A two-way between-groups MANOVA was performed to investigate the main effects 'ability group' and 'ascent category' as well as the interaction effect 'ability group*ascent category'. To this end five dependent variables were used: pre-climb HR, pre-climb $\dot{V}O_2$, somatic anxiety, cognitive anxiety and self-confidence. The independent variables were ability group (intermediate, advanced and elite) and ascent category (successful, unsuccessful and competition). The two-way between-groups MANOVA indicated non-significant differences for the main effects 'ability group' ($F_{(10,72)}$ = 1.124, p = 0.356; Pillai's Trace 0.270, partial Eta^2 = 0.135), and 'ascent category' ($F_{(10,72)}$ = 1.583, p = 0.129; Pillai's Trace 0.360, partial Eta^2 = 0.180) and with respect to the interaction effect 'ability group*ascent category' ($F_{(20,152)}$ = 0.698, p = 0.824; Pillai's Trace 0.336, partial Eta^2 = 0.084). In light of this, no further analyses were carried out. Mean ± SD data for the pre-climb variables are presented separately for descriptive purposes.

Heart rate and oxygen consumption pre-climb

Mean ± SD values for pre-climb HR and pre-climb $\dot{V}O_2$ with respect to 'ability group' and 'ascent category' are presented below in Table 5.13.

Pre-climb HR was lowest in the intermediate group but similar for the advanced and elite groups. In the advanced and elite groups pre-climb HR was greatest with respect to the unsuccessful ascents. This is also reflected in the combined mean HR values for this climb. However, upon closer inspection differences between ascent category for the combined groups were minimal (~ 2bts·min^{-1}). Data for pre-climb $\dot{V}O_2$ does not appear to show any particular trend within groups with respect to ascent category. Group totals were comparable across ability levels, with a marginal increase with the concurrent increase in ability level.

Table 5.13 Pre-climb HR and $\dot{V}O_2$ responses, with respect to ability group and ascent category, data presented is mean ± SD.

Ability group	*N*	Pre-climb HR (bts·min^{-1})	Pre-climb $\dot{V}O_2$ (mL·kg^{-1}·min^{-1})
Intermediate			
Successful	5	107.7 ± 19.9	11.4 ± 1.7
Unsuccessful	3	103.8 ± 4.8	8.6 ± 2.2
Competition	7	110.3 ± 17.6	9.4 ± 2.9
Total	**15**	**108.0 ± 16.0**	**9.9 ± 2.5**
Advanced			
Successful	9	117.3 ± 20.5	10.9 ± 1.4
Unsuccessful	3	124.4 ± 14.6	12.8 ± 4.6
Competition	10	114.9 ± 18.0	9.9 ± 2.2
Total	**22**	**117.1 ± 18.2**	**10.7 ± 2.4**
Elite			
Successful	4	115.8 ± 27.3	13.5 ± 4.6
Unsuccessful	3	124.3 ± 10.7	9.5 ± 1.2
Competition	5	114.5 ± 9.7	9.9 ± 1.7
Total	12	**116.8 ± 17.0**	**11.0 ± 3.2**
Combined			
Successful	18	114.2 ± 21.1	11.6 ± 2.6
Unsuccessful	9	116.6 ± 14.0	10.6 ± 3.4
Competition	22	113.4 ± 15.8	9.7 ± 2.2

Competitive state anxiety inventory – 2 revised

Mean ± SD scores for pre-climb somatic anxiety, cognitive anxiety and self-confidence in Table 5.14. It can be seen that differences in responses did not differ dramatically between ability groups, or with respect to ascent category. Differences were marginal and non-significant, yet a number of emerging trends can be seen. Firstly cognitive anxiety was greater than somatic anxiety in all ability groups prior to unsuccessful ascents. In addition, scores for self-confidence within each ability group were greater prior to successful ascents compared with those measured prior to unsuccessful ascents. Finally, combined scores showed that levels of cognitive anxiety were greatest overall prior to unsuccessful ascents, and were greater than levels of somatic anxiety. This was also coupled with the lowest combined score for self-confidence across the three climb categories.

Table 5.14 Mean ± SD scores for somatic anxiety, cognitive anxiety and self-confidence pre-climb. Data are presented with respect to ability group and ascent category.

Group	*n*	Somatic anxiety	Cognitive anxiety	Self-confidence
Intermediate				
Successful	5	16.6 ± 2.8	16.8 ± 5.4	30.4 ± 5.0
Unsuccessful	3	16.7 ± 6.6	19.3 ± 4.2	27.3 ± 7.0
Competition	7	18.8 ± 3.7	16.9 ± 6.0	22.9 ± 5.3
Total	**15**	**17.6 ± 4.0**	**17.3 ± 5.2**	**26.3 ± 6.2**
Advanced				
Successful	9	16.2 ± 4.0	17.6 ± 5.5	25.8 ± 4.5
Unsuccessful	3	19.1 ± 9.5	22.7 ± 9.9	24.7 ± 5.0
Competition	10	17.6 ± 5.3	16.0 ± 5.7	27.0 ± 7.1
Total	**22**	**17.2 ± 5.3**	**17.5 ± 6.3**	**26.2 ± 5.7**
Elite				
Successful	4	15.0 ± 4.7	14.5 ± 3.4	25.5 ± 6.6
Unsuccessful	3	14.8 ± 3.3	15.3 ± 1.2	18.7 ± 1.2
Competition	5	19.7 ± 5.2	15.2 ± 4.8	23.6 ± 6.8
Total	**12**	**16.9 ± 4.9**	**15.0 ± 3.5**	**23.0 ± 6.1**
Combined				
Successful	18	16.0 ± 3.7	16.7 ± 19.5	27.0 ± 5.3
Unsuccessful	9	17.3 ± 6.5	19.5 ± 6.6	24.3 ± 5.8
Competition	22	18.4 ± 4.7	16.1 ± 16.9	24.9 ± 6.5

Ascent time

Mean ± SD ascent times for ability groups and ascent category are presented in Table 5.15. A two-way between-groups ANOVA indicated there was no significant difference in ascent times for 'ability groups' ($F_{(2,40)}$ = 0.556, p = 0.578, partial Eta^2 = 0.027). Furthermore, the two-way between-groups ANOVA revealed a non-significant interaction effect for 'ability group*ascent category' ($F_{(2,40)}$ = 2.416, p = 0.065; partial

Eta^2 = 0.195), and for the main effect 'ascent category' ($F_{(2,40)}$ = 2.382, p = 0.105; partial Eta^2 = 0.39).

Table 5.15 Mean ± SD ascent time and distance (with respect to number of clips reached) for each ability groups and ascent categories.

Ability group	*n*	Distance (clips)	Ascent time (s)
Intermediate			
Successful	5	8.0 ± 0.0	183.0 ± 37.1
Unsuccessful	3	4.0 ± 1.0	158.0 ± 52.9
Competition	7	4.5 ± 1.0	103.4 ± 32.4
Total	**15**	**N/A**	**140.9 ± 51.4**
Advanced			
Successful	9	8.0 ± 0.0	163.7 ± 49.2
Unsuccessful	3	6.0 ± 1.0	135.0 ± 39.7
Competition	10	4.9 ± 1.0	132.6 ± 39.1
Total	**22**	**N/A**	**145.6 ± 44.3**
Elite			
Successful	4	8.0 ± 0.0	167.3 ± 11.5
Unsuccessful	3	5.0 ± 2.0	128.0 ± 36.0
Competition	5	5.4 ± 0.5	189.0 ± 74.1
Total	**12**	**N/A**	**166.5 ± 53.9**
Combined			
Successful	18	8.0 ± 0.0	169.8 ± 39.5
Unsuccessful	9	5.0 ± 1.5	140.3 ± 40.0
Competition	22	4.8 ± 1.0	136.1 ± 55.0

Heart rate and oxygen consumption during ascent

A two-way between-groups MANOVA was performed to investigate differences in average HR and $\dot{V}O_2$ responses to on-sight climbing for the main effects 'ability group' and 'ascent category', as well as the interaction effect 'ability group*ascent category'. Two dependent variables were used: average HR and average $\dot{V}O_2$. The independent variables were 'ability group' and 'ascent category'. There was a statistically significant difference for the main effect 'ascent category' ($F_{(4,72)}$ = 6.769, p < 0.0005; Pillai's Trace 0.547, partial Eta^2 = 0.273), but not for 'ability group' ($F_{(4,72)}$ = 2.097, p = 0.090; Pillai's Trace 0.209, partial Eta^2 = 0.105) or the interaction effect 'ability group*ascent category' ($F_{(8,72)}$ = 0.433, p = 0.898; Pillai's Trace 0.092, partial Eta^2 = 0.046). As the

MANOVA indicated a significant effect, the independent variable 'ascent category' and the dependent variables average HR and average $\dot{V}O_2$ were considered separately.

Table 5.16 Average HR and $\dot{V}O_2$ responses during ascent, presented as mean ± SD with respect to ability group and ascent category.

Group	*n*	Average HR (bts·min^{-1})	Average $\dot{V}O_2$ (mL·kg^{-1}·min^{-1})
Intermediate			
Successful	5	161.6 ± 20.4	32.3 ± 2.4
Unsuccessful	3	165.5 ± 11.3	28.3 ± 4.2
Competition	7	165.5 ± 6.8	25.4 ± 3.6
Total	**15**	**162.9 ± 15.4**	**28.3 ± 4.4**
Advanced			
Successful	9	171.6 ± 12.4	31.3 ± 4.2
Unsuccessful	3	186.1 ± 4.5	33.0 ± 6.7
Competition	10	164.0 ± 12.4	25.0 ± 2.5
Total	**22**	**169.3 ± 13.3**	**28.5 ± 5.1**
Elite			
Successful	4	167.9 ± 13.1	35.1 ± 2.9
Unsuccessful	3	167.9 ± 4.2	33.4 ± 3.1
Competition	5	162.7 ± 15.1	26.9 ± 3.4
Total	**12**	**166.7 ± 7.9**	**31.3 ± 4.8**
Combined			
Successful	18	168.0 ± 14.9	32.5 ± 3.6
Unsuccessful	9	172.0 ± 11.9	31.5 ± 4.9
Competition	22	163.9 ± 11.9	25.6 ± 3.0

Mean ± SD values for both average HR and average $\dot{V}O_2$ for the duration of ascent are presented above in Table 5.16. Further to the results of the two-way between-groups MANOVA which indicated a significant effect for 'ascent category' on combined HR and $\dot{V}O_2$, a one-way between-groups ANCOVA was conducted to compare average HR between ascent categories. The independent variable in this instance was 'ascent category' (successful, unsuccessful and competition), and the dependent variable was average HR. Participants age, sex, height, mass, percentage body fat, HR_{max} and $\dot{V}O_{2max}$ were used as covariates in this analysis. Age and HR_{max} were found to be significant covariates (age $p = 0.005$, HR_{max} $p = 0.011$) with partial Eta^2 values of 0.178

and 0.149 respectively. After adjusting for the significant covariates age and HR_{max}, there was no significant difference (uncorrected) between climb categories for average HR ($F_{(2,41)}$ = 3.038, p = 0.059, Partial Eta^2 = 0.129). The combined means (SE) for the successful, unsuccessful and competition climbs when adjusted for age and HR_{max} were 168.3 (2.6), 174.0 (4.0) and 163.1 (2.3) respectively.

A one-way between-groups ANCOVA was also conducted to compare average $\dot{V}O_2$ between climbs. The independent variable in this analysis was 'ascent category' (successful, unsuccessful and competition) and the dependent variable was average $\dot{V}O_2$ during ascent. Participants age, sex, height, mass, percentage body fat, HR_{max} and $\dot{V}O_{2max}$ were used as covariates. Maximal O_2 consumption was found to be a significant covariate (p = 0.007) with a partial Eta^2 value of 0.153. After adjusting for $\dot{V}O_{2max}$ there was a significant difference (uncorrected) between climbs for average $\dot{V}O_2$ ($F_{(2,44)}$ = 17.051, p < 0.0005, partial Eta^2 = 0.437), this was still considered significant after a Bonferroni correction was applied for multiple tests. The combined means (SE) for the successful, unsuccessful and competition climbs when adjusted for $\dot{V}O_{2max}$ were 31.9 (0.8), 31.6 (1.1) and 25.9 (0.7) respectively. Comparisons of adjusted means (with Bonferroni correction applied) indicated that average $\dot{V}O_2$ was significantly higher for the successful climb when compared to the competition climb (mean difference = 6.0, CI 3.16 – 8.83), and for the unsuccessful climb when compared to the competition climb (mean difference = 2.37, CI 2.37 – 9.04).

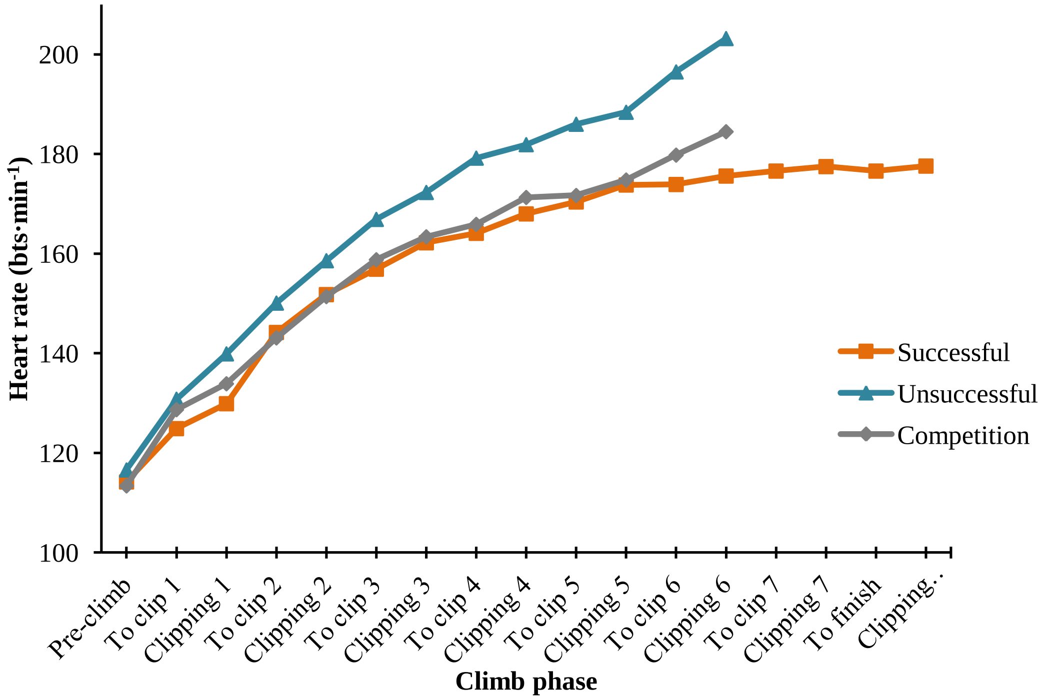

Figure 5.5 Combined ability group mean HR averaged for climb phases ('to clip' and 'clipping') for successful, unsuccessful and competition ascent categories.

In order to gain further insight into the breakdown of HR and $\dot{V}O_2$ responses during ascent with respect to category of climb (successful, unsuccessful and competition), combined mean data for HR and $\dot{V}O_2$ averaged for each phase of the climb are presented in Figure 5.5 and Figure 5.6 respectively. Figure 5.5 suggests mean HR was highest for unsuccessful ascents compared to both successful and competition ascents. These differences increased throughout ascent to the point of failure. During successful ascents HR increased linearly during the first half of the climb and appeared to plateau at the $4^{th}/5^{th}$ clip (climb phase). During the competition ascent, combined mean HR responses were similar in both value and trend, to those observed during successful ascents during the first half of the climb, yet did not exhibit a plateau and continued to increase until point of failure.

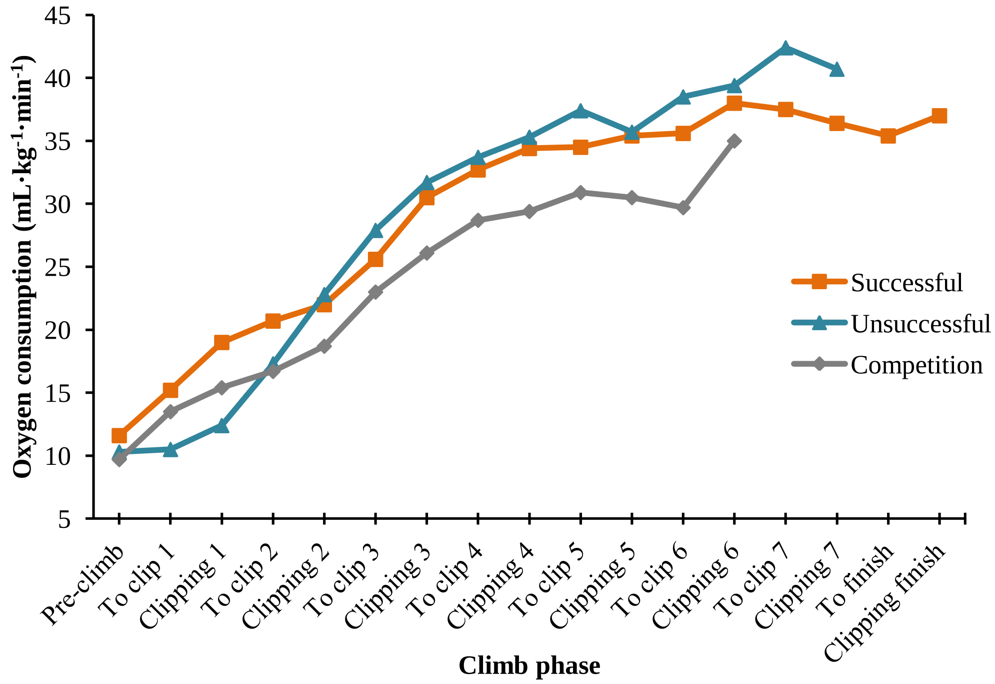

Figure 5.6 Combined ability group mean $\dot{V}O_2$ averaged for climb phases ('to clip' and 'clipping') for successful, unsuccessful and competition ascent categories.

Figure 5.6 shows mean $\dot{V}O_2$ with respect to ascent category when averaged for each phase of the climb. In the initial phases of the climb ('to clip 1 – 'clipping 2') $\dot{V}O_2$ responses for the unsuccessful ascent category were lower than the both the successful and competition categories. However, from 'clipping 2' to the point of failure $\dot{V}O_2$ for the unsuccessful ascent category remained elevated above those observed for the successful and competition ascents. In a similar manner to HR responses for successful ascents, $\dot{V}O_2$ appeared to plateau around the $4^{th}/5^{th}$ phases of the climb. Mean $\dot{V}O_2$ measured across climb phases was lowest for the competition category of ascent.

Post-climb

The dependent variables Δ post-climb cortisol, Δ peak BLa and scores for the six NASA-TLX sub-scales; mental demand, physical demand, temporal demand, performance, effort and frustration, were considered together in order to investigate differences in post-climb responses with respect to ability group and ascent category. A two-way between-groups MANOVA was performed for the main effects 'ability group' (intermediate, advanced and elite), 'ascent category' (successful, unsuccessful and competition) for grouped post-climb variables, as well as the interaction effect 'ability group*ascent category'. As stated previously eight dependent variables were used: Δ post-climb cortisol, Δ peak BLa and ratings of task demand (mental, physical, temporal, performance, effort, frustration). The two-way between-groups MANOVA indicated no significant differences for the main effect 'ability group' ($F_{(16,64)}$ = 1.095, p = 0.378, Pillai's Trace 0.648, partial Eta^2 = 0.215) or the interaction effect 'ability group*ascent category ($F_{(32,136)}$ = 0.821, p = 0.737, Pillai's Trace 0.648, partial Eta^2 = 0.162). However, a significant effect was indicated for 'ascent category' ($F_{(16,64)}$ = 1.9, p = 0.037, Pillai's Trace 0.644, partial Eta^2 = 0.322), and as such the post-climb dependent variables were considered separately in order to further investigate differences with respect to 'ascent category'.

Post-climb cortisol

Data for mean ± SD plasma cortisol concentration measured pre, post and 15 min post-climb, as well as a post-climb Δ value are presented in Table 5.17.

Table 5.17 Mean ± SD values for plasma cortisol concentration measured pre, post and 15 min post-climb and when expressed as Δ post-climb value for ability groups and ascent categories.

		Plasma cortisol concentration (ng/mL)			
Group	*n*	Pre-climb	Post-climb	15min post-climb	Δ post-climb
Intermediate					
Successful	5	134.3 ± 37.0	144.4 ± 22.7	182.1 ± 42.5	47.8 ± 66.2
Unsuccessful	3	148.1 ± 23.5	170.6 ± 46.5	193.9 ± 71.6	45.8 ± 49.2
Competition	7	146.1 ± 43.0	142.4 ± 42.6	179.7 ± 58.6	37.6 ± 78.2
Total	**15**	**142.3 ± 35.5**	**148.7 ± 36.9**	**183.3 ± 52.4**	**43.0 ± 64.0**
Advanced					
Successful	9	111.6 ± 42.8	118.2 ± 45.0	141.2 ± 38.2	29.7 ± 37.8
Unsuccessful	3	157.5 ± 31.0	181.0 ± 34.9	198.4 ± 51.7	40.8 ± 35.2
Competition	10	114.5 ± 40.1	120.7 ± 41.0	127.2 ± 40.1	7.5 ± 47.5
Total	**22**	**119.4 ± 41.6**	**127.9 ± 45.6**	**142.6 ± 45.4**	**21.7 ± 42.1**
Elite					
Successful	4	117.0 ± 34.9	140.8 ± 42.2	175.2 ± 50.7	58.2 ± 24.0
Unsuccessful	3	122.2 ± 90.5	124.3 ± 77.1	145.2 ± 53.1	23.1 ± 38.0
Competition	5	140.2 ± 30.8	137.3 ± 28.5	152.6 ± 26.9	12.4 ± 23.9
Total	**12**	**127.9 ± 47.8**	**135.2 ± 43.7**	**158.3 ± 40.5**	**30.3 ± 32.7**
Combined					
Successful	18	119.1 ± 38.7	130.5 ± 39.4	160.1 ± 44.2	41.0 ± 44.2
Unsuccessful	9	142.6 ± 51.7	158.6 ± 54.9	179.2 ± 57.5	36.6 ± 37.2
Competition	22	130.4 ± 39.8	131.4 ± 38.7	149.7 ± 48.5	17.7 ± 53.5

Typically plasma cortisol concentrations showed a concurrent increase across sampling points from pre-climb to 15 min post-climb where they appeared to be greatest, regardless of ability group or ascent category. A one-way between-groups ANOVA indicated there was no significant difference for the main effect 'ascent category' for Δ post-climb cortisol ($F_{(2,44)}$ = 1.245, p = 0.298, partial Eta^2 = 0.054).

Blood lactate

Data for combined group mean BLa concentration with respect to ascent category measured pre-climb, immediately post-climb and at 5 min intervals over the course of a 15 min passive recovery period, are presented in Figure 5.7. Mean pre-climb BLa concentrations were similar for all categories of ascent (successful, unsuccessful and competition), and all showed a peak immediately post-climb. Blood lactate remained elevated above pre-climb values for the duration of the 15 min passive recovery period. Mean BLa for the successful and unsuccessful ascent categories were similar, whilst the trend line for the competition category can be seen to be considerably lower. Delta peak BLa values (mean ± SD) for ability groups and ascent categories are presented in Table 5.18. A one-way between-groups ANOVA was performed to compare Δ peak BLa between ascent categories which indicated there was no significant effect ($F_{(2,46)}$ = 1.435, p = 0.249, partial Eta^2 = 0.059).

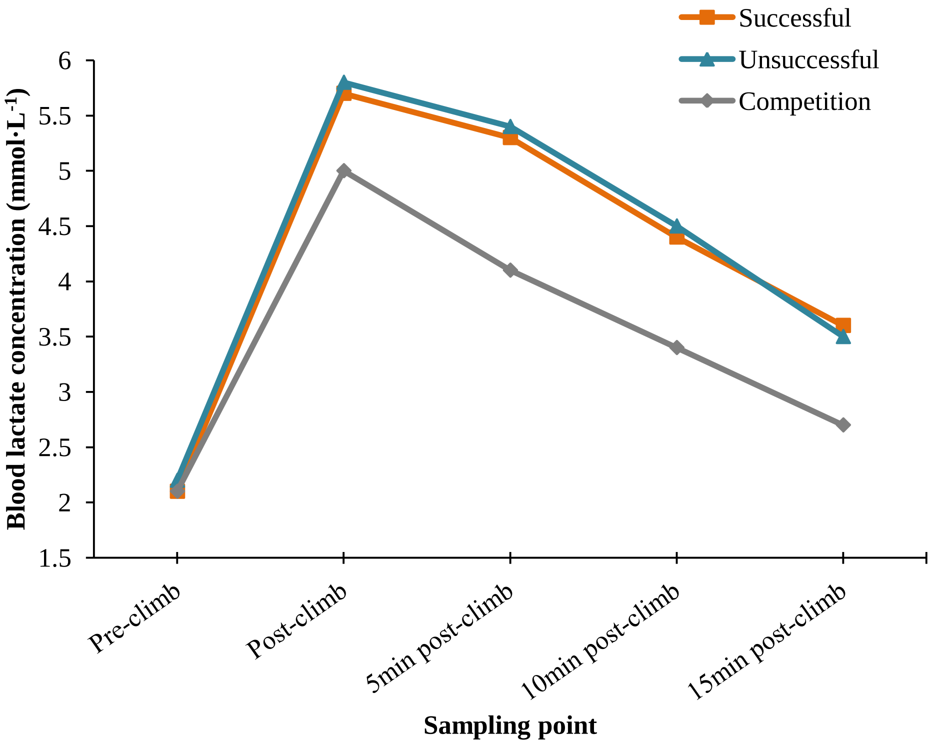

Figure 5.7 Combined group mean BLa measured pre-climb and various post-climb sampling points for successful, unsuccessful and competition ascent categories.

Table 5.18 Delta peak BLa concentration (mean ± SD) presented with respect to ability group and ascent category

Ability group	*n*	Δ Peak BLa ($mmol \cdot L^{-1}$)
Intermediate		
Successful	5	4.4 ± 2.5
Unsuccessful	3	3.5 ± 1.3
Competition	7	2.4 ± 0.6
Total	**15**	**3.5 ± 1.9**
Advanced		
Successful	9	3.2 ± 1.1
Unsuccessful	3	4.1 ± 2.6
Competition	10	2.2 ± 1.3
Total	**22**	**3.0 ± 1.5**
Elite		
Successful	4	3.9 ± 1.2
Unsuccessful	3	3.6 ± 0.3
Competition	5	4.0 ± 1.7
Total	**12**	**3.9 ± 1.2**
Combined		
Successful	18	3.7 ± 1.6
Unsuccessful	9	3.7 ± 1.5
Competition	22	2.7 ± 1.4

National Aeronautics and Space Administration Task Load Index

Ratings of task demand with respect to the six subscales identified by the NASA-TLX are presented in Table 5.19. Mean ± SD scores are presented with respect to ability group and ascent category.

Table 5.19 Mean ± SD scores for NASA-TLX subscales presented with respect to ability group and ascent category.

Ability group	*n*	Mental	Physical	Temporal	Performance	Effort	Frustration
Intermediate							
Successful	5	13.6 ± 2.2	13.8 ± 3.7	8.6 ± 5.1	15.8 ± 2.2	14.8 ± 1.6	10.6 ± 3.8
Unsuccessful	3	11.7 ± 7.5	15.0 ± 4.6	10.0 ± 8.2	10.0 ± 8.7	17.0 ± 2.6	16.3 ± 3.5
Competition	7	8.5 ± 5.0	9.0 ± 6.9	5.3 ± 5.9	9.2 ± 5.6	11.3 ± 7.0	9.7 ± 4.4
Total	**15**	**10.9 ± 4.9**	**12.5 ± 5.9**	**7.9 ± 6.0**	**12.0 ± 5.9**	**14.2 ± 5.2**	**11.0 ± 4.7**
Advanced							
Successful	9	7.1 ± 5.0	10.0 ± 5.6	5.6 ± 6.0	14.3 ± 2.5	10.7 ± 4.6	8.6 ± 7.9
Unsuccessful	3	15.3 ± 1.5	13.3 ± 4.7	8.3 ± 4.9	10.3 ± 4.5	15.3 ± 5.0	15.0 ± 0.0
Competition	10	8.2 ± 3.9	8.7 ± 4.9	7.7 ± 4.1	7.2 ± 5.7	12.1 ± 5.5	11.9 ± 3.7
Total	**22**	**9.0 ± 5.0**	**10.1 ± 5.2**	**7.1 ± 5.1**	**10.7 ± 5.2**	**12.2 ± 5.1**	**11.0 ± 5.9**
Elite							
Successful	4	7.5 ± 4.2	10.5 ± 5.2	7.0 ± 4.5	13.8 ± 4.6	10.3 ± 5.4	8.5 ± 2.9
Unsuccessful	3	9.7 ± 5.0	15.0 ± 1.7	4.0 ± 6.9	11.0 ± 6.6	15.0 ± 0.0	6.0 ± 3.6
Competition	5	10.0 ± 5.7	16.2 ± 2.2	5.8 ± 6.8	12.6 ± 2.9	15.0 ± 3.9	10.6 ± 6.6
Total	12	**9.1 ± 4.7**	**14.0 ± 4.1**	**5.8 ± 5.7**	**12.6 ± 4.2**	**13.4 ± 4.4**	**8.8 ± 5.0**
Combined							
Successful	18	9.0 ± 5.0	11.2 ± 5.1	6.7 ± 5.4	14.6 ± 2.9	11.7 ± 4.5	9.1 ± 5.9
Unsuccessful	9	12.2 ± 5.2	14.4 ± 3.5	7.4 ± 6.5	10.4 ± 5.9	15.8 ± 3.0	12.4 ± 5.5
Competition	22	8.8 ± 4.5	10.7 ± 5.9	6.5 ± 5.2	9.2 ± 5.3	12.6 ± 5.6	10.9 ± 4.6

A series of one-way between-groups ANOVA tests indicated that there were no significant differences (before correction for multiple tests) between ascent categories (successful, unsuccessful, and competition) with respect to ratings of mental demand ($F_{(2,46)}$ = 1.607, p = 0.212, partial Eta^2 = 0.065), physical demand ($F_{(2,46)}$ = 1.361, p = 0.267, partial Eta^2 = 0.056) and effort ($F_{(2,46)}$ = 2.116, p = 0.132, partial Eta^2 = 0.084). However, a significant effect for ascent category was indicated for ratings of performance ($F_{(2,46)}$ = 6.033, p = 0.005, partial Eta^2 = 0.208), which remained significant when a Bonferroni correction were applied (p = 0.04). Post-Hoc LSD showed that ratings of performance were significantly greater for the successful ascent category when compared to the unsuccessful (mean difference = 4.17, CI 0.29 – 8.04) and competition (mean difference = 5.07, CI 2.05 – 8.08). A one-way-between groups ANCOVA was conducted to compare ratings of temporal demand between ascent categories. Participants age, sex, height, mass, body fat percentage, HR_{max} and $\dot{V}O_{2max}$ were used as covariates in this analysis. Maximal HR and $\dot{V}O_{2max}$ were found to be significant covariates (HR_{max} $p = 0.046$, $\dot{V}O_{2max}$ $p = 0.021$), with partial Eta^2 values of 0.088 and 0.115 respectively. After adjusting for HR_{max} and $\dot{V}O_{2max}$ there was no significant difference between groups for ratings of temporal demand ($F_{(2,44)} = 0.422$, $p > 1.0$, partial $Eta^2 = 0.019$). The adjusted combined means (SE) for successful, unsuccessful and competition ascents were 6.1 (1.3), 7.4 (1.8) and 7.7 (1.1) respectively. Finally, a one-way between-groups ANCOVA was also conducted to compare ratings of frustration between ascent categories. Participants age, sex, height, mass, body fat percentage, HR_{max} and $\dot{V}O_{2max}$ were used as covariates in this analysis. Age was found to be a significant covariate ($p = 0.015$), with a partial Eta^2 value of 0.126. After adjusting for age there was no significant difference (uncorrected) between ascent categories for ratings of frustration ($F_{(2,45)} = 1.899$, $p = 0.162$, partial $Eta^2 = 0.078$). The adjusted combined means (SE) for successful, unsuccessful and competition ascents were 8.8 (1.2), 12.5 (1.7) and 11.1 (1.2) respectively.

5.4 Discussion

The aim of study two was to investigate differences in psychological and physiological responses of climbers with respect ability level and nature of a climbing task. In the first of two phases the pre, during and post-climb responses of intermediate, advanced and elite climbers were measured when attempting an on-sight ascent of a competition-style route. The route increased in difficulty and was set just beyond the upper limits of elite climbers' self-reported best on-sight grade (~26 Ewbank). This was in order to ensure that a fall from the route was highly likely, even for the elite climbers. It was hoped that participants would climb to the point of failure and as opposed to reaching the top of the route. Situational demand was also manipulated, with strict guidelines for route inspection, timing of ascent, and a prize incentive offered to encourage maximal effort. These conditions all served to promote a more competitive environment and style of ascent.

The anthropometric and physical characteristics of the participants recruited for the purposes of attempting a competition-style route in this study showed similar trends to those discussed in study one. However, in the absence of a lower-grade group, differences at the extremes of ability within this study were not as pronounced. Differences between the advanced and elite climbers were minimal; in fact elite climbers were shown to have a greater mass and slightly greater percentage body fat than the advanced group. These inconsistencies may be due to participant numbers, with only a limited number of participants in each ability group. Although no statistical analyses were conducted to assess both physical and fitness differences across ability groups, a trend in the data demonstrating an increase in $\dot{V}O_{2max}$ with greater climbing ability was observed. Although differences were small, the elite climbers were shown to have a greater $\dot{V}O_{2max}$ than both the intermediate and advanced groups. The $\dot{V}O_{2max}$ values reported for climbers in this study were comparable to those previously reported for 'recreational', 'high level', and 'experienced' climbers when assessed using a running test to exhaustion (Billat et al., 1995; Nicholson et al., 2007; Watts and Drobish, 1998)

Given the nature of the climbing task set, and the likelihood of a fall during ascent, an interesting finding of this study was that grouped pre-climb responses did not differ significantly between groups. Levels of pre-climb anxiety and self-confidence were measured by responses to the CSAI-2R questionnaire. Responses did not appear to vary greatly between ability groups prior to a competitive on-sight ascent. Despite a lack of significant difference across groups, elite climbers reported the highest levels of somatic anxiety pre-climb, coupled with the lowest score for cognitive anxiety. Levels of somatic anxiety are thought to refer to the physiological and affective elements of the anxiety experience that develop directly from autonomic arousal. Although differences between groups were non-significant these trends may demonstrate a greater perception of physiological arousal in elite climbers, which has previously been discussed earlier as a potential benefit to performance (Hardy et al., 1996; Jones et al., 1993; Parfitt et al., 1995). This greater perception of arousal may have been brought on by the situational demand owing to the competitive context. Sanchez et al. (2009) found that successful climbers reported higher pre-performance levels of somatic anxiety preceding elite competition, which was correlated with positive affect. As stated previously, no significant effects were observed in relation to ability group, yet these trends may suggest that as experience and technical ability increases, levels of cognitive anxiety, more commonly associated with worry or fear are diminished, yet a similar level of physiological arousal (as indicated by somatic anxiety scores) is maintained. This appears to support the previous findings of Sanchez et al. (2009) who found that successful elite sport climbers reported higher levels of pre-performance somatic anxiety than their unsuccessful counterparts. In addition, levels of somatic anxiety outweighed cognitive anxiety. High levels of arousal have also been shown to coincide with enhanced performance on physical tasks (Hardy et al., 1996; Jones et al., 1993; Parfitt et al., 1995). Jones (2003) discusses the impact of emotions such as anxiety on physical functioning and subsequent physiological arousal, stating that many athletes report that heightened levels of arousal facilitate best performance, particularly as the effects of somatic anxiety is thought to dissipate soon after activity commences .

Levels of perceived anxiety measured by responses to CSAI-2R in the current study were comparable to the range of scores reported in previous rock climbing studies incorporating varying styles of ascent (Draper et al., 2008a; Hodgson et al., 2008). However in comparing the ratings of somatic and cognitive anxiety prior to a competitive ascent in phase 1 to those obtained by Sanchez et al. (2009) during an elite climbing competition (Belgian climbing championships), levels of pre-climb cognitive anxiety were higher in the current study. These results may be attributed to participant ability range differences across studies. In the study conducted by Sanchez et al. (2009) levels of baseline ability were extremely high ranging from $7b^+$ to 8b, which when considered in relation to grade conversion tables presented in Table 3.3 is found to equate to ~ 26-31 Ewbank. Furthermore all participants included in their study were qualifying finalists in a national competition and were likely seasoned competitive climbers. In contrast although climbers classed as elite in the current study were of a high standard in terms of best on-sight, and had comparable redpoint ability, their involvement in the sport was largely recreational.

The levels of cognitive anxiety reported prior to ascent in the current study were found to be greater than those reported in the general population by Davids and Gill (1995). In reviewing levels of anxiety reported in other individual sports, perceptions of cognitive anxiety in the current study were found to be comparable to those reported by Filaire et al. (2009) for experienced tennis players prior to the first match in a tournament. However the level of competition was not specified by the authors making it difficult to draw comparisons. In contrast, levels of cognitive anxiety reported by high level field hockey players prior to matches which resulted in both victory and defeat were considerably higher (ranging from 29.57 – 32.57) than those reported prior to a competitive ascent in the current study (Aguilar et al., 2013). Nicholls et al. (2010) investigated CSAI-2R responses of 307 athletes who competed at varying levels of competition (beginner, club/university, county and national/international) across a range of both team and individual sports. In all instances, and when considered overall, levels of cognitive anxiety prior to competition in their study were higher than in the current study, with scores ranging from 21.2 (beginner) – 27.1 (national/international). The comparatively lower ratings of competitive cognitive anxiety in the current study may indicate that intensity of anxiety as measured by CSAI-2R may not be sensitive to varying levels of skill and individual nature of a single climbing performance. Alternatively the lower ratings of anxiety in the current study compared to other competitive contexts could be attributed to appraisals to simulated competition as opposed to an actual competitive event. Participants may not have placed a high degree of importance on the event or their performance as simulated competition would present low threat to social status or ego. In support of this is has previously been found that stress related appraisals evaluated by cortisol response pre-and post a simulated performance were significantly lower than at equivalent times during authentic public and competitive performances (Rohleder et al., 2007). In the current study Δ post-climb cortiol concentration appear to support a lack of stress response; particularly in advanced and elite participants with Δ values demonstrating little change pre and post-climb (Table 5.8).

Pre-climb physiological responses were examined by the assessment of HR and $\dot{V}O_2$ immediately prior to ascent. All ability groups showed similar responses, with mean HR marginally higher in advanced and elite groups. Although baseline resting HR was not measured in this study, it would appear that given the age, health status and fitness levels of the participants, the HR was considerably elevated prior to attempting the route. When expressed as a percentage of HR_{max}, pre-climb HR represented 57.9%, 61.1% and 60.1% for intermediate, advanced and elite groups respectively. Given the absence of any physical stress, this variability in HR response may be due to the perceived stressful conditions of the test. This may have resulted in variations of the activity of the parasympathetic nervous system (PNS) and/or activation of the sympathetic nervous system (SNS) which has previously been shown to occur in anxiety provoking situations (Cervantes Blásquez et al., 2009). The lack of significant difference in subjective ratings of anxiety across ability groups in this study, coupled with similar pre-climb HR responses suggest that the intensity of anxiety prior to attempting an on-sight ascent of a competition-style route were similar irrespective of ability level.

In the current study success or performance were determined by distance achieved on the test route, and ascent time. No successful ascents (reaching the top of the route) were achieved, with all participants climbing until the point of failure. It would appear that the aim of setting a route to provide an ascent which increased in difficulty to induce maximal effort whether in terms of technical demand or physical exhaustion was achieved. As anticipated, as a group the elite climbers performed best on the route, with all five participants in the group reaching the 5th climb phase, and two progressing to the 6th phase. However, in both the intermediate and advanced group a number of participants only managed to reach the 3rd or 4th phase of climb (see Table 5.7). One participant in the intermediate group reached the 6th phase of the climb, and two advanced climbers also achieved the same distance. In reviewing the breakdown of ascents with respect to ability groups, it appears that the route had two crux points, with the greatest number of falls occurring at the 3rd and 5th clipping stages. Route profile may have contributed to the difficulty at these points on the route, with a marked change in the route profile between the 3rd and 5th clip where the wall angle became steeper. Previous studies have suggested that increased angles of displacement result in greater physical difficulty owing to the increasing demand placed upon the upper body to support the weight of the climber (de Geus et al., 2006; Watts and Drobish, 1998). Therefore, increasing difficulty imposed by increasing angle of ascent, and resultant physical workload, may have contributed to point of failure, specifically among intermediate and advanced climbers.

Average HR and average $\dot{V}O_2$ measured across the duration of ascent to the point of failure was similar between groups, with no significant difference indicated for grouped average HR and average $\dot{V}O_2$. Values were ~ 25 mL·kg^{-1}·min^{-1} for all groups which is consistent with values reported in previous research during controlled bouts of rock climbing (Billat et al., 1995; Draper et al., 2008b; Draper et al., 2010; Mermier et al., 1997; Sheel et al., 2003). When expressed as percentage of HR_{max} and measured by running to exhaustion, intermediate (HR 85.4%, $\dot{V}O_2$ 55.6%), advanced (HR 87.1%, $\dot{V}O_2$ 53.7%) and elite (HR 86.8%, $\dot{V}O_2$ 56.1%) climbers remained comparable. As such, participants appeared to be working at the same intensity overall to the point of failure, yet distance climbed and duration of ascent varied suggesting the elite climbers may be have been more efficient in their ascent. In addition these contributions further highlight the disproportionate rise in HR for a given $\dot{V}O_2$ during rock climbing which has previously been reported among other rock climbing studies (Booth et al., 1999; Mermier et al., 1997; Watts and Drobish, 1998). This response was discussed in detail in study one and is thought to be the result of climbing technique (muscle recruitment), pressor response (metaboreflex), and possibly anxiety (Billat et al., 1995; Ferguson and Brown, 1997; Mermier et al., 1997; Watts and Drobish, 1998).

The average $\dot{V}O_2$ during competition-style ascents in this study were at the lower range of those in previous research, where averages of up to and above 30 $mL \cdot kg^{-1} \cdot min^{-1}$ have been reported (Bertuzzi et al., 2007; de Geus et al., 2006). The lower average $\dot{V}O_2$ during ascent for this competition-style route may be due to the lower relative physical demand in the initial phases of the route, particularly for the advanced and elite climbers. Here, as many climbers would have been ascending sub-maximally during the early phases, a large contribution from aerobic metabolism may not have been required during the initial climb phases. This lower work intensity seems probable as the studies of Bertuzzi et al. (2007), Sheel et al. (2003) and de Geus et al. (2006) all demonstrated that when climbers ascended routes graded below their estimated top-end ability, $\dot{V}O_2$ was lower compared to more difficult ascents.

Although the groups' average $\dot{V}O_2$ values in the present study were similar, a greater number of elite and advanced climbers were able to progress further and maintain longer ascent times, despite the workload intensity being similar overall. In reviewing the data for $\dot{V}O_2$ and HR during ascent averaged at each phase of the climb, it can be seen that the elite climbers showed lowest HR and $\dot{V}O_2$ through the initial climb phases of the route. This suggests that when climbing at a difficulty rating well below their maximum ability the elite climbers may have used a lower fraction of aerobic capacity, indicative of a more efficient ascent, particularly during initial sequences of the route. In support of this Bertuzzi et al. (2012) found that O_2 uptake during a specifically designed fit-climbing test did not differ significantly between elite and recreational climbers (8.4 ± 1.1 L versus 7.9 ± 1.5 L respectively). However, performance (distance climbed) was greater in the elite group compared to the recreational group. Bertuzzi et al. (2012) rated performance in terms of number of movements, with the elite group sustaining 120 ± 7 movements, compared to 78 ± 13 movements in the recreational group. Based on these findings the authors concluded that in the elite group the O_2 cost per move during climbing was significantly lower than the recreational group. In the latter phases of the climb in my study, and in particular with respect to the intermediate and elite groups, a sharp increase in $\dot{V}O_2$ was observed. This could be indicative in a shift to greater reliance on anaerobic energy production. In addition, it may be that an arm specific peak $\dot{V}O_2$ has been attained, as suggested by Billat et al. (1995). However, it should be appreciated that the averages reported in the final climb phases represent individual responses. This is because the nature of the competition route meant the number of climbers who reached this point on the route was limited.

Although not indicated as significantly different, BLa concentration measured immediately post-climb was greatest in the elite group, but lower and comparable in the intermediate and advanced groups. Post-climb BLa was above 4.0 $mmol \cdot L^{-1}$ in all groups indicating a degree of anaerobic energy production as suggested by (Billat et al., 1995). Mean Δ peak BLa for elite climbers was ~ 2 $mmol \cdot L^{-1}$ greater than the intermediate and advanced climbers. This greater BLa concentration measured post-climb in the elite group is in agreement with some of the higher BLa concentrations reported post-climb (de Geus et al., 2006; Watts et al., 2000; Watts and Drobish, 1998). This is likely to be indicative of a more sustained anaerobic contribution during the more difficult sections (crux) of the route. Previous research has indicated that more difficult ascents appear to increase the accumulation of BLa, particularly in routes which feature steeper angles of ascent (de Geus et al., 2006; Watts et al., 2000; Watts and Drobish, 1998).

The manipulation of grade in this instance was primarily achieved by the use of smaller and fewer handholds. At the upper sections of the route climbers may have been required to use a greater percentage of their maximal voluntary contraction (MVC) to maintain contact with the wall, coupled with increased time spent in isometric contraction. Studies have reported that trained climbers have a significantly higher MVC than other trained athletes, and untrained individuals. (Gajewski et al., 2009; Green and Stannard, 2010; MacLeod et al., 2007). MacLeod et al. (2007) suggested that climbers could be at a disadvantage when sustained contraction (endurance) is required; this is because occlusion of blood flow is likely to be increased with an increase in MVC. It has previously been shown that the closer the relative contraction/recruitment is to an individuals' MVC the shorter the sustainable effort, owing to restriction of blood vessels and increased occlusion (Barnes, 1980; Philippe et al., 2012). Here it may be beneficial to execute difficult sustained sections of a route more dynamically, moving quickly through difficult moves to avoid fatigue (Hörst, 2003), thus resulting in a potentially greater contribution from anaerobic energy production. Conversely increased time spent in isometric contraction owing to static time or the lack of opportunity for rest may also have contributed to large increases in BLa (Booth et al., 1999), these periods of inactivity may be represented in the greater ascent time for elite climbers (Table 5.5).

In conclusion, the observed trend suggestive of greater accumulation of BLa seen for elite climbers in this study could be indicative of increased anaerobic reliance, ischemic tolerance (lactate buffer capacity) and an offset pressor response based on time and intensity of the activity. It has been suggested that climbers may possess certain adaptations which are thought to facilitate sustained contractions, particularly for recovery during intermittent isometric episodes of work (MacLeod et al., 2007; Philippe et al., 2012). Such adaptations include increased pressor response, and a greater forearm vasodilatory capacity (Ferguson and Brown, 1997). However, Wright (2000) demonstrated that the positive effect exerted by pressor response, was removed when arms were extended above the head for particularly for long periods of time. During ascents climbers often choose particular points on the route to rest, often bringing the arms down to 'shake-out'. These short rest periods combined with enhanced vasodilatory capacity and pressor response evidenced in climbers are thought to enhance recovery (MacLeod et al., 2007; Philippe et al., 2012).

Given the increasing difficulty of the route, the elite climbers in the current study may not have been afforded the opportunity to rest. This coupled with greater muscle recruitment at an increased percentage of MVC used, and more sustained movement (based on ascent times) through difficult sections of the route, may have contributed to the higher BLa measured post-climb, with an increased reliance on anaerobic energy production. The ability of trained athletes to tolerate greater BLa accumulation at higher workloads has been well established in other activities (Gollnick et al., 1986; Stone, 1987). Given the nature of the ascent greater BLa post-climb in elite climbers could indicate a reduction in BLa clearance. The elevated BLa concentration in the elite group may also be attributable to a greater rate of lactate entry into the blood, as a result of higher muscle lactate to BLa concentration gradient, and an increased rate of lactate release from the muscle into the blood (Bishop et al., 2004). Although speculative given the lack of significant effect, the higher BLa, and greater performance observed for the elite group, compared to both the intermediate and advanced groups may be indicative of an enhanced tolerance afforded by improved buffering capabilities and an ability to cope with pain associated with cellular acidosis which is thought to be a contributing factor to fatiguing sensation. This could be indicative of desensitisation of afferent muscle nerves as suggested by Ferguson and Brown (1997).

Ratings of mental demand, physical demand and effort were not significantly different across groups, yet were found to be highest in the elite group, further supporting suggestion of a more physically exhaustive ascent. This is not surprising given the distance achieved, ascent time and BLa values reported for the elite group. All variables are indicative of increased physical effort compared to the intermediate and advanced groups. Ratings of physical demand were particularly pronounced in elite climbers, with mean score of ~ 16 as opposed to ~ 9 in for the intermediate and advanced groups. Plasma cortisol was also measured to provide an indication of physical stress during activity; however, the values reported do not appear to indicate a large response in any of the ability groups, with no significant differences observed. Given the high levels of BLa observed for elite climbers coupled with the responses given in relation to task demand it would appear that the elite climbers fell from the route due to physical exhaustion at maximal effort. In contrast, given the lower ratings of task demand in the intermediate group coupled with lower physiological responses it could be speculated that failure was due to a deficit in technical ability, or that lower-level climbers are perhaps not accustomed to producing maximal efforts during ascents.

In the second phase of this study differences in psychological and physiological responses were compared between ability groups, and with respect to the nature and outcome of ascent. This was achieved by examining difference in responses of climbers in a competitive context obtained in phase 1 with those exhibited by participants during successful and unsuccessful lead ascents in study one. The aim of this investigation was to see how unsuccessful climbers differed from those who succeeded by reaching the top of a route, and performances in a competitive context, where performance is rated by distance achieved on an ascent. It also served to compare the demands of a competition-style route which increased in difficulty, with ascents which were continuous and consistent in grade of difficulty. Typically studies investigating physiological and psychological responses to rock climbing have done so with respect to successful ascents exclusively, with emphasis being placed on reaching the top of a route. This emphasis placed on successful completion of a route in rock climbing appeared to be reflected in the ratings of performance in the current study, with significantly greater ratings of performance given with respect to successful ascents compared with both unsuccessful and competition-style ascents. It would appear that whilst climbers were aware that the competition route surpassed their ability level, they failed to rate performance relative to ability and may have only considered themselves successful if a full ascent had been achieved

Research which investigates the possible differences in psychological and physiological responses between successful ascents, unsuccessful ascents, and point of failure has not received much attention. The main findings of phase 2 of this study were that there was no significant interaction effect between ability groups and ascent categories for grouped pre, during and post-climb variables. As such, differences between respective successful, unsuccessful and competition ascents were similar regardless of ability level (intermediate, advanced and elite). There were no significant differences between ability groups for grouped pre, during and post-climb variables. However, there was a significant main effect indicated for ascent category (successful, unsuccessful, competition) for grouped variables during ascent, and post-climb. Given that differences between ability groups have largely been discussed already within this thesis, the discussion in relation to phase 2 focuses on differences in psychological and physiological responses between successful, unsuccessful and competition ascents.

In the current study, pre-climb variables were not investigated independently given the initial MANOVA analysis indicated no significant effect for ascent category. However, trends in CSAI-2R scores between categories of ascent within ability and combined ability groups presented areas for discussion. In both the intermediate and advanced ability groups, levels of cognitive anxiety were highest with respect to unsuccessful ascents, coupled with lower scores for self-confidence when compared with successful ascents. This trend was also reflected in combined mean ± SD scores; overall those who were unsuccessful reported marginally higher levels of cognitive anxiety and lower self-confidence prior to their ascent (Table 5.14). In a recent meta-analysis which examined the relative impact of cognitive anxiety and self-confidence upon sport performance Woodman and Hardy (2003) proposed that high self-confidence might protect cognitively anxious individuals from a drop in performance. Given that self-confidence has been conceptualised as one’s belief in meeting the challenge of the task to be performed (Martens et al., 1990), the findings in phase 2 may be indicative of the potential role of other emotions alongside anxiety as a determinant of successful performance as has already been highlighted and discussed in relation to the results obtained in study one. Woodman and Hardy (2003) also suggested that at higher ability levels the effect of self-confidence in relation to cognitive anxiety will be clearer as a greater degree of control over personal environment is likely. Interestingly, in the elite group, levels of cognitive anxiety pre-climb were surprisingly consistent for all ascent categories, ranging from 14.5-15.3. In contrast, self-confidence pre-climb in the elite group was notably lower prior to unsuccessful ascents (Table 5.4). These findings suggest that in the current study, self-confidence prior to ascent may have moderated success in higher ability climbers where intensity of anxiety remained similar. The scores reported in the current study appear to highlight the moderating role of self-confidence upon athletic performance and possible limitations and inadequate nature of ratings of intensity of anxiety alone. This reinforces the idea of 'interpretation of anxiety' and the presence of a directional 'facilitative' anxiety response as proposed by Jones et al. (1993) discussed earlier in relation to results presented in study one.

In the current study measures used to determine potential physiological differences prior to ascents were $\dot{V}O_2$ and HR. Although pre-climb HR was considerably elevated above resting levels (> 100 $bts \cdot min^{-1}$) for all ascents, the combined mean ± SD pre-climb HR for successful, unsuccessful and competition ascents were similar (Table 5.3). However, pre-climb HR for unsuccessful participants was greater than those recorded prior to both successful and competition ascents in the advanced and elite groups. Given the lower self-confidence reported for unsuccessful ascents, the slightly higher pre-climb HR responses may be manifestations of anxiety coupled with the lack of belief in being able to complete the ascent. In both the advanced and elite groups, the mean ± SD on-sight and redpoint grades were lower in unsuccessful climbers compared to successful climbers. Table 5.11 indicates that this discrepancy in ability between those who were successful and unsuccessful was up to two grades with respect to redpoint ability. This difference in top-end redpoint ability may have contributed to a decreased self-confidence, and belief in their ability to succeed on the ascent. This may have resulted in heightened pre-climb anxiety response owing to greater negative impact of cognitive anxiety without the moderating effect of higher self-confidence.

Although no significant differences between ascent categories were indicated for average HR, mean ± SD values were greater during unsuccessful ascents (Table 5.16).

This was despite the shorter ascent times (~ 30 s compared to successful ascents) and the shorter distance climbed. Average HR for successful, unsuccessful and competition ascents were found to correspond to 86%, 92% and 87% of maximum respectively. The fractions of maximum HR indicated that the unsuccessful ascents represented some of the highest values reported in literature to date (Billat et al., 1995; Janot et al., 2000). Elevated HR responses (>90% of HR_{max}) have typically been observed with an increase in route difficulty, particularly with respect wall profile (overhanging ascents) or in lower ability levels (beginner climbers). Average $\dot{V}O_2$ during ascent for successful unsuccessful and competition ascents was found to represent 63%, 65% and 54.9% of $\dot{V}O_{2max}$ respectively. In order to further investigate the HR and $\dot{V}O_2$ responses during ascents, the averaged data for each climb phase with respect to ascent category are presented in Figure 5.2 and Figure 5.3 respectively. The numbers of studies to have presented continuous HR and $\dot{V}O_2$ responses during rock climbing in this way are limited (Bertuzzi et al., 2007; de Geus et al., 2006; Watts et al., 2000). In the current study a leveling off of $\dot{V}O_2$ was seen during ascents, with only modest differences between successful and unsuccessful ascents. The only study to evidence a similar plateau in $\dot{V}O_2$ response as those seen in the my study was in an investigation conducted Watts et al. (2000). The authors reported that most subjects in their study evidenced a leveling off of $\dot{V}O_2$ during ascents. Furthermore, this was not thought to be representative of values above a maximal steady-state (~ 31.9 $mL \cdot kg^{-1} \cdot min^{-1}$). However, significant increases in BLa between pre-and post-climb coupled with large recovery net $\dot{V}O_2$ suggested that a true metabolic steady state was not attained. As such the authors failed to draw conclusions as to whether or not a steady-state was attained or a climbing specific $\dot{V}O_2$ limitation was present.

A number of studies have suggested that the upper body is the primary contributor to work during rock climbing, with a lack of increase in $\dot{V}O_2$ during the latter part of the ascent thought to be due to attainment of an arm specific peak $\dot{V}O_2$ (Giles et al., 2006; Sheel, 2004; Watts, 2004). This is not surprising given that studies such as those conducted by Bertuzzi et al. (2007) and Pires et al. (2011) have shown peak $\dot{V}O_2$ during upper body exercise to exhaustion in climbers to be ~ 36 mL·kg·min, which is lower than values obtained during cycling or running to exhaustion (see Table 2.8). In the current study $\dot{V}O_2$ was shown to peak and level off between 35 and 45 $mL \cdot kg^{-1} \cdot min^{-1}$ during successful and unsuccessful ascents. These values are comparable to those reported for advanced level climbers (Ability 21-23 Ewbank) in a climbing specific test to exhaustion (Booth et al., 1999). Furthermore, in a similar manner to that reported by Watts et al. (2000), large increases in BLa post-climb were evidenced (Figure 5.4). These results may be more indicative of a $\dot{V}O_2$ limitation as opposed to steady-state being achieved during ascent, as suggested by (Watts et al., 2000).

In the current study modest increases in $\dot{V}O_2$ during ascents and relatively comparable fractions of $\dot{V}O_{2max}$ utilised in successful and unsuccessful ascents were accompanied by differing HR responses. Whilst the HR response during successful ascents appeared to level off in a similar manner to $\dot{V}O_2$, during unsuccessful ascents, a continued increase in HR to the point of failure was seen. Although no statistical analysis were carried out with respect to this data, the descriptive data provided would appear to suggest that unsuccessful climbers ascended the route at a relatively higher intensity with respect to HR. This was also reflected in the trends in ratings of task demand post-climb, with unsuccessful climbers reporting that the climb required greater effort and greater physical demand compared to their successful counterparts. Further to this, average $\dot{V}O_2$ was not significantly different between successful and unsuccessful ascents, and post-climb BLa concentrations were similar for both ascents. It would therefore appear that successful climbers may have been able to complete the route using a similar fraction of maximal aerobic capacity and anaerobic energy contributions. Given the increased duration and distance reached during successful ascents, these results suggest that the successful climbers may have climbed more efficiently during their ascents. This may be explained by skill level and resultant mechanical parameters of climbing performance as discussed by Fuss and Niegl (2006). In their study the authors utilised an instrumented climbing hold in order define the mechanical parameters of climbing and analyse performance. Findings demonstrated that more experienced climbers showed smaller contact forces, shorter contact time, smaller impulse, higher friction coefficient and a more continuous movement of the centre of pressure exacted upon a hold. These factors are thought to result in an improved consistency of motion, with gripping technique becoming more secure and precise. Furthermore, grip force is applied more economically and at a required level as opposed to being excessive.

Although not examined directly in the current study, more efficient ascents may have been achieved by minimising immobilisation and isometric contraction during ascents. This suggestion is supported by the findings of Booth et al. (1999) who reported that that in the absence of repeated isometric contractions during continuous ergometer climbing, more work was performed before BLa reached similar concentrations to those observed in outdoor climbing. More specifically during continuous ergometer climbing a distance of 40 m was achieved compared to 24 m on an outdoor route for a BLa value of 4.5 $mmol \cdot L^{-1}$. The increased HR response during unsuccessful ascents in my study may be an indicator of a similar interaction, as time spent in isometric contraction has been shown to increase HR responses owing to an increased activation of the metaboreflex (Barnes, 1980; O'Leary et al., 1999; Watts and Drobish, 1998). In further support of this Watts et al. (2000) suggested that reduced presence of metaboreflex would be expected where climbers spent less time in isometric contraction, possibly with the aid of rests on route.

The HR and $\dot{V}O_2$ responses during the competition ascents differed to successful and unsuccessful ascents. Average $\dot{V}O_2$ during the competition ascent was significantly lower than successful and unsuccessful ascents. This was anticipated with respect to successful ascents due to greater distance and time spent ascending the route. However, the significant difference in $\dot{V}O_2$ between unsuccessful and competition ascents were surprising, particularly as distance achieved to point of failure, and ascent times were comparable (Table 5.15). As discussed in relation to phase 1 of study two, this may be due to the lower work intensity during the initial phases of the competition ascent, with climbers working sub-maximally given the lower grades of difficulty. Similar results were observed by (Bertuzzi et al., 2007) with elite climbers being able to ascend an 'easy' route with considerably lower contributions from aerobic and anaerobic energy systems when compared to a 'difficult' ascent.

During the competition ascent, percentage of maximal $\dot{V}O_2$ utilised was approximately 10% lower than successful and unsuccessful ascents of a continuously graded route at the limits of relative ability level. The competition route was designed to induce maximal effort to point of failure relative to ability. However, the lower average $\dot{V}O_2$ during ascent compared to that observed during ascents of continuous grade, may be indicative of a technical limitation to performance as opposed to physical exhaustion. More specifically, as the route increased in difficulty climbers may not have been subject to a sustained physical effort which would warrant a greater fraction of aerobic capacity, but lacked the ability to execute more technical moves to progress. This is also reflected in BLa concentration post-climb, particularly with respect to the intermediate and advanced climbers where Δ BLa post-climb for competition ascents are lower than those reported with respect to the consistently graded route. The suggested lack of sustained physical effort could be further supported by trends observed for NASA-TLX scores. Although not significantly different, lower ratings of physical demand and effort were given in response to attempting the competition ascents by both intermediate and advanced groups, and overall in combined ratings reported for successful, unsuccessful and competition ascents (Table 5.19).

5.5 Perspectives

Psychological and physiological responses prior to attempting an on-sight ascent of a competition-style route did not differ between intermediate, advanced and elite climbers. Perceptions of cognitive and somatic anxiety prior to ascent did not differ significantly between ability groups, this was surprising given that for lower ability climbers ‘failure’ in the form of a fall was inevitable given the difficulty of the route. Levels of somatic anxiety were highest in the elite group; greater somatic anxiety prior to competition has been shown to relate to positive affect and greater success. Lack of difference in anxiety response between groups may due to participants rating intensity of anxiety alone where influence of other emotions not evaluated may be more influential. Alternatively the lack of difference in perceptions of anxiety in relation to differing ascents and varying skill level may further highlight the ambiguous and possibly inadequate role of CSAI-2R in determining levels of anxiety to a single on-sight ascent.

Average HR and $\dot{V}O_2$ measured during competition-style ascents to the point of failure were similar between ability groups, even when expressed as a percentage of HR_{max} and $\dot{V}O_{2max}$. These results indicated that all climbers completed their ascents at the same relative intensity regardless of ability level. However given the greater distance and ascent times for the elite group it may be that they were ascending the earlier easier phases of the climb sub-maximally. Here a lower O_2 cost due to a more efficient climbing style at lower grades of difficulty is thought to have occurred.

Blood lactate concentration post-climb was greater (although differences were non-significant) for the elite climbers. I believe this to be representative of a more sustained and physically exhaustive ascent during the more difficult sections of the competition route. Furthermore the greater BLa concentration could be attributed to a greater duration spent in isometric contraction. I speculate that this may demonstrate high BLa tolerance in elite climbers who are perhaps more accustomed to maximal efforts during ascent. This was also reflected in ratings of task demand as identified by post-climb ratings obtained via the NASA-TLX. The lower BLa concentrations for intermediate and advanced groups overall, coupled with lower ratings of task demand could also be indicative of a technical limitation, as opposed to a physically exhaustive ascent.

The second phase of this study investigated differences in psychological and physiological responses between route type and successful and unsuccessful ascents. Some interesting trends which appear to warrant further investigation were observed. Although non-significant, higher levels of cognitive anxiety coupled with lower self-confidence appeared to coincide with unsuccessful ascents. Self-confidence appeared to be a greater moderator of success as opposed to ratings of intensity of anxiety. Specifically in the elite group where scores for cognitive anxiety were comparable for all ascents, yet self-confidence was considerably lower for unsuccessful ascents.

For successful and unsuccessful ascents on a route continuously graded at the upper limits of ability level, a leveling off of $\dot{V}O_2$ response was observed. In addition, average $\dot{V}O_2$ during these ascents was found to relate to similar fractions of $\dot{V}O_{2max}$. Taken together with BLa responses post-climb, I think this may indicate the presence of a climbing specific $\dot{V}O_2$ limitation, possibly owing to a greater reliance on the upper body during rock climbing. Heart rate responses of successful climbers were also shown to plateau in a similar manner to $\dot{V}O_2$. In contrast HR responses during unsuccessful ascents continued to increase in linear fashion, until point of failure. Average HR during unsuccessful ascents were found to be > 90% of HR_{max} assessed by running to exhaustion. This greater disproportionate HR - $\dot{V}O_2$ relationship during unsuccessful ascents, coupled with high levels of BLa post-climb, may indicate a less efficient ascent owing to increased time spent in isometric contraction resulting in increased activation of the muscle metaboreflex.

Ascents to the point of failure on the competition route resulted in significantly lower average $\dot{V}O_2$ compared to both successful and unsuccessful ascents, despite ascent times and distance climbed being similar to unsuccessful ascents. In addition, BLa concentration was lowest overall in response to the competition ascent. These findings further highlight both the sub-maximal workload associated with lower grades of difficulty and the greater contributions of aerobic and anaerobic energy systems required during difficult ascents.

Chapter 6
General Conclusions

A small number of studies have investigated determinants of successful climbing performance, embracing a cross-disciplinary approach; incorporating the measurement of both psychological and physiological responses to rock climbing. Although research of this nature is limited given its the relative novelty, previous studies have suggested that there may be differences in the psychological and physiological responses to rock climbing based on style of ascent. Significant differences in plasma cortisol concentration and pre-climb anxiety have been reported for intermediate climbers in a comparison of lead climbing, second ascent, and top-roping. Furthermore, significant differences in somatic and cognitive anxiety coupled with elevated in HR and $\dot{V}O_2$ responses pre-climb and during ascent for intermediate climbers during on-sight, and pre-practiced ascents have also been observed. These findings appear to highlight the differing psychological demand imposed by varying styles of ascent, and the possible interaction with resultant physiological responses which together underpin overall performance. However, characterizing the psychological and physiological responses to rock climbing relative to differing ability level is at present largely speculative. Whether psychological and physiological responses to specific bouts of rock climbing differ based on ability level and ascent style is not known. Typically previous studies have investigated the responses of successful climbers, focusing only on those who reach the top of a designated route as opposed to reaching a point of failure. Whether successful climbers differ in their responses compared with those who fall from a route is not an avenue of research which has been given much consideration

The purpose of study one was to investigate psychological and physiological responses to difficult on-sight rock climbing with respect to four ability categories (lower-grade, intermediate, advanced and elite), and two styles of ascent (lead and top-rope). The results from study one indicated that there were no significant differences between ascent styles for pre-climb variables (HR, $\dot{V}O_2$, somatic anxiety, cognitive anxiety, self-confidence and Δ pre-climb cortisol). The lack of significant difference between ascent styles for pre-climb variables, more specifically perceptions of anxiety was somewhat surprising. Previous studies have identified significant differences in anxiety response based on differing styles of ascent which were manipulated to evoke low and high stress conditions. As such an interesting finding of the current study is the suggestion that irrespective of ascent style difficult on-sight climbing elicits similar levels of pre-climb anxiety across all levels of ability. This was unexpected, particularly with respect to the lower-grade ability group where it is suggested that the discrepancy between perceived and actual risk is greatest. Furthermore experience did not appear to have a mediating effect on Δ pre-climb cortisol concentration in the current study, suggesting that elite climbers do not exhibit a habituated physical response to stress induced by on-sight rock climbing. These findings appear to indicate that an unknown on-sight ascent results in similar psychological and physiological stress responses irrespective of ability level.

Average $\dot{V}O_2$ was significantly higher during ascents in the elite group when compared to both the lower-grade and advanced groups, suggesting a greater contribution from aerobic metabolism. However when expressed as a percentage of $\dot{V}O_{2max}$ all ability groups appeared to be utilising similar fractions of maximal capacity during ascents relative to best on-sight ability. This was also true with respect to HR response. As such it would appear that elite climbers were able to successfully ascend more difficult routes at the same intensity as lower-grade climbers during their respective ascents. My findings suggest that during successful on-sight ascents of routes set relative to top end ability $\dot{V}O_2$ may not be directly related to climb difficulty or personal ability, possibly identifying the existence of a climbing specific $\dot{V}O_2$ limitation. In this instance other factors may contribute to climb demand and execution of a successful ascent, factors such as technical and tactical decisions, personal climbing style and skill. In support of this, ascent times did not differ significantly between ability groups, however a significant main effect was indicated for ascent style. In all but the elite group, climbers completed top-rope ascents significantly faster than lead ascents, demonstrating the possibility that elite climbers may have ascended the route in a similar manner regardless of ascent style, indicating a more considered style of ascent. Finally, BLa concentrations measured post-climb in advanced and elite climbers appeared to identify an enhanced rate of recovery. Taken together the findings obtained from study one suggest that a technical advantage, coupled with possible physiological adaptations gained with increased experience, training, and exposure may contribute to more efficient ascents thus affording higher level climbers with the capacity to climb routes with higher grades of difficulty, whilst exacting similar physical demand.

The purpose of study two was (1) to investigate whether psychological and physiological responses to competition-style climbing differed with respect to ability level, and (2) to investigate psychological and physiological differences based on route type and outcome (success and failure). Results from study two suggested that during competition-style ascents the intermediate and advanced climbers were limited by technical ability as opposed to physical exhaustion or increased anxiety. Elite climbers appeared to be able to maintain a more sustained physical effort during the more difficult phases of the climb. This was reflected in their greater BLa concentration reported post-climb and considerably higher ratings of task demand with respect to both physical demand and effort. I think that these observations also reflect the possibility of an increased tolerance to BLa accumulation in more experienced climbers. Furthermore I speculate that this may contribute to a greater capacity to tolerate maximal physical effort as exhibited by the elite climbers. In a similar manner to study one, average $\dot{V}O_2$ to the point of failure was similar when expressed as a percentage of $\dot{V}O_{2max}$ irrespective of ability level. My results suggest that elite climbers were ascending the earlier easier phases of the climb sub-maximally, with a potentially lower O_2 cost per movement resulting in a more efficient ascent.

Although differences between ascent categories for pre-climb variables were non-significant, trends implicating higher levels of cognitive anxiety coupled with lower self-confidence prior to unsuccessful ascents were observed. Based on these trends I suggest that self-confidence; the belief in meeting the challenge of the task may have moderated success. This moderating effect was most pronounced in the elite group where perceptions of cognitive anxiety were similar for successful, unsuccessful and competition ascents, yet self-confidence was notably lower prior to unsuccessful ascents. This finding was evident in reviewing ascent categories both within ability groups and as combined totals.

In the second study, modest increases in $\dot{V}O_2$ in the latter climb phases during ascents, and similar fractions of $\dot{V}O_{2max}$ utilised were accompanied by differing HR responses for successful and unsuccessful climbers. Heart rate during successful ascents was shown to plateau in a similar manner to $\dot{V}O_2$. In contrast, HR responses during climb phases throughout unsuccessful ascents continued to increase in a linear fashion until point of failure. This differing HR - $\dot{V}O_2$ relationship during unsuccessful ascents could be attributed to increased time spent in isometric contraction resulting in increased activation of the muscle metaboreflex. Coupled with similar BLa concentrations post-climb for successful and unsuccessful ascents, one possibility is that an attainment of a climbing specific $\dot{V}O_2$ limitation was reached. Furthermore, significantly lower $\dot{V}O_2$ during ascents of the competition route compared to successful and unsuccessful ascents, reinforces the suggestion that a greater physical demand is imposed when climbing routes relative to the upper limits of ability.

6.1 Findings summary

- Pre-climb anxiety response to difficult on-sight climbing does not appear to differ between ability groups or with respect to style of ascent.

- Although average $\dot{V}O_2$ was significantly higher during ascents for elite climbers, when expressed relative to maximal aerobic capacity all ability groups completed their respective ascents at the same relative intensity.

- Ascent times were not significantly different between lead and top-rope ascents for the elite group. This may be suggestive of a more considered style of climbing which is not influenced by ascent style.

- Elite climbers performed better during competition ascents whilst climbing at the same relative intensity as intermediate and advanced climbers with respect to $\%HR_{max}$ and $\%\dot{V}O_{2max}$.

- Trends in scores for cognitive anxiety and self confidence prior to successful and unsuccessful ascents may be indicative of a moderating role of self-confidence upon success and failure.

- Unsuccessful climbers exhibited a greater HR response during ascent, yet a similar plateau in $\dot{V}O_2$ response as seen for successful climbers, suggestive of a climbing specific $\dot{V}O_2$ limitation.

6.2 Future research

- Whether a learning effect or habituated response can be observed for psychological and physiological responses to multiple on-sight ascents, and how this differs with respect to ability level.

- The use of different measures to assess the psychological component of performance in rock climbing. Areas of interest may include, but should not be limited to task appraisals, directional interpretations of emotion and affective state.

- Investigating the psychological and physiological responses to multiple ascents of the same route.

- Investigating the psychological and physiological responses to a sequence of ascents graded below and above best self-reported ability.

- Further research which seeks to identify and quantify factors of performance relating to climbing style and/or economy with respect to ability level is of further interest.

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