Bangor University

DOCTOR OF PHILOSOPHY

Focus of attention and anxiety's respective effect on motor control

Owen, Robin

Award date:
2020

Awarding institution:
Bangor University

DOCTOR OF PHILOSOPHY

Focus of attention and anxiety's respective effect on motor control

Owen, Robin

Award date:
2020

Awarding institution:
Bangor University

Focus of attention and anxiety's respective effect on motor control

PRIFYSGOL BANGOR UNIVERSITY

School of Sport, Health, and Exercise Sciences

Author: Robin Owen

Contents

Acknowledgements

Wow, I am not sure what to say! There are so many moments and so many people that have influenced me, and I don’t know where to start. I guess I want to thank everyone I have ever met. Both the good and the bad experiences have helped me get to where I am now.

Danke Mama und Papa. Ich habe Glück das ihr meine Eltern seid. Danke Timon das du mein Bruder bist. Vielen Dank an meine Familie und Freunde die es eine Freude machen Österreich zu besuchen.

Diolch Ieuan, Rhys, and Iwan (Y Laddington Bears) am fod yn ffrindiau am byth.

Diolch Tony Jones am popeth.

Deiniol Davies, Clare McDermott, Ian Jones, Caroline Davies, and Vaughn Jones, thank you for being amazing secondary school teachers. You taught me the most valuable lesson of them all, that you can learn anything with the correct approach and persistence. Without you I would have never gained the confidence to make the most of university.

Thank you Aled, Callum, Tom J, Tom R, Aaron, Paul, Scott, Josh, Gwion, Gene, Rich, and Ryan for making my degree years brilliant fun! I am glad we haven’t lost touch and am looking forward to our next catchup.

Dior and Dan (and Joe whom we have unofficially adopted), thanks for making the George Building gossip corner the best office to do a PhD in. Thank you Eduardo, Shuge, Seamus, Nuria, and Turki for making PhD life awesome.

Ben Jones, ti yn through-and-through legend. True Welshman, Gentleman, a Ladiesman! Diolch yn fawr i ti am y proofread a more importantly am fod y math o ffrind mae pawb angen yn eu bywyd. Gobeithio wnawn ni byth managio yfed mwy na 19 shots mewn un noson! That’d be the end of us.

Thanks to all the staff at the School of Sport, Health, and Exercise Sciences Bangor. Tim, Kev, Stu, Jen, Jess, Eleri, Hans, Julian, Sam, Mark, Jamie, James, Amy, Dave, Jonathan, Lew, and Ross, you’ve been the most friendly, caring, and incredible group of academics. Sarah Trotman, Gethin Thomas, Ant Blanchfield, and Andy Cooke, thank you for being especially amazing.

Shaun Mckiernan, you’re one of the most caring and awesome people I know. Thank you so much for all of your invaluable help during my PhD!

Gavin Lawrence, thank you so much for everything. I’ll never forget when you suggested I should consider a PhD… when I was only just starting my 2nd-year undergraduate project proposal! Haha! You set me on this path and without you I am certain I’d be doing something I enjoy much less. You always make time when people need you most, and you forgive the most stupid errors. Thank you so much.

Vicky Gottwald, a hero is defined as “a person who is admired for their courage, outstanding achievements, and noble qualities”. This is you. You make such a big difference to people’s lives. Thank you so much for being amazing.

If there is anyone I forgot to mention, I am truly sorry. Thank you for being part of my life.

And to finish, my love Emily, words cannot do you justice. I can’t wait to sip on mojitos and watch movies tonight!

Work from this thesis

Published

Gottwald, V. M., **Owen**, R., Lawrence, G. P., & McNevin, N. H. (2019). An internal focus of attention is optimal when congruent with afferent proprioceptive task information. Psychology of Sport and Exercise, 47, 101634.

Additional research conducted and included in this thesis

Lawrence, G. P., **Owen**, R., Gottwald, V. M., Khan, M. A., & Allsop, J. E. (in preparation). Online Motor Control is not Completely Automatic: A comprehensive test of heightened state anxiety's effect on movement planning and correction.

Lawrence, G. P., **Owen**, R., & Gottwald, V. M. (in preparation). Anxiety's influence on movement planning and correction under conditions of no-vision.

Additional research conducted but not included in this thesis

Owen, R., Gottwald, V. M., & Lawrence, G. P. (in preparation). Do foci of attention help or hinder the one-target advantage?

Owen, R., Lawrence, G. P., & Gottwald, V. M. (in preparation). Which is worst for self-control? A comparison of three transcription-based ego-depletion methodologies.

Owen, R., Blanchfield, A. W., & Gottwald, V. M. (in preparation). Predicting undergraduate students' learning from a lecture: The role of state self-control, motivation, and mental effort.

Chapter 1: Thesis Overview

1.1 Thesis Format

This thesis comprises a literature review, three experimental chapters, and a general discussion. The research chapters are written as standalone publications and therefore, because of their related nature, feature a degree of repetition. Abbreviations are defined anew in each chapter to facilitate readability. All chapters follow American Psychological Association (APA) Style (6th Ed.) guidelines on formatting and referencing (American Psychological Association, 2010). References for all chapters are listed at the end of the thesis. Figure, table, and footnote numbering is restarted in each chapter. Co-authors are listed in the ‘work from this thesis’ section.

1.2 Thesis Abstract

This body of work investigated the (separate) effects of focus of attention and cognitive anxiety on offline planning and online correction motor control mechanisms. We assessed planning and correction processes via variability profiles of computer-based target-directed aiming movements (Khan et al., 2006), captured on either a two-dimensional tablet or three-dimensional Vicon motion capture system. Experimental Chapter 1 investigated heightened anxiety’s effect on offline movement planning and online movement correction using trajectory variability and cursor perturbations to directly test whether strategic trade-offs reduce online corrections under heightened anxiety. This effort was complemented by attempts to tease apart the therein roles of conscious processing (i.e., reinvestment) and distraction (i.e., cognitive overload) by measuring trait conscious processing propensity and manipulating cognitive resources. Results suggested online corrections are reduced under heightened anxiety when the need for correction is low (i.e., in normal trials) but increased if the need for correction is great (i.e., in perturbation trials). High reinvestment propensity positively predicted online-to-offline strategy shifts in normal trials, and depleted cognitive resources reduced online corrections in normal and perturbation trials. Experimental Chapter 2 investigated the effect of heightened anxiety on offline planning and online control when vision was unavailable and

proprioception was the sole source of relevant afferent information. Results revealed no significant differences in the efficacy nor prominence of offline planning and online correction. It was concluded that the distraction and conscious processing mechanisms associated with heightened anxiety may not impair the planning and correction of movements when based primarily on proprioceptive afferent information. Experimental Chapter 3 explored a different research domain, by investigating the effect of internal (i.e., body) and external (i.e., environmental movement effect) foci of attention on offline movement planning and online movement correction. Proprioceptive salience was manipulated across this chapter's experiments to also test whether the proposals of the constrained action hypothesis hold true when only an internal focus of attention was congruent with task-relevant afferent feedback. Results suggested that an internal focus of attention is optimal for outcome performance when congruent with afferent proprioceptive information, and that these effects originate within offline movement planning. Overall, the present thesis provides substantial clarification concerning offline and online motor control's role in outcome performance-centric anxiety and focus of attention literature.

Chapter 2: Literature Review

2.1 Target-directed Aiming

Working memory comprises four key components facilitating cognitive and motor functioning (Baddeley, 2001). The first and hierarchically uppermost component is the central executive. This is proposed to be responsible for planning, strategy selection, and attentional control. Second is the phonological loop which provides short-term phonological storage and rehearses verbal information. Third is the visuo-spatial sketchpad which is a temporary storage for visual and spatial information. Lastly is the episodic buffer which provides a link between the aforementioned components and long-term memory. The central executive is of particular relevance to target directed aiming since its attentional control forms the gateway between environmental stimuli and working memory (Carrasco, 2011; Knudsen, 2007). The central executive's top-down goal-driven system directs attention to relevant environmental stimuli whilst inhibiting attention allocation to impertinent stimuli. However, this system is in competition with the stimulus-driven system which reflexively shifts attention to stimuli that are unexpected or particularly salient. Balancing of top-down and bottom-up-based attention allocation is particularly important for motor performance because the functions comprising working memory are limited in capacity (Baddeley, 1986).

An individual attempting a target-directed aiming movement must plan appropriate motor commands before movement initiation (i.e., offline) and correct for any errors in planning during movement execution (i.e., online) (Woodworth, 1899). Offline movement planning entails the individual firstly determining their desired outcome (e.g., to hit the target) and using attention to accurately assess the initial conditions (e.g., distance, terrain, and temporal requirements) (Schmidt, 1975). Based on these factors, the individual must then select an appropriate generalized motor program (i.e., the programme controlling the class of actions) and use knowledge from previous outcomes and their response specifications (i.e., the absolute force, absolute time, and effector used) to select appropriate response specifications for the present movement (Schmidt, 1975; Wallace, 1981). Once an appropriate response has been determined, an efference copy of the response specification is made, the motor commands are sent to the effector muscles, the movement is initiated, and expected sensory consequences are generated (Schmidt, 1975).

Due to its top-down nature, offline planning requires cognitive resources (i.e., effort and attention) to be executed both quickly and effectively (Hick, 1952; Henry & Rogers, 1960; Rosenbaum, Loukopoulos, Meulenbroek, Vaughan, & Engelbrecht, 1995; Glover & Dixon, 2001; 2002). For example, Glover and Dixon (2002) demonstrated that movements' planned spatial characteristics are affected by the conscious perception of writing printed on to-be-grasped objects. When "LARGE" was printed on the objects, grip aperture was increased early in movement. When "SMALL" was printed on the objects, grip aperture was decreased early in movement. Since early spatial movement features are primarily determined by planning processes, this finding provided evidence for offline planning's top-down cognitive nature (see also, Glover and Dixon 2001). Similarly, quickly planning complex movements (Henry & Rogers, 1960) or quickly planning an appropriate response out of numerous alternatives (Hick, 1952; Hyman, 1953) has been shown to require more time (i.e., reaction time) because of greater cognitive demands. In sum, providing further evidence to support offline planning is effortful and attention-demanding in nature.

Following movement planning and movement initiation, an individual has to control their movement online. Woodworth's (1899) two-component model of limb control was the first to explicate the phases comprising human movement control. In his seminal study, Woodworth had participants move a pencil back and forth between two continuous vertical lines on a rotating piece of paper. Movement time (by requiring participants to move between targets in sync with a metronome) and vision (by requiring participants to open / close their eyes) were concurrently modified. Woodworth observed that participants' movements initially featured a ballistic component designed to get the pen close to the target area (i.e., an initial adjustment), followed by a slower homing in component which utilised visual feedback to hit the target (i.e., concurrent control). Interestingly, when movements were rapid because metronome intervals were short, there was no difference between eyes-open and eyes-closed conditions; neither exhibited concurrent control. This led Woodworth to conclude that movements generally comprise of two components, an initial impulse and concurrent control, and that sufficient time is necessary for visual feedback to be processed for concurrent control. Although the two-component model of limb control has since been refined (see, Elliott et al., 2010; 2017; Keele, 1968; Meyer, Abrams, Kornblum, Wright, & Smith, 1988), many of its suggestions still form the foundation of contemporary aiming and movement literature.

One of the most recent and comprehensive refinements of Woodworth's (1899) two component model is the multiple process model of Elliott and colleagues (2010; 2017). Specifically, it is proposed that the initial impulse is not entirely ballistic because there are three phases of online control (two of which occur during the initial impulse). Firstly, the initial impulse may be corrected online if there is a mismatch between the efference copy and the efferent outflow (e.g., because of noise in the motor system). Secondly, the initial impulse may be controlled further if there is a mismatch between the expected sensory consequences and the early dynamic properties of the limb (inferred via peripheral vision and proprioception). Thirdly, and in line with the concurrent control phase of Woodworth's model, as the limb nears the target and central vision, the individual can initiate limb-target online control if feedforward models suggest the current dynamic properties of the limb are unlikely to hit the target.

Conversely to offline planning, online correction of limb movement is a proposedly automatic and attention-free process; it integrates reafferent visual and proprioceptive information to facilitate spatial corrections to initial planning error (Briere & Proteau, 2011; Proteau, Roujoula, & Messier, 2009; Reichenbach, Franklin, Zatka-Haas, & Diedrichsen, 2014; Reichenbach, Thielscher, Peer, Bülthoff, & Bresciani, 2009). Reichenbach et al. (2014) provided evidence pertaining to online correction automaticity by demonstrating that corrections to cursors representing the limb were unaltered when cursor luminance manipulated attention allocation. Accordingly, online cursor corrections have also been shown to occur without the knowledge of participants, uninfluenced by repeat occurrences, and uninhabitable even when instructed to do so (Brière & Proteau, 2011; Proteau, et al., 2009; Veyrat-Masson et al., 2010).

Interestingly, individuals can strategically prioritise either offline planning or online correction's contribution to movement. Khan and Franks (2000) found that online correction is prioritised over offline planning following extensive practice (see also, Elliott, Chua, Pollock, & Lyons, 1995). Participants reached peak velocity earlier in their movement, and thus, for the same movement time, spent more time on online correction following extensive practice. It was suggested that this prioritisation of online processes may be because practice improved the online processing of visual information to implement rapid limb trajectory corrections. Conversely, Hansen, Glazebrook, Anson, Weeks, and Elliott (2006) found that offline planning was prioritised over online correction if participants were uncertain concerning upcoming targets' position or the availability of vision (see also, Cheng, Luis, & Tremblay, 2008; Khan, Elliott, Coull, Chua, & Lyons, 2002). In such instances, participants planned their movements more carefully (i.e., longer reaction time) and made reduced corrections to their movement.

Offline and online contributions can be inferred via trajectory variability (Khan et al., 2006). Inherent noise in the visuomotor system causes random error in planning and thus variability across trials (i.e., the standard deviation of within-subject error). Less variability early in movement (i.e., at 25% movement distance or before peak velocity) is indicative of increased offline planning efficacy because at this point there will have been insufficient time to process and implement corrections online. Reductions in variability later in movement (i.e., variability after 50% movement distance or after peak velocity) is indicative of online control efficacy because at this point online correction processes should converge trajectories towards the target. However, it is important to note that planning-related variability differences early in movement can be subtle and not manifest until later in the trajectory. In such instances, ratio profiles between independent variable conditions can discern increased offline planning efficacy over increased online correction efficacy, when variability is primarily reduced later in movement but trajectories have similar overall form (i.e., similar ratio profiles throughout the trajectory).

Support for trajectory variability's utility in inferring offline and online contributions stems from studies manipulating vision and movement time. Khan, Lawrence, Franks, and Buckolz (2004) had participants perform computer-based target-directed aiming movements under full vision, no-vision, early-vision, and late-vision conditions. Results revealed that the no-vision condition had linearly increasing and significantly greater variability at all movement percentiles, suggesting a relative absence of online correction. Early and full-vision conditions exhibited online correction via significantly reduced variability late in movement (i.e., between 75 and 100% movement distance) compared to the late and no-vision conditions. Late-vision had less variability later in movement compared to no-vision, but ratio analysis revealed that trajectories followed a similar profile to the no-vision condition; this suggested reduced variability late in movement in the late-vision condition was because late visual information was used offline to better plan subsequent movements. In a similar task to Khan et al. (2004), Khan, Lawrence, Franks, and Elliott (2003) had participants perform their aiming trials within movement times of 150, 250, 350, and 450ms under vision and no-vision conditions. Variability profiles between vision and no-vision conditions at 150ms did not differ, suggesting an absence of online correction because of insufficient time to process visual information. The 250, 350, and 450ms conditions exhibited evidence of offline and online motor control, with variability reducing later in movement and profiles differing from that of the no-vision condition.

2.2 Anxiety and Performance

Anxiety has been conceptualised into cognitive, somatic, and behavioural dimensions (Borkovec, 1976). Cognitive anxiety comprises worrisome thoughts, negative feelings, and an inability to concentrate. Somatic anxiety comprises autonomic reactivity such as shaking, sweating, and heightened heart rate. Behavioural anxiety comprises changes in facial expression, communication, and movement. Generally, it is assumed that anxiety and its therein dimensions are the product of increased performance pressure (i.e., factors which increase the importance of performing well), particularly when the consequences of not performing well are perceived as negative/threatening (Spielberger & Charles, 1970; Vealey, 1990). An individual's propensity to experience heightened state anxiety (i.e., temporary and situation-specific anxiety) in response to pressure, is predicted by their trait anxiety (i.e., the inherent propensity to experience heightened anxiety more frequently and intensely) (Krane, Joyce, & Rafeld, 1994; Spielberger, 1972). Individuals with high trait anxiety are more likely to experience heightened state anxiety (of cognitive, somatic, and / or behavioural nature) in situations of heightened performance pressure.

The precise mechanisms governing the relationship between heightened state anxiety and outcome performance (i.e., end-result success within tasks) are subject to considerable debate. An early model used to explain the anxiety-performance relationship was the inverted U hypothesis of Yerkes and Dodson (1908). It suggested that anxiety and performance have a curvilinear relationship wherein increased physiological arousal increases performance up to an optimal point, after which further arousal decreases performance (Landers & Boutcher, 1986; Oxendine, 1970). Although numerous investigations purportedly support the inverted U hypothesis (Anderson, 1990; Sonstroem & Bernardo, 1982), it has also been subject to an array of criticism (Eysenck, 1982; Fazey & Hardy, 1987; Neiss, 1988); chief among these criticisms being its lack of consideration for multidimensionality and associated interactions.

In an attempt to address this limitation, Fazey and Hardy (1988) proposed a three-dimensional cusp catastrophe model, featuring four distinct 'faces' which incorporated predictions of prior theories (Martens, Burton, Vealey, Bump, & Smith, 1990; Yerkes & Dodson, 1908). Performance was assigned to the y axis, cognitive anxiety was assigned to the z axis, and physiological arousal (and corresponding somatic anxiety) was assigned to the x axis. On the model's left face, where physiological arousal was low, cognitive anxiety was hypothesised to feature a positive linear relationship with performance. On the right face, where physiological arousal was high, cognitive anxiety was hypothesised to feature a negative linear relationship with performance. On the back face, where cognitive anxiety was low, arousal was hypothesised to feature an inverted u shaped relationship with performance. Lastly, on the front face, where cognitive anxiety was high, increased arousal was hypothesised to increase performance up to an optimal point, after which there would be a catastrophic drop in performance from a high performance platform, to a low performance platform. A return to the high performance platform from the low performance platform was hypothesised to require a reduction in arousal beyond the point of catastrophe in a hysteresis-like manner.

Empirical support for the cusp catastrophe model exists, but findings have been equivocal (Hardy, Beattie, & Woodman, 2007; Hardy & Parfitt, 1991; Hardy, Parfitt, & Pates, 1994; Hardy, Woodman, & Carrington, 2004). For example, Hardy and Parfitt (1991) measured basketball set shooting performance under high and low anxiety, in counterbalanced conditions of increasing and decreasing physiological arousal (manipulated via shuttle runs). Results revealed a three-way interaction, support for hysteresis at the front face of the model, and support for cognitive anxiety's role in maximum and minimum performance. However, jumps between performance platforms were not as substantial as hypothesised, and under conditions of low cognitive anxiety there was no dominant inverted u relationship between arousal and performance. Therefore, these results only provided partial support for the cognitive anxiety and physiological arousal-based cusp catastrophe theory.

A key limitation of Fazey and Hardy's (1988) cusp catastrophe model is that the mechanisms behind performance catastrophes are ambiguous. It is not clear 'why' heightened cognitive anxiety and physiological arousal interact to cause performance catastrophes. Therefore, Hardy (1999) proposed an alternative, entirely cognitive model. It was suggested that physiological arousal on the cusp catastrophe model of Fazey and Hardy (1988) could be replaced with effort required by the task. High cognitive anxiety combined with high required task effort may make individuals perceive themselves as having a low chance of success, and consequently participants may disengage from a task and catastrophically reduce the amount of effort they invest if the chance of success is perceived as too small. Once this catastrophic drop in effort/performance has occurred, the required task effort may need to decrease beyond the point of disengagement before individuals perceive it to be worth reengaging (a pattern in-line with hysteresis). This model was tested by Hardy et al. (2007) and Beattie and Davies (2010) with results finding strong support for its hypotheses.

However, a limitation of Hardy's (1999) cognitive model is that it only accounts for performance catastrophes when individuals 'disengage' from the task. It does not account for performance impairments / catastrophes when participants continue to 'engage' with the task. Two prominent mechanistic explanations accounting for such instances are the distraction-based attentional control theory (Derakshan & Eysenck, 2009; Eysenck, Derakshan, Santos, & Calvo, 2007) and conscious processing-based reinvestment theory (Masters, 1992; Masters & Maxwell, 2008). The attentional control theory comprises 6 primary hypotheses. Firstly, it was hypothesised that worrisome thoughts associated with cognitive anxiety consume working memory's limited capacity by acting as a distraction, leaving less resources available for concurrent task processing. This reduction in working memory may impair task performance but can be counteracted via the mobilisation of increased mental effort. Secondly, increased task demands decrease the likelihood that sufficient additional cognitive resources can be mobilised to compensate for the deleterious effects of anxiety on task performance. Thirdly, anxiety generates a shift in dominance from individuals' goal-directed system (i.e., attending to task-relevant stimuli) to their stimulus-driven system (i.e., searching for potentially irrelevant threat-related stimuli). This is likely because fourthly and filthy, anxiety proposedly impairs the central executive's inhibition (i.e., inhibiting task-irrelevant stimuli processing and responses) and shifting functions (i.e., shifting attention between stimuli and task components). Lastly, anxiety was hypothesised to impair the central executive's updating function (i.e., updating working memory with new task information) when task demands are sufficiently great. Substantial empirical evidence exists for all 6 hypotheses (Berggren, Richards, Taylor, & Derakshan, 2013; Derakshan, Smyth, & Eysenck, 2009; Eysenck, 1985; Eysenck, Payne, & Derakshan, 2005; Pishyar, Harris, & Menzies, 2004) and for distraction's detrimental effect on outcome motor performance (Murray & Janelle, 2003; Nieuwenhuys, Pijpers, Oudejans, & Bakker, 2008; Wilson, Vine, & Wood, 2009; Wilson, Wood, & Vine, 2009).

The other prominent mechanistic account for the anxiety-performance relationship is the conscious processing-based reinvestment theory of Masters (1992) (for review, see Masters & Maxwell, 2008). Novice task performance is guided by attentionally-intensive declarative memory in a step-by-step manner (i.e., verbal-based conscious processing of task execution), and expert task performance is guided by procedural memory as one movement 'chunk' comprising several smaller steps (i.e., nonverbal and unconscious processing of the task execution) (Anderson, 1982; Fitts & Posner, 1967; Salmoni, 1989). The reinvestment theory proposes that skilled performance can break down under conditions of heightened cognitive anxiety, if individuals attempt to consciously process / control movements using declarative rule-based knowledge. Although this may be a well-intentioned coping strategy to maintain performance under anxiety, the consensus in the literature is that conscious processing generally impairs outcome motor performance (Beilock & Carr, 2001; Hardy, Mullen, & Jones, 1996; Jackson, Ashford, & Norsworthy, 2006; Kinrade, Jackson, & Ashford, 2010; Masters, 1992).

Interestingly, it has been demonstrated that an individual's propensity to engage in conscious processing is a personality trait. Initially, Masters, Polman, and Hammond (1993) developed the 20 item reinvestment scale from previously validated questionnaires related to conscious processing (e.g., "I reflect about myself a lot"). This questionnaire was superseded by the movement specific reinvestment scale of Masters, Eves, and Maxwell (2005) which aimed to increase validity by directly linking items to movement. This questionnaire featured 10 items comprising the subscales movement self-consciousness (e.g., "I am self-conscious about the way I look when I am moving") and conscious motor processing (e.g., "I am always aware of how my body works when I am carrying out movement"). Movement self-consciousness was defined as an individual's concern about their 'style' of moving, and conscious motor processing was defined as an individual's contemplation of movement processes; the latter was suggested to be conceptually closer aligned with reinvestment-based movement performance decrements. Several studies have found the movement specific reinvestment scale to have strong validity (Masters et al., 2005; Orrell, Masters, & Eves, 2009; Zhu, Poolton, Wilson, Maxwell, & Masters, 2011). It is noteworthy that recent work suggests that the type of reinvestment an individual engages in (movement self-consciousness or conscious motor processing) may determine whether heightened anxiety has facilitative or debilitative effects on task performance and consistency (Malhotra, Poolton, Wilson, Omuro, & Masters, 2015; Malhotra, Poolton, Wilson, Uiga, & Masters, 2015; Toner & Moran, 2011), but this research has been scarce and contradictory to date.

A factor proposed to govern whether individuals experience conscious processing or distraction under conditions of heightened anxiety is the type of stressors comprising the pressure environment (DeCaro et al., 2011). Outcome pressure (i.e. personally-important performance-dependent repercussion) is suggested to facilitate distraction, whilst monitoring pressure (i.e. movement observation by important others) is suggested to facilitate conscious processing. However, a limitation of this notion is its disregard for individual differences. Since conscious processing propensity is a personality trait (Masters et al., 2005), in an environment that constitutes of outcome pressure, individuals high in conscious processing propensity may employ conscious processing as a coping strategy instead of being distracted. Conversely, under monitoring pressure, individuals low in conscious processing propensity may be distracted by the observation of others instead of engaging in conscious processing. Therefore, precisely predicting the occurrence of distraction versus conscious processing based on the pressure environment, seems debatable.

Additional factors for consideration within the anxiety-performance relationship are self-control, psychophysiology, and personality. Firstly, self-control is suggested to be a global resource that can be depleted across different tasks that require behavioral control (Baumeister, Vohs, & Tice, 2007; Baumeister, Bratslavsky, Muraven, & Tice, 1998). When this resource is depleted by primary acts of self-control, individuals are suggested to be in a state of 'ego-depletion' and exhibit impaired self-control. Although the precise origin of this resource is under debate (Kurzban, Duckworth, Kable, & Myers, 2013; Lange & Eggert, 2014), a large body of evidence appears to demonstrate its existence (Hagger, Wood, Stiff, & Chatzisarantis, 2010). Of note to the present research is that Englert and Bertrams (2015a) have linked self-control resources to the attentional control theory's mechanisms (Eysenck et al., 2007). It is suggest that the act of mobilising cognitive resources to overcome the deleterious effects of heightened anxiety requires self-control; therefore, if an individual is depleted of their self-control, they may not be able to mobilise compensatory effort or strategies (for experimental evidence, see Englert & Bertrams, 2012; Englert & Bertrams, 2015b; Englert & Bertrams, 2016; Englert, Zwemmer, Bertrams, & Oudejans, 2015c). However, despite the aforementioned literature advocating ego-depletion's existence, substantial criticism and contradictory evidence has recently emerged which centres on: academic malpractice (Wolff, Baumann, & Englert, 2018); publication bias (Carter & McCullough, 2014; Vadillo, Gold, & Osman, 2016); inconsideration of moderators (Wolff, Sieber, Bieleke, & Englert, 2019); and inadequate characterisation of the ego-depletion effects / methods (Etherton et al., 2018). In sum, there is as-of-yet no firm consensus concerning ego-depletion's existence and role within the anxiety-performance relationship.

Thirdly, a compelling account for the psychophysiological mechanisms underlying the anxiety-performance relationship, is the biopsychosocial model of challenge and threat (Blascovich

& Tomaka, 1996; Blascovich, Seery, Mugridge, Norris, & Weisbuch 2004). It suggests that when an individual perceives task demands (i.e., pressure applied) as greater than their available resources (e.g., skills, knowledge, and external support), a threat appraisal is applied to the situation. Conversely, when an individual perceives their available resources as greater than the task demands, a challenge appraisal is applied to the situation. These appraisals were demonstrated to be linked to psychophysiological factors and sports performance by Blascovich et al. (2004). Amateur baseball and softball players had cardiovascular indexes of challenge and threat appraisals measured while giving an anxiety-inducing speech. Participants who adopted threat appraisal activated the hypothalamic pituitary-adrenal pathway which, via the release of dopamine, decreased blood-flow to the brain and working muscles. Alternatively, a challenge appraisal activated the sympathomedullary pathway which, via the release of epinephrine, increased blood-flow to the brain and body. It was reasoned that these psychophysiological mechanisms accounted for challenge / threat appraisals' respective facilitative and debilitative effects on performance. These findings were replicated in amateur golfers by Moore, Wilson, Vine, Coussens, and Freeman (2013).

Lastly, among many personality factors, narcissism, punishment sensitivity, and mental toughness have particularly significant effects on the anxiety-performance relationship. Firstly, Individuals high in narcissism have been shown to seek admiration and glory (Wallace, & Baumeister, 2002). Therefore, high pressure situations provide an optimal opportunity for narcissists to satisfy this desire (Roberts, Woodman, & Sedikides, 2018) and a number of studies support high narcissism's beneficial effects on performance in heightened anxiety conditions (Geukes, Mesagno, Hanrahan, & Kellmann, 2013; Roberts, Woodman, Hardy, Davis, & Wallace, 2013; Roberts et al., 2019). Secondly, individuals high in punishment sensitivity demonstrate earlier and stronger defensive responses to cope with upcoming pressure situations (Gray & McNaughton, 2000; McNaughton & Corr, 2004; Mobbs, Hagan, Dalgleish, Silston, & Prévost, 2015). Such responses have been shown to be facilitative to performance under heightened anxiety when athletes have sufficient time to identify upcoming threats and implement appropriate defensive responses (Manley, Beattie, Roberts, Lawrence, & Hardy, 2018); something that is suggested to be more likely when participants also have low reward sensitivity (Hardy, Bell, & Beattie, 2014). Lastly, individuals higher in mental toughness demonstrate increased likelihood to perform and achieve personal goals when faced with pressure from stressors in sporting contexts (Beattie, Alqallaf, Hardy, & Ntoumanis, 2019; Bell, Hardy, & Beattie, 2013; Hardy et al., 2004).

Despite a plethora of research, there are still significant research lacunas within the anxiety-performance relationship. Anxiety mechanisms have primarily been investigated in isolation, with little consideration for their interaction. Similarly, literature has primarily used outcome performance as its primary dependent variable and not considered how movement planning and control processes contribute to outcome performance. Lawrence, Khan, and Hardy (2013) were the first to propose two contrasting variability-based outcome hypotheses to quantify distraction and conscious processing's potentially differential effects on offline and online motor control. The variability method of Khan et al. (2006) was used to directly link the two-component model of upper limb control (Woodworth, 1899) to reinvestment theory (Masters, 1992) and attentional control theory (Eysenck et al., 2007). The resource-diminishing mechanisms of distraction were hypothesised to only have a detrimental effect on relatively resource-intensive offline planning. Conversely, the automaticity-diminishing mechanisms of conscious processing were hypothesised to only have a negative effect on automatic online correction of cursor trajectories. Results suggested heightened state anxiety had a positive effect on offline planning and negative effect on online corrections. Therefore, these findings were attributed to automaticity-impairing conscious processing mechanisms.

Allsop, Lawrence, Gray, and Khan (2017) and Cassell, Beattie, & Lawrence (2018) replicated these findings but suggested that participants may strategically mobilise additional cognitive resources (e.g., mental effort) to improve offline planning to compensate for conscious processing-impaired online correction processes. Roberts et al. (2018) tested this notion by assessing heightened state anxiety's effect on offline and online motor control processes (via variability profiles) whilst concurrently measuring how frequently participants attempt to perform these processes (via , time to peak velocity and the number of trials with two-component sub-movements). Although results for variability under anxiety again suggested increased offline planning and reduced online correction, additional indexes showed no change. Therefore, Roberts and colleagues suggested that the resource shift from online control to offline planning in the presence of anxiety was unlikely to be 'strategic' because participants still attempted to perform online control (despite its reduced prominence in variability profiles). However, it is important to note that neither Lawrence et al. (2013), Allsop et al. (2017), Cassell et al. (2018), nor Roberts et al. (2018) directly tested the efficacy of movement planning nor movement corrections *when essential to outcome performance*. Since outcome performance was generally maintained in the aforementioned studies, variability analysis (and the additional measures of Roberts and colleagues) allow for offline and online processing's prominence to be quantified but do not allow for definitive assessment of their efficacy. In essence, it is currently unclear when offline / online processes are improved / impaired under heightened state anxiety and when individuals simply make more / less use of them (possibly for strategic reasons).

2.3 Focus of Attention

Early work has suggested that focusing attention on any element of movement execution generally prohibits attainment of peak performance (Anderson, 1983; Fitts & Posner, 1967; Kimble & Perlmuter, 1970; Masters, 1992; Wulf & Weigelt, 1997). Today's understanding is more nuanced and rests on foundations laid by Wulf, Höß, and Prinz (1998). In their study, participants who were instructed to focus on the wheels of a ski-simulator platform achieved greater slalom performance than participants who were instructed to focus on their feet and participants who were given no focus instruction. This principal study demonstrated an external focus of attentions' benefit to performance and coined foci of attention definitions; an external focus of attention comprises focusing on environmental movement effects, and an internal focus of attention comprises focusing on body kinaesthesia.

Wulf et al. (1998) initially attributed an external focus of attention's performance benefit to common coding (Prinz, 1997). Specifically, it was suggested that an external focus facilitates performance by increasing congruence between the processing of afferent sensory information and efferent motor commands: by basing both on the same performance-relevant environmental stimuli. However, contemporary research predominantly accounts for focus of attention effects via the constrained action hypothesis (Wulf, McNevin, & Shea, 2001). This hypothesis states that an external focus benefits performance by facilitating automaticity in movement execution and prevents conscious constraining of the motor system via an internal focus of attention. Wulf et al. (2001) provided evidence for this conjecture by having participants perform a balancing task and probe-reaction time task concurrently. Probe reaction time was measured as the time between an auditory stimulus during the balancing task and the participant's response via a handheld button. Participants who adopted an external focus of attention demonstrated greater balancing performance (suggesting improved motor organisation), reduced probe reaction times (suggesting increased automaticity and attentional capacity), and increased high-frequency movement adjustments (suggesting a less constrained motor system) compared to an internal focus of attention.

Empirical support for the constrained action hypothesis has been plentiful. For instance, participants adopting an external focus of attention within a cyclic single-leg extension task exhibited reduced (i.e., more efficient) muscle electromyography, shorter (i.e., improved) movement durations, reduced cognitive dual-task cost, and more fluent / regular movement (Kal, van der Kamp, & Houdijk, 2013). Overall, these results demonstrated that an external focus of attention increased movement automaticity and efficiency. Within a balancing task, participants adopting an external focus further from their body, performed better and demonstrated improved high-frequency adjustments than participants adopting an external focus closer to their body (McNevin, Shea, Wulf, 2003), demonstrating that focusing further from the body reduced constraining of the motor system. Lastly, and again within a balance-board task, participants who adopted an external focus of attention performed better than participants who continuously shadowed (i.e., repeated out loud) a story given to them during the balancing task (Wulf & McNevin, 2003): demonstrating that an external focus of attention's benefits stem from motor organisation based on the desired external movement effects.

Although principal evidence proposing and supporting the constrained action hypothesis primarily stems from balancing tasks and student populations (McNevin et al., 2003; Wulf et al., 1998; Wulf & McNevin, 2003), subsequent research supports adopting an external focus across a wide variety of tasks and populations. Additional tasks in which an external focus was found to yield performance or efficiency benefits include: basketball free throws (Zachry, Wulf, Mercer, & Bezodis, 2005), standing long jump (Porter, Ostrowski, Nolan, & Wu, 2010); golf (Bell & Hardy, 2009; Wulf & Su, 2007); gymnastics (Abdollahipour, Wulf, Psotta, & Palomo Nieto, 2015); and shot put (Makaruk, Porter, & Makaruk, 2013). Additional populations in which an external focus was found to yield benefits include: stroke patients (Durham et al., 2014; Fasoli, Trombly, Tickle-Degnen, & Verfaellie, 2002); children with intellectual disabilities (Chiviacowsky, Wulf, & Ávila, 2013); and individuals with Parkinson's disease (Landers, Wulf, Wallmann, & Guadagnoli, 2005; Wulf, Landers, Lewthwaite, & Toöllner, 2016). However, despite the remarkable transferability of external focus of attention benefits, considerable debate exists whether an external focus of attention is best for novices in complex sport skills.

Beilock, Carr, MacMahon, and Starkes (2002) had novice and experienced football players perform a slalom dribbling task with either their dominant foot or their non-dominant foot. Concurrently, players performed each of these dribbling conditions under either dual-task or skill-focus conditions. In the skill-focus condition, players were instructed to mentally note the side of their foot that last contacted the ball and, upon hearing a randomly timed tone while dribbling, state that side aloud. In the dual-task condition, players were instructed to attend to an auditory list of words and, upon hearing a target word, state this target word aloud. Results revealed that, when experienced players performed the slalom-task with their dominant foot, dribbling performance was best in the dual-task condition. With their non-dominant foot, where experienced players' performance was arguably closer to a novice-like state, performance was best in the skill-focus condition. Novice players performed best in the skill-focused condition with their dominant and non-dominant foot. Subsequent research corroborated this pattern of results (Beilock, Bertenthal, McCoy, & Carr, 2004; Castaneda & Gray, 2007; Perkins-Ceccato, Passmore, & Lee, 2003) and it was suggested that novice performance benefits from attention allocation to the step-by-step processing of body coordination prevalent at this stage of learning. However, these findings confound with the constrained action hypothesis of Wulf et al. (2001). Based on the constrained action hypothesis, one would expect the dual-task condition of Beilock et al. (2002) to function similarly to an external focus of attention (i.e., directing attention away from body-focused movement processes) and facilitate novice and expert performance with their dominant and non-dominant foot.

Whilst Beilock and colleagues manipulated attentional focus via secondary tasks, Wulf and colleagues (1988; 2001; 2003) manipulated attentional focus via verbal instructions (e.g., "focus on the swing of the bat"). Although the dual-task manipulation may divert attention away from internal motor processes, it may add additional attentional demands and may not facilitate the organisation of motor systems based on the desired external movement effects (Land, Tenenbaum, Ward, & Marquardt, 2013; Wulf & McNevin, 2003): overall producing inferior performance within novices compared to a skill-focus. This suggestion is supported by the findings of Wulf and Su (2007) who manipulated focus of attention via verbal instructions and, in line with the constrained action hypothesis, observed that expert and novice golfers performed best with an external focus of attention. Numerous studies since further corroborated these findings and overall advocate an external focus of attention's use across the skill-level continuum (Bell & Hardy, 2009; Marchant, Clough, & Crawshaw, 2007; McKay & Wulf, 2012).

Although the constrained action hypothesis has accumulated substantial empirical evidence across task types and populations (Wulf, 2013), recent research suggests focus of attention effects may be contingent on task and instruction nuances. In a study featuring dart throwing as the primary task, Russell, Porter, and Campbell (2014) compared an external focus with high task relevance (i.e., directing attention to the dart board) to an external focus with low task relevance (i.e., directing attention to a secondary balancing task performed using a sheet). Results revealed the external focus with high task relevance yielded superior dart throwing accuracy. Contrariwise, in a golf-putting task, Pelleck and Passmore (2017) compared an internal focus with high task relevance ("focus on your hands gripping the club and the position of your elbows") to an internal focus with low task relevance ("focus on distributing your weight evenly through both feet"). Results revealed that the internal focus with high task relevance was more detrimental to putting accuracy than the internal focus with less task relevance. Together, the results of Pelleck and Passmore (2017) and Russell et al. (2014) strongly suggest that the facilitative or constraining effects external and internal foci of attention respectively have on motor processes, may be contingent on the instructions' task relevance: likely mediated via common coding (Prinz, 1997).

The findings of Pelleck and Passmore (2017) and Russell et al. (2014) exemplify how prior literature has perhaps overlooked several nuances within focus of attention effects. Two additional such factors upon which will be elaborated include (1) task demands and (2) movement planning / correction. Concerning the former, given the need for congruence between task demands and focus of attention instruction, it is conceivable that a set of task conditions exist wherein internal focus instructions yield superior performance and / or efficiency to external focus instructions. Specifically, such task conditions may occur when proprioception is the primary facilitator of outcome performance (e.g., reproducing body positions without the availability of vision). In such conditions, based on Prinz's (1997) action effect principle, an internal focus of attention may yield superior performance by allowing motor processes to be coded in accordance with the proprioceptive movement goal. These proposals are also in line with the specificity of practice hypothesis which proposes that the source of afferent information most relevant to performance is typically prioritised (Proteau, 1992; Coull, Tremblay, & Elliott, 2001). In proprioceptive tasks, one would expect attention placement on body kinaesthesia (i.e., focusing internally) to be most relevant and facilitate optimal organisation of motor processes in accordance with the intended internal movement effects.

Although an external focus was best for performance in studies which featured proprioceptive tasks, closer inspection of their methods reveal several limitations that may obfuscate / mask internal focus benefits. For instance, Lohse et al. (2011) and Lohse (2012) compared internal and external focus of attention differences within an isometric force production task; participants had to reproduce set percentages of their maximum voluntary contraction on a force plate below their foot. Results revealed that an external focus yielded superior force reproduction accuracy over an internal focus. However, this finding may be a product of muddled focus instructions. In the internal focus condition, participants were instructed to focus on the muscle of their calf and to contract their muscle more / less, whilst in the external focus condition participants were instructed to focus on the push of their foot against the platform and push against the platform harder / less. The inclusion of the 'foot' in the external focus instruction means that participants may have inadvertently adopted an internal focus (i.e., force transferred via the foot). Therefore, both focus conditions may have been 'internal', and the condition focusing on the foot and force platform may have facilitated superior performance because it featured greater congruence with the intended outcome (i.e., force exerted via the foot on the platform) (Prinz, 1997). Methodological confounds of other studies reporting an external focus superior within highly proprioceptive tasks include: focus instructions that may not have been congruent with the internal task demands / may only direct attention to a subset of task-relevant proprioception (Land et al., 2013; Makaruk et al., 2013; Sherwood, Lohse, & Healy, 2014); insufficiently strict vision acuity classification of participants to make the task wholly proprioceptive (McNamara, Becker, & Silliman-French, 2017); and simple task demands which reduce the depth /

usefulness of proprioceptive information (Freedman, Caligiuri, Wulf, & Robin, 2007; Greig & Marchant, 2014; Halperin, Williams, Martin, & Chapman, 2016).

In support of past literature's aforementioned limitations, a wealth of circumstantial evidence exists which is at variance with the constrained action hypothesis' (Wulf et al., 2001) rigid championing of an external focus of attention regardless of task conditions. For instance, several prominent lines of research advocate internal-like processing of information, such as: body-perspective / kinaesthetic imagery (Hardy & Callow, 1999), process goals (Zimmerman & Kitsantas, 1997), and somaesthetic awareness for movement refinement (Shusterman, 2008; Toner & Moran, 2015). More direct evidence suggesting focus of attention effects can indeed be contingent on task characteristics, stems from Lawrence, Gottwald, Hardy, and Khan (2011). The authors of this study hypothesised that form sports like gymnastics (i.e., sports judged on body shape) do not have a clear external movement effect and may therefore not benefit from an external focus of attention. Accordingly, results revealed that the learning of movement form did not benefit from a particular focus of attention. Research has since disputed the validity of this finding (Abdollahipour, Wulf, Psotta, & Palomo Nieto, 2015) but has itself been criticised for methodological and applied shortcomings (Collins, Carson, & Toner, 2016).

The other nuance warranting elucidation within literature is external and internal foci of attention's effect on movement planning and correction. Seminal focus of attention research (McNevin et al., 2003; Wulf et al., 1998; Wulf & McNevin, 2003) utilised balance-board and ski-simulator tasks whose dynamic and continuous nature make it hard to discern movement planning and corrections' respective contribution to outcome performance; it could even be argued that such tasks are primarily governed by corrective processes and not planning. The majority of studies since have focused on outcome performance and not considered movement planning nor correction's role therein (e.g., Bell & Hardy, 2009; Pelleck & Passmore, 2017; Russell et al., 2014; Wulf & Su, 2007; Zachry et al., 2005). A noteworthy exception stems from Lohse and colleagues (2010; 2011; 2012;

2014) who investigated focus of attention effects specifically on movement planning within non-continuous tasks (i.e., tasks which are of short duration and feature a clear beginning, middle, and end; e.g., golf putt). In a dart-throwing task with vision, Lohse, Sherwood, and Healey (2010) found that preparation time between trials, as a measure of movement planning, was reduced under an external focus of attention: suggesting an external focus of attention benefits planning and outcome performance differences originate therein. However, future research may be well advised to consider concurrent movement planning and correction contributions to outcome performance; strategic trade-offs between planning and corrective processes cannot be ruled out at present (Elliott et al., 2014; Elliott, Chua, Pollock, & Lyons, 1995; Khan, Elliott, Coull, Chua, & Lyons, 2002). Lohse and colleagues observed worse movement planning with an internal compared to external focus of attention, but concurrently an internal focus of attention may facilitate improved / compensatory correction processes.

2.4 Purpose of Experiments

The present literature review highlights that the separate effects of anxiety and focus of attention on the offline planning and online correction of movement would benefit from further investigation. The dichotomous reasoning of Lawrence et al. (2013), that offline planning is only affected by distraction and that online correction is only affected by conscious processing, requires explicit scrutiny. Accordingly, Experimental Chapter 1 comprised three experiments wherein: online correction efficacy was directly tested under heightened anxiety via cursor jumps; trait conscious processing propensity was correlated with planning and correction indices; and the availability of self-control was experimentally manipulated to exacerbate distraction effects. In sum, these methods enabled us to provide a thorough and rigorous assessment of heightened anxiety's effect on visuo-motor control processes. To extend this line of research into proprioception-only task domains, Experimental Chapter 2 comprised one experiment wherein the effect of heightened anxiety on proprioception-based movement planning *and* correction was investigated for the first time. Lastly, to our knowledge, no study to date had simultaneously investigated offline planning and online correction under different foci of attention. Experimental Chapter 3 comprised three experiments wherein focus of attention's relationship with offline planning, online correction, and instructional congruence was assessed.

Chapter 3: Experimental Chapter 1

Online motor control is not completely automatic: A comprehensive test of heightened state anxiety's effect on movement planning and correction.

A myriad of studies have shown that heightened state anxiety can have a negative effect on performance via conscious processing or distraction mechanisms (Beilock & Carr, 2001; Gucciardi & Dimmock, 2008; Hardy, Mullen, & Jones, 1996; Murray & Janelle, 2003; Nieuwenhuys Pijpers, Oudejans, & Bakker, 2008). More recently, researchers have attempted to explicate the respective effects of distraction and conscious processing on offline (i.e., pre-movement) planning and online (i.e., mid-movement) correction (Allsop, Lawrence, Gray, & Khan, 2017; Cassell, Beattie, & Lawrence, 2018; Lawrence, Khan, & Hardy, 2013; Roberts, Wilson, Skultety, & Lyons, 2018). However, participants' ability to make corrections under heightened anxiety is yet to be directly tested. In Experiment 1, we utilised cursor perturbations (i.e., unpredictable jumps in the cursor used to represent movement of the limb) to provide a direct test of online correction efficacy. In Experiment 2, we replicated Experiment 1 with a larger sample size and measures of correction initiation latency and trait conscious processing propensity. Lastly, in Experiment 3, we manipulated participants' availability of cognitive resources to exacerbate the effects of distraction mechanisms on offline planning and online correction.

Distraction-based attentional control theory (Eysenck, Derakshan, Santos, & Calvo, 2007) and conscious processing-based reinvestment theory (Masters, 1992) are now well-established in the literature as the most prominent mechanistic explanations for the anxiety-performance relationship. Attentional control theory proposes that heightened state anxiety impairs the central executive's attentional shifting (i.e., changing attention allocation between task-relevant stimuli) and inhibition (i.e., inhibiting attention allocation to task-irrelevant stimuli). In turn, worrisome thoughts have greater leeway to *distract* and occupy attentional capacity and impair performance once attentional capacity is exceeded. However, these detrimental effects can be overcome provided sufficient cognitive resources are available and mobilised (e.g., mental effort). Reinvestment theory suggests that the automatic motor performance of skilled performers can be disrupted if attempts are made to consciously process movements using declarative memory. Although this may be a well-intended trait coping strategy (i.e., trait conscious processing propensity), the net result is often impaired performance (Masters & Maxwell, 2008). Both distraction and conscious processing approaches have garnered sizable empirical evidence in relation to outcome performance (e.g. goals scored) as the primary dependent variable (Beilock & Carr, 2001; Gucciardi & Dimmock, 2008; Hardy et al., 1996; Murray & Janelle, 2003; Nieuwenhuys et al., 2008; Wilson, Wood, & Vine, 2009). However, much less is known about the effect of these processes on the offline planning and online correction of movements.

Recently, research has utilised upper limb target-directed aiming tasks and therein variability profiles in an attempt to address the aforementioned research lacuna (viz., Allsop et al., 2017; Cassell et al., 2018; Lawrence et al., 2013; Roberts et al., 2018). Upper limb aiming movements can be broken into offline and online phases. Offline planning is the effortful (i.e., attention demanding) use of information from prior movements to plan upcoming movements via feedforward mechanisms (Glover et al., 2004; Glover & Dixon, 2002; Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979; Wolpert & Kawato, 1998). Online movement correction is the automatic (i.e., attention-free and uninhibitable) use of reafferent feedback mechanisms to detect and correct movement errors (Reichenbach, Franklin, Zatka-Haas, & Diedrichsen, 2014; Reichenbach, Thielscher, Peer, Bülthoff, & Bresciani, 2009; Veyrat-Masson, Brière, Proteau, 2011; Wolpert & Kawato, 1998). Offline planning and online correction can be inferred from movement variability (i.e., the within subject SD at different points of the unfolding limb trajectory). Offline planning is represented in the early portions of trajectory variability and online correction is represented in the latter portions of trajectory variability (for a review, see Khan et al., 2006). Research using this methodology to investigate anxiety's effect on offline planning and online correction has consistently observed reduced online correction and increased offline planning (Allsop et al., 2017; Cassell et al., 2018; Lawrence et al., 2013). This, along with concurrent increases in self-reported mental effort under conditions of heightened state anxiety led Allsop et al. (2017) to suggest that participants may 'strategically' dedicate increased cognitive resources to improve offline planning and compensate for conscious processing-impaired online correction (also see Cassell et al., 2018). Roberts et al. (2018) tested this notion by assessing spatial variability alongside measures of how frequently participants attempted to engage in planning and correction processes (i.e., time to peak velocity and the number of trials with two-component sub-movements). Variability results again suggested increased offline planning and reduced online correction under heightened anxiety, but measures of online correction prominence remained unchanged. Therefore, offline-to-online shifts under heightened anxiety may not be 'strategic'. Strategic shifts should change how frequently participants try to engage in offline planning and online correction.

However, it is important to note that neither the studies of Lawrence et al. (2013), Allsop et al. (2017), Cassell et al. (2018), nor Roberts et al. (2018) necessitated online corrections to maintain outcome performance. In essence, it is as-of-yet unclear whether online correction processes were impaired under heightened state anxiety or whether individuals simply made less use of them (strategic or not). For this reason, the effect of distraction and conscious processing mechanisms on movement planning and correction processes is also ambiguous. One way to test participants' ability to undertake online corrections independently of offline planning is via early-movement cursor jumps. When these cursor jumps occur randomly and infrequently in peripheral vision, they are unexpected and force participants to correct their movement during execution to hit their target. These jump corrections have been suggested to be a valid test of automatic / attention fee online correction; they occur without the knowledge of participants, are uninfluenced by repeat occurrences, are independent of cued attention, and cannot be inhibited (Brière & Proteau, 2011; Chen & Saunders, 2018; Proteau, Roujoula, & Messier, 2009; Reichenbach et al., 2014; Tremblay et al., 2017; Veyrat-Masson et al., 2010). Hence, while both jump and no-jump trials should *allow* for the continuous and automatic utilisation of reafferent visual feedback for corrections, jump trials should *necessitate* this to maintain outcome performance.

3.1 Experiment 1

The primary purpose behind Experiment 1, was to directly manipulate the need for online correction. Of all trials, 20% featured cursor perturbations (i.e., jumps). This aimed to establish whether increased offline planning is a strategic control mechanism that *reduces* the need for online correction when anxious, or whether the presence of anxiety directly impairs online correction processes. Thus, for no-jump trials where online correction is not externally induced, we hypothesised that heightened compared to low state anxiety conditions would exhibit similar or reduced variability early in movement (i.e., increased offline planning) and rising variability later in movement (i.e., reduced online correction) (Allsop et al., 2017; Lawrence et al., 2013; Roberts et al., 2018). For jump trials where online corrections are externally induced and necessitated to maintain outcome performance, we hypothesised heightened anxiety would produce impaired correction magnitude and variability. Overall, such findings would suggest heightened state anxiety indeed directly *impairs* online correction processes.

3.1.1 Methods.

Participants. The experiment sample comprised of 14 university students (all male, $\text{mean}_{\text{age}} = 19.46$, $SD_{\text{age}} = 1.20$). G*Power (G*Power 3; Faul, Erdfelder, Lang, & Buchner, 2007) sample size estimation for Experiment 1 confirmed 14 participants necessary to provide power = .8 for the interaction between trial block (baseline and transfer) and distance (at 25, 50, 75, and 100%) of the movement trajectory when alpha = .05 and $\eta_p^2 = .10$; a conservative effect size estimation based on Lawrence et al. (2013) and Allsop et al. (2017). All participants were: naïve to the hypotheses being tested; self-reported right hand dominant; with normal or corrected to normal vision; and offered course credit together with the chance to win £100 in exchange for participating. The experiment was reviewed by, granted ethical approval from, and conducted in accordance with the ethical guidelines laid out by, the institutional ethics committee.

Anxiety and effort scales. Cognitive state anxiety was assessed via the Mental Readiness Form-3 (MRF-3) (Krane, 1994) which comprises three polar-opposite Likert scales: 1 (not worried) to 11 (worried), 1 (confident) to 11 (not confident), and 1 (not tense) to 11 (tense). For the purpose of present studies, only the cognitive anxiety (worry) measure was used during analysis. Task mental effort was assessed via the Rating Scale of Mental Effort (RSME) (Zijlstra, 1993) which comprises a 1-150 vertical scale with 9 anchors starting from 3 (no mental effort at all) to 114 (extreme mental effort).

Apparatus. A Calcomp 3 digitizing tablet was placed horizontally in front of participants (size = 122 x 91.5 cm, sample rate = 200 hz). Aiming movements were performed on this tablet using a stylus. The X / Y position of the stylus on the tablet corresponded, with one-to-one mapping, to the X / Y position of a round cursor (white, 1cm diameter) on a black background displayed using a 37 inch Mitsubishi Diamond Pro monitor (refresh rate = 85 hz) located 33cm in front the participants' eyes and 20 cm above the tablet (see Figure 1). An opaque shield obscured participants' vision of their hand. The tablet was interfaced with a PC via a serial link and all visual stimuli on the monitor were produced using Visual Basic and Direct X Software. A circular 'start position' (green, 1 cm diameter) was displayed at the bottom centre of the monitor. Three circular 'targets' (red, 1 cm diameter) were each displayed 24cm centre-to-centre from the start position; one target was directly above the start position and the other two targets were located 10° either side (angle subtended from the home position). The distance between the start position and targets formed a visual angle of 40°. Participants' chair and chinrest were adjustable to ensure their eyes were midway between the start and targets. Cursor, targets, and the start position remained visible throughout testing.

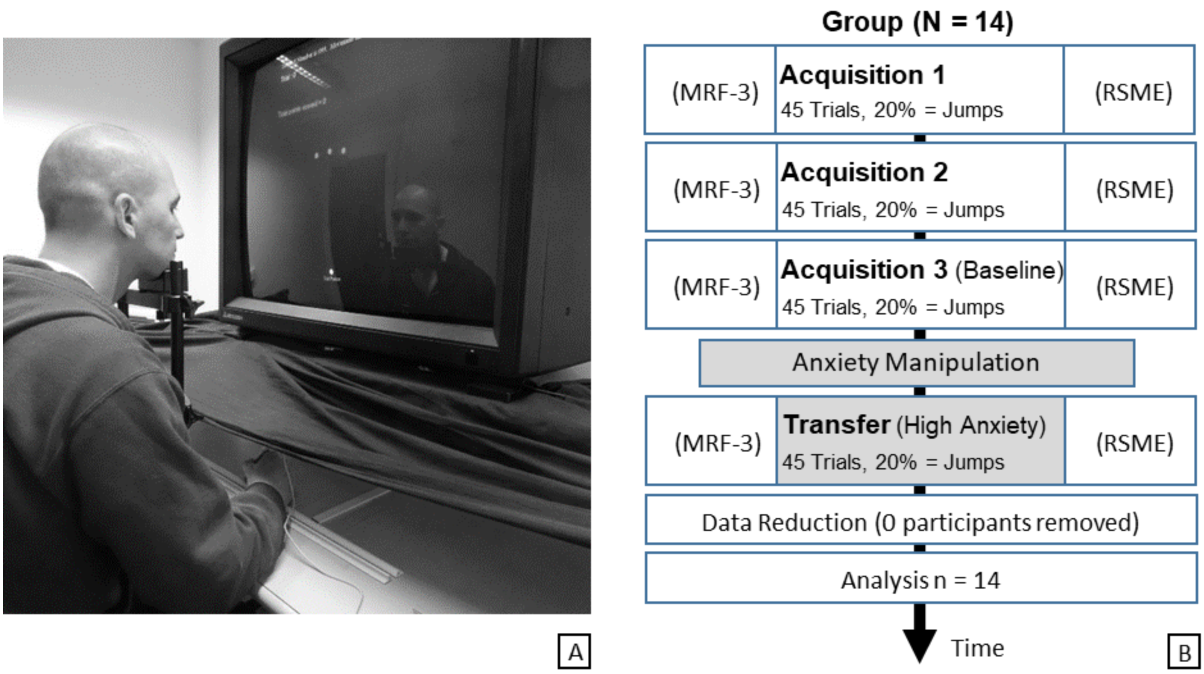


Figure 1. Panel A displays participant, apparatus, and on-screen setup. Panel B displays Experiment 1's schematic. The mental readiness form-3 (MRF-3) was completed by participants before every block of trials and the rating scale of mental effort (RSME) was completed after every block of trials. In the final block of trials participants were transferred to heightened state anxiety.

Task and Procedure. Participants began each trial by centring their cursor over the start position. Once the cursor was steadily aligned, the experimenter initiated the trial, and the target participants had to aim for turned green. Following a random 500-1500 ms delay, a go-tone signalled participants to initiate their movement towards the target. Target order was randomized within each block of trials and between participants; with the condition that all targets occurred before any given target was repeated. At the beginning of testing, the experimenter demonstrated four correct trials. It was emphasised to participants that: (1) they had to keep their eyes on the target throughout movement execution; (2) reaction time to the go-tone was not important; (3) they had to make one smooth and straight movement as closely as possible through and past the target centre; and (4) they did not have to stop on the target (thus giving the task a directional but not amplitude requirement). Once participants had gone through and past the target arc, they had to come to a complete stop. The target would become red again and participants had to return to the start position ready for the next trial. At this point knowledge of results in the form of movement time (MT) (ms) and a point score (see Allsop et al., 2017) was presented on the monitor. MT had to be 450ms (+/-10%) and movements outside this criterion were immediately repeated until correct.[1]

All participants had to complete three blocks of 45 trials under low state anxiety for acquisition followed by one transfer block of 45 trials under heightened state anxiety. Therefore, Experiment 1 adopted a within-participant pre-post-test design wherein the final acquisition block acted as a baseline. A combination of outcome and monitoring pressure was utilised to heighten cognitive state anxiety; this method has repeatedly been shown successful in laboratory settings (Allsop, et al., 2017; DeCaro, Thomas, Albert, & Beilock, 2011; Lawrence et al., 2013; Wilson, Smith & Holmes, 2007). Participants were informed that: (1) their cursor movements on the monitor were being filmed for future analysis; (2) they were being paired with another participant who had improved their performance by 20%, and that they too needed to improve by 20% for either their partner or themselves to be entered into a £100 prize draw; and (3) their partners would be emailed who they were paired with and whether they had achieved the 20% performance increase. Following testing, participants were debriefed and informed that everyone would be entered into the prize-draw regardless of performance and that they were not filmed, nor paired with a partner. Cognitive state anxiety was assessed via the MRF-3 immediately before each block. Mental effort was assessed via the RSME immediately after each block of trials (see Figure 1 panel B).

In each block of trials, a randomized 20% of trials featured a cursor perturbation. In these 'jump trials', perturbations occurred 100 ms after movement initiation shifted the on-screen cursor

[1] Although trials were immediately repeated in Experiment 1 if MT was outside 450ms +/-10%, jump trial error was calculated using the first jump trial, not a repeated trial. Therefore, error calculation was in line with Experiment 2 and 3 where jump trials were not repeated based on MT.

15mm to the right of its current position, perpendicularly to the straight line connecting the start position and trial target (Veyrat-Masson, et al., 2010). The rationale for randomly distributed and infrequent cursor jumps, that occurred outside of central vision (> 10° visual angle), was to make offline planning irrelevant and force participants to initiate a sizable online correction (Proteau et al., 2009; Veyrat-Masson et al., 2010).

Data reduction and dependent measures. Stylus displacement data were filtered using a second-order dual-pass Butterworth filter with a 10 Hz low-pass cut-off frequency. The initiation of movement was defined as the point in time that the cursor moved 1 mm from the home position. The movement endpoint was the point at which the trajectory crossed the arc subtended by the three targets (see Khan et al., 2003b). Trials were immediately repeated if participants' movement trajectories did not reach this point. The above calculations were performed on raw data from the task software (Visual Basic) in real time via a custom LabView analysis programme. MT and points scored for trial knowledge of results, were transferred back from LabView to Visual basic within 400ms of data collection cessation.

Dependent variables consisted of: MRF-3 cognitive state anxiety, RSME mental effort, MT, constant error, and variability. MT was defined as the interval in time (ms) between movement initiation and movement endpoint. Error (mm) was calculated at 25, 50, 75, and 100% of movement distance as the stylus' deviation from the longitudinal axis connecting the start position and target on each trial. Error to the right of this line was numerically positive whereas error to the left of the line was numerically negative. Trials where ≥ 25% of error across the movement trajectory deviated by ≥ 2 standard deviations from the respective within-participant block, target and jump / no-jump mean, were eliminated prior to analysis.[2] Constant error was calculated as the within-participant mean error. Variability was calculated as the within-participant standard deviation of error.

In no-jump trials, endpoint (100% movement distance), constant error and variability were used to evaluate outcome performance. Directional variability at 25, 50, 75, and 100% movement distance was used to evaluate offline planning and non-necessitated online corrections. Reduced outcome performance would reflect increases in constant error and variability at endpoint. Reduced offline planning would reflect increased variability at 25% movement distance. Reduced non-necessitated online corrections would reflect increases in variability between 75 and 100% movement distance (see Khan et al., 2006).

In jump trials, endpoint constant error was used to evaluate correction magnitude and variability was used to evaluate correction consistency: together providing an overall measure of outcome performance / necessitated online corrections. Note, error reflected that of the stylus, not the cursor. Therefore, constant error of -15 mm at 100% movement distance would reflect perfect correction magnitude against the +15 mm rightward jumps. Reduced necessitated online corrections would reflect less negative / more positive constant error (i.e., decreased correction magnitude) and greater positive variability (i.e., decreased correction consistency).

Analyses. For brevity and clarity, our analysis focused on the baseline (low anxiety) and transfer (heightened anxiety) trial blocks. Likewise, all analysis below used data collapsed across targets because no significant target (left, middle & right) x block (baseline & transfer) interaction was observed at endpoint. Paired samples t-tests compared baseline and transfer block MT, MRF-3 state anxiety, and RSME mental effort scores. Fully repeated measures 2 block (baseline & transfer)

[2] In Experiment 1, error was collected at every 5% of movement distance but only used for outlier removal. In Experiment 2 and 3, error was calculated at every 2.5%. Trajectory error of a given trial had to deviate > 2 standard deviations at ≥ 25% of these measurements to be excluded. In Experiment 1, of all trials at baseline and transfer respectively, 4.17% and 3.97% were removed. In Experiment 2, of all trials at baseline and transfer respectively, 3.63% and 4.30% were removed. In Experiment 3, of all trials at baseline and transfer respectively, 3.47% and 3.58% were removed.

x 4 movement distance (25, 50, 75, & 100%) ANOVAs separately analysed constant error and variability. Note, jump and no-jump trial data were analysed separately using the above analyses. Jump trials' endpoint constant error and variability in acquisition 1, 2, and, 3 were also compared via separate 3 (block) one way repeated measures ANOVAs to confirm correction efficacy was 'automatic' and uninfluenced by practice. Greenhouse-Geisser corrected tests are reported when sphericity was violated. Omnibus interactions and main effects were broken down using planned repeated contrasts, Bonferroni corrected ANOVAs, and two-tailed t-tests: $p = .05$.

3.1.2 Results.

Monitored confounds.

State anxiety. All participants reported increased state anxiety at transfer compared to baseline. State anxiety increased significantly ($t(13) = -7.02$, $p < .001$, 95% CI [-4.48, -2.37]) from baseline ($M = 2.50$, $SD = 1.29$) to transfer ($M = 5.93$, $SD = 2.02$).

Mental effort. Correspondingly with anxiety, mental effort also significantly increased ($t(13) = -5.37$, $p < .001$, 95% CI [-29.35, -12.51]) from baseline ($M = 76.79$, $SD = 22.42$) to transfer ($M = 97.71$, $SD = 12.83$).

Movement time. For no-jump trials, no significant difference was observed ($t(13) = -.34$, $p = .740$, 95% CI [-4.68, 3.41]) between baseline ($M = 447.53$ ms, $SD = 5.88$) and transfer ($M = 448.17$ ms, $SD = 6.72$). Similarly, for jump trials, no significant difference was observed ($t(13) = -.13$, $p = .902$, 95% CI [-12.94, 11.51]) between baseline ($M = 462.99$ ms, $SD = 15.47$) and transfer ($M = 463.70$ ms, $SD = 14.16$). Thus, differences in error between baseline and transfer should not be attributable to a speed-accuracy trade-off.

Practice effect for jump trials. No participant reported explicitly noticing the cursor jumps, even when debriefed. Neither endpoint correction constant error nor endpoint variability significantly changed across acquisition trial blocks (F(2, 26) = 1.13, p = .339, η_p^2 = .08; F(2, 26) = .94, p = .400, η_p^2 = .07, respectively). Therefore, differences between jump trials in baseline and transfer should not be due to practice effects.

No-Jump Trials.

No-jump constant error. The 2 block x 4 movement distance ANOVA revealed a significant main effect for movement distance (F(1.67, 21.76) = 45.24, p < .001, η_p^2= .78), but no significant main effect for block (F(1,13) = 1.33, p = .269, η_p^2 = .09), nor block x movement distance interaction (F(1.88, 24.39) = 1.36, p = .275, η_p^2 = .10). Endpoint constant error for transfer (M = -.68 mm, SD = 1.46) was not significantly different to baseline (M = -.42 mm, SD = 1.08).

No-jump variability. Analysis revealed a significant main effect for movement distance (F(1.82, 23.67) = 116.77, p < .001, η_p^2 = .90), a non-significant main effect for block (F(1, 13) = 1.96, p = .185, η_p^2 = .13), and a block x movement distance interaction (F(1.42, 18.44) = 3.60, p = .061, η_p^2 = .22) that approached significance.[3] As shown in Figure 2, there was no difference at 25% of movement distance, but variability tended to be lower at transfer compared to baseline at 75% and 100% of the movement.

[3] Comparison between baseline and the 2nd acquisition trial block revealed there was a significant 2 block x 4 distance interaction (F(1.410, 18.33) = 5.41, p = .022, η_p^2 = .29) wherein error between acquisition 2 and baseline remained similar until and including 75% movement distance, after which baseline featured significantly reduced variability compared to acquisition 2. Therefore, although the baseline to transfer interaction was non-significant, anxiety reversed the block-on-block change in online correction from better to worse.

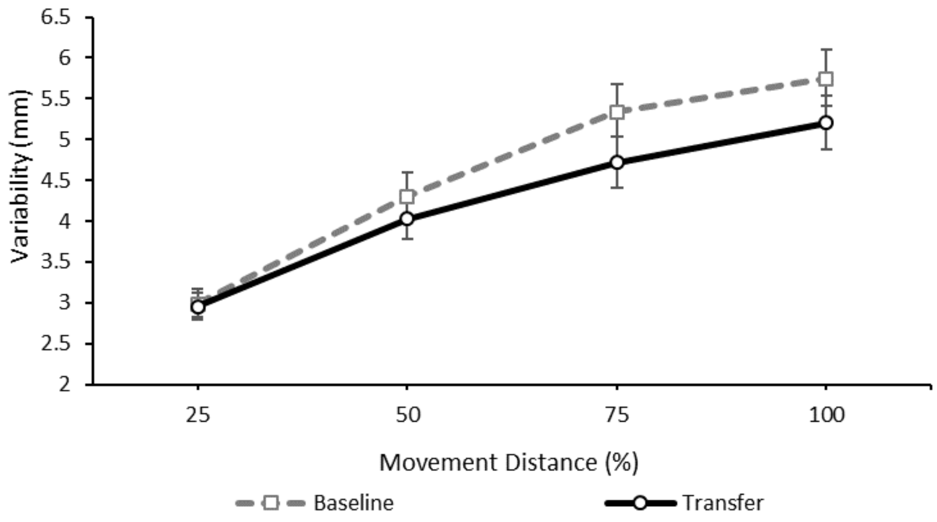


Figure 2. Experiment 1 no-jump trial variability (mm) at baseline (i.e. low state anxiety) and transfer (i.e. heightened state anxiety) at 25, 50, 75, and 100% movement distance. Variability at 25% movement distance is indicative of decreased offline planning and variability between 75 and 100% movement distance is indicative of decreased movement correction. Error bars = +/-1 standard error of the mean.

Jump Trials.

Jump constant error. As shown in Figure 3, the 2 block x 4 movement distance ANOVA revealed a significant main effect for distance ($F(1.77, 23.02) = 88.45$, $p < .001$, $\eta_p^2 = .87$), a significant main effect for block ($F(1, 13) = 6.57$, $p = .024$, $\eta_p^2 = .34$), and significant block x distance interaction ($F(1.44, 18.75) = 5.94$, $p = .016$, $\eta_p^2 = .31$). Contrasts revealed a significant difference between 25 and 50%, and 50% and 75% of movement distance, resulting in significantly greater transfer correction magnitude come endpoint ($M = -10.99$ mm, $SD = 2.64$) compared to baseline ($M = -9.23$ mm, $SD = 2.85$).

Jump variability. The 2 block x 4 movement distance ANOVA showed a significant main effect for distance ($F(3, 39) = 113.69$, $p < .001$, $\eta_p^2 = .90$), but no significant effect for block ($F(1, 13) = .59$, $p = .455$, $\eta_p^2 = .04$), nor block x distance interaction ($F(1.77, 23.01) = .17$, $p = .817$, $\eta_p^2 =$

.01). Correction variability at endpoint in transfer (*M*=6.65 mm, *SD*=1.70) was not significantly different to baseline (*M* = 7.36 mm, *SD* = 2.51).

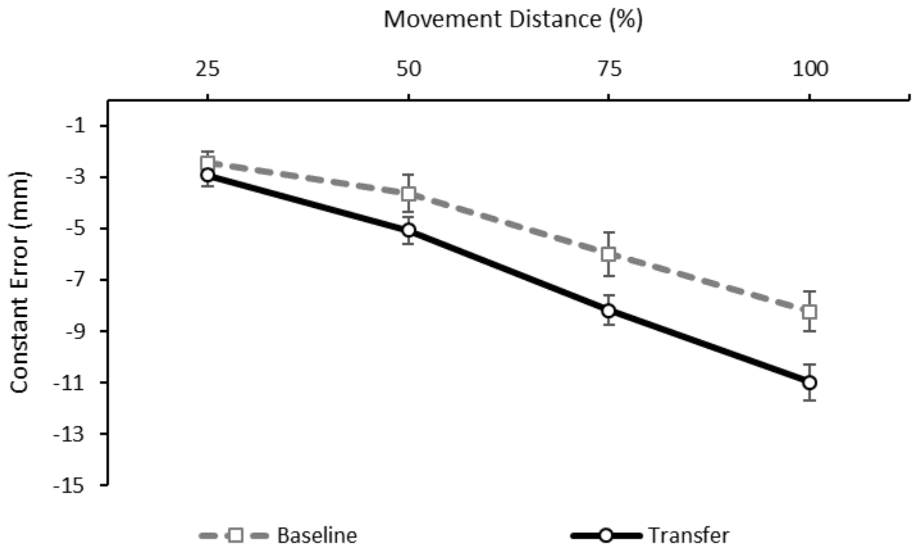


Figure 3. Experiment 1 jump trial constant error at baseline (i.e. low state anxiety) and transfer (i.e. heightened state anxiety) at 25, 50, 75, and 100% movement distance. Note, increased negative constant error, closer to -15 mm, indicates greater correction magnitude and therefore increased necessitated online corrections. Error bars = +/-1standard error of the mean.

3.1.3 Discussion.

Offline planning is the effortful preparation of movements before their initiation and online correction is the automatic detection and correction of errors during movement execution (Elliott et al., 2017). In no-jump trials, participants were free to use a combination of offline planning and online correction to attain their level of outcome performance. In jump trials however, online correction was necessitated to hit the target. A successful anxiety manipulation enabled Experiment 1 to investigate the effects of heightened anxiety; participants reported significantly increased state anxiety and invested mental effort in the transfer block.

In line with previous literature and our hypothesising, no-jump trials displayed a tendency for maintained offline planning and reduced online correction under heightened anxiety (Allsop et al., 2017; Cassell et al., 2018; Lawrence et al., 2013; Roberts et al., 2018). Variability at 25% movement distance did not differ between low and heightened anxiety, and variability profiles levelled off between 75 and 100% of movement distance in the low anxiety but not heightened anxiety condition. Endpoint (i.e., 100% movement distance) variability and constant error did not significantly differ between low and heightened anxiety conditions. As hypothesised, this suggests participants were able to maintain outcome performance despite heightened anxiety though an increase in mental effort and offline motor processes.

However, jump trial results showed the converse to what was hypothesised. Endpoint correction magnitude significantly increased and endpoint variability was maintained under heightened anxiety compared to low anxiety. Overall, this signified increased online correction and improved jump trial outcome performance. Therefore, if the need for correction is great enough (e.g., via artificial cursor jumps), participants may still be able to initiate a correction and benefit from the additional effort invested into the task. However, this notion contradicts prior findings advocating online correction's automaticity (Brière & Proteau, 2011; Franklin & Wolpert, 2008; Proteau et al., 2009; Reichenbach et al., 2014; Reichenbach et al., 2009).

3.2 Experiment 2

The results of Experiment 1 question whether online correction of cursor trajectories is wholly 'automatic', and therefore also question whether reductions in online correction under heightened anxiety can be attributed to the automaticity-impairing mechanisms of conscious processing. Given Experiment 1's unexpected jump trial findings, the first aim of Experiment 2 was to replicate Experiment 1 using a larger sample size and more rigorous design (i.e., via the inclusion of a control group). The second aim of Experiment 2 was to tease apart distraction and conscious processing effects. Conscious processing propensity is suggested to be a stable personality trait that can be measured via the movement specific reinvestment scale (Masters, Eves & Maxwell, 2005). Therefore, individuals high in conscious processing propensity should consciously process movement execution under heightened state anxiety, whereas individuals low in conscious processing propensity should be distracted. The final aim of Experiment 2 was to consider the temporal characteristics of corrections. Heightened state anxiety seems to improve endpoint jump correction magnitude, but it is unclear whether this is because corrections have reduced initiation latency or increased spatial acuity.

Based on the results of Experiment 1, we hypothesised that the heightened anxiety group would exhibit robust offline planning and reduced online correction in no-jump trials, and improved online correction in jump trials compared to the low anxiety control group. We also hypothesised that lower conscious processing propensity (and thus presumed distraction) would have a negative relationship with offline planning efficacy (measured in no-jump trials), and that higher conscious processing propensity (and thus presumed conscious processing) will have a negative relationship with online correction efficacy (measured in no-jump and jump trials). Lastly, we hypothesised that, heightened anxiety would have a beneficial effect on correction latency in cursor jump trials.

3.2.1 Methods.

Participants. For Experiment 2, participation incentives and inclusion criteria were identical to Experiment 1. The experiment sample comprised of 60 university students randomized into two equally sized groups (control and experimental). Post data reduction, the control group kept its n of 30 (13 females, 17 males, $M_{\text{age}} = 19.4$, $SD_{\text{age}} = 1.499$) but the experimental group n reduced to 22 (12 females, 9 males, $M_{\text{age}} = 19.545$, $SD_{\text{age}} = 2.483$). G*Power (G*Power 3; Faul, et al., 2007) sample size estimation deemed 14 participants per group (control and experimental) necessary, to provide power =.8 for the interaction between trial block (baseline and transfer) and distance (at 25, 50, 75, and

100%) of the movement trajectory, when alpha = .05 and η_p^2 = .10. Thus, final sample size exceeded minimum power requirements.

Anxiety, effort, and conscious processing scales. As in Experiment 1, cognitive state anxiety was assessed via the MRF-3 (Krane, 1994) and task mental effort was assessed via the RSME (Zijlstra, 1993). New to Experiment 2, trait conscious motor processing was assessed via the movement specific reinvestment scale (MSRS) (Masters, et al., 2005). This measure comprises of 2 subscales (movement self-consciousness and conscious motor processing) comprising 5 items each. Items are answered via a 7-point Likert scale ranging from strongly disagree to strongly agree. For this experiment, only the conscious motor processing subscale was analysed since it is suggested to be more closely linked to the negative effects of anxious reinvestment / conscious processing (Masters, et al., 2005). This subscale includes statements such as “I am always trying to think about my movements when I carry them out”.

Apparatus, task, and procedure. The apparatus, task, and procedure were identical to Experiment 1, barring 5 exceptions. The first difference was that Experiment 2 contained a control group which was not transferred to heightened state anxiety in their final block of trials, termed transfer (see Figure 5). Immediately before the final block of trials, participants in this group were instructed to “please continue hitting the targets as accurately as you can”. Secondly, all participants completed the MSRS at the beginning of testing. Thirdly, before starting their acquisition blocks, participants completed 15 familiarisation trials which did not contain cursor jumps – to further conceal their occurrence. This was because, despite participants in Experiment 1 reportedly not noticing the cursor jumps, the experimenter observed that the endpoint error of jump trials early in testing surprised some participants. Fourthly, jump trials were never repeated, regardless of MT, to avoid implicit practice effects; at the beginning of testing, participants were told a cover story stating that a random set of trials were accepted irrespective of MT. Finally, to accurately investigate whether heightened anxiety influenced correction latency, cursor jumps occurred at 7.5% of movement distance instead of 100ms post movement initiation.

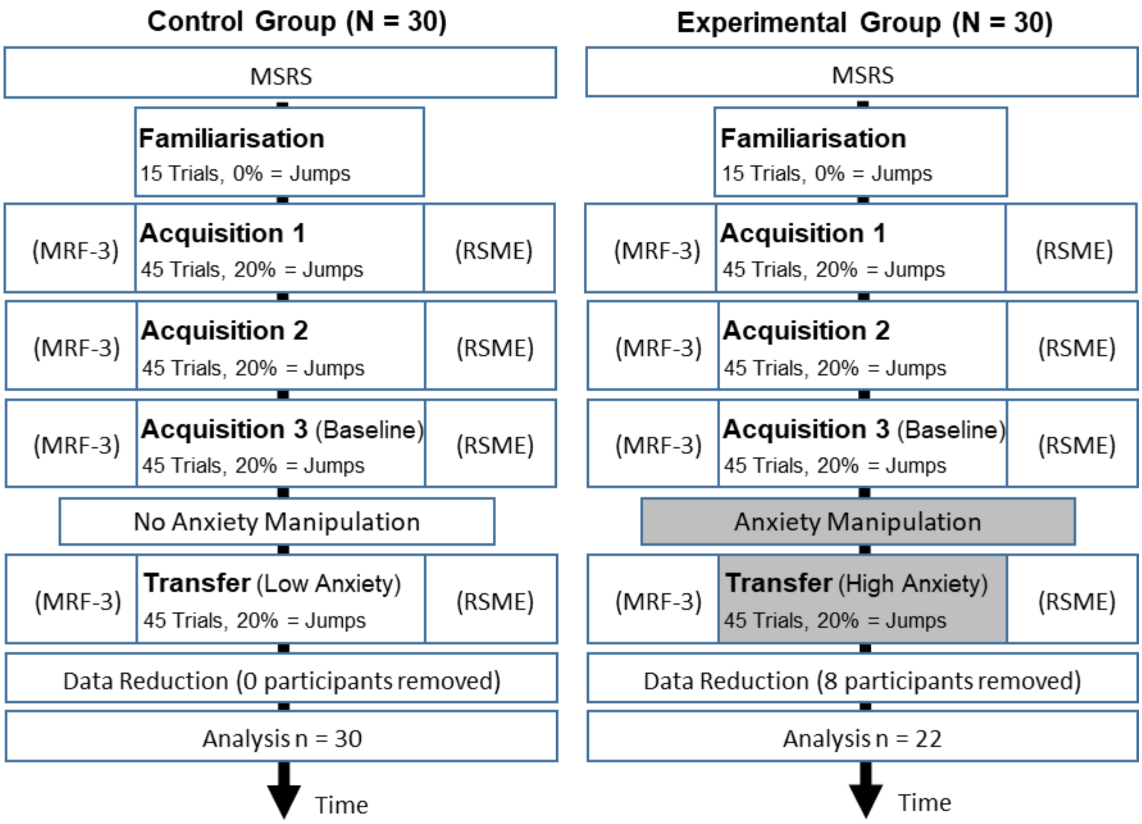


Figure 5. Experiment 2's schematic. The MSRS was completed at the beginning of testing. Barring familiarisation, the mental readiness form-3 (MRF-3) was completed before every block of trials) and the rating scale of mental effort (RSME) was completed after every block of trials. In the final block of trials, the control group was transferred to another block of low anxiety trials, whilst the experimental group was transferred to heightened anxiety. Experimental participants who did not increase their MRF-3 score from baseline to anxiety were excluded from further analysis during data reduction.

Data reduction and dependent measures. Participants who did not respond to the anxiety manipulation (i.e., did not have a heightened transfer MRF-3 score compared to baseline) were removed from subsequent analysis. Therefore, 8 participants in the experimental group (N = 30) were excluded from all subsequent analysis: making final experimental n 22. Barring two exceptions, all subsequent data reduction and dependent measures were also identical to Experiment 1.

Firstly, participants completed the MSRS at the start of testing. The mean score on this scale formed a new dependent variable, used to ensure conscious processing propensity of groups was the same. More importantly however, MSRS, RSME, and MRF-3 scores were hierarchically linearly correlated with markers of offline planning (no-jump variability at 25% movement distance), non-necessitated online correction (late no-jump variability increase: variability at 100% minus 75% movement distance), and necessitated online correction efficacy (jump trial constant error and variability at endpoint). This was to explicate distraction and conscious processing mechanisms underlying heightened state anxiety performance changes. For conciseness and because the detrimental effects of conscious processing should primarily only occur when anxious (Masters & Maxwell, 2008), only the correlations of the experimental group are reported.

Secondly, to calculate correction initiation latency, in every block of trials and for every participant, the no-jump constant error was subtracted from jump constant error at every 2.5% of movement distance to attain within participant jump trials' mean deviation from no-jump trials at each of these points. Based on the methods of Proteau et al. (2009), participants' correction initiation was identified when this deviation reached a more negative value than -1mm and continually became more negative with every 2.5% of movement distance: i.e., suggesting the stylus progressed in the opposite direction to that of the cursor jump for the remainder of the movement. The time interval (ms) between the cursor jump and correction initiation was used to denote correction latency. From within-participant correction latency, mean group correction latency was calculated for statistical analysis. A positive effect of anxiety on correction latency would reflect corrections being initiated, overall, at a reduced latency.

Analyses. As in Experiment 1, analysis focused on baseline (low anxiety) and transfer (heightened anxiety for the experimental group, low anxiety for control). Data was collapsed across targets because no significant target (left, middle, & right) x block (baseline & transfer) interactions were observed at endpoint. Separate 2 group (experimental & control) x 4 movement distance (25, 50, 75, & 100%) ANOVAs with repeated measures on distance analysed MT, MRF-3 state anxiety, and RSME mental effort scores respectively. Separate 2 group (control & experimental) x 2 block (baseline & transfer) x 4 movement distance (25, 50, 75, & 100%) ANOVAs with repeated measures on block and movement distance analysed constant error and variability. Separate 2 group x 2 block ANOVAs with repeated measures on block were also performed on constant error and variability at 100% movement distance. Note, jump and no-jump trial data was analysed identically but separately using the above analyses, except that jump trials' endpoint constant error and variability in acquisition 1, 2, and 3 were submitted to a repeated measures ANOVA to confirm correction efficacy was automatic and uninfluenced by practice. Greenhouse-Geisser corrected tests are reported when sphericity was violated. Omnibus interactions and main effects were broken down using planned repeated contrasts, Bonferroni corrected ANOVAs, and two-tailed t-tests: alpha = .05.

Independent-samples t-tests compared control and experimental groups' MSRS trait conscious processing. Separate hierarchical linear regressions containing MSRS trait conscious processing propensity in step 1, RSME mental effort in step 2, and MRF-3 state anxiety in step 3 were performed with the following dependent variables: no-jump variability at 25% movement distance (indicator of offline planning efficacy); no-jump variability increase between 75% and 100% of movement distance (indicator of non-necessitated online correction efficacy); and jump constant error and variability, respectively, at 100% movement distance (together, key indicators of necessitated online correction efficacy). All variables were standardised into z-scores prior to regression analyses.[4] For conciseness, regressions of only the experimental group's transfer data are reported.

3.2.2 Results.

Monitored confounds.

State anxiety. Analysis revealed a significant main effect for block ($F(1, 50) = 51.71$, $p < .001$, $\eta_p^2 = .51$), group ($F(1, 50) = 15.74$, $p < .001$, $\eta_p^2 = .24$), and group x block interaction ($F(1, 50) = 86.21$, $p < .001$, $\eta_p^2 = .63$). Interaction breakdown revealed control and experimental groups' anxiety was not significantly different at baseline ($M = 3.37$, $SD = 1.63$; $M = 3.14$, $SD = 1.75$, respectively), but significantly different at transfer ($M = 2.93$, $SD = 1.55$; $M = 6.55$, $SD = 1.87$, respectively). Within-group changes in state anxiety between blocks were significant for both control and experimental groups: i.e., state anxiety of the experimental group increased whilst the control group's decreased.

Mental effort. Analysis revealed a significant main effect for block ($F(1, 50) = 18.10$, $p < .001$, $\eta_p^2 = .27$), and a block x group interaction ($F(1, 50) = 21.99$, $p < .001$, $\eta_p^2 = .31$), but no main effect for group ($F(1, 50) = 1.75$, $p = .193$, $\eta_p^2 = .03$). Interaction breakdown revealed control and experimental groups' mental effort was not significantly different at baseline ($M = 84.33$, $SD = 15.63$; $M = 79.91$, $SD = 18.28$, respectively), but significantly different at transfer ($M = 83.43$, $SD = 15.96$; $M = 98.46$, $SD = 14.45$, respectively). Within-group mental effort changes were only significant for the experimental group: i.e., mental effort of the experimental group increased whilst the control group's did not.

---

[4] Moderated hierarchical regression was also performed for all dependent variables of interest (with transfer state anxiety as the x variable, conscious processing as the M variable) but revealed no significant moderating effect, potentially because of underpowered sample size for regression.

Conscious processing. Trait conscious motor processing of the control group (M = 4.54, SD = .52) was not significantly different ($t(50) = 1.51$, $p = .138$, 95% CI [-.10, .73]) to that of the experimental group (M = 4.23, SD = .97).

Movement time. For no-jump trials, no significant main effect for block ($F(1, 50) = .21$, p = .649, $\eta_p^2 < .01$), main effect for group ($F(1, 50) = 2.55$, $p = .117$, $\eta_p^2 = .05$), nor block x group interaction was observed ($F(1, 50) = 1.32$, $p = .256$, $\eta_p^2 = .03$). For jump trials, no significant main effect for block ($F(1, 50)$ = .3.39, $p = .075$, $\eta_p^2 = .06$), main effect for group ($F(1, 50) = 1.00$, p = .480, $\eta_p^2 = .01$), nor block x group interaction was observed ($F(1, 50) = .51$, $p = .480$, $\eta_p^2 = .01$). Therefore, baseline and transfer differences should not be a product of speed-accuracy trade-offs.

Practice effect for jump trials. As in Experiment 1, no participant reported explicitly noticing the cursor jumps, even when debriefed. Neither the control nor experimental group changed their endpoint constant error across acquisition 1, 2, and 3 ($F(2, 58) = 1.39$, $p = .257$, $\eta_p^2 = .05$; $F(2, 42)$ = .22, $p = .805$, $\eta_p^2 = .01$, respectively for groups). Similarly, neither the control nor experimental group differed in variability across acquisition 1, 2, and, 3 ($F(2, 42) = 1.45$, $p = .246$, $\eta_p^2 = .07$; $F(1.60, 46.31) = .54$, $p = .545$, $\eta_p^2 = .02$, respectively for groups). Therefore, differences between jump trials in baseline and transfer should not be due to practice effects.

No-jump trials.

No-jump constant error. Analysis found no significant 2 group x 2 block x 4 distance interaction ($F(1.86, 93.12) = 2.90$, $p = .064$, $\eta_p^2 = .06$). Endpoint constant error analysis revealed no significant main effect for block ($F(1, 50) = .20$, $p = .661$, $\eta_p^2 < .01$), group ($F(1, 50) = 1.47$, $p = .231$, $\eta_p^2 = .03$), nor block x group interaction ($F(1, 50) = .29$, $p = .594$, $\eta_p^2 = .01$).

No-jump variability. Results showed a significant omnibus 2 group x 2 block x 4 distance interaction ($F(2.32, 115.95) = 3.25$, $p = .035$, $\eta_p^2 = .06$) (see Figure 6). Breakdown comparing control and experimental groups at baseline revealed a significant distance main effect (F(1.95, 97.59) =

212.06, $p < .001$, $\eta_p^2 = .81$), and no group main effect ($F(1, 50) = .54$, $p = .468$, $\eta_p^2 = .01$), nor group x distance interaction ($F(1.95, 97.59) = .48$, $p = .616$, $\eta_p^2 = .01$). Breakdown comparing groups at transfer revealed a significant main effect for distance ($F(2.02, 101.06) = 237.54$, $p < .001$, $\eta_p^2 = .83$), and group x distance interaction ($F(2.02, 101.06) = 8.50$, $p < .001$, $\eta_p^2 = .15$), but no main effect for group ($F(1, 50) = 2.64$, $p = .110$, $\eta_p^2 = .05$). Breakdown of transfer offline planning revealed that variability at 25% movement distance was significantly lower in the experimental group compared to the control group. Breakdown of transfer looking at non-necessitated online correction revealed that, variability in the control group did not significantly increase between 75% and 100% of movement distance, whereas that of the experimental group did. Analysis comparing groups' endpoint variability between baseline and transfer showed a significant main effect for block ($F(1, 50) = 8.34$, $p = .006$, $\eta_p^2 = .14$), but not group ($F(1, 50) = .11$, $p = .747$, $\eta_p^2 < .01$), nor group x block interaction ($F(1, 50) = .57$, $p = .455$, $\eta_p^2 = .01$): however, within-group breakdown showed endpoint variability for the experimental group did not change, whereas the control group's decreased significantly.

Linear hierarchical regression results for conscious processing propensity, mental effort, and state anxiety's respective predictive power of offline planning (variability at 25% movement distance) and non-necessitated online correction (variability increase between 70 and 100% movement distance) are reported in table 1. Higher trait conscious processing significantly predicted reduced non-necessitated online correction. However, no other significant relationships were observed.

Table 1

Hierarchical linear regression predicting experimental group transfer block error in no-jump trials. Confidence intervals and standard error based on 1000 bootstrap samples, bias corrected and accelerated.

Dependent Variables	Step (coefficient of determination) & Independent variables (95% CI)	b	SE B	p
Variability at 25% movement distance	Step 1 ($r^2 = .02$, $\Delta R^2 = .02$)			
	Conscious Processing (-0.50, 0.10)	0.15	0.15	.50
	Step 2 ($r^2 = .03$, $\Delta R^2 < .01$)			
	Conscious Processing (-0.51, 0.09)	-0.16	0.16	.50
	Mental Effort (-0.37, 0.33)	-0.07	0.17	.76
	Step 3 ($r^2 = .08$, $\Delta R^2 = .06$)			
	Conscious Processing (-0.53, 0.26)	-0.10	0.18	.69
	Mental Effort (-0.48, 0.26)	-0.17	0.20	.50
	State Anxiety (-0.09, 0.56)	0.26	0.18	.31
Variability increase between 75 and 100% movement distance [a]	Step 1 ($r^2 = .23$, $\Delta R^2 = .23$)			
	Conscious Processing (0.18, 0.89)	0.48	0.20	.02
	Step 2 ($r^2 = .26$, $\Delta R^2 = .03$)			
	Conscious Processing (0.18, 0.84)	0.49	0.19	.02
	Mental Effort (-0.31, 0.56)	-0.18	0.26	.51
	Step 3 ($r^2 = .28$, $\Delta R^2 = .02$)			
	Conscious Processing (0.15, 0.74)	0.46	0.20	.03
	Mental Effort (-0.43, 0.67)	-0.24	0.30	.45
	State Anxiety (-0.69, 0.23)	0.16	0.26	.54

Note. CI = confidence interval, conscious processing = MSRS conscious motor processing score, mental effort = RSME mental effort score, and state anxiety = MRF-3 cognitive state anxiety score.

[a] At baseline, the correlation between variability increase and CMP in step 1 was not significant ($r^2 = .04$, 95% CI = -.71 to .26, b = -.22, p = .26).

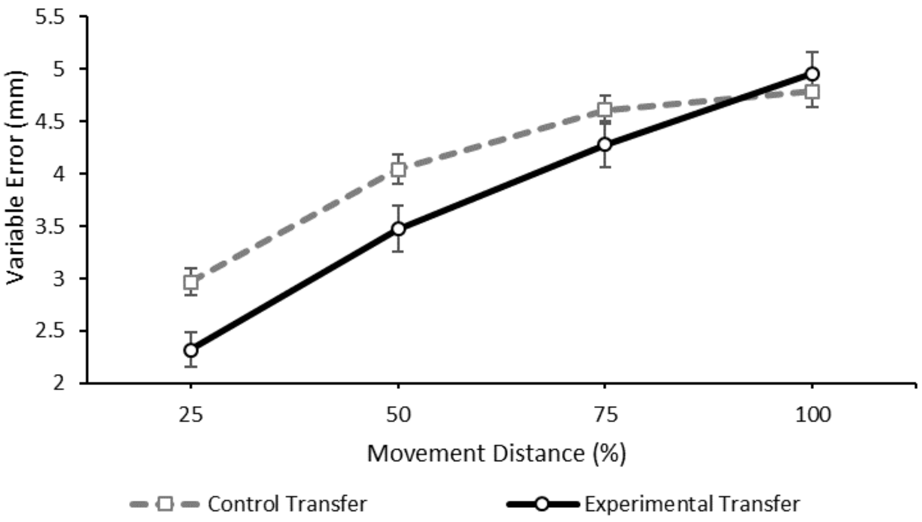


Figure 6. Experiment 2 no-jump trial variability (mm) at transfer for the control (i.e., low state anxiety) and experimental groups (i.e., heightened state anxiety) at 25%, 50%, 75%, and 100% movement distance. Error bars = +/-1 standard error of the mean.

Jump Trials.

Jump constant error. No significant group x block x distance interaction was observed (F(1.59, 79.73) = 1.46, p = .239, η_p^2 = .03). However, the block x group interaction was only marginally non-significant (F(1, 50) = 3.80, p = .057, η_p^2 = .07) (see Figure 7) and breakdown showed the hypothesised effects. Separate 2 block x 4 distance ANOVAs for each group revealed that the control group had no main effect for block (F(1, 29) = .06, p = .813, $\eta_p^2 < .01$) but the experimental group did (F(1, 21) = 6.77, p = .016, η_p^2 = .24). Further analysis suggested that omnibus interaction significances may have been diluted across distance; the 2 group x 2 block ANOVA at 100% movement distance showed no significant block (F(1, 50) = 3.14, p = .083, η_p^2 = .06) nor group (F(1, 50) = .05, p = .822, $\eta_p^2 < .01$) main effect, but a significant block x group interaction (F(1, 50) = .4.44, p = .040, η_p^2 = .08). Specifically, whilst the control group did not change their outcome correction magnitude between baseline (M = -9.49 mm, SD = 2.99) and transfer (M = -9.36 mm, SD = 3.43), the experimental group significantly improved from baseline (*M* = -8.46 mm, *SD* = 3.14) to transfer (*M* = -10.02 mm, *SD* = 3.04).

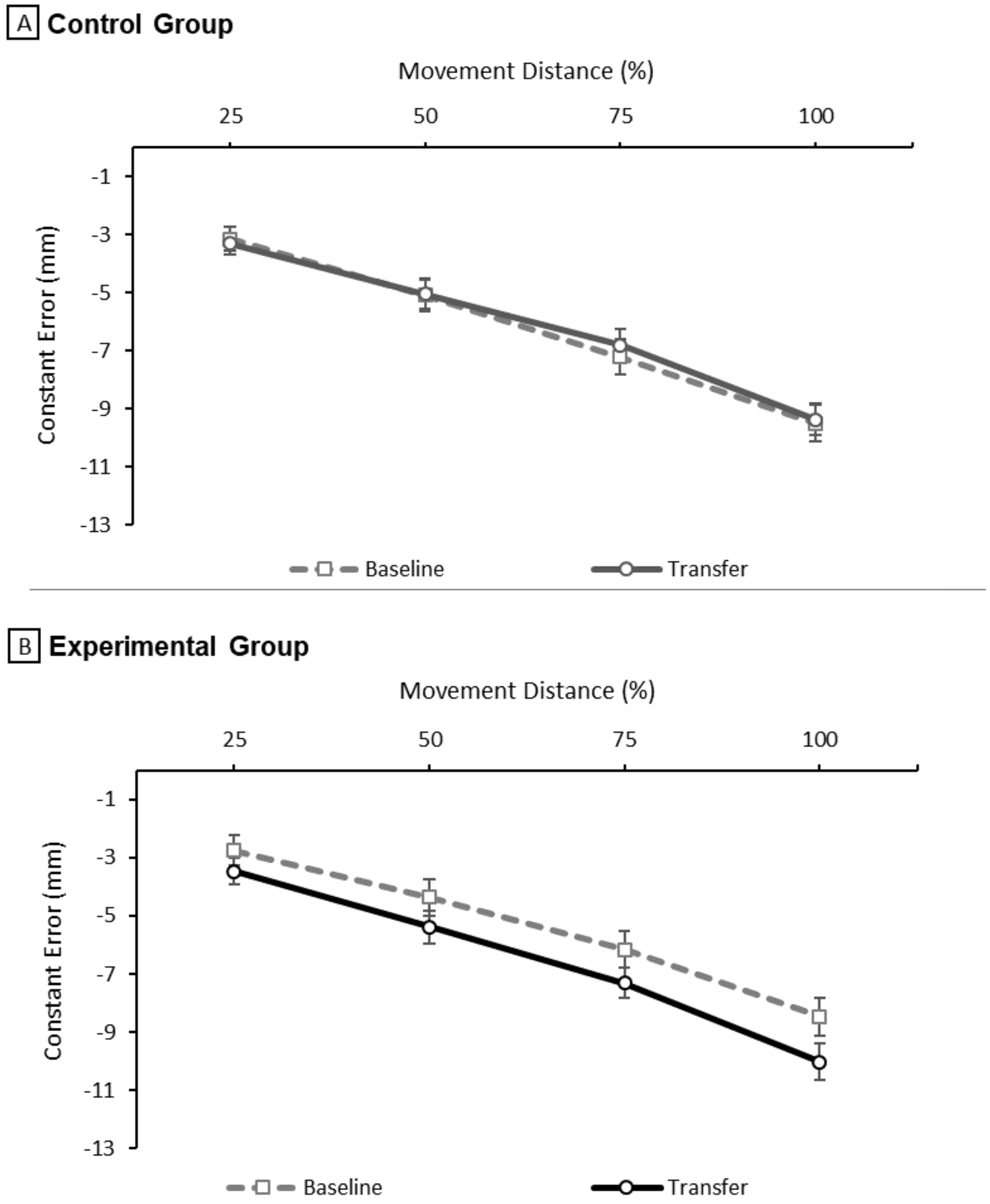


Figure 7. Panel A (top) shows Experiment 2 control group jump trial constant error at baseline (low state anxiety) and transfer (to another block of low state anxiety). Panel B (bottom) shows Experiment 2 experimental group jump trial constant error at baseline (low state anxiety) and transfer (to heightened state anxiety). Error bars = +/-1 standard error of the mean**.**

Linear hierarchical regression investigating conscious processing propensity, mental effort, and state anxiety's respective predictive power of jump trials' endpoint constant error revealed no significant relationships (see Table 2).

Jump variability. No significant group x block x distance interaction ($F(1.82, 90.77) = .68$, $p = .496$, $\eta_p^2 = .01$) or block x group interaction ($F(1, 50) = 1.11$, $p = .298$, $\eta_p^2 = .02$) was found. Correspondingly, analysis of outcome variability found no significant main effect for block ($F(1, 50) = 1.10$, $p = .299$, $\eta_p^2 = .02$), group ($F(1, 50) = .38$, $p = .542$, $\eta_p^2 = .01$) nor group x block interaction ($F(1, 50) = 1.36$, $p = .249$, $\eta_p^2 = .03$).

Linear hierarchical regression investigating conscious processing propensity, mental effort, and state anxiety's respective predictive power of jump trials' endpoint variability revealed no significant relationships (see Table 2).

Correction latency. No significant main effect for block ($F(1, 50) = .90$, $p = .347$, $\eta_p^2 = .02$), main effect for group ($F(1, 50) = 1.53$, $p = .222$, $\eta_p^2 = .03$) nor block x group interaction was observed ($F(1, 50) < .01$, $p = .963$, $\eta_p^2 < .01$). The control and experimental group correction latency did not differ significantly at baseline ($M = 191.20$ ms, $SD = 39.75$; $M = 200.50$ ms, $SD = 29.72$, respectively) nor transfer ($M = 185.97$ ms, $SD = 34.36$; $M = 194.73$ ms, SD = 23.87). Latencies also did not differ significantly within the groups between baseline and transfer.

Table 2

Hierarchical linear regression predicting experimental group transfer block error in jump trials. Confidence intervals and standard error based on 1000 bootstrap samples, bias corrected and accelerated.

Dependent Variables	Step (coefficient of determination) & Independent variables (95% CI)	b	SE B	p
Constant error	Step 1 ($r^2 < .01$, $\Delta R^2 < .01$)			
at 100%	Conscious Processing (-0.34, 0.53)	.02	0.19	.88
movement	Step 2 ($r^2 < .01$, $\Delta R^2 = .01$)			
distance	Conscious Processing (-0.41, 0.58)	.02	0.20	.91
	Mental Effort (-0.50, 0.45)	-.04	0.22	.85
	Step 3 ($r^2 < .01$, $\Delta R^2 = .01$)			
	Conscious Processing (-0.46, 0.39)	.01	0.30	.98
	Mental Effort (-0.86, 0.77)	-.02	0.27	.94
	State Anxiety (-1.12, 0.58)	-.06	0.48	.89
Variability	Step 1 ($r^2 = .04$, $\Delta R^2 = .04$)			
at 100%	Conscious Processing (-0.80, 0.33)	-0.20	0.26	.47
movement	Step 2 ($r^2 = .10$, $\Delta R^2 = .06$)			
distance	Conscious Processing (-0.77, 0.31)	-0.18	0.27	.54
	Mental Effort (-0.22, 0.72)	0.25	0.19	.19
	Step 3 ($r^2 = .11$, $\Delta R^2 = .01$)			
	Conscious Processing (-0.78, 0.27)	-0.16	0.31	.62
	Mental Effort (-0.54, 1.05)	0.21	0.25	.37
	State Anxiety (-0.58, 0.43)	0.11	0.27	.61

Note. CI = confidence interval, Conscious Processing = MSRS conscious motor processing score, mental effort = RSME mental effort score, and state anxiety = MRF-3 cognitive state anxiety score.

3.2.3 Discussion.

The purpose of Experiment 2 was threefold. Firstly, it endeavoured to replicate the findings of Experiment 1 whilst utilising a control group and a larger sample. Secondly, it aimed to investigate the effect of heightened state anxiety on corrections' temporal latencies. Finally, it aimed to use individuals' trait conscious processing propensity to approximate distraction and conscious processing's respective effects on offline planning and online correction. A successful anxiety manipulation enabled Experiment 2 to fulfil these aims; the experimental group reported heightened state anxiety and mental effort in the transfer block, whilst the control group did not.

As hypothesised, transfer no-jump trials under heightened anxiety (experimental group) exhibited increased offline planning and reduced online correction compared to the low anxiety (control group) trials. Jump trials on the other hand exhibited increased online correction in the experimental group between (low anxiety) baseline and (heightened anxiety) transfer, but not in the control group. Concurrent analysis of jump trial corrections' temporal latencies showed no significant differences between the low anxiety control and the heightened anxiety experimental group. To explicate the distraction / conscious processing mechanisms underpinning the aforementioned findings, the experimental group's transfer block data was used to correlate trait conscious processing propensity with indexes of no-jump offline planning, no-jump online correction, and jump online correction efficacy. Results revealed that trait conscious processing propensity positively predicted variability increases between 75 and 100% movement distance (i.e. reduced online correction); no other correlations were significant.

Overall, Experiment 2's results lend further credibility to the notion that online correction may be attention demanding. Online correction in no-jump trials may be reduced because when planning their movements offline, individuals high in conscious processing propensity may attenuate online correction in advance (perhaps in an effort to gain greater explicit control during movement execution), but overturn this plan online if the need for correction is great. A limitation of the correlational analysis performed above is the experiment's sample size. Although power exceeded what was necessary to find significant omnibus ANOVA interactions, Experiment 2's power was far below what is commonplace in correlational research (VanVoorhis & Morgan, 2007). Therefore, no definitive conclusions can be drawn from the herein correlational results.

3.3 Experiment 3

Fiedler (2011) highlighted the importance of replicating findings with multiple stimuli to ensure they are a product of the phenomenon, instead of the specific set of stimuli within a single experiment. Therefore, the aim of Experiment 3 was to use self-control depletion to specifically exacerbate distraction-based anxiety mechanisms over conscious processing. The strength model of self-control suggests that initial acts of central executive-based self-control (e.g. overriding impulsive / automatic behavioural responses) consume a limited global resource (Muraven, Tice, & Baumeister, 1998; Muraven & Baumeister, 2000). When this resource is depleted, individuals are suggested to be in a state of 'ego-depletion', and thereby likely exhibit impaired performance in subsequent acts requiring self-control. Notably for the present study, the mobilisation of cognitive resources, to compensate for the deleterious effects of heightened state anxiety, is proposed to be a depletable self-control act (Englert & Bertrams, 2015a). Therefore, differences between an anxious group with self-control resources intact and anxious self-control depleted group would likely be due to distraction-based mechanisms. Concurrently, self-control depletion may prevent individuals from consciously processing movements, by reducing the resources required to direct attention to movement processes.

In Experiment 3 we aimed to use a self-control depleting transcription task to exacerbate distraction effects. Transcription-based self-control tasks have repeatedly been shown successful at inducing self-control depletion and impaired performance under anxious / distracting conditions (Englert & Bertrams, 2012; Englert & Bertrams, 2015b; Englert & Bertrams, 2016; Englert, Zwemmer, Bertrams, & Oudejans, 2015c). In these tasks, participants have to omit specific letters in their transcription of a standard piece of text which should require the volitional exertion of self-control to combat usually automatic and well-rehearsed writing habits. We hypothesised that self-control depletion following a transcription task would impair offline planning, non-necessitated online correction, and necessitated online correction: suggesting that online correction processes, similarly to offline planning processes, are indeed resource-reliant.

3.3.1 Methods.

Participants. Experiment 3 participation incentives and inclusion criteria were identical to Experiment 1 and 2. The experiment sample comprised of 62 university students randomized into two groups (self-control full and self-control depleted); exact sample size aimed to match Experiment 2 (n = 60), but additional sample availability resulted in a final n of 62. Post data reduction, the self-control full group n reduced to 23 (14 females, 9 males, M_{age} = 22.478, SD_{age} = 6.022) and the self-control depleted group n reduced to 29 (16 females, 13 males, M_{age} = 21.131, SD_{age} = 3.502). True self-control depletion effect size is a contentious topic within literature (Carter & McCullough, 2014; Etherton et al., 2018; Vadillo et al., 2016; Wolff, Baumann & Englert, 2018); using a medium effect size of η_p^2 = .06, G*Power (G*Power 3; Faul et al., 2007) sample size estimation deemed 24 participants per group (self-control full and self-control depleted) necessary, to provide power = .8 for the interaction between trial block (baseline and transfer) and distance (at 25, 50, 75, and 100%) of the movement trajectory, when alpha = .05. Therefore, final sample size should be adequate.

Measures. A total of five new questionnaires were administered in Experiment 3, in addition to those of Experiment 2. The purpose of these was to act as manipulation checks and monitor potential trait personality and state confounds (namely: self-efficacy, narcissism, trait cognitive anxiety, trait self-control resources, and trait depletion-sensitivity). For brevity, clarity, and because no significant differences were observed, results are not reported in this manuscript.

The apparatus, task and procedure of Experiment 3 were identical to those of Experiment 2, barring the herein following exceptions. Firstly, the order of all trait personality questionnaires at the beginning of testing was randomized across participants to reduce systematic questionnaire fatigue effects. Immediately following the baseline block of trials, participants' self-control was experimentally manipulated by instructing them to transcribe a piece of text from one sheet of paper onto another for six minutes. The self-control depletion group was instructed to transcribe the text as quickly and accurately as possible whilst always omitting the letters 'e' and 'a' from all transcribed words. The self-control full group were instructed to transcribe the text as quickly and accurately as possible with no additional criterions given.[5] The transcribed piece of text in the present experiment was generated from dictionary example sentences for 50 random words generated via an online tool ("randomwordgenerator.com", n.d); no parameters other than word number was entered into the random word generator (i.e., 1). For every generated word, the first listed example sentence provided in the dictionary was used. Generated words for which there was no example sentence (n = 6), or in situations where two independent researchers deemed example sentences not neutral within the context of the study (n=7), were not included in the final text. Male names in the text were replaced with 'he' or 'his', whilst female names were replaced with 'she' or 'her' (n = 3).[6] The final text contained: 37 sentences / 252 words / 1176 characters excluding spaces; 'a' and 'e' were the most frequent letters in the text (frequency of 87 and 155, respectively) and were, therefore, the ones to be omitted in the depletion condition. Sentence order was not randomized between participants and

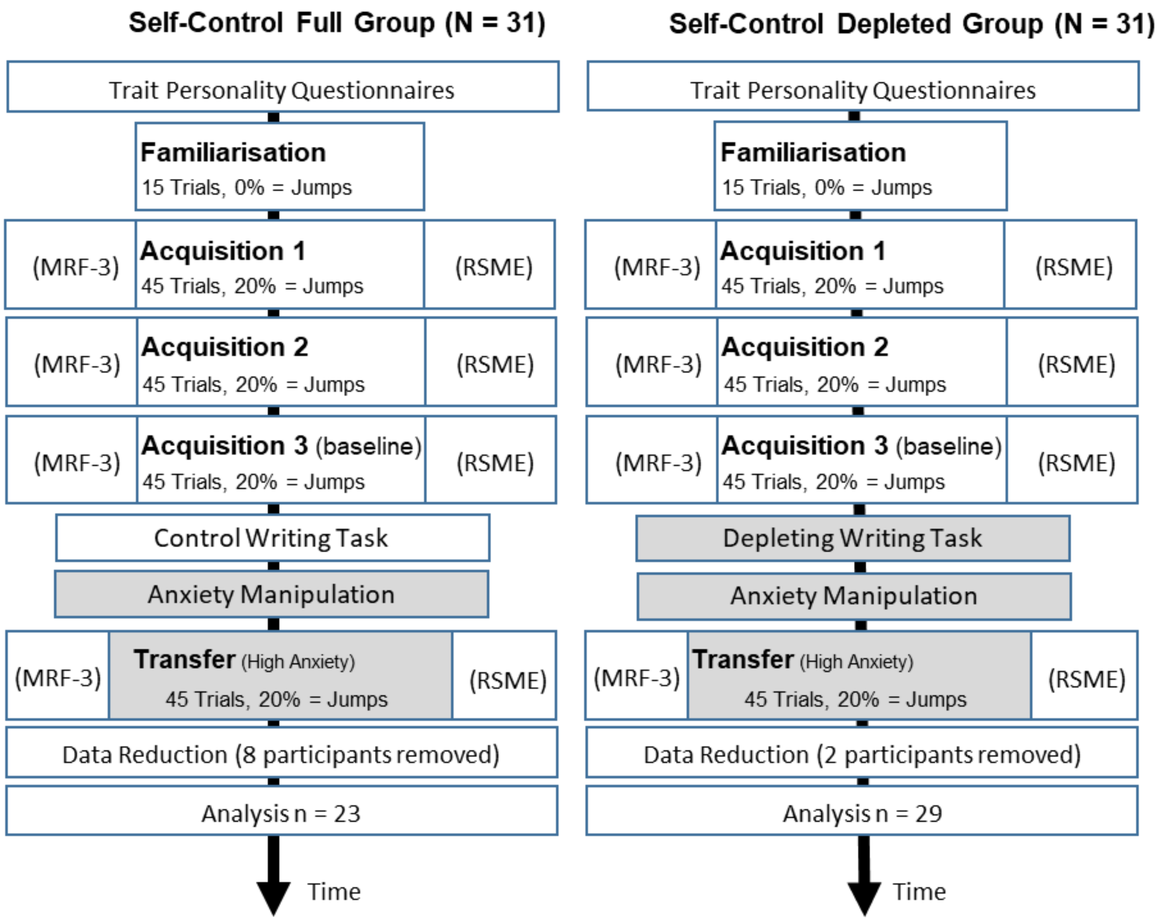
[5] Instructions were worded in an autonomy depriving manner for the self-control depleted group, and autonomy neutral manner for the control group (Englert & Bertrams, 2015b).

Experimental Group Instructions: "You now have to transcribe the following text by hand on a separate sheet of paper. You have to transcribe the text as quickly as possible and you also have to avoid mistakes. Finally, you have to always omit the letters 'e' and 'a' while transcribing the text. You must follow these instructions and you have to work on the task until the experimenter stops you."

Control Group Instructions: "Transcribe the following text by hand on a separate sheet of paper. Transcribe the text as quickly as possible and avoid making mistakes. Please work on the task until the experimenter stops you."

[6] Names were considered to reduce the neutrality of the text because of the associations they may hold.

sentences were arranged as one large paragraph in single-spaced Arial font size 12.[7] Immediately following the transcription task, all participants completed a self-efficacy check questionnaire (see Figure 8). The self-control depletion manipulation's effectiveness in the present experiment was assessed via transfer RSME (Zijlstra, 1993). This was because individuals with depleted self-control resources should find the task more taxing and therefore report increased invested mental effort. Using the RSME in this way should also measure self-control depletion's *direct effect on participants during the task*, rather than indirectly before it as is contemporary within self-control depletion literature (for examples see Englert & Bertrams, 2012; Englert & Bertrams, 2015b; Englert & Bertrams, 2016; Englert et al., 2015c).



[7] Arranging the sentences as a solid paragraph should require inhibition of surrounding text, scanning for current segment and make switching between sentences more taxing.

Figure 8. Diagram of Experiment 3's schematic. Trait personality questionnaires were completed by participants in a randomized order at the beginning of testing. Barring familiarisation, the mental readiness form-3 (MRF-3) was completed before every block of trials) and the rating scale of mental effort (RSME) was completed after every block of trials. In the final block of trials both, the self-control full group and self-control depleted, groups were transferred to heightened anxiety. Participants who did not increase their MRF-3 score from baseline to anxiety were excluded from further analysis during data reduction.

Data reduction and dependent measures. Again, participants who did not respond to the anxiety manipulation (i.e., did not have a heightened transfer MRF-3 score compared to baseline) were removed from subsequent analysis. Therefore, 8 participants in the self-control full group (N = 31), and 2 participants in the self-control depleted group (N = 31) were excluded from all subsequent analysis: leaving final group n at 23 and 29, respectively. Data reduction and dependent measures of Experiment 3 were identical to Experiment 2, barring the addition of new dependent variables including number of words transcribed, number of errors in transcription, and 'a's / 'e's omitted. Errors in transcription were defined as: (1) the incorrect spelling of a word; (2) incorrect punctuation; (3) omission of a word, punctuation, or passage of text; and (4) when the self-control depleted group did not omit a / e in a word. The 'a's and 'e's of omitted words or passages in the text were not counted towards the number of 'a's and 'e's omitted by participants.

Analyses. The analysis for the two groups in Experiment 3 was identical to Experiment 2 with the addition of independent samples t-tests for: words transcribed, errors in transcription, and As & Es omitted.[8]

[8] A significant target (left, middle, & right) x block (baseline & transfer) interaction was observed for self-control full group's no-jump endpoint VE. However, to be in line with Experiment 1 and 2, and because no significant target x block x group interactions were observed, target data was again collapsed for analyses.

3.3.2 Results.

Monitored confounds.

State anxiety. State cognitive anxiety (MRF-3) analysis revealed a significant main effect for block ($F(1, 50) = 165.32$, $p < .001$, η_p^2=.77), but no significant main effect for group ($F(1, 50) = 1.30$, $p = .568$, $\eta_p^2 = .01$), nor group x block interaction ($F(1, 50) = 1.98$, $p = .165$, ${}^{2}{}_{p}^{2} = .04$). self-control full and self-control depleted groups' anxiety was not significantly different at baseline ($M = 3.65$, $SD = 1.95$; $M = 3.69$, $SD = 2.29$, respectively) nor transfer ($M = 6.26$, $SD = 1.79$; $M = 6.58$, $SD = 2.51$, respectively). Within-group changes in state anxiety between blocks were significant for both groups.

Mental effort. Mental effort (RSME) analysis revealed a significant main effect for block ($F(1, 50) = 21.65$, $p < .001$, $\eta_p^2 = .30$), but no significant main effect for group ($F(1, 50) = .81$, $p = .373$, $\eta_p^2 = .02$), nor block x group interaction ($F(1, 50) = .50$, $p = .485$, $\eta_p^2 = .01$). However, despite the non-significant omnibus interaction, as hypothesised, the self-control depleted and self-control full groups' mental effort was not significantly different at baseline ($M = 77.48$, $SD = 19.32$; $M = 74.22$, $SD = 21.87$, respectively), but in transfer, the self-control depleted group reported significantly greater mental effort than the self-control full group ($M = 90.93$, $SD = 18.42$; $M = 84.13$, $SD = 28.42$, respectively). Within-group mental effort changes were significant for both groups.

Self-control depletion transcription. The self-control full group ($M = 155.00$, $SD = 27.73$) transcribed significantly more words ($t(50) = 3.15$, $p = .003$, 95% CI[8.95, 40.44]) than the self-control depletion group ($M = 130.31$, $SD = 28.36$). Number of errors was also significantly greater ($t(50) = -2.07$, $p = .044$, 95% CI[-4.12, -.06]) for the self-control depletion group ($M = 4.48$, $SD = 3.71$) than for the self-control full group ($M = 2.39$, $SD = 3.71$). The self-control depletion group omitted 98% of 'a's & 'e's in their transcribed text ($M = 123.52$, $SD = 27.46$) whilst the self-control full group omitted none ($M = 0$, $SD = 0$).

Movement time. For no-jump trials, analysis revealed no significant main effect for block (F(1, 50) = .15, p = .698, η^2 < .01), main effect for group (F(1, 50) = .03, p = .856, η_p^2 < .01), nor block x group interaction (F(1, 50) = .48, p = .484, η_p^2 = .01). For jump trials, analysis again revealed no significant main effect for block (F(1, 50) = 1.99, p = .164, η_p^2 = .04), main effect for group (F(1, 50) = .76, p = .387, η_p^2 = .02), nor block x group interaction (F(1, 50) = .04, p = .849, η_p^2 < .01).

Practice effect for jump trials. Again, no participant reported explicitly noticing the cursor jumps, even when debriefed. Constant error of neither the self-control full nor self-control depleted groups changed their outcome correction magnitude across acquisition 1, 2, and 3 (F(2, 44) = .10, p = .905, η_p^2 = .01; F(2, 56) = .41, p = .669, η_p^2 = .01, respectively for each group). Variability of both self-control full and self-control depleted groups demonstrated a significant effect across acquisition 1, 2, and 3 (F(2, 44) = 26.04, p = .004, η_p^2 = .23; F(2, 56) = .5.29, p = .008, η_p^2 = .16). However, in both groups, repeated contrasts breakdown of variability revealed that although acquisition 1 had significantly more variability than acquisition 2, acquisition 3 was not significantly different from acquisition 2. Therefore, this finding was deemed not to delegitimise differences observed between baseline and transfer.

No-jump trials.

No-jump constant error. Analysis found no significant 2 group x 2 block x 4 distance, nor 2 block x 4 distance interaction (F(1.59, 79.51) = .21, p = .757, η_p^2 < .01; F(1.60, 81.42) = 1.62, p = .208, η_p^2 = *.03*, respectively). Endpoint constant error analysis revealed no significant main effect for block (F(1, 50) = .05, p = .821, η_p^2 < .01), group (F(1, 50) = .01, p = .930, η_p^2 < .01), nor block x group interaction (F(1, 50) = .06, p = .802, η_p^2 = .00).

No-jump variability. Contrary to expectations, analysis found no significant 2 group x 2 block x 4 distance, nor 2 block x 4 distance interaction (F(1.85, 92.29) = .39, p = .661, η_p^2 = .01; F(1.85, 92.29) = 1.54, p = .221, η_p^2 = .03, respectively). Similarly, neither the baseline nor transfer block respectively had significant 2 group x 4 distance interactions. However, interestingly in transfer, whilst the self-control depleted group increased their variability significantly as a function of distance, the self-control full group did not increase significantly between 75% and 100% of movement distance (see figure 9). Variability at 25% of movement distance did not differ significantly between groups or blocks. Endpoint variability analysis revealed a significant main effect for block (*F*(1, 50) = 8.63, p = .005, η_p^2 = .15), but no main effect for group (*F*(1, 50) = .54, p = .465, η_p^2 = .01) nor group x block interaction (*F*(1, 50) = 1.39, p = .245, η_p^2 = .03). Breakdown revealed both groups decreased their endpoint variability in transfer compared to baseline, but only the self-control full group did so significantly (see Figure 9).

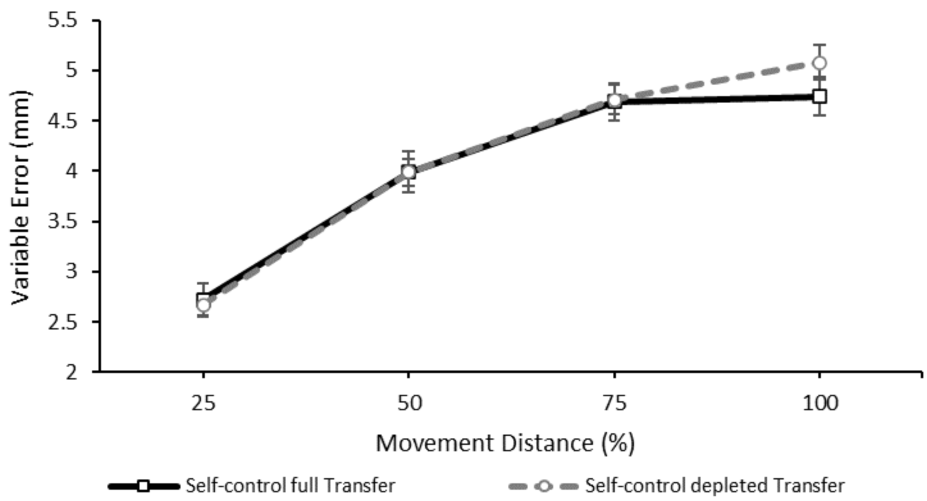


Figure 9. Experiment 3 no-jump variability of self-control full and self-control depleted groups at transfer at 25, 50, 75, and 100% movement distance. Error bars = +/-1standard error of the mean.

Jump trials.

Jump constant error. Although no significant group x block x distance interaction was observed (*F*(1.60, 79.83) = .42, p = .615, η_p^2 = .01), a significant block x distance interaction was (*F*(1.60, 79.83) = 11.46, $p < .001$ η_p^2 = .19). Within-group breakdown showed that self-control full and self-control depleted groups had no significant main effect for block (*F*(1, 22) = .14, p = .711, η_p^2

= .01; $F(1, 28) < .01$, $p = .964$, $\eta_p^2 < .01$, respectively) but did have significant block x distance interactions ($F(1.50, 33.07) = 6.78$, $p = .007$, $\eta_p^2 = .24$; $F(1.65, 46.18) = 4.70$, $p = .019$, $\eta_p^2 = .14$, respectively). Repeated contrast breakdown showed that these interactions took place between 75 and 100% movement distance for both groups (see Figure 10). Endpoint constant error showed a significant block ($F(1, 50) = 8.24$, $p = .006$, $\eta_p^2 = .14$) and group ($F(1, 50) = 4.81$, $p = .033$, $\eta_p^2 = .09$) main effect, but no significant block x group interaction ($F(1, 50) = .46$, $p = .503$, $\eta_p^2 = .01$). At baseline, self-control full (*M* = -9.87 mm, *SD* = 2.63) and self-control depleted (*M* = -8.56 mm, *SD* = 3.19) groups did not differ significantly, but at transfer self-control full (*M* = -11.12 mm, *SD* = 2.33) had a significantly greater correction magnitude than the self-control depleted group (*M* = -9.33 mm, *SD* = 2.97). Note, the self-control full group significantly increased its endpoint correction magnitude from baseline to transfer, whereas the self-control depleted group did not.

Jump variability. No significant group x block x distance interaction ($F(1.80, 90.20) = 1.91$, $p = .158$, $\eta_p^2 = .04$) nor block x group interaction ($F(1, 50) = 1.56$, $p = .218$, $\eta_p^2 = .03$) were found. Correspondingly, analysis of outcome variability found no significant main effect for block ($F(1, 50) = .01$, $p = .940$, $\eta_p^2 < .01$), group ($F(1, 50) = 3.05$, $p = .087$, $\eta_p^2 = .06$) nor group x block interaction ($F(1, 50) = 2.55$, $p = .117$, $\eta_p^2 = .05$).

Correction latency. No significant main effect for block ($F(1, 50) = .07$, $p = .786$, $\eta_p^2 < .01$), main effect for group ($F(1, 50) = .53$, $p = .471$, $\eta_p^2 = .01$) nor block x group interaction was observed ($F(1, 50) = 1.04$, $p = .314$, $\eta_p^2 = .02$). I.e. self-control full and self-control depleted group correction latency did not differ significantly at baseline (*M* = 196.60 ms, *SD* = 26.25; *M* = 195.71 ms, *SD* = 41.03, respectively) nor transfer (*M* = 188.73 ms, *SD* = 19.88; *M* = 200.25 ms, *SD* = 40.28). Latencies did also not differ significantly within-groups between blocks.

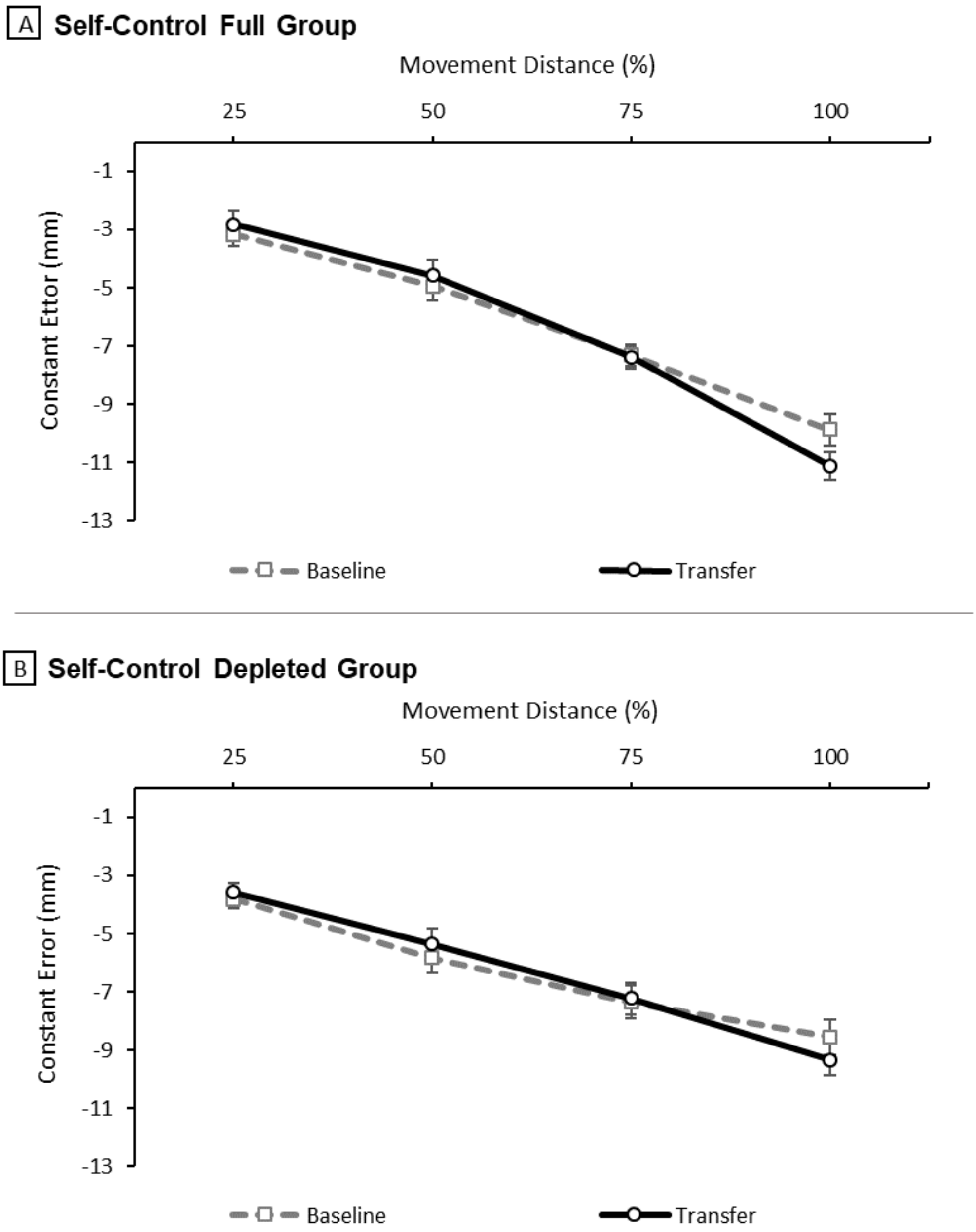


Figure 10. Panel A (top) shows Experiment 3 self-control full group jump trial constant error at baseline (low state anxiety) and transfer (to heightened state anxiety). Panel B (bottom) shows Experiment 3 self-control depleted group jump trial constant error at baseline (low state anxiety) and transfer (to heightened state anxiety). Error bars = +/-1standard error of the mean.

3.3.3 Discussion.

Regulating cognitive resources to counteract the distraction-based effects of anxiety, is proposedly initiated through limited-in-quantity self-control (Englert & Bertrams, 2015a). Therefore, when individuals are depleted of self-control resources, compensatory mobilisation of cognitive resources should be more difficult, and distraction-based effects on motor performance should be amplified. Experiment 3's primary aim was to use self-control depletion to specifically highlight distraction effects, and further differentiate how offline planning and online correction processes are affected by distraction and conscious processing.

Our investigation into this aim was facilitated by a successful anxiety manipulation; both groups reported significantly increased state anxiety in the transfer block. Likewise, the self-control depletion manipulation appeared effective in demanding differing levels of self-control from participants. The self-control depleted group, which had to overwrite automatic writing habits to omit the letters 'e' and 'a' in their transcription, wrote significantly fewer words and made significantly more errors than the self-control full group. Accordingly, the self-control depleted group subsequently reported significantly greater mental effort *during* the anxiety transfer block, than the self-control full group. This suggests the self-control depleted group's ability to use self-control to mobilise anxiety-compensatory cognitive resources was successfully reduced by the transcription task and made the aiming task more difficult / effortful. Additional extraneous variables that may account for group differences also exhibited no significant differences, namely: self-efficacy, narcissism, trait cognitive anxiety, trait conscious processing, trait self-control resources, and trait self-control depletion sensitivity.

Although no significant differences in offline planning were observed, breakdown of online correction results revealed our hypothesised effects as significant. In no-jump trials, the self-control depleted group displayed significantly reduced online correction, compared to the self-control group. Concurrently, in jump trials, the self-control depleted group did not increase its correction acuity under heightened anxiety, whereas the self-control full group did. This suggests that, as hypothesised, online correction of cursor trajectories were impaired in the self-control depleted group because they had insufficient self-control available to mobilise sufficient cognitive resources. Overall, Experiment

3 lends support to the conclusions drawn from experiments 1 and 2; elements within the online processing of reafferent cursor information for error detection and correction, likely require attentional resources to function.

3.4 General Discussion

A wealth of literature has rationalised heightened state anxiety's effect on outcome performance (e.g., target accuracy) via distraction or conscious processing mechanisms (Beilock & Carr, 2001; Gucciardi & Dimmock, 2008; Hardy et al., 1996; Murray & Janelle, 2003; Nieuwenhuys et al., 2008). However, it is far from clear whether these mechanisms are indeed mutually exclusive, and whether they differentially affect proposedly effortful offline movement planning and proposedly automatic online movement corrections (Allsop et al., 2017; Roberts et al., 2018). For the first time: (1) heightened state anxiety's effect on online movement correction was directly tested in cursor jump trials; (2) heightened anxiety's effect on jump trials' correction initiation latency, as well as endpoint acuity, was examined; (3) participants' trait conscious processing propensity was used to predict distraction and conscious processing effects on movement planning and correction; and (4) participants were experimentally self-control depleted to further differentiate between distraction and conscious processing effects.

Monitored confounds.

Facilitating this study's aims were successful anxiety manipulations and absence of numerous key confounds. Firstly, across all three experiments, participants reported significantly greater cognitive state anxiety and invested mental effort in heightened anxiety transfer, compared to baseline / low anxiety transfer blocks: suggesting our state anxiety manipulation was successful. Secondly, jump and no-jump trials' respective MT featured no significant differences between baseline and transfer; therefore, observed changes in error between baseline and transfer should not be down to speed-accuracy trade-offs. Thirdly, in line with past literature, jump trials' correction endpoint variability and constant error did not change across acquisition blocks (Brière & Proteau, 2011; Proteau et al., 2009; Veyrat-Masson et al., 2010); thus, subsequent changes in jump corrections between baseline and transfer should not be down to practice effects. Finally, in Experiment 3 the self-control depleted group transcribed significantly less text, made significantly more errors, and importantly reported significantly more invested mental effort in the transfer block compared to the self-control full group; this suggesting the self-control depletion manipulation was successful.

Performance measures and theoretical implications.

The present study directly tested online correction efficacy under heightened state anxiety via cursor jumps. No-jump trials required a cursor to be moved rapidly, through and past, a target 24cm away from a start position. Jump trials were identical but featured a large lateral cursor perturbation early in movement. Therefore, in no-jump trials, participants were free to use a combination of offline planning and online correction to attain their level of outcome performance. In jump trials however, because of cursor perturbations' infrequent, consciously undetected, and random occurrence in peripheral vision, offline planning was impertinent, and online correction was necessitated for good outcome performance. In no-jump trials, improved offline planning was inferred from reduced variability at 25% of movement distance, and improved online correction was inferred from greater reductions / levelling off in variability between 75% and 100% of movement distance (Khan et al., 2006). In jump trials, improved online correction was inferred via reduced endpoint constant error *and* variability (Veyrat-Masson et al., 2010).

In line with numerous past studies (Allsop et al., 2017; Cassell et al., 2018 Lawrence et al., 2013; Roberts et al., 2018), we initially hypothesised that heightened state anxiety would reduce online correction in no-jump and jump trials, whilst increasing or not changing offline planning in no-jump trials. Although, no-jump trials in Experiment 1 exhibited maintained offline planning and reduced online correction, jump trials surprisingly exhibited increased online correction. Experiment

2 verified this pattern of results via a considerably larger sample size (i.e., ~4x greater) and a more robust design (i.e., randomised controlled trial design) . No-jump trials exhibited increased offline planning and reduced online correction, while jump trials again exhibited increased online correction. Additionally, Experiment 2 demonstrated that reductions in no-jump trial online correction were predicted by higher trait conscious processing propensity and that jump trial corrections were not initiated with reduced latency but seemingly increased spatial acuity. In Experiment 3, when participants were experimentally depleted of their self-control, and were therefore less able to mobilise anxiety-compensating cognitive resources, online correction acuity was reduced in jump and no-jump trials. The findings of experiments 1, 2, and 3 provide the first direct evidence to conjecturing that online correction processes of limb / cursor trajectories may not be wholly automatic (Roberts et al., 2018). Were online correction processes indeed wholly automatic and outside of attention, it should not have been affected by changes in anxiety and cognitive resource.

Prior research has demonstrated that online cursor-based corrections exhibit numerous characteristics synonymous with automaticity. Online corrections have been shown to initiate without the knowledge of participants (Proteau et al., 2009), effective from the first trial (Brière & Proteau, 2011; Proteau et al., 2009), independent of cued attention (Reichenbach et al., 2014), and be uninhibitable (Franklin & Wolpert, 2008). Although at first glance our findings appear at odds with these findings, they may actually complement them. Firstly, we propose that heightened anxiety can make individuals adopt an offline planning-focused strategy wherein they plan not to make online corrections (i.e., they attenuate online correction initiation). Secondly, individuals' propensity to adopt this strategy may be an attempt to gain more explicit control over movements and positively predicted by conscious processing propensity. A similar strategy has been observed by Khan, Elliott, Coull, Chua, and Lyons (2002) when individuals were uncertain about upcoming visual conditions. Thirdly, when the need for correction is great enough (e.g., via artificial cursor jumps), participants' strategy to attenuate online corrections may be automatically overturned online. Previous studies (e.g., Franklin & Wolpert, 2008) may have found online correction to be uninhibitable because the need for correction created by cursor jumps was too great. Lastly, endogenously allocated (i.e., within-participant) cognitive resources may facilitate *optimal* online spatial processing. The availability of these resources may benefit correction efficacy when individuals' offline planning-focused strategy is overturned. Previous studies (e.g., Reichenbach et al., 2014) may not have observed changes in online correction efficacy, despite manipulating attention allocation, because large endogenous increases in attention specifically aimed at improving the spatial characteristics of performance are necessary to alter the efficacy of online corrections based on reafferent limb information. Anxious distraction-compensatory mechanisms may elicit such an endogenous change.

Admittedly, the notion that this strategy shift can be reversed online is speculative. Yet, in the face of limited research specifically on anxiety-induced endogenous resource shifts, this certainly warrants further scrutiny. A contrasting explanation may involve the efference copies which store representations of the motor commands used to initiate a movement (Miall & Wolpert, 1996; Wolpert, Ghahramani, & Jordan, 1995; Wolpert & Kawato, 1998). From these representations, feed-forward models can generate expected trajectories to inform online correction. It is conceivable that anxiety-induced distraction may divert resources away from the creation and / or utilisation of these efference copies, or that anxiety-induced conscious processing may induce the breakdown of automatic efference copy creation and / or utilisation. Regardless of the precise distraction / conscious processing mechanisms, an impaired efference copy (and therefore impaired feed-forward model) in no-jump trials may cause underestimation in error: resulting in reduced no-jump online correction under heightened anxiety, even when sufficient cognitive resources are available. In jump trials on the other hand, cursor perturbations likely produce more error than inherent noise in the motor system, and therefore the need for corrections may be more apparent / less likely to be underestimated. Concurrently, impaired efference copy processes may reduce the salience of planning-based trajectory expectations and allow online corrections to organise themselves more freely and appropriately to cursor perturbations specifically: provided sufficient cognitive resources are available.

Although the present set of experiments have gone some way in elucidating the distraction and conscious processing mechanisms which underlie changes in offline planning and online correction under heightened anxiety, further investigation is still needed. Our results in Experiment 2 suggest that individuals high in conscious processing propensity are more likely to attenuate their online correction when the need for correction is low (i.e., in no-jump trials). Concurrently, manipulation of self-control in Experiment 3 demonstrates that changes in online correction under heightened anxiety may be down to a change in cognitive resources. The present findings, along with those of Roberts et al. (2018), strongly suggest that conscious processing and distraction effects extend beyond the dichotomous theorising of Lawrence et al. (2013). Both offline planning and online correction can seemingly benefit from increased cognitive resources mobilised by distraction-compensatory mechanisms. Therefore, conversely to Lawrence et al.'s (2013) theorising, distraction may be able to affect online correction, whilst conscious processing may be able to affect offline planning. It is also conceivable that distraction and conscious processing effects can take place concurrently (especially if conscious processing / reinvestment is a coping strategy for distraction). In such instances, individuals' planning, correction, and outcome performance may be impaired the most, through distracted and half-baked attempts to engage in conscious processing / reinvestment.

Potential limitations and future directions.

To date, a key limitation of investigations into anxiety's effect on offline planning and online correction, is that reductions in outcome performance were not observed under heightened anxiety (Allsop et al., 2017; Roberts et al., 2018). This suggests that, based on distraction theories, the deleterious effects of heightened state anxiety are overcome by participants via the mobilisation of additional cognitive resources (Eysenck et al., 2007). Therefore, whilst the motor control strategies underlying maintained / improved outcome performance under heightened anxiety have been elucidated by past studies and the present experiments, the motor control changes which underlie distraction-based performance failure are not. We encourage future studies to increase task difficulty alongside the introduction of anxiety, to overload participants' attentional capacity and clearly induce a reduction in outcome performance. Likewise, it is uncertain how anxiety-induced conscious processing mechanisms manifest themselves on offline planning and online correction when outcome performance is impaired. It also cannot be said for certain whether prior studies investigating anxiety's effect on motor control (e.g., Allsop et al., 2017) observed conscious processing effects at all: it is possible that both impairments in online correction and improvement in offline planning under anxiety were the product of resource-based distraction mechanisms. We encourage future studies to include conditions with and without opportunities to generate rule-based declarative knowledge because this should determine conscious processing-induced deautomatisation of motor control (Bellomo, Cooke, & Hardy, 2018; Masters & Maxwell, 2008).

3.5 Conclusion.

The present study aimed to elucidate how anxiety-induced distraction and conscious processing mechanisms affect the offline planning and online correction of movements. Results reaffirm that heightened anxiety can benefit offline planning. Conversely to past suggestions however, when necessitated by cursor jumps, online correction was not 'impaired' and instead exhibited improved spatial acuity under heightened state anxiety provided sufficient compensatory cognitive resources were mobilised / available. The implications of this finding are threefold: firstly, both offline and online correction can benefit from increased cognitive resources mobilised by distraction-compensatory mechanisms; therefore secondly, the dichotomous reasoning of Lawrence et al. (2013), that distraction mechanisms only affect offline planning and conscious processing mechanisms only affect online correction, is inaccurate; and finally, provides strong evidence against the labelling of online cursor / limb trajectory correction processes as wholly 'automatic and attention free'. Were this form of online correction truly automatic and outside of attention, correction efficacy should not have changed within or between participant groups, across the same conditions. We propose that the online correction of limb trajectories be defined as highly consistent, but inhibitable by visuomotor performance strategies and improved by increases in endogenously allocated cognitive resources focused on optimal spatial functioning. The precise distraction and conscious processing mechanisms that underlie anxious movement planning and correction still require ample investigation.

Chapter 4: Experimental Chapter 2

Anxiety’s influence on movement planning and correction under conditions of no-vision.

It is well known that heightened anxiety can have both positive and negative effects on movements' outcome performance (i.e., how accurate / often a target has been hit) (Eysenck, Derakshan, Santos, & Calvo, 2007; Masters & Maxwell, 2008). More recently, studies looked beyond outcome performance to determine how offline movement planning and online movement correction processes are affected by heightened state anxiety (Allsop, Lawrence, Gray, & Khan, 2016; Cassell, Beattie & Lawrence, 2018; Lawrence, Khan, & Hardy, 2013; Roberts, Wilson, Skultety, & Lyons, 2018). Results suggested that heightened anxiety impaired automatic online correction efficacy but not attention-demanding offline planning efficacy. Importantly, these findings were observed in tasks where visual information was available. It is not yet known how heightened state anxiety affects offline planning and online correction when proprioception is the sole relevant source of afferent information.

Two dichotomous theories have established themselves at the forefront of anxiety-performance research. Namely, the distraction-based attentional control theory of Eysenck, Derakshan, Santos, and Calvo (2007) and the conscious processing-based reinvestment theory of Masters (1992). The attentional control theory suggests heightened state anxiety reduces processing efficiency by impairing the central executive's shifting (i.e., directing attention allocation between task-relevant stimuli) and inhibition (i.e., inhibiting attention allocation to task-irrelevant stimuli). In turn, potential threats and anxious thoughts have greater leeway to impair outcome performance by *distracting* attentional resources away from task-relevant motor processes. However, the attentional control theory also proposes that these detrimental effects of anxiety can be overcome, up to a point, by mobilising additional cognitive resources (e.g. mental effort). The reinvestment theory suggests that the automatic, usually skilful and attention-free process of skill execution of experts can be disrupted under heightened anxiety if an individual reinvests attention and tries to *consciously process* skill execution using declarative knowledge. Although conscious processing can be a trait coping strategy of the individual, it ultimately results in impaired outcome performance (Masters & Maxwell, 2008).

However, previous literature has not ventured beyond outcome performance, to quantify the effect of distraction and conscious processing on offline movement planning and online movement correction. Offline movement planning is the effortful and attention-demanding preparation of actions prior to movement initiation (Glover & Dixon, 2001; 2002; Glover, Rosenbaum, Graham, & Dixon, 2004; Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979). Online movement correction is the automatic detection and correction of errors during movement execution (Briere & Proteau, 2011; Proteau, Roujoula, & Messier, 2009; Reichenbach, Franklin, Zatka-Haas, & Diedrichsen, 2014). Based on the characteristics of these mechanisms, Lawrence et al. (2013) proposed two contrasting variability-based outcome hypotheses to quantify the differential effects of distraction and conscious processing on offline and online motor control. Firstly, the resource-diminishing mechanisms of distraction were hypothesised to only have a detrimental effect on the attentionally-demanding offline planning of cursor trajectories. Conversely, the automaticity-diminishing mechanisms of conscious processing were hypothesised to only have a negative effect on the automatic online correction of cursor trajectories. Results revealed that heightened anxiety reduced online correction but increased offline planning; a finding replicated by Allsop et al. (2017), Casell et al. (2018), and Roberts et al. (2018). The consensus at present is that additional cognitive resources may be mobilised under heightened anxiety (in line with distraction-based theories), which improve movement planning and compensate for impaired online movement correction (via conscious processing) (Allsop et al., 2017; Casell et al., 2018). Importantly, this mobilisation in additional resources to improve offline planning may not be a ‘strategic’ choice employed by individuals. Roberts et al. (2018) observed unchanged prioritisation of offline planning and online correction under heightened anxiety compared to low anxiety.

Despite the aforementioned studies going a long way towards explicating anxiety's effect on motor control when vision is available, it is not yet known how anxiety affects movement planning and correction when proprioception is the sole relevant source of afferent information. The present investigation explored the effect of heightened state anxiety on both the efficacy and prioritisation of offline planning and online correction in a target-directed aiming task performed without the availability of vision (i.e., when proprioception was the sole relevant source of afferent information). Variability profiles were used to infer motor control efficacy (Khan et al., 2003; Khan, Lawrence, Franks, & Buckolz, 2004). Increased offline planning efficacy was inferred via reduced variability early in movement trajectories (because at this point there is insufficient time for corrections to be initiated) and increased online correction efficacy was inferred via reductions in variability later in movement (because at this point corrections should converge movements towards the target). Time to and after peak velocity were used to assess motor control prioritisation (Khan, Elliott, Coull, Chua, & Lyons, 2002). Increased prioritisation of offline planning was inferred from greater time to peak velocity and less time spent after peak velocity (because in this case the initial pre-planned impulse is prioritised and less time is given to home in on the target). Increased prioritisation of movement correction was inferred from less time spent to peak velocity and greater time spent after peak velocity (because in this case the initial pre-planned impulse serves to bring the limb closer to the target before carefully homing in on it). Because of the exploratory nature of this experiment, no a-priori hypotheses were formulated.

4.1.1 Methods

Participants.

The sample comprised of 20 participants (male = 10, female = 10, $mean_{age}$ = 21.35, SD_{age} = 2.68). These participants were pseudo-randomised into an experimental and control group (such that each group contained equal number of males and females). All participants were: naïve to the hypotheses being tested; self-reported right hand dominant; with normal or corrected to normal vision; and offered course credit together with the chance to win £100 in exchange for participating. The study was conducted in-line with institutional ethics guidelines.

Questionnaire measures.

Measures included the Mental Readiness Form-3 (MRF-3) (Krane, 1994), Rating Scale of Mental Effort (RSME) (Zijlstra, 1993), and the Sport Anxiety Scale-2 (SAS-2) (Smith, Cumming, & Grossbard, 2006). The MRF-3 comprised three items rated on a 11 point Likert scale assessing worrisome thoughts (1 = not worried and 7 = worried), body tension (1 = not tense and 11 = tense), and confidence (1 = confident and 7 = not confident). The RSME comprised a 150 cm vertical scale with 9 anchors starting from 3 cm (no mental effort at all) to 114 cm (extreme mental effort). The SAS-2 comprised of 3 subscales (trait cognitive anxiety, somatic anxiety, and concentration) assessed using 5 items each rated on a Likert scale ranging from 1 (not at all) to 4 (very much). Only the cognitive anxiety subscale was analysed for the purpose of this study (e.g., “I worry that I will play badly”).

Apparatus.

A Calcomp 3 digitizing tablet was placed horizontally in front of participants (size = 122 x 91.5 cm, sample rate = 200 hz). A 37 inch Mitsubishi Diamond Pro monitor (refresh rate = 85 hz) was located 33cm in from participants’ eyes and 20 cm above the tablet. Aiming movements were performed using a stylus on the tablet. The stylus was placed between plastic rails that only allowed for horizontal movements (i.e., along the x-axis). In the centre of the monitor, two vertical lines (white, 3 cm) were displayed 24 cm apart. The left line acted as the start position and the right line acted as the target position. The x-axis position of the stylus on the tablet corresponded with one-to-one mapping to the X axis position of a cursor (white, 3 cm vertical line) between the start and target position. Note, the cursor was only visible when on or left of the start position to prevent participants from learning the target position using vision. Participants' chair and chinrest were adjustable to ensure their eyes were midway between the start and target.

Procedure.

At the beginning of each trial, participants had to centre their cursor over the start position. Once centred, the experimenter initiated the trial. Following a randomised delay between 500 and 1500 ms, a tone signalled participants to initiate their movement towards the target. Participants were instructed to: (1) keep their eyes on the target throughout the movement; (2) react swiftly to the tone but that their exact reaction time did not matter; (3) make one smooth movement (i.e., without jerks / multiple stops); and (4) come to a complete stop where they think the target is. Following movement end, participants were provided with knowledge of results in the form of movement time (the interval in ms between the cursor moving 3mm from the start position and end) and a point score (error less than +/-5 mm was awarded 5 points which was reduced by one whole integer with every +/- 5 mm of error). Movement time was required to be 450 ms (+/-10%).[1] Movements outside of the criterion movement time were repeated immediately until correct.

All participants completed 10 familiarisation trials, 3 x 25 acquisition trials, and 25 transfer trials. Participants completed the: SAS-2 before the familiarisation block to assess trait cognitive anxiety; MRF-3 immediately before every acquisition block and the transfer block to assess state cognitive anxiety; and RSME immediately after every acquisition block and the transfer block to assess mental effort. Prior to the transfer trials and corresponding MRF-3, the control group was told to "please continue hitting the targets as accurately as you can", while the experimental group had their anxiety manipulated. The manipulation comprised a combination of outcome and monitoring pressure (DeCaro, Thomas, Albert, & Beilock, 2011) and entailed participants being told that: (1) their movements on the monitor were being filmed for later analysis by master's students; (2) they

[1] A 450 ms (+/-10%) movement time criterion was set because this should provide sufficient time for online correction to occur in amplitude-only tasks performed without the availability of vision (Khan et al., 2003).

were paired with another participant; (3) both they and their partner had to improve their aiming accuracy by 20% from the previous block of trials to be entered into the prize-draw; (4) and that their partner had already achieved this performance increase. At the end of testing, participants were informed that there was no partner, they were not filmed, and that all participants were entered into the prize draw.

Data reduction and dependent variables.

Stylus displacement data were filtered using a second-order dual-pass Butterworth filter with a 10 Hz low-pass cutoff. Movement error was the distance (mm) between the target and the stylus and calculated at peak acceleration (pkA), peak velocity (pkV), peak negative acceleration (pkNa), movement end (end), and every 2.5% of movement distance. Movement error beyond the target (i.e., overshoots) were labelled numerically positive and movement error before the target (i.e., undershoots) were labelled numerically negative. Movement start was the point where the cursor moved 1 mm from the start position. End was defined as the point where the cursor's velocity dropped below 0 mm/s. The aforementioned calculations were performed on raw task software data (Visual Basic) via a custom LabView (National Instruments) analysis program. Movement time and points scored were displayed on the monitor within 400 ms of movement end to provide knowledge of results. Trials where ≥ 25% of movement error across the movement trajectory deviated by ≥ 2 standard deviations from the respective within-participant block were eliminated prior to analysis (this equated to 3.33% of all trials).

Dependent variables comprised trait cognitive anxiety, state cognitive anxiety, mental effort, outcome performance, offline planning efficacy, online correction efficacy, offline planning prioritisation, and online correction prioritisation. Trait cognitive anxiety was assessed via the mean of the SAS-2 trait cognitive anxiety subscale items. State cognitive anxiety was assessed via the MRF-3 worry subscale item. Mental effort was assessed by measuring the distance from 0 to the marked point on the 150 cm RSME scale. Greater outcome performance was assessed via reduced root mean square error at movement end; this was calculated as the square root of end constant error (i.e., mean of within-participant error) and end variability (i.e., standard deviation of within-subject error) squared and added together. Offline movement planning and online movement correction efficacy were assessed via variability profiles (Khan et al., 2006). Reduced offline planning efficacy was inferred via the concurrent occurrence of: (1) increased variability early in movement (i.e., up to pkV); (2) decreased outcome performance; and (3) unchanged variability ratios (i.e., experimental variability divided by control variability at transfer) across kinematic landmarks up to pkV. Reduced online correction efficacy was inferred via the concurrent occurrence of increasing variability later in the movement (i.e., after PkV) and increasing variability ratios (i.e., experimental variability divided by control variability at transfer) after pkV. Prioritisation of offline and online motor control were assessed via time to peak velocity and time after peak velocity (Khan et al., 2002; Khan et al., 2006). Namely, increased prioritisation of offline planning was inferred via increased time to pkV and decreased time after pkV, and increased online correction prioritisation was inferred via decreased time to pkV and increased time after pkV.

Analysis.

For brevity and clarity, our analysis focused on the final block of acquisition trials (from here on simply referred to as 'acquisition') and transfer.[2] An independent samples t-test compared control and experimental group trait anxiety. Acquisition and transfer block state cognitive anxiety, mental effort, outcome performance, and motor control prominence measures (time to pkV and time after pkV) were analysed using 2 group (control and experimental) x 2 trial block (acquisition and transfer) ANOVAs with repeated measures on the second factor. To assess motor control efficacy, variability was analysed using a 2 group (control and experimental) x 2 trial block (acquisition and transfer) x 4

[2] This approach has previously been taken by Lawrence et al. (2013).

kinematic landmark (pkA, pkV, pkNa, and end) ANOVA featuring repeated measures on the latter two factors, and variability ratios were analysed using a one-way repeated measures ANOVA on kinematic landmark (pkA, pkV, pkNa, and end) at transfer. Greenhouse-Geisser corrected tests are reported when sphericity was violated. Omnibus interactions and main effects were broken down using planned repeated contrasts. Alpha was set at .05.

4.1.2 Results

Anxiety and mental effort scales.

Analysis revealed no significant difference in trait cognitive anxiety between the control and experimental group ($t(18) = -.06$, $p = .955$, 95% CI [-.75, .71]). Analysis of cognitive state anxiety revealed a significant trial block x group interaction ($F_{1,18} = 18.67$, $p < .001$, $\eta_p^2 = .51$) and main effect for block ($F_{1,18} = 16.47$, $p = .001$, $\eta_p^2 = .48$) but no significant main effect for group ($F_{1,18} = 2.55$, $p = .127$, $\eta_p^2 = .12$). Breakdown of the interaction revealed the experimental group had significantly greater state cognitive anxiety than the control group at transfer ($M = 7.20$, $SD = 1.99$ and $M = 3.80$, $SD = 2.89$, respectively) but not acquisition ($M = 4.00$, $SD = 2.45$ and $M = 3.90$, $SD = 2.92$, respectively). Analysis of mental effort revealed a significant trial block x group interaction ($F_{1,18} = 6.29$, $p = .022$, $\eta_p^2 = .26$) and a significant main effect for block ($F_{1,18} = 2.10$, $p = .164$, $\eta_p^2 = .11$) but no significant main effect for group ($F_{1,18} = .52$, $p = .480$, $\eta_p^2 = .03$). Breakdown of the interaction revealed the experimental group invested significantly greater mental effort than the control group at transfer ($M = 89.10$, $SD = 21.26$ and $M = 71.70$, $SD = 21.45$, respectively) but not acquisition ($M = 71.90$, $SD = 24.84$ and $M = 76.30$, $SD = 21.76$, respectively).

Outcome performance.

Analysis of outcome performance (i.e., endpoint root mean square error) revealed no significant main effect for block ($F_{1,18} = 3.82$, $p = .066$, $\eta_p^2 = .18$), main effect for group ($F_{1,18} = 3.32$, $p = .085$, $\eta_p^2 = .16$), nor group x block interaction ($F_{1,18} = 1.45$, $p = .244$, $\eta_p^2 = .08$). However, it is noteworthy that outcome performance being similar for experimental and control groups at acquisition (*M* = 21.56, *SD* = 6.84 and *M* = 19.00, *SD* = 4.76, respectively) but the experimental group trended towards having inferior outcome performance compared to the control group at transfer (*M* = 28.10, *SD* = 12.08 and *M* = 20.56, *SD* = 4.84, respectively).

Offline and online motor control efficacy.

Analysis of variability revealed a significant main effect for kinematic landmark ($F_{1.82, 32.78}$ = 42.18, $p < .001$, $\eta_p^2 = .70$) but no significant main effect for block ($F_{1,18}$ = 0.06, $p = .818$, $\eta_p^2 = .00$), main effect for group ($F_{1,18}$ = .16, $p = .695$, η_p^2 = 01), group x block interaction ($F_{1,18}$ = 1.24, $p = .280$, $\eta_p^2 = .07$), kinematic landmark x group interaction ($F_{1.82, 32.78}$ = .58, $p = .552$, $\eta_p^2 = .03$), block x kinematic landmark interaction ($F_{1.79,32.28}$ = .57, $p = .551$, $\eta_p^2 = .03$), nor group x block x kinematic landmark interaction (*F* $F_{1.79,32.28}$ = .33, $p = .695$, $\eta_p^2 = .02$) (see Figure 1). Breakdown of the kinematic landmark main effect revealed variability increased significantly from pkA to pkV ($F_{1,18}$ = 6.14, $p = .023$, $\eta_p^2 = .25$) and pkV to pkNa ($F_{1,18}$ = 48.46, $p < .001$, $\eta_p^2 = .73$) but decreased significantly from pkNa to end ($F_{1,18}$ = 6.31, $p = .022$, $\eta_p^2 = .26$). Analysis of the variability ratio between the control and experimental group revealed no significant main effect for block ($F_{1,18}$ = 2.39, $p = .157$, $\eta_p^2 = .21$), kinematic landmark ($F_{1.63,14.66}$ = 1.00, $p = .375$, $\eta_p^2 = .10$), nor block x kinematic landmark interaction ($F_{1.51,13.56}$ = .75, $p = .454$, $\eta_p^2 = .07$).

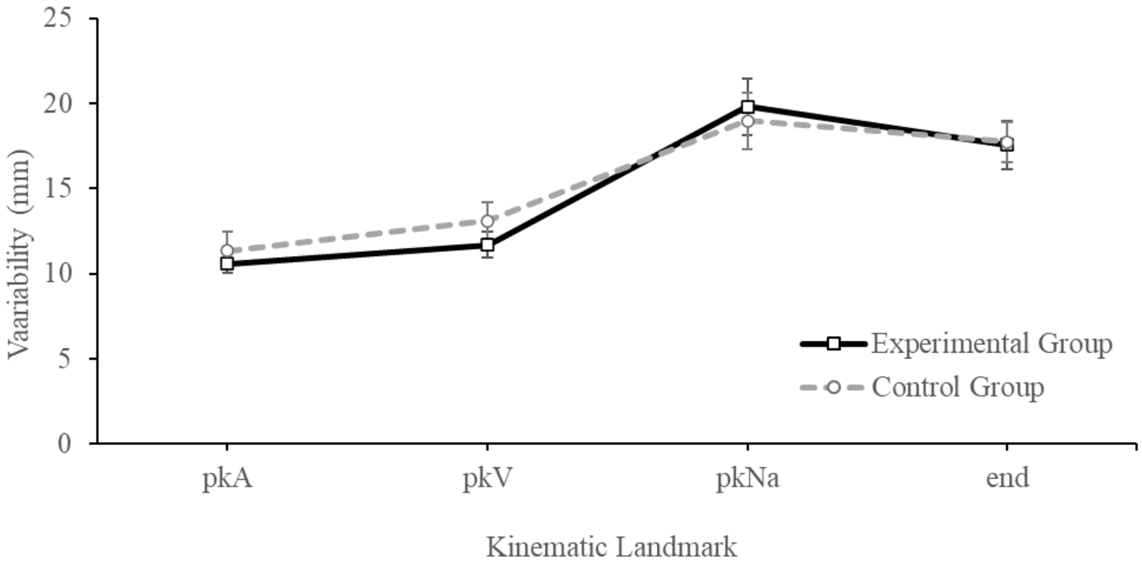


Figure 1. Transfer trial block variability at pkA, pkV, pkNa, and end of the experimental (heightened anxiety) and control (low anxiety) group. Error bars = 1 Sem.

Offline and online motor control prioritisation.

Analysis of time to pkV revealed no significant main effect for block ($F_{1,18}$ = .67, p = .425, η_p^2 = .04), main effect for group ($F_{1,18}$ = .21, p = .651, η_p^2 = .01), nor group x block interaction ($F_{1,18}$ = .08, p = .775, η_p^2 = .01). Likewise, analysis of time after pkV revealed no significant main effect for block ($F_{1,18}$ = .03, p = .857, η_p^2 < .01), main effect for group ($F_{1,18}$ < .01, p = .982, η_p^2 < .01), nor group x block interaction ($F_{1,18}$ = .08, p = .775, η_p^2 = .01).

4.1.3 Discussion

Research to date reports that heightened state anxiety impairs online movement correction efficacy but not offline planning efficacy in target-directed aiming tasks when performed with visual information available (Allsop et al., 2016; Cassell et al., 2018; Lawrence et al., 2013; Roberts et al., 2018). The present study investigated the effect of heightened anxiety on offline planning and online control when vision was not available and proprioception was the sole source of relevant afferent information. Participants performed three blocks of 25 acquisition trials of an amplitude-only target-directed aiming task under conditions of low state anxiety, followed by 25 transfer trials wherein the experimental group had their anxiety heightened and the control group did not. Analysis of self-reported state cognitive anxiety and mental effort suggested our anxiety manipulation was successful. At transfer, the experimental group exhibited significantly greater state cognitive anxiety and mental effort than the control group (having not done so at acquisition).

Results revealed that heightened state anxiety generated no significant change in motor control efficacy. Neither variability up to pkV, variability after pkV, nor outcome performance featured significant differences between the heightened anxiety and low anxiety control group at transfer, and variability ratios (between the experimental and control group) showed no significant change at transfer. Similarly, prioritisation of offline planning and online correction was also unchanged by heightened state anxiety. Neither time to pkV nor time after pkV were significantly different between groups at transfer. Overall, these findings suggest that neither the efficacy nor prioritisation offline planning and online correction of movements are affected by heightened state anxiety when proprioception is the only source of relevant afferent information.

It is possible that the generally rapid and less attention-demanding nature of proprioceptive information processing compared to visual information processing may make it less susceptible to anxious distraction and conscious processing. For example, not having to convert complex visuo-spatial information into proprioceptive force parameters for movement planning and correction (Sarlegna & Sainburg, 2009) may reduce task demands to a point where anxious distraction is less likely to overload attentional capacity (Eysenck et al., 2007); relevant evidence for this conjecture stems from Coombes et al. (2009) who observed unaltered proprioceptive pinch-force planning efficacy regardless of task difficulty. Alternatively, the rapid and generally less accurate nature of proprioceptive processing (Cluff, Crevecoeur, & Scott, 2015; Scott, 2016) may make it less likely for participants to accumulate declarative knowledge with which to engage in conscious processing under heightened anxiety (Masters, 1992); a wealth of research has demonstrated that without the build-up of declarative knowledge, reinvestment is less likely to take place (Masters & Maxwell, 2008).

Limitations of the present study include the employed task's relative simplicity, absence of reaction time constraints, and lack of vision condition for comparison. Although both our study and Coombes et al. (2009) observed no decrease in offline planning efficacy, planning *efficiency* assessed via reaction time was reduced in the most difficult task condition of Coombes and colleagues. Therefore, it is conceivable that performing a sufficiently complex task under heightened anxiety may reduce planning *efficiency* to a point where attentional capacity is overloaded (Eysenck et al., 2007) and offline planning efficacy is impaired. This decrease in efficacy may also extend to online correction if it is indeed not as automatic and attention-free as previously thought (Roberts et al., 2018). To increase task complexity, a three-dimensional target directed aiming task could be employed (e.g., Carrozzo, McIntyre, Zago, & Lacquaniti, 1999) with efficacy of offline planning and online correction processes inferred via ellipsoids (Hansen, Elliott, & Khan, 2008). To prevent participants from compensating for anxiety's deleterious effects by investing more effort via increased reaction time (Eysenck et al., 2007), a criterion could be set; for example, participants could be required to initiate movements with similar reaction times in the heightened anxiety conditions compared to low anxiety conditions. Lastly, the addition of a vision condition would allow proprioceptive and vision-based offline planning and online correction processes to be directly compared under heightened anxiety.

4.1.4 Conclusion

The present study extended the body of literature investigating the effect of heightened anxiety on the offline planning and online correction of movements (Allsop et al., 2016; Cassell et al., 2018; Lawrence et al., 2013; Roberts et al., 2018). Heightened anxiety does not appear to affect the efficacy nor prioritisation of offline planning and online correction in tasks where proprioception is the sole source of relevant afferent information. We encourage future studies to test the validity of this conclusion by featuring high levels of task complexity, constraints on the time spent planning movements, and direct comparison between vision to no-vision conditions.

Chapter 5: Experimental Chapter 3

An internal focus of attention is optimal when congruent with afferent proprioceptive task information.

Provision of effective instructions can play a significant role in shaping the quality of deliberate practice and subsequently help maximise skill acquisition (Ericsson, Krampe & Tesche-Römer, 1993). Equally, recent literature has begun to identify contexts where certain instructions can impede performance. There is now a compelling body of evidence that demonstrates the advantages of adopting an external (i.e., centered toward movement effects) over internal (i.e., centred toward body movements) focus of attention, in governing several characteristics of skill execution such as accuracy, consistency, and economy (for a review see Wulf, 2013). One mechanism thought critical in accounting for these advantages is movement planning (e.g. Prinz, 1997; Lohse, Sherwood & Healy, 2010). Whilst we are typically aware of the intended goal of particular movements, it is the responsibility of the executive motor system for the selection, programming, and initiation of the action: often a complex pattern of specific muscle activities. In sporting actions, we will plan where a particular limb will finish up at the end of a movement (Woodworth, 1899; Schmidt, Zelaznik, Hawkins, Frank, & Quinn Jr, 1979). It is this planning process specifically, that is often suggested to account for attentional focus differences.

Focus differences were first recognised during early experimental research requiring participants to focus on movement effects as opposed to body movements themselves (Wulf, Höb, & Prinz, 1998). When this happened, performance was superior. As well as performance accuracy, advantages in attentional capacity have contributed to the development of the constrained action hypothesis (Wulf, McNevin, & Shea, 2001). This suggests that focusing on the effects of one's movements promotes automaticity in movement execution and prevents any undesirable interference in response programming and control (likely to occur as a result of focusing internally). Findings have also been accounted for with Prinz's (1997) action effect principle, which emphasizes a compatible relationship between movement planning and outcome. Thus, if actions are planned and controlled in relation to their effects, then focusing externally should facilitate performance by enhancing congruence between movement planning and the desired response. Similarly, Wulf and

Lewthwaite's (2016) OPTIMAL (optimising performance through intrinsic motivation and attention for learning) theory of motor learning proposes enhanced goal-action coupling when using an external focus of attention. Offering further support for this notion, Wulf (2015) states that "adopting an external focus is related to the *planning* of movement, but has nothing to do with the processing of intrinsic feedback or bodily awareness, or lack thereof" (p.337). However, regardless of theoretical hypotheses, pertinent variables are yet to be rigorously tested, including the effect of focus of attention on movement planning and control mechanisms, especially in non-continuous tasks. A minority of researchers have begun to explore planning processes as a function of focus of attention, but as a secondary aim and often with methodological limitations in the approach adopted (e.g. Lohse et al., 2010; Lohse, 2012).

Work by Lohse et al. (2010) hypothesised higher levels of explicit processing when employing an internal focus of attention in a dart-throwing task. Dependent variables included a proxy measure of planning (preparation time between throws) with explicit processing expected to be reflected via increases in inter-trial intervals when adopting an internal focus. Findings were consistent with this notion and viewed as a manifestation of enhanced planning when using an external focus of attention. However, Lohse (2012) concedes the rudimentary nature of this approach to investigate planning. This measure was refined accordingly to calculate pre-movement times, this time in an isometric force production task. Pre-movement times were measured as the time from the 'go' signal to a change in recorded force of +/-1 lb. Findings revealed lower pre-movement times for those adopting an external focus of attention early on in the learning process.

However, attentional focus researchers have negated to consider important modifications that may be made *during* an action to achieve an intended goal i.e., motor control. Seminal attentional focus studies investigating balance board performance (e.g., Wulf et al., 1998; Wulf et al., 2001) imply that benefits of an external focus of attention may be due to corrections made during the movement. One could consider this to be online control and therefore less related to planning. In an aiming movement, these control mechanisms involve any movement adjustments necessary to correct discrepancies between the end of a limb's initial impulse and its target (Woodworth, 1899; Elliott, Helsen & Chua, 2001). With both planning and control mechanisms heavily integrated, it would be remiss not to consider them in the context of one another, especially being that aiming movements incorporate both pre-planned offline (feedforward) and online (somatosensory) adjustments (Elliott, Chua, Pollock, & Lyons, 1995; 20 & Kawato, 1998; Khan, Elliott, Coull, Chua, & Lyons, 2002; Elliott et al., 2014).

Whilst the aforementioned findings (Lohse et al., 2010; Lohse, 2012) are in line with attentional focus hypotheses surrounding movement planning, we would argue that in the absence of motor control measures, it is difficult to fully understand information processing or 'trade-offs' between planning and control in the context of focus of attention. Ironically, findings are accounted for using Willingham's (1998) control-based learning theory (COBALT), which only reinforces the importance of investigating differences in output control as well as planning. COBALT is a neuropsychological theory of skill learning. Its framework provides support for a series of perceptual-motor processes, which occur largely outside of conscious control (i.e., goal selection), motor sequencing (i.e., planning), and muscle activation. However, target selection and planning processes can also occur as a more conscious process whereby they are coded in egocentric as opposed to allocentric space. Lohse (2012) suggests that adopting an internal focus of attention is more likely to induce this egocentric coding and thus, conscious control over actions. This is arguably more attention demanding and accounts for increased planning demands, which then manifest through longer inter-trial intervals and pre-movement times. However, Willingham (1998) proposes that both conscious and unconscious modes of skill execution can be helpful to performance.

In the absence of any investigations into movement 'control' in conjunction with planning processes, the current set of studies are the first to include rigorous measures of these mechanisms. In turn, this also provides a novel application of Khan et al.'s (2006) variability methodology, which has been shown to provide a robust measure of both planning (i.e., *offline* cognitive processing of feedback between trials for movement planning) and control (i.e., *online* adjustments made during a movement) processes. This approach has been most often adopted in rapid aiming tasks, which afford a rigorous analysis of kinematic profiles of movements. The methodological technique initially stems from Woodworth's (1899) aforementioned two-component model of goal-directed aiming (for a more recent review see Elliott et al., 2001). This provides a detailed analysis of two proposed phases of target-aiming movements: an initial impulse phase, which consists of central planning to move the limb into the vicinity of the target followed by an adjustment phase, which controls the movement using sensory feedback in order to reach the target. Measures of variability provide useful indications of these components' relative contributions to movement execution. Whilst errors early on in an action tend to be indicative of poor motor planning, control processes typically occur online and can be reflected in error corrections made later in a movement trajectory (see Khan et al., 2006 for a review).

Furthermore, literature has also observed instances where attentional shifts *towards* and not away from movements have been advocated, such as process goals (Zimmerman & Kitsantas, 1997) or external/kinaesthetic motor imagery (Hardy & Callow, 1999). Similarly, the philosophical concept of a functional 'somaesthetic awareness' (Shusterman, 2011) has been proposed by Toner and Moran (2015) for use in making movement adjustments for error correction or when re-learning movements. This is in line with arguments made by Collins, Carson, and Toner (2015) highlighting reported benefits from athletes sometimes adopting a focus towards particular aspects of a movement. They suggest that optimal focus is dependent on factors such as familiarisation with instructions, focus relevance and availability of physical implements during execution (see also Lawrence, Gottwald, Hardy, & Khan, 2011). These movement related techniques are clearly contradictory to Wulf's persuasive recommendations cautioning against a 'movement centred' focus (see Wulf, 2013 for a review). We hypothesize that these discrepancies are likely a result of task nuances and that adopting a movement centred focus may actually add value in particular contexts yet to be explored. When performing an aiming movement, available sensory information in the form of either visual or proprioceptive and kinaesthetic information is utilised in guiding the limb to the target via offline and online motor control (Crossman & Goodeve, 1983). According to specificity of practice hypothesis (Proteau, 1992; Coull, Tremblay, & Elliott, 2001), the source of afferent information most useful to performance execution is typically prioritised for processing. In an aiming task where proprioception is an arguably important source of information, we might expect this to manifest via enhanced processing (e.g. planning or control) when using an internal and not external focus of attention. This is in line with the aforementioned phenomenon of a facilitative somaesthetic awareness (Shusterman, 2011). Interestingly, Porter, Wu, and Partridge (2010) reveal that 84.6% of athletes surveyed report that instructions provided in their training still induce an internal focus of attention, regardless of Wulf and colleagues' recommendations. Whilst this may be a function of undesirable coaching methods, it may also be an indication of potential benefits of an internal focus in some contexts e.g. when importance of proprioceptive information is high for task success. The current series of experiments are aimed at better understanding this research lacuna in the context of offline motor planning and online motor control mechanisms. We conducted three experiments that differed systematically in the need for proprioceptive processes to meet task goals, whilst incorporating rigorous measures of planning and control.

5.1 Experiment 1

In Experiment 1 we compared the utilisation of afferent information for offline planning and online motor control processes under different attentional focus conditions. Participants completed a computer-based rapid-aiming task, under either internal or external attentional foci. We hypothesized benefits in offline planning when adopting an internal focus of attention, in line with specificity theory. In a task of this nature, we expected greater congruence between internal compared with external focus instructions and the required movement production.

5.1.1 Method.

Participants.

Forty participants, who reported right-hand-dominance and normal / corrected-to-normal vision, were randomised into two groups: internal focus of attention (n = 20) and external focus of attention (n = 20). G*Power (G*Power 3; Faul, Erdfelder, Lang, & Buchner, 2007) sample size estimation deemed 14 participants per group necessary to provide power = .8 for the interaction between focus of attention and within movement trajectory variability when alpha = .05 and η_p^2 = .05. Thus, final sample size exceeded minimum power requirements. The experiment was conducted in accordance with institutional ethical guidelines.

Apparatus and task.

The experimental task comprised a target-directed computer-based aiming movement, performed using a handheld stylus on a Calcomp III digitising tablet (122cm x 91.5cm & sample rate 200Hz) placed horizontally in front of participants (see figure 1). An opaque shield obscured participants' vision of their hand/stylus. Stylus position was denoted via a white circular cursor (1cm diameter) on a black background using a 37" Mitsubishi Diamond Pro monitor (refresh rate = 85hz) located 33cm in front of the participant and 20cm above the digitizing tablet. The X/Y movement of the stylus on the tablet plane corresponded 1-to-1 to the X/Y movement of the cursor on the monitor plane. A green circular 'start' marker (1cm diameter) was located at the bottom of the monitor. Three circular 'target' markers (red, 1cm diameter) were each displayed 20cm centre-to-centre from the start position marker; one target was directly above the start marker and the other two targets were at 10° to either side (angle subtended from the home position). The rationale for including multiple targets was purely to increase task complexity and thus for analysis purposes, data was later collapsed across targets. To begin each trial, participants steadied their cursor over the start marker, after which one of the targets turned green. Following a random 500-1500ms delay, a GO-tone signalled participants to initiate movement towards the target. Participants were instructed to: (1) make their movements as smoothly as possible; (2) stay within a criterion movement time (MT) of 400-500ms to allow sufficient time for processing of visual information (Carlton, 1992; Khan et al., 2003)[1]; and (3) be as accurate as possible in stopping their cursor over the target - therefore giving the task a directional and amplitude component. Once participants had come to a complete stop, the target became red again and participants had to return to the start position, ready for the next trial; concurrently, knowledge of results in the form of MT and a point score (see Allsop, Lawrence, Gray & Khan, 2017) was presented on the monitor[2]. It was explained to participants at the beginning of testing that they were not required to make movements as fast as possible and that as long as they moved within 400-500ms, their performance would be determined by aiming accuracy and not reaction time nor MT. If trials had a MT <400ms or >500ms, they were repeated until correct.

Figure 1. Experiment 1. The task was a target-directed aiming movement, performed using a handheld stylus on a digitising tablet whereby the X/Y movement of the stylus on the tablet plane corresponded

[1] Based on the rationale for including a MT criterion, we have not included any MT analysis within dependent measures and results sections.

[2] The point score was a direct measure of performance and calculated using a combination of how close the participant was to meeting the criterion MT (in terms of absolute error) and how close their movement finished in relation to the target (end-point error). A maximum of five points were possible for each of the two components, meaning a maximum of 10 points were possible on any one trial. The maximum score of 10 was achieved if MT fell within ±10 ms of the criterion MT and cursor error fell within ±5 mm of the criterion target distance. These points reduced by one whole integer for every additional ±10 ms and every additional ±5 mm that the cursor fell outside of the criterion MT and the criterion target distance, respectively.

to the X/Y movement of the cursor on the monitor plane. Participants were required to move the cursor from the start position to one of three targets as quickly and accurately as possible.

Procedure.

The experimenter demonstrated the task up to five times to participants. Before starting their first trial, participants in the internal group were instructed to focus on the fluid motion of their hand, and participants in the external group were instructed to focus on the fluid motion of the pen. Participants were given attentional focus reminders every 10 trials. Participants completed three experimental phases: acquisition (90 trials), retention (30 trials), and transfer (30 trials). Retention trials required participants to perform the same task with no focus reminders. The transfer task was the same as retention, but targets were located 25cm as opposed to 20cm from the start position. Target order was randomised within each block of trials, under the condition that the same target could not appear twice in a row.

Data reduction and dependent measures.

Displacement data was filtered using a second-order dual-pass Butterworth filter with a 10Hz low-pass cut-off frequency. A two-point central finite difference algorithm was used to calculate instantaneous velocity data from displacement data. This process was repeated to calculate acceleration data from velocity data. Movement initiation was defined as the point at which the cursor moved 2mm from the start position. Movement end was defined as the point where absolute velocity of the stylus fell below 1mm/s: thus prohibiting reversal movements. The 100% start-to-target distance was defined as the point at which the cursor crossed the invisible arc subtended by the three targets. Amplitude error comprised the stylus' orthogonal deviation (mm) from the same invisible arc. Overshoots were numerically positive whilst undershoots were numerically negative. Directional error comprised the stylus' orthogonal deviation (mm) from the longitudinal axis connecting the home and target marker. Deviation to the left of this axis was numerically negative whilst deviation to the right of this axis was numerically positive. Trials whose amplitude or directional error deviated by

>2SD from the given participant's trial block mean for >25% of the movement distance were removed prior to analysis (4.40% of all trials were removed).

Outcome performance was inferred from constant error (CE), absolute error (AE), and variable error (VE): each calculated once from amplitude error (at movement end) and once from directional error (at 100% start-to-target distance). CE and VE respectively comprised the within-participant mean and standard deviation of error. AE comprised the within-participant mean of absolute error. Planning and online motor control's role in the production of outcome performance was inferred from variability (i.e., within-participant standard deviation) throughout amplitude and directional components of movement. Amplitude variability was calculated at peak acceleration (pka), peak velocity (pkv), peak negative acceleration (pkna), and movement end (end) from the cursor's numerical orthogonal deviation in amplitude (mm) from the start position. Directional variability was calculated from directional error, at 25, 50, 75, and 100% of the start-to-target distance. Offline planning efficacy was inferred from variability at pka to pkv in the amplitude component, and from variability at 25% of the start-to-target distance in the directional component. Corrective feedback loops should have had insufficient time to initiate before these points and therefore improved planning efficacy can be inferred from reduced variability (Khan et al., 2006). Online motor control efficacy was inferred from changes in variability between pkv, pkna, and end for the amplitude component and changes in variability between 75% and 100% of movement distance for the directional component. In line with variability methodology, this 'deceleration' typically reflects corrective processes via the 'braking of the limb in order to accurately home in on the target'. Improved online motor control efficacy can be inferred from reductions in variability between these points (Khan et al., 2006). Finally, to rule out speed-accuracy trade-offs, MT (ms) (time interval between movement start and movement end) was calculated and compared between focus conditions.

Analysis.

Since the rationale for including multiple targets within the task was for task complexity purposes only (as opposed to any theoretical hypotheses), data were collapsed across targets. Outcome performance was inferred from separate 2 Focus of Attention (external and internal) x 3 Trial Block (acquisition, retention, and transfer) ANOVAs on endpoint amplitude and directional CE, AE, and VE (i.e., 6 omnibus ANOVAs). Offline planning's contribution to outcome performance in the amplitude component of movement was inferred from a 2 Focus of Attention (external and internal) x 3 Trial Block (acquisition, retention, and transfer) x 2 Marker (pka and pkv) ANOVA on amplitude component VE. Offline planning's contribution to outcome performance in the directional component of movement was inferred from a 2 Focus of Attention (external and internal) x 3 Trial Block (acquisition, retention, and transfer) ANOVA on directional component VE at 25% movement distance. Online control's contribution to outcome performance in the amplitude component of movement was inferred from a 2 Focus of Attention (external and internal) x 3 Trial Block (acquisition, retention, and transfer) x 3 Marker (pkv, pkna, and end) ANOVA on amplitude component VE. Online control's contribution to outcome performance in the directional component of movement was inferred from a 2 Focus of Attention (external and internal) x 3 Trial Block (acquisition, retention, and transfer) x 2 Distance (75 and 100%) ANOVA on directional component VE. Greenhouse-Geisser corrected tests are reported when the sphericity assumption was violated in omnibus analyses. Significant omnibus interactions were broken down using planned repeated contrasts.

5.1.2 Results.

Outcome performance

Amplitude component. The results of the 3 Trial Block x 2 Focus of Attention ANOVAs on endpoint amplitude CE, AE, and VE are shown in Table 1B. Analysis of CE revealed a significant main effect for focus of attention and a significant Trial Block x Focus of Attention interaction. The significant focus of attention main effect revealed that the internal group generally had less endpoint amplitude CE than the external group. Breakdown of the Trial Block x Focus of Attention interaction revealed the internal group significantly decreased whilst the external group significantly increased their CE from acquisition to immediate retention ($F_{1, 38} = 4.34$, $p = .044$, $\eta_p^2 = .10$) but not significantly from immediate retention to transfer ($F_{1, 38} = 2.20$, $p = .146$, $\eta_p^2 = .06$) (see Figure 2). Analysis of AE revealed a significant main effect for focus of attention and a significant Trial Block x Focus of Attention interaction. The focus of attention main effect revealed that the internal group generally had less endpoint amplitude AE than the external group. Breakdown of the Trial Block x Focus of Attention interaction revealed a significant interaction from acquisition to immediate retention and a non-significant interaction from immediate retention to transfer ($F_{1, 38} = 4.10$, $p = .050$, $\eta_p^2 = .10$; $F_{1, 38} = 2.05$, $p = .161$, $\eta_p^2 = .05$, respectively). Analysis of VE revealed only the main effect for Focus of Attention as significant: wherein the internal group generally had less endpoint amplitude VE than the external group.

Directional component. The results of the 3 Trial Block x 2 Focus of Attention ANOVAs on 100% start-to-target distance CE, AE, and VE are shown in Table 1B. Analysis of CE revealed no significant main effects nor interaction. Analysis of AE revealed only the main effect for trial block as significant. Breakdown of this main effect revealed no significant change from acquisition to immediate retention but a significant increase from immediate retention to transfer ($F_{1, 38} = .15$, $p = .699$, $\eta_p^2 < .01$; $F_{1, 38} = 18.46$, $p < .001$, $\eta_p^2 = .33$, respectively). Analysis of VE also revealed only the main effect for trial block as significant. Breakdown of this main effect revealed no significant change from acquisition to immediate retention but a significant increase from immediate retention to transfer ($F_{1, 38} = .79$, $p = .379$, $\eta_p^2 = .02$; $F_{1, 38} = 13.85$, $p = .001$, $\eta_p^2 = .27$, respectively).

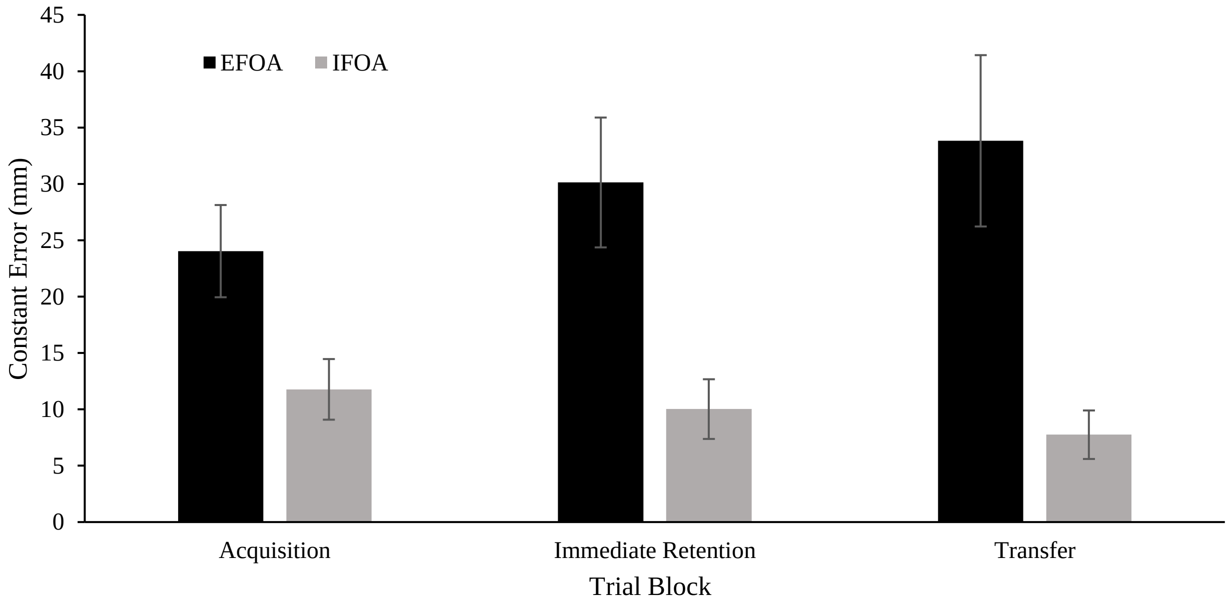


Figure 2. Experiment 1. External and internal group means (+/-1 SEm) endpoint amplitude CE at acquisition, immediate retention, and transfer.

Offline planning / online control contributions to outcome performance.

Amplitude component. The results of the 2 Focus of Attention x 3 Trial Block x 2 Marker ANOVA on amplitude variability to infer offline planning efficacy are shown in Table 1d. This analysis revealed a significant main effect for focus of attention and no significant interaction involving focus of attention. The results of the 2 Focus of Attention x 3 Trial Block x 3 Marker ANOVA on amplitude variability to infer online motor control efficacy are also shown in Table 1D. This analysis revealed a significant main effect for focus of attention and no significant interaction involving focus of attention. Overall, the presence of a significant main effect for focus of attention in both analyses (wherein an internal focus produced less variability than an external focus) and absence of significant interactions involving focus of attention, suggest that changes in offline planning and not online control were the primary contributor to the internal focus group's superior endpoint amplitude performance.

Directional component. The results of the 2 Focus of Attention x 3 Trial Block ANOVA on directional variability to infer offline planning efficacy are shown in Table 1d. This analysis revealed no significant focus of attention main effect and no significant interaction involving focus of attention. The results of the 2 Focus of Attention x 3 Trial Block x 2 Distance ANOVA on directional variability to infer online control efficacy are shown in Table 1D. This analysis also revealed no significant focus of attention main effect and no significant interaction involving focus of attention. In sum, no significant offline planning and online control differences emerged between focus of attention groups in the directional component of movement.

Table 1

Descriptives and statistical results of Experiment 1 omnibus analysis.

Table 1 (A): Descriptives of outcome performance

Component	Focus of attention	Trial Block	CE	AE	VE
Amplitude	External	Acquisition	24.04 (18.29)	26.08 (16.79)	16.67 (6.52)
		Retention	30.13 (25.76)	31.78 (25.75)	14.76 (12.27)
		Transfer	33.83 (33.99)	36.09 (32.62)	16.19 (8.85)
	Internal	Acquisition	11.77 (12.03)	14.17 (10.94)	11.24 (4.10)
		Retention	10.02 (11.84)	12.16 (11.05)	9.04 (2.38)
		Transfer	7.75 (9.62)	10.66 (8.20)	9.89 (3.99)
Directional	External	Acquisition	.512 (1.32)	6.78 (1.58)	8.41 (2.04)
		Retention	-0.96 (3.44)	6.76 (3.10)	8.04 (3.73)
		Transfer	-1.14 (5.09)	8.56 (3.75)	10.17 (3.73)
	Internal	Acquisition	.42 (3.44)	6.34 (3.03)	7.98 (3.39)
		Retention	-.23 (2.94)	6.06 (2.46)	7.76 (3.09)
		Transfer	-.33 (3.94)	6.69 (2.73)	8.76 (3.00)

Table 1 (B): Statistics of outcome performance

Component	Effect	CE	AE	VE
Amplitude	2 FOA x 3 Trial Block Interaction	$F_{1.27, 48.27} = 3.93$, $p = .044$, $\eta_p^2 = .09$**	$F_{1.40, 53.23} = 3.89$, $p = .040$, $\eta_p^2 = .09$**	$F_{1.70, 64.68} = .076$, $p = .900$, $\eta_p^2 = .002$
	FOA Main Effect	$F_{1, 38} = 11.15$, $p = .002$, $\eta_p^2 = .23$**	$F_{1, 38} = 11.72$, $p = .001$, $\eta_p^2 = .24$**	$F_{1, 38} = 10.04$, $p = .003$, $\eta_p^2 = .21$**
	Trial Block Main Effect	$F_{1.27, 48.27} = .74$, $p = .481$, $\eta_p^2 = .02$	$F_{1.40, 53.23} = .902$, $p = .379$, $\eta_p^2 = .02$	$F_{1.70, 64.68} = 1.58$, $p = .217$, $\eta_p^2 = .04$
Directional	2 FOA x 3 Trial Block Interaction	$F_{1.56, 59.40} = .39$, $p = .631$, $\eta_p^2 = .01$	$F_{1.45, 55.14} = 1.78$, $p = .185$, $\eta_p^2 = .05$	$F_{2, 76} = .54$, $p = .586$, $\eta_p^2 = .01$
	FOA Main Effect	$F_{1, 38} = .45$, $p = .504$, $\eta_p^2 = .01$	$F_{1, 38} = .1.69$, $p = .202$, $\eta_p^2 = .04$	$F_{1, 38} = 1.04$, $p = .314$, $\eta_p^2 = .03$
	Trial Block Main Effect	$F_{1.56, 59.40} = 2.63$, $p = .093$, $\eta_p^2 = .07$	$F_{1.45, 55.14} = 5.38$, $p = .014$, $\eta_p^2 = .12$**	$F_{2, 76} = 5.95$, $p = .004$, $\eta_p^2 = .14$**

Table 1 (C): Descriptives of variability for planning and control contributions

Component	Focus of attention	Trial Block	VE at PkA	VE at PkV	VE at PkNA	VE at Endpoint
Amplitude	External	Acquisition	12.23 (4.62)	20.39 (4.75)	23.03 (4.83)	16.67 (6.52)
		Retention	12.95 (4.47)	19.09 (6.37)	21.25 (10.72)	14.76 (12.27)
		Transfer	15.45 (4.92)	22.28 (5.74)	22.01 (6.03)	16.19 (8.85)
	Internal	Acquisition	8.91 (3.32)	14.85 (2.76)	19.77 (4.14)	11.24 (4.10)
		Retention	8.03 (2.63)	13.98 (2.91)	16.53 (2.61)	9.04 (2.38)
		Transfer	11.83 (6.53)	16.14 (3.77)	18.20 (5.26)	9.89 (3.99)
Component	**Focus of attention**	**Trial Block**	**VE at 25%**	**VE at 50%**	**VE at 75%**	**VE at 100%**
Directional	External	Acquisition	3.73 (.78)	5.42 (1.26)	6.93 (1.60)	8.41 (2.04)
		Retention	3.53 (1.23)	5.15 (1.87)	6.51 (2.66)	8.04 (3.73)
		Transfer	3.98 (1.05)	6.11 (1.74)	8.27 (2.73)	10.17 (3.73)
	Internal	Acquisition	3.56 (1.02)	5.24 (1.66)	6.86 (2.33)	7.98 (3.39)
		Retention	3.17 (1.14)	4.71 (1.57)	6.07 (1.84)	7.47 (2.35)
		Transfer	3.76 (1.09)	5.84 (1.61)	7.47 (2.27)	8.76 (3.00)

Table 1 (D): Statistics of variability for planning and control contributions

Offline Planning

Component	Effect	VE at PkA and PkV	Component	Effect	VE at 25% Movement Dist.
Amplitude	2 FOA x 3 Trial Block x 2 Marker	$F_{1, 76} = .84$, $p = .438$, $\eta_p^2 = .02$	Directional	2 FOA x 3 Trial Block	$F_{2, 76} = .20$, $p = .816$, $\eta_p^2 = .05$
	2 FOA x 3 Trial Block	$F_{2, 76} = 1.93$, $p = .879$, $\eta_p^2 < .01$		FOA Main Effect	$F_{2, 76} = .79$, $p = .380$, $\eta_p^2 = .02$
	2 FOA x 2 Marker	$F_{1, 38} = 1.27$, $p = .267$, $\eta_p^2 = .03$		Trial Block Main Effect	$F_{2, 76} = 5.30$, $p = .007$, $\eta_p^2 = .12$**
	3 Trial Block x 2 Marker	$F_{1, 76} = 1.18$, $p = .313$, $\eta_p^2 = .03$			
	FOA Main Effect	$F_{1, 38} = 30.62$, $p < .001$, $\eta_p^2 = .45$**			
	Trial Block Main Effect	$F_{2, 76} = 12.66$, $p < .001$, $\eta_p^2 = .25$**			
	Marker Main Effect	$F_{1, 38} = 72.35$, $p < .001$, $\eta_p^2 = .66$**			

Online Control

Component	Effect	VE at PkV, PkNA, and endpoint	Component	Effect	VE at 75 and 100% Movment Dist.
Amplitude	2 FOA x 3 Trial Block x 3 Markers	$F_{3.24, 123.05} = .22$, $p = .895$, $\eta_p^2 = .01$	Directional	2 FOA x 3 Trial Block x 2 Distance	$F_{2, 76} = .56$, $p = .58$, $\eta_p^2 = .01$
	2 FOA x 3 Trial Block	$F_{2, 76} = .14$, $p = .870$, $\eta_p^2 < .01$		2 FOA x 3 Trial Block	$F_{2, 76} = .507$, $p = .604$, $\eta_p^2 = .01$
	2 FOA x 2 Marker	$F_{2, 76} = .80$, $p = .455$, $\eta_p^2 = .02$		2 FOA x 2 Distance	$F_{1, 38} = 1.33$, $p = .256$, $\eta_p^2 = .03$
	3 Trial Block x 2 Marker	$F_{3.24, 123.05} = 1.67$, $p = .173$, $\eta_p^2 = .04$		3 Trial Block x 2 Distance	$F_{2, 76} = .84$, $p = .437$, $\eta_p^2 = .02$
	FOA Main Effect	$F_{138} = 16.80$, $p < .001$, $\eta_p^2 = .31$**		FOA Main Effect	$F_{1, 38} = .86$, $p = .359$, $\eta_p^2 = .02$
	Trial Block Main Effect	$F_{2, 76} = 5.02$, $p = .001$, $\eta_p^2 = .12$**		Trial Block Main Effect	$F_{2, 76} = 7.36$, $p = .001$, $\eta_p^2 = .16$**
	Marker Main Effect	$F_{2, 76} = 39.93$, $p < .001$, $\eta_p^2 = .51$**		Distance Main Effect	$F_{1, 38} = 86.66$, $p < .001$, $\eta_p^2 = .70$**

* p < .052. ** p < .05.

5.1.3 Discussion.

Experiment 1 employed a novel use of variability methodology to investigate planning and control mechanisms under an internal and external focus of attention. This was carried out in a task where proprioceptive salience was hypothesized to be high. Participants performed a target-aiming task, during which key kinematic variables indicative of motor planning and control processes could be measured (see Khan et al., 2006). We hypothesized that the proprioceptive nature of the task may contribute to atypical findings based on the philosophical concept of a functional ‘somaesthetic awareness’ (Shusterman, 2011): wherein the increased congruence between task-relevant information and an internal focus of attention would yield performance and processing benefits compared to an external focus.

Findings confirmed that participants adopting an internal focus were more accurate in their movements comparative to those adopting an external focus. This was manifested via reduced errors throughout all experimental phases as well as decreasing levels of error between acquisition and retention. Participants adopting an external focus displayed the opposite pattern of results. Furthermore, variability findings were reflective of more consistent (i.e., less variable) movements under an internal focus of attention. It is likely that in a rapid-aiming target-directed movement, higher levels of variability may be detrimental to movement accuracy. This is inconsistent with Lohse et al. (2010) where enhanced performance was manifested by increased variability. However, Bernstein (1967) suggests that movements are constrained to the point that they are most functional. The presence of a focus of attention main effect for amplitude variability, but absence of significant interactions involving focus of attention (which would be indicative of movement adjustments made during the movement), suggests that the primary contributor to improved endpoint amplitude performance of the internal group was offline planning.

Thus, an internal focus of attention may possess some facilitative attributes when performing a task of this nature, where fine motor adjustments are required (whether made during a movement or prior to). The results of Experiment 1 are likely a reflection of unequal levels of proprioceptive information available under different focus conditions in a task of this manner. Participants adopting an internal focus of attention may have been better afforded proprioceptive information (i.e., somaesthetic awareness) due to the nature of their instructions. This important role of attentional focus in skill refinement has been deliberated previously in a series of commentaries (see Toner & Moran, 2015, Wulf, 2015; Toner & Moran, 2016), which propose that focusing on the body can be of benefit for refining skills and making movement adjustments. It is therefore plausible that an internal focus may possess the required characteristics for these error-correction mechanisms to occur most effectively. This benefit may be further enhanced within tasks that are more 'proprioceptive' in nature.

However, it might be argued that a rapid aiming task with both visual and proprioceptive information available was not truly proprioceptive in nature and makes it difficult to determine the extent to which discrete modes of information (i.e., visual versus proprioceptive awareness), were most useful to participants' motor execution when adopting different attentional foci. Thus, the rationale behind Experiment 2 was to remove this confound by applying task constraints which accentuated the significance of proprioceptive information for successful performance. This was to confirm whether tasks where proprioception is integral to performance, benefit from adopting an internal compared to external focus of attention.

5.2 Experiment 2

In aiming tasks, available sensory information through vision or proprioception is fundamental for successful movement execution (Crossman & Goodeve, 1983). As previously mentioned, specificity of practice hypothesis (Proteau, 1992; Coull et al., 2001) proposes that the source of afferent information deemed most useful to successful performance is usually prioritised for processing. Identifying the source of this information is helpful in informing both theoretical advancement as well as the development of practical performance and learning interventions

(Toussaint, Meugnot, Badets, Chesnet, & Proteau, 2016). Experiment 2 aimed to remove the confound of visual information from Experiment 1 and provide robust evidence for the benefits of an internal focus when congruent with sources of task relevant afferent information available. Otherwise, the task remained unchanged.

We hypothesised that if those adopting an internal focus are indeed able to process proprioceptive information more readily and in line with specificity theory (Proteau, 1992), then we would expect to see a further benefit of an internal focus under no vision conditions. Khan et al. (2006) suggest that variability profiles differ depending on afferent information available. It is thus plausible that the availability of visual feedback will modulate focus of attention effects on movement variability.

5.2.1 Methods.

The only difference between Experiment 2 and Experiment 1's methodological approach was that vision of the cursor on the screen was removed at the beginning of each trial until movement end (e.g. consistent with Chua & Elliott, 1993; Khan et al., 2003). Targets remained visible throughout. Participants were again randomised into two groups; internal (n=20) and external (n=20) and provided with the same instructions as per Experiment 1. Sample size was based on the estimation detailed in Experiment 1. Of all trials, 3.03% were identified as outliers and removed prior to analysis. Again, target data was collapsed based on experimental hypotheses.

5.2.2 Results.

Outcome performance.

Amplitude component. The results of the 3 Trial Block x 2 Focus of Attention ANOVAs on endpoint amplitude CE, AE, and VE are shown in Table 2B. Analysis of CE revealed a significant main effect for trial block and focus of attention. Breakdown of the main effect for trial block revealed CE generally increased (i.e., greater overshoot) from acquisition to immediate retention ($F_{1, 38} = 4.94$,

$p = .032$, $\eta_p^2 = .12$) and decreased from immediate retention to transfer ($F_{1, 38} = 42.54$, $p < .001$, $\eta_p^2 = .53$). To break down the main effect for focus of attention, one sample t-tests comparing each group's mean CE across trial blocks to 0 were performed. This analysis revealed the external group generally undershot the target ($t(19) = -1.87$, $p = .078$, 95% CI [-32.20, 1.85]) and the internal group generally overshot the target ($t(19) = 4.11$, $p = .001$, 95% CI 10.44, 32.13]). Analysis of AE revealed only the Trial Block x Focus of Attention interaction as significant. Breakdown of this interaction revealed that there was no interaction between acquisition and immediate retention ($F_{1, 38} = 2.08$, $p = .157$, $\eta_p^2 = .05$), but between immediate retention and transfer, the external group significantly increased whilst the internal group decreased their AE ($F_{1, 38} = 11.61$, $p = .002$, $\eta_p^2 = .23$). Analysis of VE revealed only the main effect for trial block as significant. Breakdown of this trial block revealed that generally VE increased significantly from acquisition to immediate retention ($F_{1, 38} = 17.64$, $p < .001$, $\eta_p^2 = .32$) and from immediate retention to transfer ($F_{1, 38} = 9.38$, $p = .004$, $\eta_p^2 = .20$).

Directional component. The results of the 3 Trial Block x 2 Focus of Attention ANOVAs on 100% start-to-target distance CE, AE, and VE are shown in Table 2B. Analysis of CE revealed no significant main effects nor interaction. Analysis of AE revealed a significant main effect for trial block and focus of attention. The focus of attention main effect revealed that generally, the internal group had less AE than the external group (see Figure 3). Breakdown of the main effect for trial block revealed that generally AE significantly increased from acquisition to immediate retention ($F_{1, 38} = 8.32$, $p = .006$, $\eta_p^2 = .18$) and from immediate retention to transfer ($F_{1, 38} = 7.54$, $p = .009$, $\eta_p^2 = .17$). Analysis of VE revealed a significant main effect for trial block and a near-significant main effect for focus of attention. The main effect for focus of attention trended towards the internal group exhibiting less VE than the external group. Breakdown of the main effect for trial block revealed that generally AE significantly increased from acquisition to immediate retention ($F_{1, 38} = 17.64$, $p < .001$, $\eta_p^2 = .32$) and from immediate retention to transfer ($F_{1, 38} = 9.38$, $p = .004$, $\eta_p^2 = .20$).

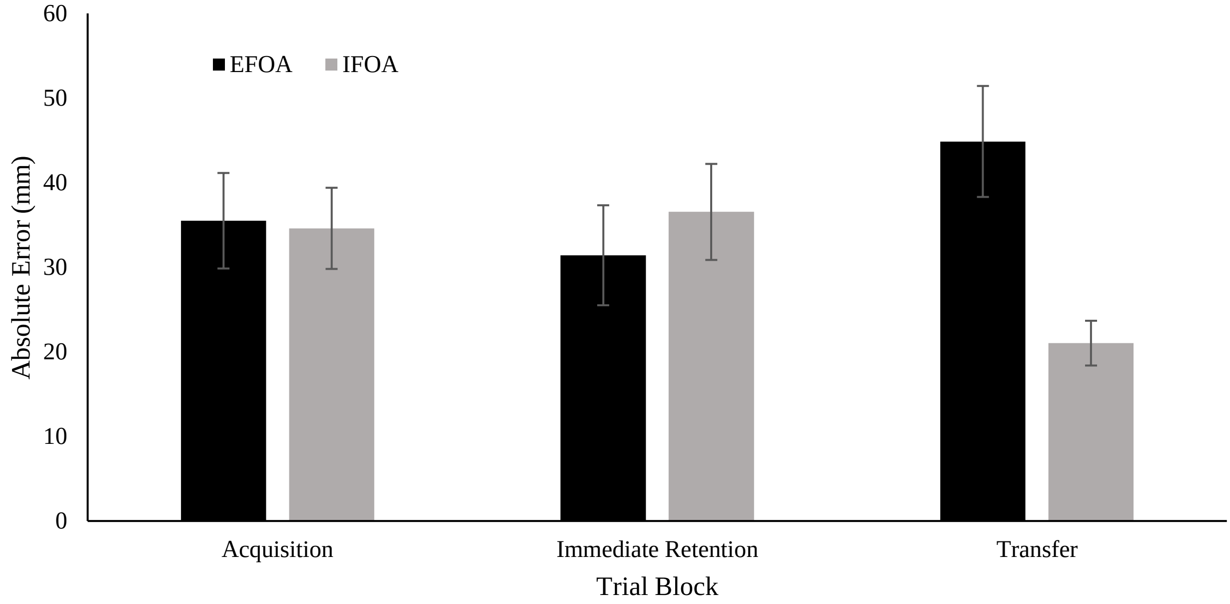


Figure 3. Experiment 2. External and internal group means (+/-1 SEm) endpoint amplitude AE at acquisition, immediate retention, and transfer.

Offline planning / online control contributions to outcome performance.

Amplitude component. The results of the 2 Focus of Attention x 3 Trial Block x 2 Marker ANOVA on amplitude variability to infer offline planning efficacy are shown in Table 2D. This analysis revealed no significant main effects nor interactions involving focus of attention. The results of the 2 Focus of Attention x 3 Trial Block x 3 Marker ANOVA on amplitude variability to infer online motor control efficacy are also shown in Table 2. This analysis also revealed no significant main effects nor interactions involving focus of attention. In sum, within the amplitude component we observed no differences in offline planning / online control based on focus of attention.

Directional component. The results of the 2 Focus of Attention x 3 Trial Block ANOVA on directional variability to infer offline planning efficacy are shown in Table 2D. This analysis revealed a significant focus of attention main effect and no significant interaction involving focus of attention. The results of the 2 Focus of Attention x 3 Trial Block x 2 Distance ANOVA on directional variability to infer online control efficacy are shown in Table 2. This analysis revealed a significant focus of attention main effect and a significant Focus of Attention x Trial Block x Distance interaction. The focus of attention main effect revealed that the internal focus group generally had less VE than the external focus group. Breakdown of the Focus of Attention x Trial Block x Distance interaction revealed that from immediate retention to transfer only, the external group increased their VE less between 75 and 100% movement distance than the internal group ($F_{1, 38} = 4.69$, $p = .037$, $\eta_p^2 = .11$): at first glance suggesting increased online correction in the external group at transfer. However, given (1) this effect being exclusive to transfer, (2) transfer likely increasing task difficulty compared to immediate retention, and (3) the internal group exhibiting superior planning and outcome performance compared to the external group, the external focus group likely exhibits increased online control at transfer because worse planning provides greater scope for correction: rather than greater corrections being a specific benefit of an external focus of attention. In sum, the consistent focus of attention main effects and absence of Focus of attention x Distance interaction across trial blocks, suggest that offline planning likely accounts for focus of attention differences in outcome performance.

Table 2

Descriptives and statistical results of Experiment 2 omnibus analysis.

Table 2 (A): Descriptives of outcome performance

Component	Focus of attention	Trial Block	CE	AE	VE
Amplitude	External	Acquisition	-7.30 (40.71)	35.49 (25.24)	23.49 (7.44)
		Retention	24.03 (29.36)	31.41 (26.42)	17.76 (8.48)
		Transfer	-35.17 (38.68)	44.86 (29.33)	26.90 (25.77)
	Internal	Acquisition	-3.07 (40.11)	34.59 (21.45)	24.12 (7.52)
		Retention	30.71 (29.77)	36.53 (25.38)	18.36 (9.70)
		Transfer	9.12 (18.50)	21.02 (11.83)	9.78 (5.43)
Directional	External	Acquisition	.92 (10.91)	36.35 (22.28)	42.81 (28.09)
		Retention	-3.31 (12.79)	31.47 (24.02)	35.15 (30.20)
		Transfer	2.91 (14.63)	34.66 (23.96)	39.37 (30.21)
	Internal	Acquisition	-3.03 (5.94)	22.32 (10.13)	27.13 (12.26)
		Retention	-5.42 (10.96)	19.33 (12.03)	22.04 (13.63)
		Transfer	-2.45 (12.55)	22..06 (15.71)	25.21 (17.37)

Table 2 (B): Statistics of outcome performance

Component	Effect	CE	AE	VE
Amplitude	2 FOA x 3 Trial Block Interaction	$F_{1.36, 51.82}$ = 1.489, p = .232, η_p^2 = .04	$F_{1.37, 51.90}$ = 8.54, p = .002, η_p^2 = .18**	$F_{1.49, 56.51}$ = 2.54, p = .103, η_p^2 = .06
	FOA Main Effect	$F_{1, 38}$ = 14.29, p = .001, η_p^2 = .27**	$F_{1, 38}$ = 1.09, p = .302, η_p^2 = .03	$F_{1, 38}$ = .29, p = .592, η_p^2 = .008
	Trial Block Main Effect	$F_{1.36, 51.82}$ = 25.301, p < .001, η_p^2 = .40**	$F_{1.37, 51.90}$ = .16, p = .767, η_p^2 = .004	$F_{1.49, 56.51}$ = 5.08, p = .016, η_p^2 = .12**
Directional	2 FOA x 3 Trial Block Interaction	$F_{1.59, 60.282}$ = .16, p = .851, η_p^2 = .004	$F_{1.63, 61.90}$ = .25, p = .732, η_p^2 = .007	$F_{1.61, 61.20}$ = .346, p = .708, η_p^2 = .009
	FOA Main Effect	$F_{1, 38}$ = 2.07, p = .159, η_p^2 = . 05	$F_{1, 38}$ = 5.04, p = .031, η_p^2 = .12**	$F_{1, 38}$ = 4.02, p = .052, η_p^2 = .10*
	Trial Block Main Effect	$F_{1.59, 60.28}$ = 2.77, p = .082, η_p^2 = .07	$F_{1.63, 61.90}$ = 4.37, p = .023, η_p^2 = .10**	$F_{1.61, 61.20}$ = 8.46, p = .001, η_p^2 = .18**

Table 2 (C): Descriptives of variability for planning and control contributions

Component	Focus of attention	Trial Block	VE at PkA	VE at PkV	VE at PkNA	VE at Endpoint
Amplitude	External	Acquisition	12.50 (8.08)	17.11 (3.36)	25.09 (4.23)	23.49 (7.44)
		Retention	11.08 (6.44)	15.27 (5.28)	21.00 (9.31)	17.76 (8.48)
		Transfer	15.00 (14.03)	18.07 (11.08)	28.23 (23.22)	26.90 (25.80)
	Internal	Acquisition	14.25 (5.76)	20.21 (4.28)	27.56 (8.27)	24.76 (7.52)
		Retention	11.77 (4.29)	17.12 (4.80)	22.93 (9.25)	18.36 (9.70)
		Transfer	13.06 (4.88)	18.73 (4.88)	23.29 (6.50)	19.78 (5.43)
Component	**Focus of attention**	**Trial Block**	**VE at 25%**	**VE at 50%**	**VE at 75%**	**VE at 100%**
Directional	External	Acquisition	11.67 (6.74)	22.84 (14.59)	34.36 (23.02)	42.81 (28.09)
		Retention	10.02 (8.00)	19.20 (17.23)	28.94 (26.83)	35.15(30.20)
		Transfer	12.09 (9.40)	23.89 (21.07)	34.58 (29.13)	39.37 (30.21)
	Internal	Acquisition	7.06 (2.99)	12.89 (5.97)	19.87 (9.53)	27.13 (12.26)
		Retention	5.61 (2.84)	10.50 (6.21)	16.06 (10.20)	22.04 (13.63)
		Transfer	6.37 (3.50)	11.66 (7.43)	17.989 (12.71)	25.21 (17.37)

Table 2 (D): Statistics of variability for planning and control contributions

Offline Planning					
Component	**Effect**	**VE at PkA and PkV**	**Component**	**Effect**	**VE at 25% Movement Dist.**
Amplitude	2 FOA x 3 Trial Block x 2 Marker	$F_{2, 76}$ = .22, p = .802, η_p^2 = .01	Directional	2 FOA x 3 Trial Block	$F_{1.49, 56.55}$ = 1.18, p = .303, η_p^2 = .03
	2 FOA x 3 Trial Block	$F_{1.44, 33.32}$ = 2.00, p = .157, η_p^2 = .05		FOA Main Effect	$F_{1, 38}$ = 6.91, p = .012, η_p^2 = .15**
	2 FOA x 2 Marker	$F_{1, 38}$ = .79, p = .380, η_p^2 = .02		Trial Block Main Effect	$F_{1.49, 56.55}$ = 6.94, p = .005, η_p^2 = .15**
	3 Trial Block x 2 Marker	$F_{2, 76}$ = .30, p = .740, η_p^2 = .01			
	FOA Main Effect	$F_{1, 38}$ = .36, p = .552, η_p^2 = .01			
	Trial Block Main Effect	$F_{1.44, 33.32}$ = 5.95, p = .010, η_p^2 = .14**			
	Marker Main Effect	$F_{1, 38}$ = 25.18, p < .001, η_p^2 = .40**			
Online Control					
Component	**Effect**	**VE at PkV, PkNA, and endpoint**	**Component**	**Effect**	**VE at 75 and 100% Movment Dist.**
Amplitude	2 FOA x 3 Trial Block x 3 Markers	$F_{2.31, 87.81}$ = 1.82, p = .162, η_p^2 = .05	Directional	2 FOA x 3 Trial Block x 2 Distance	$F_{1.31, 52.12}$ = 4.35, p = .032, η_p^2 = .10
	2 FOA x 3 Trial Block	$F_{1.32, 50.15}$ = 2.22, p = .136, η_p^2 = .06		2 FOA x 3 Trial Block	$F_{1.59, 60.21}$ = .39, p = .630, η_p^2 = .01
	2 FOA x 2 Marker	$F_{1.46, 50.54}$ = 1.71, p = .196, η_p^2 = .04		2 FOA x 2 Distance	$F_{1, 38}$ = .06, p = .810, η_p^2 < .01
	3 Trial Block x 2 Marker	$F_{2.31, 87.81}$ = 1.80, p = .165, η_p^2 = .05		3 Trial Block x 2 Distance	$F_{1.31, 49.71}$ = 5.34, p = .017, η_p^2 = .12**
	FOA Main Effect	$F_{1, 38}$ < .01, p = .993, η_p^2 < .01		FOA Main Effect	$F_{11, 38}$ = 4.77, p = .035, η_p^2 = .11**
	Trial Block Main Effect	$F_{1.32, 50.15}$ = 4.47, p = .030, η_p^2 = .11**		Trial Block Main Effect	$F_{1.59, 60.21}$ = 7.28, p = .003, η_p^2 = .16**
	Marker Main Effect	$F_{1.46, 50.54}$ = 25.23, p < .001, η_p^2 = .40**		Distance Main Effect	$F_{1. 38}$ = 92.82, p < .001, η_p^2 = .71**

* $p < .052$. ** $p < .05$.

5.2.3 Discussion.

The rationale behind Experiment 2 was to investigate motor programming strategies under conditions of enhanced afferent information in the mode of proprioception. This was the first experiment to consider both planning and control mechanisms as a function of focus of attention in a truly proprioceptive task. In line with Experiment 1 findings, we hypothesised enhanced accuracy for those adopting an internal as opposed to external focus. This was as a consequence of enhanced congruence between an internal focus of attention and afferent information available in the form of proprioception. Additionally, it was expected that increased movement accuracy would be coupled with evidence of enhanced planning strategies under an internal focus. To test this, Experiment 2 applied task constraints through the removal of visual information to accentuate the significance of proprioceptive information for successful performance.

Error data provided further support for Experiment 1 findings, with some nuances. Amplitude CE data suggests that participants tended to make greater errors and overshoot the target when using an internal focus, whilst those adopting an external focus tended to undershoot with smaller errors. However, amplitude AE data provides a clearer picture during later experimental phases, with the external group increasing error between retention and transfer and the internal group showing the converse pattern of results. Amplitude VE findings reinforce this pattern of results, showing a marginally significant main effect (p = .05) for focus of attention, with those adopting an internal focus displaying more consistent movements. Furthermore, directional variability findings suggest that the primary contributor to the improved directional outcome performance of the internal group was increased efficacy of offline planning. This was reflected in decreased directional variability early on in movement trajectories and supports the notion of a facilitative somaesthetic awareness. It should however be noted that benefits of end-point amplitude accuracy were accounted for only in directional and not amplitude variability findings. It might be that an absence of amplitude variability findings were a consequence of differences in the 'functionality' of variability between an internal and external focus. This may account for no differences here in line with Berstein (1967) and Lohse et al. (2010) degrees of freedom. Experiments 1 and 2 differed in the extent to which the task emphasised the importance of proprioceptive information for performance success. This was achieved through the availability of vision. However, Experiment 3 allowed us to manipulate the strength or 'potency' of proprioceptive feedback. We felt that this would provide more robust evidence for an argument recommending that focus of attention should be congruent with afferent information pertinent for task success.

5.3 Experiment 3

Experiment 2 lends support to the notion that an internal attentional focus may be effective for both movement planning and accuracy when performance-relevant afferent information primarily stems from proprioception. Experiment 3 sought to provide further evidence for this by manipulating proprioceptive salience. Participants had to encode body (i.e., leg) positions and reproduce them as accurately as possible. This task was adopted from Toussaint et al.'s (2016) methodology, which investigated leg-positioning recall, where the availability of proprioceptive information was modified in an effort to prevent neglect of proprioceptive feedback. In this case, proprioceptive information was manipulated by attaching small weights to the ankle of participants. Findings revealed that when both vision and proprioception were available, proprioceptive information was neglected and vision was the dominant force in producing accurate movements. However, the addition of ankle weight increased 'proprioceptive strength' during the task, thus reducing proprioceptive neglect. The current experiment aimed to investigate whether different attentional foci facilitate the utilisation of proprioceptive information to reproduce accurate movements and whether modifying the strength of proprioceptive information would encourage greater congruence between participants' internal focus of attention and the goal of the task.

Electromyography (EMG) of the quadriceps was also measured to provide a rigorous measure of movement efficiency. Afferent information was manipulated in different ways. Firstly vision was removed. Toussaint et al.'s (2016) work emphasizes the dominant role of visual feedback in goal directed movements when available and thus, removal of this allowed researchers to isolate proprioceptive information. Secondly, it was felt that the nature of this task better allowed for participants to code the target location proprioceptively compared to Experiments 1 and 2: further increasing proprioception's relevance to movement accuracy. Thirdly, based on the findings of Toussaint and colleagues, weight was added to the ankle of one group in an effort to increase the strength of proprioceptive information available during the task.

Thus, the rationale for the final experiment was to investigate whether manipulating the congruence between an internal focus of attention and the afferent information available, enhances the extent to which movements are executed successfully. It was hypothesised that, in line with Experiments 1 and 2, an internal focus would facilitate performance by directing participants' attention to task-relevant proprioceptive information. Furthermore, it was expected that attentional focus differences would be more pronounced in the group performing with an ankle weight due to increased potency of proprioceptive information.

5.3.1 Methods.

Participants.

The makeup of participants in Experiment 3 (n=40) replicated that of Experiments 1 and 2, other than an additional participation criterion being no history of nervous or muscular disorders. Participants were randomised into weight (n=20) and no-weight groups (n=20). Sample size was again based on the estimation detailed in Experiment 1.

Apparatus.

Participants were seated in the middle of a 12-camera volume (Vicon Nexus, sampling at 240hz) on a chair modified to minimise camera obstruction and allow participants' non-dominant leg to move freely and comfortably around the knee joint. As in Toussaint et al. (2016) and Toussaint and Blandin (2010), participants' non-dominant leg was used to perform the task: to reduce the chance of a ceiling effect and increase task novelty (Beilock, Carr, MacMahon, & Stalkes, 2002). The weight group had a 0.5kg sand-bag wrapped tightly around the base of their non-dominant leg's ankle, whilst the no-weight group did not. Leg movement in 3D space was captured via the coordinates of four reflective markers: one placed on the lateral condyle, medial condyle, lateral malleolus, and medial malleolus. A custom Microsoft Visual Basic script computed a live mid-point between the condyle markers, and between the malleolus markers, respectively. From these midpoints, a digital plane was computed to represent the lower leg position. At the beginning of testing, participants were asked to let their leg hang freely and relaxed. This position denoted their start position in every trial and a wooden box was placed so their heel gently touched the front face of the box when in this position (to aid start-position consistency). Before every trial, the experimenter ensured participants' leg was within +/-1 degree of the starting position. Leg angle was calculated live (at 240hz) as the difference in position between the start position and the plain representing their lower leg. Single-differential electromyography (EMG) surface electrodes (DE 2.1, Delsys, Boston, MA) were placed on the vastus medialis and vastus lateralis of participants' non-dominant leg to provide an electromyographical measure of leg extension efficiency (Alkner, Tesch, & Berg, 2000). Electrode placement and site preparation was in line with SENIAM recommendations (Hermens et al., 1999). Each EMG electrode's signal was 10k amplified (Bagnoli-2, Delsys) and digitized at 2500Hz using a computer running Spike2 software (Cambridge Electronic Design).

Experimental procedure and design.

Every trial comprised an encoding and recall phase respectively. For the encoding phase, participants were instructed to slowly extend their leg from the start position until a tone sounded – indicating participants were within +/-1° of the target position. Participants then had to hold and mentally encode this angle for 2 seconds. Once the tone had sounded for 2 seconds: the precise leg position was recorded as the 'encoded position'; the tone changed to a higher pitch; and participants had to return to the start position. Upon participants' return to the start position, following a random foreperiod between 1.5 and 2.5 seconds, the recall phase was initiated via a GO-tone for movement initiation. For the recall phase, participants were instructed to: reproduce the target angle as accurately as possible (basing task exclusively on the amplitude); produce one smooth and straight movement within a MT between 500 and 1000ms; not concern themselves with their reaction time; and hold their recalled position for 1 second at the end, before returning to the start position (ready for the next trial) (see figure 4). Following each trial, participants were provided with knowledge of results on a monitor in front of them; this consisted of recall phase error (i.e., by how many degrees they had undershot or overshot the target position) and MT (i.e. the ms time interval between movement initiation and end). If trials had a MT <500ms or >1000ms, they were repeated until correct. As in Toussaint et al. (2016), participants were not permitted to open their eyes from the beginning of the encoding phase, to the end of the recall phase: thus creating a proprioception-only task.

Figure 4. Experiment 3. This was a leg-extension task whereby participants had to extend their leg from a start position to a target position. Participants were required to reproduce a pre-encoded target position as accurately as possible.

Experimental trial blocks constituted familiarisation (15 trials), acquisition 1 (30 trials), transfer 1 (30 trials), acquisition 2 (30 trials) and transfer 2 (30 trials). Familiarisation and acquisition targets were 122, 132 and 142°. In transfer, participants were given new targets, which were 117, 127 and 147°. Participants were informed of this. Target order was randomised between participants and trial blocks: with the stipulation that targets were never repeated immediately. At familiarisation, participants were given no focus of attention instructions. At acquisition 1, half of participants were given external focus of attention instructions (“focus on the markers, and how you move them to their correct position”) and the other half internal focus of attention instructions (“focus on your leg, and move it to its correct position”). At acquisition 2, participants were given the focus of attention instructions they did not receive in acquisition 1. It was highlighted to participants that it was very important for them to stick to their prescribed focus of attention. At acquisition, focus reminders were provided at every trial for the first five trials, after which they were given every 10 trials. At transfer, participants were given no reminders. As a manipulation check, after every block of trials, participants were given a piece of paper to write down what they focused on in their block of trials; participants were asked to provide sufficient detail for someone else to replicate their focus. In summary the present study design entailed a within-group trial block factor and counterbalanced within-group focus of attention factor for weight and no-weight groups.

Data reduction and dependent measures.

During testing, a custom Microsoft Visual Basic two-point central finite difference algorithm was used to calculate instantaneous velocity data from displacement data. This process was repeated to calculate acceleration data from velocity data. Movement initiation was defined as the data point where velocity dropped to <1 degree per second. Movement end was defined as one data point before leg velocity reached ≤0: meaning movements could not have a reversal in movement direction. MT for participants' post-trial feedback was defined as the time (ms) between movement initiation and movement end. Recall phase error for participants' feedback was defined as the angular deviation between leg angle at movement end and the target position; overshoots were labelled numerically positive and undershoots numerically negative. For post-testing analysis, using a custom LabView script, leg displacement data was filtered using a second-order dual-pass Butterworth filter with a 10Hz low-pass cut-off frequency. Movement start, end and time were re-calculated using this filtered data. Additionally, four kinematic markers were calculated using custom LabView scripts. Namely, peak acceleration (pka), peak velocity (pkv), peak negative acceleration (pkna) and movement end (end). Encoding error for analysis was calculated as the angular deviation between movement end and the encoded position. Overshoots were labelled numerically positive and undershoots numerically negative.

Trials whose angular movement distance deviated by >2SD from the given participant's trial block mean for >25% of the movement distance were removed prior to analysis (2.07% of all trials). Data of participants who did not change their focus (n=5) between acquisition 1 and 2, based on two researchers' impression of the manipulation check responses, were also removed from analysis (see below examples and resulting group sizes[13]). Dependent measures were based on LabView-filtered data and included: MT; encoding CE (mean within-participant encoding error); and encoding VE (standard deviation of within-participant encoding error). Spatial variability throughout the amplitude of movement was assessed via variability in movement degrees at each kinematic marker (i.e., pka, pkv, pkna, and end). There was no directional component to the task.

Vastus medialis and vastus lateralis EMG activity (in V) for each trial was analysed offline from 20ms before movement start until movement end: using custom MATLAB scripts (MathWorks Inc., Natick, MA). EMG activity was filtered using a bidirectional fourth order bandpass (20-450hz) Butterworth filter, rectified, and integrated to attain a measure of muscular activation within the context of time (i.e., iEMG).

Analysis.

For brevity and clarity, the analysis on endpoint CE, endpoint AE, endpoint VE, and VE at each kinematic marker, used data collapsed across targets; separate 3 Target (low, medium, and high) x 2 Trial Block (acquisition and transfer) x 2 Focus of Attention (internal and external) ANOVAs for each weight group were performed on endpoint CE, AE, and VE to ensure collapsing targets was appropriate and revealed no significant interactions involving targets. To ensure the counterbalanced subsets of participants did not differ at the beginning of testing, familiarisation iEMG and familiarisation endpoint MT, CE, AE, and VE were submitted to independent samples t-tests which compared external-to-internal and internal-to-external focus of attention subgroups, within each weight condition (i.e. two comparisons per-

[13] Examples statements that suggested participants did not adhere to the appropriate focus: an external focus that was reported as focusing on "using muscle memory based on how tense the leg muscle is", "leg speed and trying to keep my leg still" or comments which suggested the participant was using neither an internal nor external focus e.g. "my mind was more neutral", "I wasn't really focused on a specific thing". Post data-reduction n=35 (No-weight external 1st then internal = 10; No-weight internal 1st then external = 8; Weight external 1st then internal = 7; Weight internal 1st then external = 10).

dependent variable). To investigate focus of attention's effect on outcome performance, separate 2 Trial Block (acquisition and transfer) x 2 Order (external-to-internal and internal-to-external) x 2 Focus of Attention (internal & external) ANOVAs were performed for each weight group. To investigate focus of attention's effect on muscular efficiency, iEMG of the vastus lateralis and iEMG of the vastus medialis were then analysed using separate 2 Weight (weighted and no-weight) x 2 Trial Block (acquisition and transfer) x 2 Order (external-to-internal and internal-to-external) x 2 Focus of Attention (internal & external) ANOVAs. The effect of focus of attention on offline planning was investigated via separate 2 Trial Block (acquisition and transfer) x 2 Focus of Attention (internal and external) 2 Order (external-to-internal and internal-to-external) x 2 Marker (pka and pkv) ANOVAs for each weight group (weighted and no-weight). The effect of focus of attention on online control was investigated via separate 2 Trial Block (acquisition and transfer) x 2 Focus of Attention (internal and external) x 2 Order (external-to-internal and internal-to-external) x 3 Marker (pkv, pkna, and end) ANOVA for each weight group (weighted and no-weight). The purpose of the order factor was to determine whether switching from an internal to an external focus of attention, or vice versa, impacted performance. The assumption for sphericity held in all analyses since no more than two levels of within-subject factors were compared.

5.3.2 Results.

Test of equivalence for counterbalanced subsets.

T-tests comparing familiarisation CE of external-to-internal and internal-to-external focus of attention subgroups within weight and no-weight groups revealed no significant difference in the no-weight group ($t(16) = -.45$, $p = .659$, 95% CI [-4.83, 3.14] nor the weight group ($t(15) = 1.06$, $p = .306$, 95% CI [-1.52, 4.52]). T-tests comparing familiarisation AE of external-to-internal and internal-to-external subgroups within weight and no-weight groups revealed no significant difference in the no-weight group ($t(16) = -.79$, $p = .444$, 95% CI [-

4.37, 2.01] nor the weight group (t(15) = 1.07, p = .302, 95% CI [-1.12, 3.38]). T-tests comparing familiarisation VE of external-to-internal and internal-to-external focus of attention subgroups within weight and no-weight groups revealed no significant difference in the no-weight group (t(16) =-1.53, p = .144, 95% CI [-1.39, .22]) nor the weight group (t(15) = 1.29, p = .216, 95% CI [-.31, 1.25]). The T-tests comparing familiarisation iEMG of external-to-internal and internal-to-external focus of attention subgroups within weight (t(16) = -.17, p = .869, 95% CI [-.04, .03]; t(16) = .64, p = .533, 95% CI [-.01, .03], respectively for vastus medialis and vastus lateralis) and no-weight (t(15) = 1.41, p = .178, 95% CI [-.01, .06]; t(16) = -.10, p = .924, 95% CI [-.03, .03], respectively for vastus medialis and vastus lateralis) groups revealed no significant difference and therefore subgroups should be comparable.

Outcome performance.

Results of the 2 Focus of Attention x 2 Trial Block x 2 Order ANOVAs on weight and no-weight groups' CE, AE, and VE are shown in table 3B. Analysis of the no-weight group CE revealed a near-significant Trial Block x Focus of Attention x Order interaction (see figure 5, panels A, C, and E) and a significant main effect for trial block: with no other significant main effects nor interactions. The main effect for trial block revealed acquisition generally featured significantly less CE than transfer. Analysis of the weighted group CE revealed a near-significant focus of attention main effect and significant Focus of Attention x Order interaction (see figure 5, panels B, D and F): with no other significant main effects nor interactions. Specifically, when weighted participants adopted an internal focus towards the end of testing, their CE was significantly reduced. Analysis of the no-weight group AE revealed only a significant main effect for trial block: wherein acquisition generally featured significantly less AE than transfer. Analysis of the weighted group AE revealed no significant main effects nor interactions. Analysis of the no-weight group VE revealed only a significant trial block main effect: wherein acquisition generally featured significantly less VE than transfer. Analysis of the weighted group VE revealed no significant main effects nor interactions.

Offline planning / online control contributions to outcome performance.

Results of the 2 Trial Block x 2 Focus of Attention x 2 Marker ANOVAs performed on the weight and no-weight groups to infer offline planning efficacy are shown in Table 3D. Analysis of the no-weight group revealed only significant main effects for trial block and marker and a significant Focus of Attention x Trial Block interaction. Breakdown of the Focus of Attention x Trial Block x Order interaction revealed that when an internal focus of attention came second, variability was reduced. Analysis of the weighted group revealed significant main effects for trial block and marker and a significant Focus of Attention x Trial Block x Marker x Order interaction. Breakdown of this interaction also revealed that when an internal focus of attention came second, variability was reduced but only in acquisition and at peak velocity (by which point differences in planning should be at their most prominent). Results of the 2 Trial Block x 2 Focus of Attention x 2 Marker ANOVAs performed on the weight and no-weight groups to infer online control efficacy are shown in Table 3D. Analysis of neither the no-weight group nor the weighted group revealed any significant interactions involving markers. In sum, these results suggest that differences in outcome performance based on focus of attention are primarily facilitated via changes in planning.

Table 3

Descriptives and statistical results of Experiment 3 omnibus analysis.

Table 3 (A): Descriptives of outcome performance

Ankle	Focus of attention	Order	Trial Block	CE	AE	VE
Weighted	External	before an internal FOA	Acquisition	4.58 (2.47)	5.13 (2.28)	3.75 (1.29)
			Transfer	5.01 (2.19)	5.26 (2.02)	3.57 (.67)
		after an internal FOA	Acquisition	4.44 (3.42)	5.30 (2.64)	3.53 (.70)
			Transfer	5.12 (2.19)	5.79 (3.01)	3.81 (1.19)
	Internal	before an external FOA	Acquisition	4.50 (3.39)	5.34 (2.58)	3.39 (1.09)
			Transfer	5.12 (3.52)	5.86 (2.81)	4.05 (1.01)
		after an external FOA	Acquisition	3.02 (2.04)	4.19 (1.18)	3.76 (.71)
			Transfer	2.80 (2.31)	3.80 (1.58)	3.49 (.95)
No-Weight	External	before an internal FOA	Acquisition	4.79 (2.41)	5.19 (1.99)	3.45 (.82)
			Transfer	6.49 (3.14)	6.82 (2.86)	4.17 (1.11)
		after an internal FOA	Acquisition	6.23 (4.60)	6.74 (4.02)	3.81 (.94)
			Transfer	6.11 (4.97)	6.58 (4.57)	3.93 (1.30)
	Internal	before an external FOA	Acquisition	5.10 (4.58)	5.95 (3.74)	3.71 (.72)
			Transfer	6.81 (3.94)	7.33 (3.29)	3.87 (.87)
		after an external FOA	Acquisition	5.69 (3.35)	5.97 (3.16)	3.46 (.81)
			Transfer	6.17 (3.10)	6.54 (3.29)	4.29 (1.21)

Table 3 (B): Statistics of outcome performance

Ankle	Effect	CE	AE	VE
Weighted	2 FOA x 2 Block x 2 Order Interaction	$F_{1, 15} = .34$, $p = .567$, $\eta_p^2 = .02$	$F_{1, 15} = .33$, $p = .575$, $\eta_p^2 = .02$	$F_{1, 15} = .59$, $p = .456$, $\eta_p^2 = .04$
	2 FOA x 2 Trial Block Interaction	$F_{1, 15} = .48$, $p = .501$, $\eta_p^2 = .03$	$F_{1, 15} = .26$, $p = .616$, $\eta_p^2 = .02$	$F_{1, 15} = .24$, $p = .631$, $\eta_p^2 = .02$
	2 FOA x 2 Order Interaction	$F_{1, 15} = 4.74$, $p = .046$, $\eta_p^2 = .24$**	$F_{1, 15} = 3.17$, $p = .095$, $\eta_p^2 = .18$	$F_{1, 15} = .05$, $p = .821$, $\eta_p^2 < .01$
	2 Block x 2 Order Interaction	$F_{1, 15} = .44$, $p = .517$, $\eta_p^2 = .029$	$F_{1, 15} = .81$, $p = .382$, $\eta_p^2 = .05$	$F_{1, 15} = 2.86$, $p = .112$, $\eta_p^2 = .16$
	FOA Main Effect	$F_{1, 15} = 4.45$, $p = .052$, $\eta_p^2 = .23$*	$F_{1, 15} = 2.64$, $p = .125$, $\eta_p^2 = .15$	$F_{1, 15} < .01$, $p = .968$, $\eta_p^2 < .01$
	Trial Block Main Effect	$F_{1, 15} = .83$, $p = .376$, $\eta_p^2 = .05$	$F_{1, 15} = .29$, $p = .598$, $\eta_p^2 = .02$	$F_{1, 15} = .38$, $p = .550$, $\eta_p^2 = .02$
	Order Main Effect	$F_{1, 15} = .48$, $p = .498$, $\eta_p^2 = .03$	$F_{1, 15} = .84$, $p = .374$, $\eta_p^2 = .05$	$F_{1, 15} = .02$, $p = .891$, $\eta_p^2 < .01$
No-Weight	2 FOA x 2 Block x 2 Order Interaction	$F_{1, 16} = 4.47$, $p = .051$, $\eta_p^2 = .22$*	$F_{1, 16} = 3.66$, $p = .074$, $\eta_p^2 = .17$	$F_{1, 16} = .01$, $p = .912$, $\eta_p^2 < .01$
	2 FOA x 2 Trial Block Interaction	$F_{1, 16} = .19$, $p = .671$, $\eta_p^2 = .01$	$F_{1, 16} = .13$, $p = .723$, $\eta_p^2 = .01$	$F_{1, 16} = .06$, $p = .808$, $\eta_p^2 < .01$
	2 FOA x 2 Order Interaction	$F_{1, 16} = .20$, $p = .660$, $\eta_p^2 = .01$	$F_{1, 16} = .07$, $p = .793$, $\eta_p^2 < .01$	$F_{1, 16} = .18$, $p = .675$, $\eta_p^2 = .01$
	2 Block x 2 Order Interaction	$F_{1, 16} = .01$, $p = .943$, $\eta_p^2 < .01$	$F_{1, 16} = .49$, $p = .494$, $\eta_p^2 = .03$	$F_{1, 16} = 4.02$, $p = .062$, $\eta_p^2 = .21$
	FOA Main Effect	$F_{1, 16} = .15$, $p = .708$, $\eta_p^2 = .01$	$F_{1, 16} = .06$, $p = .815$, $\eta_p^2 < .01$	$F_{1, 16} < .01$, $p = .991$, $\eta_p^2 < .01$
	Trial Block Main Effect	$F_{1, 16} = 5.73$, $p = .029$, $\eta_p^2 = .26$**	$F_{1, 16} = 5.81$, $p = .028$, $\eta_p^2 = .27$**	$F_{1, 16} = 8.36$, $p = .011$, $\eta_p^2 = .34$**
	Order Main Effect	$F_{1, 16} = .03$, $p = .864$, $\eta_p^2 < .01$	$F_{1, 16} = .137$, $p = .716$, $\eta_p^2 = .01$	$F_{1, 16} < .01$, $p = .971$, $\eta_p^2 < .01$

Table 3 (C): Descriptives of variability for planning and control contributions

Ankle	Focus of attention	Order	Trial Block	VE at PkA	VE at PkV	VE at PkNA	VE at Endpoint
Weighted	External	before an internal FOA	Acquisition	1.62 (.50)	4.37 (.91)	7.26 (1.15)	7.49 (1.01)
			Transfer	1.76 (.67)	5.56 (.69)	9.99 (1.05)	11.28 (1.10)
		after an internal FOA	Acquisition	1.98 (.88)	4.16 (.68)	7.09 (.91)	7.64 (1.06)
			Transfer	2.12 (.73)	6.03 (.83)	10.41 (1.39)	11.51 (1.62)
	Internal	before an external FOA	Acquisition	2.19 (1.09)	4.63 (.65)	7.54 (1.01)	8.19 (.84)
			Transfer	2.50 (.80)	5.84 (.93)	10.03 (.98)	11.12 (1.28)
		after an external FOA	Acquisition	1.57 (.52)	4.26 (.80)	7.21 (1.36)	7.74 (1.15)
			Transfer	1.45 (.51)	5.71 (.63)	9.98 (.97)	11.20 (1.22)
No-Weight	External	before an internal FOA	Acquisition	2.04 (.71)	4.57 (.71)	7.45 (.97)	7.52 (1.06)
			Transfer	2.28 (.57)	5.28 (.76)	9.21 (.63)	10.64 (1.23)
		after an internal FOA	Acquisition	1.72 (.90)	4.50 (.96)	7.40 (1.00)	8.15 (1.41)
			Transfer	1.88 (.63)	6.03 (.97)	10.78 (1.25)	12.05 (2.26)
	Internal	before an external FOA	Acquisition	2.48 (1.81)	5.25 (1.34)	8.37 (1.45)	8.84 (1.51)
			Transfer	2.36 (.79)	5.97 (1.14)	10.32 (1.30)	11.49 (1.73)
		after an external FOA	Acquisition	1.78 (.72)	3.88 (.91)	6.90 (.68)	7.41 (1.17)
			Transfer	1.71 (.79)	5.39 (.70)	9.41 (.91)	10.63 (1.38)

Table 3 (D): Descriptives of variability for planning and control contributions

Offline Planning			Online Control		
Ankle	Effect	VE at PkA and PkV	Ankle	Effect	VE at PkV, PkNA, and endpoint
Weighted	2 FOA x 2 Trial Block x 2 Marker x 2 Order	$F_{2, 15} = 16.22, p = .001, \eta_p^2 = .52$**	Weighted	2 FOA x 2 Trial Block x 3 Marker x 2 Order	$F_{2, 30} = .16, p = .851, \eta_p^2 = .01$
	2 FOA x 2 Trial Block x 2 Marker	$F_{2, 15} = .78, p = .391, \eta_p^2 = .05$		2 FOA x 2 Trial Block x 3 Marker	$F_{2, 30} = 1.18, p = .322, \eta_p^2 = .07$
	2 FOA x 2 Marker x 2 Order	$F_{2, 15} = 1.06, p = .319, \eta_p^2 = .07$		2 FOA x 3 Marker x 2 Order	$F_{2, 30} = .06, p = .941, \eta_p^2 < .01$
	2 FOA x 2 Marker	$F_{2, 15} = .02, p = .896, \eta_p^2 < .01$		2 FOA x 3 Marker	$F_{2, 30} = .11, p = .895, \eta_p^2 = .01$
	2 FOA x 2 Trial Block x 2 Order	$F_{2, 15} = .39, p = .542, \eta_p^2 = .03$		2 FOA x 2 Trial Block x 2 Order	$F_{1, 15} = 2.12, p = .166, \eta_p^2 = .12$
	2 FOA x 2 Trial Block	$F_{2, 15} = .37, p = .552, \eta_p^2 = .02$		2 FOA x 2 Trial Block	$F_{1, 15} = 2.22, p = .157, \eta_p^2 = .13$
	2 FOA x 2 Order	$F_{2, 15} = 2.17, p = .162, \eta_p^2 = .13$		2 FOA x 2 Order	$F_{1, 15} = .02, p = .887, \eta_p^2 < .01$
	FOA Main Effect	$F_{2, 15} = .44, p = .517, \eta_p^2 = .03$		FOA Main Effect	$F_{1, 15} = .07, p = .795, \eta_p^2 = .01$
	Trial Block Main Effect	$F_{2, 15} = 66.17, p < .001, \eta_p^2 = .82$**		Trial Block Main Effect	$F_{1, 15} = 331.93, p < .001, \eta_p^2 = .95$**
	Marker Main Effect	$F_{2, 15} = 248.90, p < .001, \eta_p^2 = .94$**		Marker Main Effect	$F_{1.36, 20.33} = 432.73, p < .001, \eta_p^2 = .97$**
	Order Main Effect	$F_{2, 15} = 2.70, p = .121, \eta_p^2 = .15$		Order Main Effect	$F_{2, 30} = .28, p = .607, \eta_p^2 = .02$
No-Weight	2 FOA x 2 Trial Block x 2 Marker x 2 Order	$F_{2, 16} = 2.15, p = .162, \eta_p^2 = .12$	No-Weight	2 FOA x 2 Trial Block x 3 Marker x 2 Order	$F_{2, 32} = .80, p = .457, \eta_p^2 = .05$
	2 FOA x 2 Trial Block x 2 Marker	$F_{2, 16} = .26, p = .618, \eta_p^2 = .02$		2 FOA x 2 Trial Block x 3 Marker	$F_{2, 32} = 1.46, p = .248, \eta_p^2 = .08$
	2 FOA x 2 Marker x 2 Order	$F_{2, 16} = 1.08, p = .315, \eta_p^2 = .06$		2 FOA x 3 Marker x 2 Order	$F_{2, 32} = 1.02, p = .374, \eta_p^2 = .06$
	2 FOA x 2 Marker	$F_{2, 16} = .16, p = .691, \eta_p^2 = .01$		2 FOA x 3 Marker	$F_{2, 32} = .02, p = .984, \eta_p^2 < .01$
	2 FOA x 2 Trial Block x 2 Order	$F_{2, 16} = 4.99, p = .040, \eta_p^2 = .24$**		2 FOA x 2 Trial Block x 2 Order	$F_{1, 16} = 10.62, p = .005, \eta_p^2 = .40$**
	2 FOA x 2 Trial Block	$F_{2, 16} = .70, p = .415, \eta_p^2 = .04$		2 FOA x 2 Trial Block	$F_{1, 16} = 1.37, p = .258, \eta_p^2 = .08$
	2 FOA x 2 Order	$F_{2, 16} = 7.40, p = .015, \eta_p^2 = .32$**		2 FOA x 2 Order	$F_{1, 16} = 2.58, p = .128, \eta_p^2 = .14$
	FOA Main Effect	$F_{2, 16} = .17, p = .682, \eta_p^2 = .01$		FOA Main Effect	$F_{1, 16} = .04, p = .853, \eta_p^2 < .01$
	Trial Block Main Effect	$F_{2, 16} = 14.87, p = .001, \eta_p^2 = .48$**		Trial Block Main Effect	$F_{1, 16} = 117.18, p < .001, \eta_p^2 = .92$**
	Marker Main Effect	$F_{2, 16} = 508.04, p < .001, \eta_p^2 = .97$**		Marker Main Effect	$F_{1.25, 20.02} = 180.47, p < .001, \eta_p^2 = .92$**
	Order Main Effect	$F_{2, 16} = 2.13, p = .164, \eta_p^2 = .12$		Order Main Effect	$F_{2, 32} = 6.27, p = .023, \eta_p^2 = .28$**

* p < .052. ** p < .05.

Muscle activity.

The 2 Focus of Attention x 2 Trial Block x 2 Weight x Order ANOVA on the vastus lateralis iEMG revealed a significant main effect for focus of attention ($F_{1,31} = 4.86$, $p = .035$, $\eta_p^2 = .14$) and Focus of Attention x Weight x Order interaction ($F_{1,31} = 8.06$, $p = .008$, $\eta_p^2 = .21$). Specifically, an internal (M = .058, SD = .029) generally yielded lower iEMG compared to an external focus (M = .060, SD = .024) and the Focus of Attention x Weight x Order interaction followed the same pattern of results as CE. The 2 Focus of Attention x 2 Trial Block x 2 Weight x Order ANOVA on the vastus medialis iEMG revealed a main effect for focus of attention and Focus of Attention x Weight x Order interaction which trended in the same direction (as the vastus laterialis data) but were not significant ($F_{1,31} = 2.92$, $p = .097$, $\eta_p^2 = .09$; $F_{1,31} = 3.35$, $p = .077$, $\eta_p^2 = .10$, respectively).

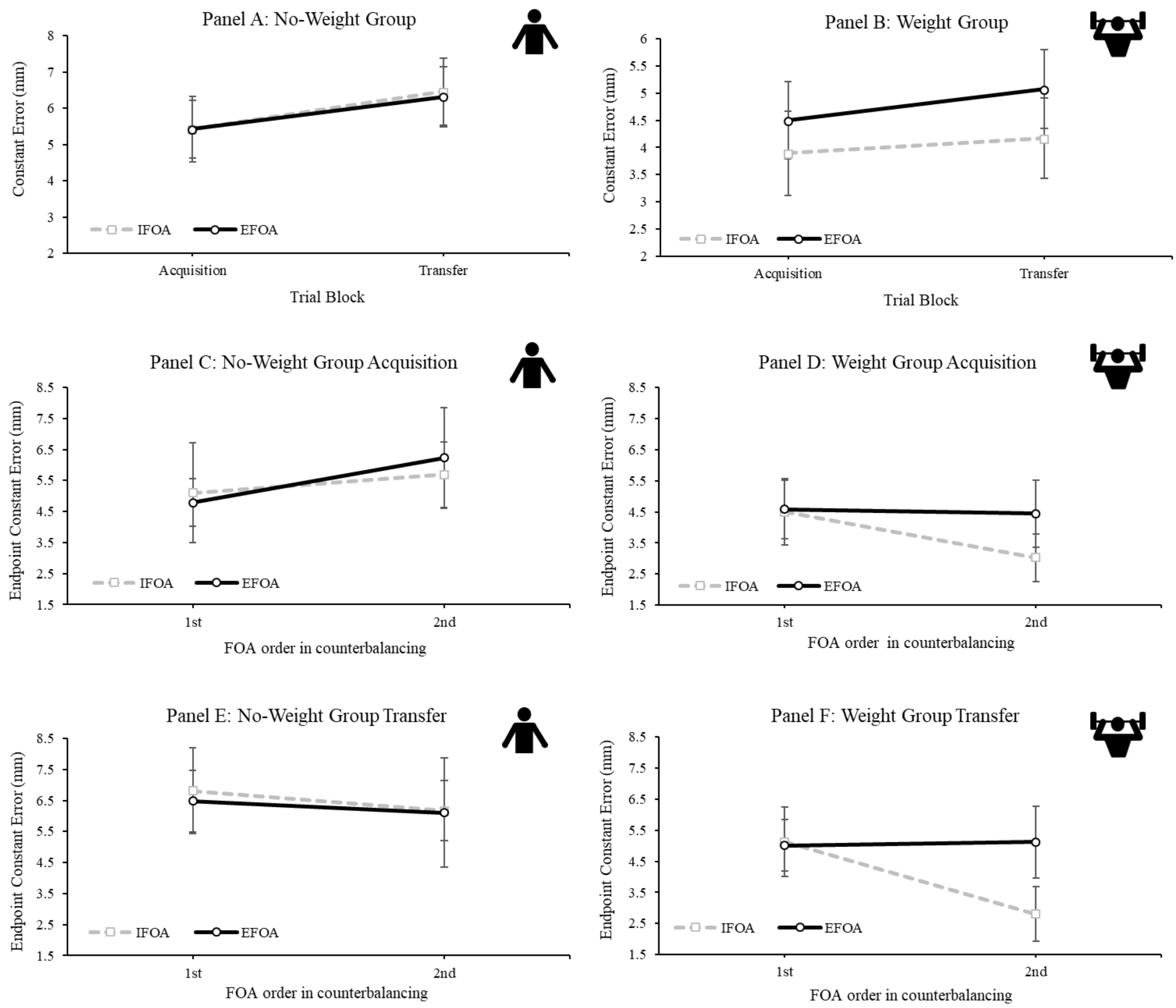


Figure 5. Experiment 3. Panel A and B show CE for the internal and external focus conditions at acquisition and transfer for the no-weight and weight groups, respectively. Panels C, D, E and F show CE for each focus of attention when they appear as the first (i.e., initial) focus of attention in the counterbalanced order, and when they occur second. Panels C and E display the no-weight group's acquisition and transfer, respectively. Panels D and F display the weight group's acquisition and transfer, respectively. Error bars equal +/- 1 standard error.

5.3.3 Discussion.

Experiment 3 utilised an amplitude-only leg extension task based on that of Toussaint et al. (2016). Participants were tasked with encoding target leg positions and accurately reproducing them in one fast target-directed movement, under counterbalanced external and internal focus of attention instructions. We aimed to ascertain whether, contrary to the assertions of the constrained action hypothesis (Wulf et al., 2001), an internal focus of attention can facilitate superior performance: specifically, when proprioceptive feedback strength was increased via an ankle weight. It was hypothesised that, compared to an external focus of attention, an internal focus would facilitate superior performance, because it guides participants' attention to task-relevant proprioceptive information. These external / internal focus of attention differences were hypothesised to be stronger in the group performing with an ankle weight.

Outcome performance was inferred from overall endpoint CE, AE, and VE. Results revealed that for the weighted group, participants who adopted an internal focus later in testing, reduced their CE during acquisition trials. Furthermore, the weighted group's CE exhibited a near-significant focus of attention main effect (p = .052) and a significant focus of attention by marker interaction: wherein adopting an internal focus reduced CE compared to an external focus. Specifically, an internal focus significantly reduced CE when it was the second focus participants were given (i.e., later in testing, after an external focus). These effects were not significant for the weighted group's AE, but followed the same trends as per their CE. Concerning the weighted group's endpoint VE, there was no difference between external and internal groups. Past studies may help us understand the mechanisms behind our observed focus of attention order effects (McNevin, Shea, & Wulf, 2003; Wulf et al., 1998). Focus of attention effects in novices seemingly manifest during later testing phases. Therefore, in Experiment 3, an internal focus may have been more beneficial when provided following an external focus because by that point, it could be argued that participants were more accustomed to utilising the proprioceptive feedback of the task. There is a body of literature suggesting enhanced proprioceptive neural mechanisms over time through neuroplasticity as a function of practice / dependency (Schwenkreis, Pleger, Höffken, Malin & Tegenthoff. 2001; Goble, 2010; Xerri, 2012).

In sum, the endpoint results of Experiment 3 demonstrate that an external focus does not always facilitate 'best' performance. Instead the improved CE and (although non-significantly) improved AE, combined with decreases in VE at pkv, suggest that an internal focus overall facilitated superior outcome performance over an external focus when the task was reliant on proprioception and proprioceptive strength was high (i.e. within the weight group). The internal focus' performance superiority seemingly originated within offline movement planning based on decreased variability at key kinematic markers attributable to planning mechanisms (i.e., pkv) for those adopting an internal focus. Concurrently, an internal focus yielded less EMG compared to an external focus, suggesting that adopting an internal focus facilitates more efficient / appropriate planning of muscle activation when tasks are proprioception-based. Overall, Experiment 3 lends further credence to the notion that, contrary to the constrained action hypothesis of Wulf et al. (2001), an internal focus can be superior to an external focus: provided proprioceptive strength and pertinence is high.

Analyses were conducted to ensure the aforementioned performance differences were due to focus of attention instructions and not confounds. Focus of attention effects were investigated using a repeated measures design and data analysis considered whether focus of attention order (i.e., external focus 1st and internal focus 2nd, or vice versa) influenced findings. To ensure the external-to-internal and internal-to-external subsets of participants within each weight group were comparable, independent samples t-tests compared these subsets' endpoint MT, CE, AE, and VE at familiarisation (i.e., the beginning of testing where participants were not yet prescribed a focus of attention). This analysis revealed no significant differences.

5.4 General Discussion

The last decade has seen considerable advances in our understanding of the more pertinent characteristics in formulating effective instruction. Endorsement of externally focused and implicit information in promoting automaticity of movements seems well grounded in the literature, with mechanisms such as Prinz's (1997) 'action-effect principle' and Wulf et al.'s (2001) 'constrained action hypothesis' conveying similar messages. Nevertheless, this theoretical understanding has failed to align with mechanisms accounting for the benefits of process goals and external/kinaesthetic motor imagery, both of which encourage attentional shifts towards and not away from movements. The current investigation has attempted to begin to address this research lacuna, over three experiments designed to identify nuances where an internal focus may be useful. This is in line with a proposed facilitative 'somaesthetic awareness' (Shusterman, 2011; Toner & Moran, 2015) when making error corrections or re-learning movements.

In essence, it has not yet been specifically tested whether it is changes in offline planning, online movement adjustments, or both forms of motor control that facilitate improved outcome performance with an external focus of attention, nor whether an internal focus of attention also has the capability to enhance components of motor control / outcome performance when pertinent task information is of proprioceptive (i.e. internal) nature. A noteworthy effort to partially address the former research lacuna was by Lohse and colleagues (2010; 2012). Two studies respectively utilised time between trials and pre-movement time to infer offline movement planning efficiency. In line with the conjecturing of the constrained action hypothesis (Wulf et al., 2001), both studies demonstrated that an external focus of attention facilitated improved force-production accuracy, whilst concurrently reducing the time used for offline planning: indicating reduced conscious processing and increased automaticity compared to an internal focus of attention. However, two limitations of these studies are that, firstly, time used for offline planning was a measure of efficiency (i.e., how many cognitive resources were utilised) rather than efficacy (i.e., how good the movement plan was) and secondly, online motor control's role within performance was not explicitly measured. Therefore, offline planning and/or online motor control's precise contribution to the creation of outcome performance under different foci of attention is unknown. Our first experiment aimed to address this question via a fast target-directed visual aiming task, wherein the variability methodology of Khan et al. (2006) was used to simultaneously infer offline planning and online motor control's contribution to outcome performance.

The results of Experiment 1 revealed no differences between foci in the directional component of movement, but within the amplitude component, the internal group displayed reduced (i.e. superior) movement endpoint CE, AE, and VE compared to the external group. In sum, participants exhibited superior outcome performance when an internal focus was adopted. Variability findings confirmed that focus of attention-based differences manifest within offline movement planning. The internal group demonstrated overall reduced variability throughout movement compared to the external group, but the shape of these variability profiles did not differ. The underlying processes yielding Experiment 1's results are likely several fold. Firstly, the fine motor skill nature of our visual-aiming task likely raised the pertinence of proprioceptive information. The internal group may have been able to exploit the congruent (i.e., internal in nature) feedback of the task and achieve better performance than the external group via improved movement planning. Secondly, differences may have manifested within the amplitude component of movement because the impulse and resultant proprioceptive feedback generated to move the hand an amplitude of 20cm, to the target, should be exponentially greater than any impulse / feedback generated within the directional component.

Experiment 2 and 3 aimed to further Experiment 1 by increasing the congruence between pertinent task characteristics and participants' internal focus of attention. Experiment 2 removed vision during the aiming task to increase proprioceptive task demands (i.e., participants had to identify target locations through proprioception only). In line with our hypotheses, results revealed that an internal focus overall yielded superior outcome performance within the amplitude and direction components of movement. Analysis of variability throughout movement lent further credence to the notion that focus of attention effects originate within offline movement planning for non-continuous tasks. As in Experiment 1, movement variability was reduced with an internal compared to an external focus, but the shape of variability profiles did not differ. Finally, Experiment 3 aimed to build on Experiment 2 via the utilisation of a leg-extension task and the modulation of proprioceptive feedback strength: via a weight attached to a single group of participants' ankles. The provision of an ankle weight should increase proprioceptive feedback strength by increasing musculotendinous mechanoreceptor sensitivity (Bullock-Saxton, Wong, & Hogan, 2001; Suprak, Ostering, Donkelaar, & Karduna, 2007). Results within the no-weight group demonstrated significantly lower ($p = 0.05$) CE values when adopting an internal focus of attention second. Additionally, the weight group demonstrated less endpoint CE when adopting an internal compared to an external focus. Concurrently, across both weight-groups, an internal focus yielded more efficient muscle activation compared to an external focus, and the shape of internal and external variability profiles were again indicative of enhanced planning mechanisms under an internal focus.

In sum, our findings provide strong support to the notion that focus of attention-based performance differences originate within offline movement planning for non-continuous tasks.

Additionally, our results support the notion of facilitative somaesthetic awareness and that an internal focus congruent with task demands can benefit performance and efficiency. This finding makes logical sense when one considers an external focus also has to be congruent with the intended external movement outcome to facilitate optimal performance (e.g. focusing on the dart-board when the task requires the dart-board to be hit) (Land, Tenenbaum, Ward, & Marquardt, 2013; Russell, Porter, & Campbell, 2014). Similarly, Pelleck and Passmore (2017) show that when novice golfers adopted an internal focus more closely related to a putting task, where there was a clear external outcome demand and proprioceptive salience was arguably low, a number of performance variables suffered including accuracy, EMG and movement kinematics. It is possible that had the external focus direction within Experiment 1 and 2 been directed towards the target as opposed to the cursor itself, task demands may have been more congruent with an external focus and thus, it could be argued that we would have seen a benefit of an external focus in this instance. However, the authors wanted to maintain comparability between internal and external instructions to avoid a confound as per recommendations from Wulf (2013).

However, it should be noted that the current study is not the first to investigate focus of attention effects within tasks featuring high proprioceptive demands, but is the first with the explicit aim of investigating internal focus of attention and task congruence. Limitations of prior studies which prohibit the generalisation of their results to this research question include: task instructions muddling an internal and external focus (Lohse et al., 2011; Lohse, 2012); internal focus instructions that may not have been congruent with the external task demands / may only have directed attention to a small subset of task-relevant proprioception (Land et al., 2013; Makaruk, Porter, & Makaruk, 2013; Sherwood, Lohse, & Healy, 2014); and tasks which were primarily dependent on online motor corrections (Schlesinger, Porter, & Russell, 2013). It is important to highlight that despite proprioception’s arguably heightened pertinence in force production tasks, prior studies adopting this approach have shown some converse results to that of the current research in target-directed aiming tasks (e.g. Freedman, Caligiuri, Wulf, & Robin, 2007). We argue that the simplistic nature of these tasks is a likely contributor to this. In these instances, task simplicity would have meant reduced availability of proprioceptive information to enhance planning and thus, no benefits from an internal focus.

5.5 Conclusion

Theoretical implications derived from attentional focus literature advocate a perpetual external focus for optimal movement execution, but this is incompatible with promotion of widely used process goals and external/kinaesthetic imagery for practitioners. The current findings refute the rigidity of the constrained action hypothesis and provide evidence that an internal focus can facilitate superior performance and efficiency over an external focus when congruent with task demands. This has strong implications for sports or tasks where proprioceptive salience is high, such as diving, artistic gymnastics or weightlifting. Where traditional attentional focus literature would advocate external instructions and feedback within these tasks (see Wulf, 2013 for a review) e.g. a focus towards the surface of the water, support surface or bar respectively, the current findings would suggest a focus on the body movements themselves. In line with the principles underlying specificity theory (Proteau, 1992), sources of afferent information most useful to performance execution are typically prioritised during processing. Thus, adopting an internal focus within these sports should enhance congruence between the 'instructions and feedback provided' and the 'availability of pertinent afferent information for task execution', which is largely proprioceptive in nature within these sports (see Figure 6 for sporting examples with varying degrees of pertinence of proprioceptive and visual information for task execution). We suggest internal instructions and feedback for tasks high in pertinence of proprioceptive information but low in pertinence of visual information and external instructions and feedback for tasks low in pertinence of proprioceptive information but high in pertinence of visual information. With this in mind, it is therefore not a surprise that there seems more robust evidence for benefits of an external compared to internal focus when most sports / tasks rely heavily on visual information for task success (e.g. towards a ball or target). Clearly not all tasks can be classified as exclusively high or low in pertinence of proprioceptive and visual information for task execution. Thus, we would suggest that this works on a continuum basis with some sports likely benefitting from both forms of instructions and feedback in different situations. This is in line with aforementioned arguments made by Collins et al. (2015) and Lawrence et al. (2011) discussing nuances of attentional focus instructions dependent on instructional familiarisation, task relevance and salience of movement effects for task execution.

The present experiments also provide compelling evidence that attentional focus effects manifest within offline movement planning for non-continuous tasks. This may have practical implications for performance under pressure where athletes are more likely to adopt strategies (such as an internal focus in proprioceptive tasks) to improve movement planning as a reaction to pressure inhibiting the effectiveness of error corrections made during a movement (see Allsop, Lawrence, Gray & Khan, 2017). By focusing on the body, findings suggest a shift in importance to offline planning processes, which subsequently should also inhibit any decrements in response programming under pressure.

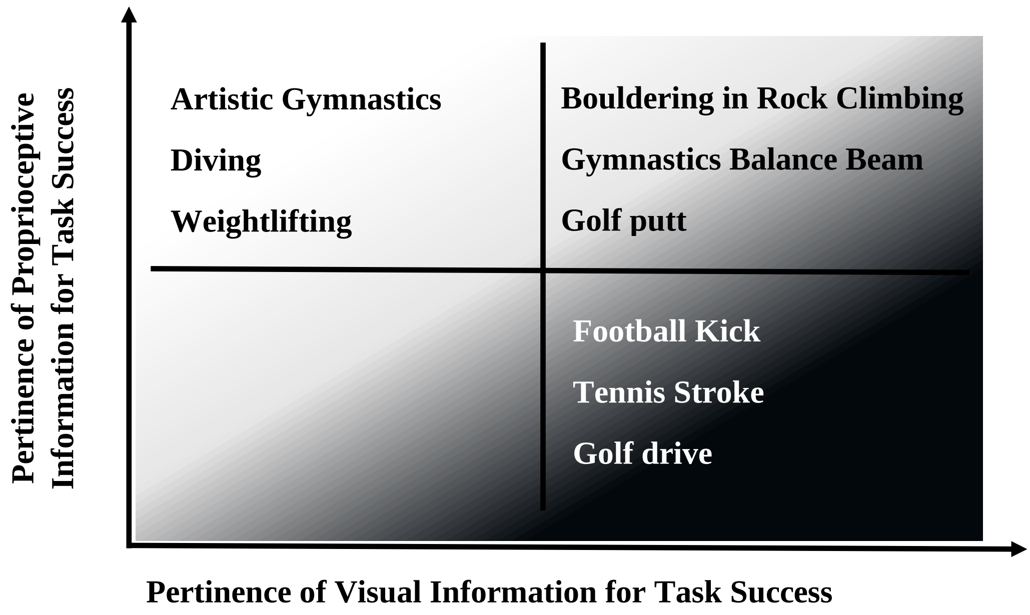


Figure 6. The above image categorises example sports based on the pertinence of proprioceptive and visual afferent information for successful task execution. Based on the findings, the authors would advocate internal instructions and feedback for tasks high in pertinence of proprioceptive information but low in pertinence of visual information (highlighted in lighter background). For tasks low in pertinence of proprioceptive information but high in pertinence of visual information (highlighted in darker background) we would advocate external instructions and feedback.

Chapter 6: General Discussion

Outcome performance (e.g., the number of goals / points scored) has traditionally been the dominant focus of sport psychology research questions (e.g., Beilock & Carr, 2001; Gucciardi & Dimmock, 2008; Hardy, Mullen, & Jones, 1996; Wulf, McNevin, & Shea, 2001; Wulf & Su, 2007). This has arguably been at the detriment of better understanding underlying motor control mechanisms. The present thesis attempts to explicate the roles of offline movement planning (i.e., the effortful planning of actions prior to movement initiation) (Glover & Dixon, 2002; Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979) and online movement correction (i.e., the automatic correction of actions during movement execution) (Veyrat-Masson, Brière, Proteau, 2011) in prominent research domains bereft of consideration for motor control processes. Specifically: Experimental Chapter 1 consisted of three separate experiments designed to investigate the effect of heightened state anxiety on offline planning and online correction while also considering personality and the availability of cognitive resources; Experimental Chapter 2 contained a single experiment with the purpose of investigating the effect of heightened anxiety on offline planning and online correction when proprioception was the sole relevant source of afferent feedback; and Experimental Chapter 3 consisted of three separate experiments that investigated the effect of external (i.e., environmental movement effects) and internal (i.e., body) foci of attention instructions on offline planning and online correction, while also considering instruction congruence with afferent task feedback.

6.1 Heightened anxiety's effect on offline planning and online correction

Cognitive explanations of the anxiety-performance relationship have settled on two dichotomous theories; the conscious processing-based reinvestment theory (Masters, 1992) and the distraction-based attentional control theory (Eysenck, Derakshan, Santos, & Calvo, 2007). Reinvestment theory suggests that anxiety makes individuals use declarative knowledge to consciously process their movements. Although this is a well-intentioned coping strategy

(Masters, Eves, & Maxwell, 2005), the net result is impaired outcome performance (Masters & Maxwell, 2008). Attentional control theory suggests that anxiety distracts individuals, impairs central executive functioning, and consequently reduces processing efficiency (Eysenck et al., 2007). Individuals can mobilise compensatory effort to maintain or even improve task processing, but only up to a point. If anxiety and task demands are great enough, outcome performance is impaired.

Although a wealth of empirical evidence exists for both distraction and conscious processing-based accounts of the anxiety-performance relationship (Beilock & Carr, 2001; Gucciardi & Dimmock, 2008; Hardy et al., 1996; Murray & Janelle, 2003; Nieuwenhuys et al., 2008; Wilson, Wood, & Vine, 2009), two notable ambiguities remain. Firstly, it is not clear how heightened state anxiety and associated distraction / conscious processing mechanisms affect offline planning and online correction processes. Secondly, it is unclear whether conscious processing and distraction processes are mutually exclusive, as implied by the literature, or more closely linked. Lawrence, Khan, and Hardy (2013) were the first to attempt to clarify these ambiguities. Results from both amplitude and direction-based upper limb target-directed aiming tasks suggested that distraction-compensatory effort improved offline movement planning and that automaticity-diminishing mechanisms of conscious processing impaired automatic online movement correction. Since then, a select number of studies have replicated this general pattern of results with measures of offline planning improved or unchanged, and measures of online correction impaired by heightened anxiety (Allsop, Lawrence, Gray, & Khan, 2016; Cassell, Beattie, & Lawrence, 2018; Roberts, Wilson, Skultety, & Lyons, 2018).

6.1.1 Offline planning with vision.

Surprisingly, research is yet to observe impaired offline planning efficacy under heightened anxiety conditions when vision is available. Studies have either observed improved or unchanged offline planning efficacy under heightened anxiety (Allsop et al., 2016; Lawrence et al., 2013; Roberts et al., 2018). We surmise that this may be because the aiming tasks employed by previous studies are insufficiently taxing on attentional capacity. If offline planning is indeed effortful and attention demanding as suggested by the literature (Glover & Dixon, 2001; 2002; Glover, Rosenbaum, Graham, & Dixon, 2004; Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979), it should be impaired under conditions of excessive attentional demands. Evidence to support this conjecture stems from Coombes et al. (2009) who noted that offline planning *efficiency* (measured via reaction time) was only impaired in the most difficult condition of a force reproduction task. Therefore, in line with attentional control theory (Eysenck, 2007), a combination of sufficiently high task demands and anxiety should impair offline planning *efficiency* to a point where no more additional compensatory effort can be mobilised to maintain offline planning efficacy.

Experiment 3 of Experimental Chapter 1 attempted to increase task demands whilst performing a target-directed aiming task under heightened anxiety conditions by directly manipulating participants' availability of self-control resources. Although the notion of self-control as a limited resource has received widespread debate (Carter & McCullough, 2014; Etherton et al., 2018; Vadillo, Gold, & Osman, 2016; Wolff, Baumann & Englert, 2018), relatively recent studies which combined self-control depletion with heightened anxiety have shown consistent effects (Englert & Bertrams, 2012; Englert & Bertrams, 2015b; Englert & Bertrams, 2016; Englert, Zwemmer, Bertrams, & Oudejans, 2015c). The mobilisation of cognitive resources to compensate for the deleterious effects of heightened state anxiety is proposed to be a depletable self-control act (Englert & Bertrams, 2015a); if self-control resources are depleted prior to anxious conditions, performance may be impaired because compensatory cognitive resources cannot be mobilised. Therefore, working memory engaged in effortful offline movement planning should be more likely to overload via anxiety-induced distraction in participants depleted of their self-control. In our experiment, participants performed a target-directed aiming task with vision, but had their self-control resources either experimentally depleted via an inhibition-transcription task (in the self-control depleted group) or unchanged via a control-transcription task (in a self-control full group), prior to being transferred to a heightened state anxiety trial block. Results revealed no significant differences in offline planning between self-control depleted and full conditions under heightened anxiety.

The findings of Experiment 3 of Experimental Chapter 1 may not have observed changes in offline planning because the planning-focused strategy adopted by participants mobilised sufficient cognitive resources to maintain planning efficacy, despite depleted self-control. Future studies may wish to utilise distractors in addition to self-control depletion to overload attentional capacity. In a study by Englert Bertrams, Furley, and Oudejans (2014), participants completed either a control transcription task or a self-control depleting transcription task (similar to our study). Subsequently, participants performed a basketball free-throw task under heightened anxiety conditions while distracting worrisome thoughts were played through a speaker. Results revealed that participants depleted of their self-control reported allocating more attention to the distractors and performed worse on the task than the group with self-control resources intact. Therefore, a combination of heightened anxiety, increased task complexity, distractors, and self-control depletion may be needed to overload attentional capacity and yield impaired offline planning efficacy under heightened anxiety for the first time. Distractors could be auditory (e.g., Englert et al., 2014) or visual (e.g., Welsh & Elliott, 2004) and a sufficiently complex task may be a three-dimensional aiming task (e.g., Carrozzo, McIntyre, Zago, & Lacquaniti, 1999) with offline planning and online correction inferred via ellipsoids (Hansen, Elliott, & Khan, 2008).

6.1.2 Online correction with vision.

Experimental Chapter 1 identified that a potential limitation of prior literature was that the effect of anxiety on online correction efficacy used paradigms that only afforded the inference of online control via the use of variability profiles. Specifically, it was not known if online correction was reduced through impairment (i.e., conscious processing) or lower necessity (i.e., improved planning under heightened anxiety lessening the need for online correction) because experimental paradigms did not 'force' the need for online corrections. To address this, Experimental Chapter 1 directly tested online correction efficacy via cursor jumps, which occurred shortly after movement initiation and necessitated the initiation of a correction to hit the target and maintain outcome performance. We hypothesised that our findings would replicate the consistent pattern of prior studies (Allsop et al., 2016; Cassell et al., 2018; Lawrence et al., 2013; Roberts et al., 2018) and observe improved or unchanged offline planning in normal trials and impaired online correction in both normal and jump trials under anxiety. However, the results of Experiment 1 revealed that although offline planning was unchanged and online correction was reduced in normal trials, online correction in jump trials was actually improved. This finding was replicated in Experiment 2 (with a larger sample-size and stronger study design), with the additions that reduced normal trial corrections correlated with high trait conscious processing propensity and that jump trial corrections were greater because of improved acuity, not improved latency. Lastly, Experiment 3 revealed that participants experimentally depleted of their self-control resources exhibited reduced correction in normal and jump trials compared to participants with intact self-control presumably because they were less able to mobilise anxiety-compensatory resources.

The findings of Experimental Chapter 1 have implications on long-held assumptions concerning online correction's automaticity. A wealth of past literature has demonstrated that online correction to reafferent visual feedback initiate without the knowledge of participants

(Proteau, Roujoula, & Messier, 2009), are effective from the first trial (Brière & Proteau, 2011; Proteau et al., 2009), are independent of cued attention (Reichenbach, Franklin, Zatka-Haas, & Diedrichsen 2014), and cannot be inhibited (Franklin & Wolpert, 2008). However, contrary to these findings, the results of Experimental Chapter 1 suggest that such online corrections can also be affected by anxiety (i.e., increased when the need for correction is great or decreased when the need for correction is low), personality (i.e., decreased when an individual has greater trait conscious processing propensity), and cognitive resources (i.e., reduced when self-control is depleted under anxiety). These results provide strong evidence against the labelling of online correction as wholly ‘automatic’.

On one hand, participants may be planning their movements with the intention of making no corrections (particularly if high in reinvestment propensity) and consequently exhibit less corrections in normal trials. A similar phenomenon can be observed in Khan, Elliott, Coull, Chua, and Lyons (2002) when participants were uncertain if they were going to get visual feedback in trials. However, when the need for correction is great enough (e.g., because of cursor jumps), online corrections may be initiated automatically and exhibit improved spatial acuity through endogenously (i.e., within-participant) allocated anxiety-compensatory attention. Previous studies (e.g., Reichenbach et al., 2014) may not have observed similar findings because large endogenous increases in attention (similarly to those elicited by distraction-compensatory mechanisms) specifically aimed at improving the spatial characteristics of performance are necessary alter the efficacy of online corrections based on reafferent limb information. On the other hand, anxiety-induced distraction and / or reinvestment may interfere with the creation and /or utilisation of feedforward efference copies (Miall & Wolpert, 1996; Wolpert & Kawato, 1998). In normal trials this may result in the underestimation of error and reduced online correction, but in jump trials the cursor perturbations may pass an error threshold subsequent to which more ‘murky’ planning-based efference copies allow corrections to be organised more freely and appropriately based on afferent online visual information. It is important to note however that both explanations for our results are speculative at present.

Another area which Experimental Chapter 1 began to explicate is the effect of anxious distraction and conscious processing on the offline planning and online correction of movement. Lawrence et al. (2013) hypothesised that distraction should only impair effortful offline planning and conscious processing should only impair online correction. Reductions in offline planning efficacy were hypothesised to support distraction mechanisms and reductions in online correction were hypothesised to support conscious processing mechanisms. However, if online correction is indeed not wholly 'automatic', and even benefits from endogenously allocated attention as suggested by Experimental Chapter 1, distraction mechanisms may also impair online correction. Additionally, since the mechanisms of an internal focus of attention share similarities with conscious processing, Experimental Chapter 3's findings that focus of attention differences originated within offline planning suggest that anxious conscious processing could also impair offline planning.

To tease apart anxious distraction and conscious processing mechanisms, Experiment 2 of Experimental Chapter 1 utilised the movement specific reinvestment scale (Masters, et al., 2005). Measures of offline planning and online correction efficacy were separately correlated with the movement specific reinvestment scale. Results revealed that reductions in the online correction of normal trials were predicted by trait conscious processing propensity but improved offline planning was not. Therefore, the grouping of participants to create means may have resulted in misleading results in previous studies (e.g., Lawrence et al., 2013; Allsop et al., 2016). It is possible that offline planning was improved in most participants via distraction-compensatory mechanisms, but online correction was only impaired in participants high in conscious processing propensity. The grouping of data may have made results overlap and appear as if improved planning compensated for impaired correction.

In line with the findings of Experimental Chapter 1, Payne, Wilson, and Vine (2019) reasoned that research's present focus on the comparison of grouped data across a relatively narrow set of variables may obfuscate the true mechanisms behind results. Under heightened anxiety conditions, participants may experience a complex interaction between: beneficial or detrimental attentional capacity changes (Eysenck et al., 2007); detrimental conscious processing (Masters, 1992); beneficial or detrimental psychophysiological changes (Blascovich, Seery, Mugridge, Norris, & Weisbuch 2004); detrimental disengagement-induced performance catastrophes (Hardy, 1999); reduced self-control from repeated bouts (Englert & Bertrams 2015a); and personality (e.g., Wallace, & Baumeister, 2002; Bell, Hardy, & Beattie, 2013). A more holistic approach combined with innovative analysis techniques is needed to accurately explicate the anxiety-performance relationship.

A possible future direction of travel to achieve a holistic approach could constitute: firstly, the experimental manipulation of distraction and conscious processing; secondly, the splitting of analysis based on challenge / threat appraisal and self-reported disengagement; and lastly, the use of regression analysis to investigate the influence of personality factors. Concerning the first point, one group of participants could comprise participants with high conscious processing propensity (Masters et al., 2005) who have acquired the task with explicit task instructions (Lam, Maxwell, & Masters, 2009). This group should be most likely to engage in conscious processing and have a bank of declarative task knowledge with which to interrupt automatic performance. Another group could be made up of participants with low conscious processing propensity (Masters et al., 2005) who have acquired the task via analogy learning (Lam et al., 2009). This group should be least likely to engage in conscious processing and lack declarative task knowledge with which to do so. Distraction could be manipulated in a small number of trials through visual (Welsh & Elliott, 2004) and / or auditory distractors (Englert et al., 2014). In these trials, distraction effects should be exacerbated. Concerning the second point, self-reported and / or psychophysiological measures of task engagement (Fairclough, Moores, Ewing, & Roberts, 2009; Fuller et al., 2018) and challenge / threat appraisals (Blascovich, et al., 2004; Tomaka, Blascovich, Kelsey, & Leitten, 1993) could be collected, based on which analysis could be split (i.e., median splits or entirely separate analyses). Distraction and conscious processing mechanisms may manifest differently if a participant is challenged, threatened, or disengaged from the task. Concerning the final point, correlation analysis could be utilised in a similar way to Experiment 1 in Experimental Chapter 1 to ascertain the moderating effects of narcissism (Wallace, & Baumeister, 2002), punishment sensitivity (Gray & McNaughton, 2000), and mental toughness (Gucciardi, Hanton, & Mallett, 2012). The utilisation of a holistic approach which adopts many or even all of the aforementioned methods would allow for novel insights into the mechanisms of the anxiety-performance relationship.

6.1.3 Offline planning and online correction with proprioception.

In Experimental Chapter 2 we aimed to extend on previous anxiety and motor control research by investigating heightened anxiety's effect on the planning and correction of movement when proprioception was the sole source of relevant afferent feedback. Participants performed a computerised upper-limb target-directed aiming task, with vision of the cursor representing the limb removed at movement initiation. Offline planning and online correction efficacy were inferred from variability profiles. Results revealed no significant difference in offline planning nor online correction efficacy (inferred via early and late movement trajectory variability, respectively). Similarly, results revealed no significant difference in offline planning and online correction distribution (inferred via time to peak velocity and time after peak velocity, respectively). These findings resembled those of Coombes, Higgins, Gamble, Cauraugh, & Janelle (2009). In their study, participants performed a force reproduction task at different difficulties under heightened anxiety. Results revealed that although offline planning efficiency (inferred from greater reaction time) was reduced in the most difficult task condition under heightened anxiety, offline planning efficacy was not impaired in any condition. We concluded that distraction and conscious processing mechanisms associated with heightened anxiety may not impair the planning and correction of movements when they are based primarily on proprioceptive afferent information. The lower attentional demands placed on individuals when processing proprioceptive information compared to vision (Sarlegna & Sainburg, 2009) may make attentional capacity less likely to be overloaded when anxious distraction takes place. This may help participants maintain offline planning and online correction efficacy, based on the conclusions of Experimental Chapter 1 that both offline and online correction processes may require attentional resources. Meanwhile, the inherently rapid, crude, and implicit nature of proprioception (Cluff, Crevecoeur, & Scott, 2015; Scott, 2016) may make it less likely for participants to accumulate explicit verbal declarative knowledge with which to engage in conscious processing. Based on Experimental Chapter 1, this may protect online correction efficacy when the need for correction is low and individuals are high in conscious processing propensity.

Future research may wish to test our proposals concerning anxiety’s effect on proprioceptive motor control by utilising similar methods to those described in our discussion of anxiety’s effect on vision-based motor control processes. To investigate the role of attentional capacity in anxiety’s effect on proprioceptive motor control, participants could be depleted of their self-control resources prior to performing the task, under conditions of heightened state anxiety with distracting worrisome thoughts being played through speakers (Englert et al., 2014). To test the effect of conscious processing on proprioceptive motor control, some participants could acquire the proprioceptive task with explicit instructions provided by the researcher, and another group could acquire the task with either analogy instructions (Lam et al., 2009) or a secondary articulatory suppression task (Hardy, Mullen, & Jones, 1996). If offline planning and online correction efficacy remain unchanged under heightened anxiety in the distraction and conscious processing-inducing conditions, this would provide strong evidence to suggest that motor control based on proprioceptive information is indeed unaffected by anxiety mechanisms.

6.2 Focus of attention's effect on offline planning and online correction

Focus of attention research has repeatedly demonstrated that an external focus (i.e., on an environmental movement effect) facilitates outcome performance while an internal focus (i.e., on the body) hinders it (Bell & Hardy, 2009; Pelleck & Passmore, 2017; Russell, Porter, & Campbell, 2014; Wulf & Su, 2007; Zachry, Wulf, Mercer, & Bezodis, 2005). Initially this finding was accounted for through common coding (Prinz, 1997). An external focus was suggested to yield superior outcome performance by increasing the congruence between the processing of afferent sensory visual information and external task demands. Since then, common coding has been superseded by the constrained action hypothesis (Wulf, McNevin, & Shea, 2001) as the leading explanation for focus of attention effects (Wulf, 2013). An external focus is suggested to benefit outcome performance by facilitating automatic movement execution. This allows more attention to be dedicated to other aspects of the task and prevents conscious constraining of the motor system. Research supporting the constrained action hypothesis and an external focus of attention's facilitative effect on outcome performance is plentiful (Wulf, 2013).

Studies investigating focus of attention have featured tasks reliant on either offline planning (Lohse at al., 2010; 2011; 2012; 2014) or online correction (Wulf et al., 2001; McNevin, Shea, Wulf, 2003). In both instances, an external focus of attention was found to yield superior results. However, prior to Experimental Chapter 3, no study had specifically investigated focus of attention's *concurrent* effect on offline planning and online correction. This is a noteworthy omission given the complex trade-offs that can occur between offline planning and online correction (Khan et al., 2006). In Experiment 1 of Experimental Chapter 3, participants performed an upper limb target-directed aiming task with vision while adopting either an internal or external focus of attention. Offline planning and online correction efficacy were inferred from trajectories' variability profiles (Khan et al., 2006). Results revealed that an internal focus of attention exhibited overall superior outcome performance which originated from improved offline planning. Experiment 2 (in the same task but without the availability of vision) and Experiment 3 (in a highly proprioceptive leg extension task) replicated this pattern of results. We conclude that these results provide evidence for Wulf's (2015) conjecturing that focus of attention effects are primarily related to the planning of movement.

On the face of it, this conclusion appears incompatible with studies that have found focus of attention differences in continuous balancing tasks reliant on online correction (Wulf et al., 2001; McNevin, Shea, Wulf, 2003); if focus of attention effects only manifest in offline planning, no differences between external and internal foci of attention should have been found in these studies. However, while balancing on the board, participants likely plan balancing patterns during movement execution, instead of purely and continuously correcting online to maintain balance (i.e., on the fly). These instances of planning, which could technically be defined as either offline or online, may be the mediator of focus of attention differences in continuous balancing tasks. Future research may wish to investigate whether focus of attention differences in continuous balancing tasks are contingent on the integration of elementary balancing components into single memory units (i.e., chunking) (Willingham, 1998). The availability of chunked balancing patterns may be necessary for effective planning to take place and focus of attention differences to appear.

To further test whether focus of attention differences originate within offline planning, the contributions of offline planning and online correction should be investigated when an external focus of attention yields optimal outcome performance. All three experiments in Experimental Chapter 3 observed offline planning differences when an internal focus of attention facilitated superior outcome performance. When an external focus of attention facilitates optimal outcome performance, differences in online correction may be observed. The automaticity-enhancing mechanisms of an external focus of attention (Wulf et al., 2001) may benefit the automatic elements of online correction. Therefore, additional research is necessary to firmly conclude that focus of attention differences exclusively originate within offline planning.

6.3 Focus of attention and task congruence

Paradoxically, the literature contradicts itself concerning the potential benefits / detriments of internal-like foci of attention and their associated mechanisms. On the one hand, kinaesthetic imagery (Hardy & Callow, 1999), process goals (Zimmerman & Kitsantas, 1997), and movement refinement research (Shusterman, 2008; Toner & Moran, 2015) advocate an internal-like focus of attention for superior outcome performance, but anxious-performance (Beilock & Carr, 2001; Masters & Maxwell, 2008), focus of attention (Beilock, Carr, MacMahon, & Starkes, 2002; Wulf, Höß, & Prinz, 1998; Wulf et al., 2001), and skill learning research (Anderson, 1982; Fitts & Posner, 1967; Salmoni, 1989) advocate against. We reasoned that the effectiveness of an internal versus external focus of attention is contingent on internal (i.e., body) and external (i.e., environmental) task demands. The aim of Experimental Chapter 3 was to investigate whether tasks primarily proprioceptive and body-focused in nature, could harbour conditions where an internal focus facilitates superior outcome performance over an external focus of attention.

Experiment 1 of Experimental Chapter 3 comprised a computer-based upper limb target-directed aiming task with vision of the cursor available. Based on this task's fine motor requirements, we hypothesised that the processing of relevant proprioceptive information would benefit from a congruent internal focus of attention. Accordingly, results revealed superior outcome performance with a congruent internal focus of attention ("focus on the fluid motion of your hand") compared to an incongruent external focus of attention ("focus on the fluid motion of the pen"). Experiment 2 replicated Experiment 1 when removing vision of the cursor to increase proprioceptive demands further; again, results revealed superior outcome performance with an internal focus of attention. Lastly, Experiment 3 comprised a leg extension task where participants had to encode and recall leg positions with or without a 0.5kg ankle weight attached. Performance, movement kinematics, and muscle efficiency were assessed using 3D motion capture and electromyography. We reasoned that the ankle weights manipulated the congruence between the internal focus of attention and the afferent information available by either increasing or decreasing proprioceptive salience. Results revealed that an internal focus of attention facilitated superior outcome performance only under conditions of high proprioceptive salience (i.e., with an ankle weight). Measures of electromyography also suggested that an internal focus of attention yielded overall superior muscle / movement efficiency.

Overall, our results suggested that somaesthetic awareness (Toner & Moran, 2015), namely awareness of the body induced by an internal focus of attention, can facilitate optimal outcome performance and efficiency when congruent with task demands. Prior studies may not have observed the same result despite featuring proprioceptive tasks because they featured: task instructions that muddled internal and external foci (Lohse et al., 2011; Lohse, 2012); internal focus instructions that may not have been congruent with the external task demands / may only have directed attention to a subset of task-relevant proprioception (Land et al., 2013;

Makaruk, Porter, & Makaruk, 2013; Sherwood, Lohse, & Healy, 2014); high task simplicity reducing availability of useful proprioceptive information (Freedman, Caligiuri, Wulf, & Robin, 2007); and tasks which were primarily dependent on online motor corrections (Schlesinger, Porter, & Russell, 2013).

To ascertain the validity of our suggestions, we encourage future studies to make the investigation of focus of attention instructions and their congruence with task demands an explicit aim. Our findings suggest that the rigid championing of an external focus of attention by the constrained action hypothesis (Wulf et al., 2001) may require revision. If both an internal and external focus of attention can aid performance, provided they are congruent with task demands, a 'holistic' focus of attention that simultaneously directs attention to relevant external and internal aspects of a task, may facilitate optimal performance (e.g., "Focus on feeling the swing of the club"). Similarly, researchers may wish to combine internal foci of attention with 'analogy learning' instructions (e.g., Lam et al., 2009) to create similarly 'holistic' instructions (e.g., "Imagine creating the swing of a grandfather clock pendulum, visualise and feel the pendulum hitting the ball towards the target"). Such a focus may direct participants' attention to relevant visual and proprioceptive afferent information while the analogy component prevents them from using this information to consciously interfere / process / constrain actions.

6.4 General conclusions

Across seven research studies totalling 276 participants, this thesis investigated the separate effects of heightened anxiety and focus of attention on the offline planning and online correction of movement. Firstly, Experimental Chapter 1 shows that heightened state anxiety can help or hinder online correction efficacy depending on: the availability of cognitive resources; conscious processing propensity; and how great the need for correction is. This finding disputes the long-held belief that online movement correction based on reafferent limb information is automatic. Secondly, Experimental Chapter 2 features findings that suggest heightened state anxiety does not affect the offline planning and online correction of movements when proprioception is the sole source of relevant afferent information. This highlights that future anxiety-performance research may need to consider what type of afferent feedback is dominant in tasks when investigating the anxiety-performance relationship. Lastly, Experimental Chapter 3 provides evidence to suggest that foci of attention effects originate within offline planning and that an internal focus of attention can facilitate superior performance over an external focus of attention, provided it is congruent with task demands. This finding demonstrates that present literature's rigid advocation in favour of an external focus of attention should be revised. Overall, the experimental chapters of this thesis provide tangible advances in our understanding of the planning and correction mechanisms that underlie prominent behavioural research domains.

6.5 Applied implications

The conclusions of this thesis provide valuable avenues for implementation research and future applied practice. For example, coaches, teachers, and athletes may wish to consider which focus of attention (i.e., internal or external) yields optimal performance based on task demands (e.g., planning, adjustment, proprioceptive, visual, or otherwise). For example, for a task such as Olympic Weightlifting, previous studies would have recommended an external focus of attention. However, based on our findings and the proprioceptive demands of this sport, an internal focus of attention may facilitate optimal efficiency and performance. Similarly, the advances in understanding of our work in regards to the anxiety-performance relationship would suggest that fine motor skill sports (such as darts) may be impacted more negatively by heightened state anxiety than gross-motor sports (such as football). Specifically, the fine corrections necessary for skilful shots may suffer more from heightened anxiety than the larger and more apparent errors present in football, especially if an athlete is high in conscious processing propensity. Similarly, this thesis highlights the need for athletes to have sufficient availability of cognitive resources, especially when performance of a task under heightened anxiety depends on effective online correction (e.g. white-water kayaking). Implementation research will play an important role in verifying our aforementioned conjectures.

References

Abdollahipour, R., Wulf, G., Psotta, R., & Palomo Nieto, M. (2015). Performance of gymnastics skill benefits from an external focus of attention. *Journal of Sports Sciences*, *33*, 1807-1813.

Alkner, B. A., Tesch, P. A., & Berg, H. E. (2000). Quadriceps EMG/force relationship in knee extension and leg press. *Medicine and Science in Sports and Exercise*, *32*, 459-463.

Allsop, J. E., Lawrence, G. P., Gray, R., & Khan, M. A. (2017). The interaction between practice and performance pressure on the planning and control of fast target directed movement. *Psychological Research*, *81*, 1004-1019.

American Psychological Association. (2010). *Publication manual of the American psychological association (6th ed.)*. Washington: American Psychological Association.

Ames, D. R., Rose, P., & Anderson, C. P. (2006). The NPI-16 as a short measure of narcissism. *Journal of Research in Personality*, *40*, 440-450.

Anderson, J. R. (1982). Acquisition of cognitive skill. *Psychological review*, *89*, 369-390.

Anderson, J. R. (1983). *Cognitive science series. The architecture of cognition.* Hillsdale, NJ: Harvard University Press.

Anderson, K. J. (1990). Arousal and the inverted-U hypothesis: A critique of Neiss's "Reconceptualizing arousal." *Psychological Bulletin*, *107*, 96-100.

Baddeley, A. D. (2001). Is working memory still working?. *American Psychologist*, 56, 851–864.

Baddeley, A.D. (1986). *Working memory*. Oxford: Clarendon Press.

Baumeister, R. F., Bratslavsky, E., Muraven, M., & Tice, D. M. (1998). Ego depletion: Is the active self a limited resource?. *Journal of Personality and Social Psychology*, *74*, 1252.

Baumeister, R. F., Vohs, K. D., & Tice, D. M. (2007). The strength model of self-control. *Current Directions in Psychological Science*, 16, 351-355.

Beattie, S., & Davies, M. (2010). A test of engagement versus disengagement in catastrophe models. *British Journal of Psychology*, *101*, 361-371.

Beattie, S., Alqallaf, A., Hardy, L., & Ntoumanis, N. (2019). The mediating role of training behaviors on self-reported mental toughness and mentally tough behavior in swimming. *Sport, Exercise, and Performance Psychology*, *8*, 179.

Beilock, S. L., & Carr, T. H. (2001). On the fragility of skilled performance: What governs choking under pressure?. *Journal of Experimental Psychology: General*, *130*, 701.

Beilock, S. L., Bertenthal, B. I., McCoy, A. M., & Carr, T. H. (2004). Haste does not always make waste: Expertise, direction of attention, and speed versus accuracy in performing sensorimotor skills. *Psychonomic Bulletin & Review*, *11*, 373-379.

Beilock, S. L., Carr, T. H., MacMahon, C., & Starkes, J. L. (2002). When paying attention becomes counterproductive: impact of divided versus skill-focused attention on novice and experienced performance of sensorimotor skills. *Journal of Experimental Psychology: Applied*, *8*, 6.

Bell, J. J., & Hardy, J. (2009). Effects of attentional focus on skilled performance in golf. *Journal of Applied Sport Psychology*, *21*, 163-177.

Bell, J. J., Hardy, L., & Beattie, S. (2013). Enhancing mental toughness and performance under pressure in elite young cricketers: A 2-year longitudinal intervention. *Sport, Exercise, and Performance Psychology*, *2*, 281–297.

Bellomo, E., Cooke, A., & Hardy, J. (2018). Chunking, conscious processing, and EEG during sequence acquisition and performance pressure: A comprehensive test of reinvestment theory. *Journal of Sport and Exercise Psychology*, 40, 135-145.

Berggren, N., Richards, A., Taylor, J., & Derakshan, N. (2013). Affective attention under cognitive load: reduced emotional biases but emergent anxiety-related costs to inhibitory control. *Frontiers in Human Neuroscience*, *7*, 188.

Bernstein, N. (1967). *The co-ordination and regulation of movement.* London: Pergamon Press.

Bertrams, A., Englert, C., & Dickhäuser, O. (2010). Self-control strength in the relation between trait test anxiety and state anxiety. *Journal of Research in Personality*, *44,* 738-741.

Blascovich, J., & Tomaka, J. (1996). The biopsychosocial model of arousal regulation. *Advances in Experimental Social Psychology,* 28, 1–51.

Blascovich, J., Seery, M. D., Mugridge, C. A., Norris, R. K., & Weisbuch, M. (2004). Predicting athletic performance from cardiovascular indexes of challenge and threat. *Journal of Experimental Social Psychology*, *40*, 683-688.

Borkovec, T. D. (1978). Physiological and cognitive processes in the regulation of anxiety. In G. E. Schwartz, & D. Shapiro (Eds.), *Consciousness and Self-regulation: Advances in Research* (pp. 261–312). New York: Plenum Press.

Brière, J., & Proteau, L. (2011). Automatic movement error detection and correction processes in reaching movements. *Experimental Brain Research*, *208,* 39-50.

Bullock-Saxton, J. E., Wong, W. J., & Hogan, N. (2001). The influence of age on weight-bearing joint reposition sense of the knee. *Experimental Brain Research*, *136*, 400-406.

Button, K. S., Ioannidis, J. P., Mokrysz, C., Nosek, B. A., Flint, J., Robinson, E. S., & Munafò, M. R. (2013). Power failure: why small sample size undermines the reliability of neuroscience. *Nature Reviews Neuroscience, 14,* 365.

Carlton, L. G. (1992). Visual processing time and the control of movement. In L. Proteau & D. Elliott (Eds.), V*ision and Motor Control* (pp. 3-31). North-Holland: Amsterdam.

Carrasco, M. (2011). Visual attention: the past 25 years. *Vision research*, *51*, 1484-1525.

Carrozzo, M., McIntyre, J., Zago, M., & Lacquaniti, F. (1999). Viewer-centered and body-centered frames of reference in direct visuomotor transformations. *Experimental Brain Research*, *129,* 201-210.

Carter, E. C., & McCullough, M. E. (2014). Publication bias and the limited strength model of self-control: has the evidence for ego depletion been overestimated?. *Frontiers in Psychology*, *5,* 823.

Cassell, V. E., Beattie, S. J., & Lawrence, G. P. (2018). Changing performance pressure between training and competition influences action planning because of a reduction in the efficiency of action execution. *Anxiety, Stress, & Coping*, *31*, 107-120.

Castaneda, B., & Gray, R. (2007). Effects of focus of attention on baseball batting performance in players of differing skill levels. *Journal of Sport and Exercise Psychology*, *29*, 60-77.

Chen, Z., & Saunders, J. A. (2018). Volitional and automatic control of the hand when reaching to grasp objects. *Journal of Experimental Psychology: Human Perception and Performance, 44*, 953–972.

Cheng, D. T., Luis, M., & Tremblay, L. (2008). Randomizing visual feedback in manual aiming: reminiscence of the previous trial condition and prior knowledge of feedback availability. *Experimental Brain Research*, *189*, 403-410.

Chiviacowsky, S., Wulf, G., & Ávila, L. T. G. (2013). An external focus of attention enhances motor learning in children with intellectual disabilities. *Journal of Intellectual Disability Research*, *57*, 627-634.

Chua, R., & Elliott, D. (1993). Visual regulation of manual aiming. *Human Movement Science, 12,* 365-401.

Cluff, T., Crevecoeur, F., & Scott, S. H. (2015). A perspective on multisensory integration and rapid perturbation responses. *Vision Research*, *110*, 215-222.

Collins, D., Carson, H. J., & Toner, J. (2016). Letter to the editor concerning the article "Performance of gymnastics skill benefits from an external focus of attention" by Abdollahipour, Wulf, Psotta, & Nieto (2015). *Journal of Sports Sciences*, *34*, 1288-1292.

Coull, J., Tremblay, L., & Elliott, D. (2001). Examining the specificity of practice hypothesis: is learning modality specific?. *Research Quarterly for Exercise and Sport, 72,* 345-54.

Cooke, A., Gallicchio, G., Kavussanu, M., Willoughby, A., McIntyre, D., & Ring, C. (2015). Premovement high-alpha power is modulated by previous movement errors: Indirect evidence to endorse high-alpha power as a marker of resource allocation during motor programming. *Psychophysiology*, *52*, 977-981.7

Cooke, A., Kavussanu, M., Gallicchio, G., Willoughby, A., McIntyre, D., & Ring, C. (2014). Preparation for action: Psychophysiological activity preceding a motor skill as a function of expertise, performance outcome, and psychological pressure. *Psychophysiology*, *51*, 374-384.

Coombes, S. A., Higgins, T., Gamble, K. M., Cauraugh, J. H., & Janelle, C. M. (2009). Attentional control theory: Anxiety, emotion, and motor planning. *Journal of Anxiety Disorders*, *23*, 1072-1079.

Coull, J., Tremblay, L., & Elliott, D. (2001). Examining the specificity of practice hypothesis: Is learning modality specific?. *Research Quarterly for Exercise and Sport*, *72,* 345-354.

Crossman, E. R., & Goodeve, P. J. (1983). Feedback control of hand-movement and Fitts' Law. *Quarterly Journal of Experimental Psychology*, *35*, 251-78.

DeCaro, M. S., Thomas, R. D., Albert, N. B., & Beilock, S. L. (2011). Choking under pressure: Multiple routes to skill failure. *Journal of Experimental Psychology: General*, *140*, 390.

Derakshan, N., & Eysenck, M. W. (2009). Anxiety, processing efficiency, and cognitive performance: New developments from attentional control theory. *European Psychologist*, *14,* 168-176.

Derakshan, N., Smyth, S., & Eysenck, M. W. (2009). Effects of state anxiety on performance using a task-switching paradigm: An investigation of attentional control theory. *Psychonomic Bulletin & Review*, *16*, 1112-1117.

Durham, K. F., Sackley, C. M., Wright, C. C., Wing, A. M., Edwards, M. G., & Van Vliet, P. (2014). Attentional focus of feedback for improving performance of reach-to-grasp after stroke: a randomised crossover study. *Physiotherapy*, *100*, 108-115.

Elliott, D., Chua, R., Pollock, B.J., & Lyons, J. (1995). Optimizing the use of vision in manual aiming: the role of practice. *The Quarterly Journal of Experimental Psychology Section A*, *48*, 72-83.

Elliott, D., Dutoy, C., Andrew, M., Burkitt, J. J., Grierson, L. E., Lyons, J. L., ... & Bennett, S. J. (2014). The influence of visual feedback and prior knowledge about feedback on vertical aiming strategies. *Journal of Motor Behavior*, *46*, 433-443.

Elliott, D., Hansen, S., Grierson, L. E., Lyons, J., Bennett, S. J., & Hayes, S. J. (2010). Goal-directed aiming: two components but multiple processes. *Psychological Bulletin*, *136*, 1023.

Elliott, D., Helsen, W. F., & Chua, R. (2001). A century later: Woodworth's (1899) two-component model of goal-directed aiming. *Psychological Bulletin*, *127*, 342.

Elliott, D., Lyons, J., Hayes, S. J., Burkitt, J. J., Roberts, J. W., Grierson, L. E., ... & Bennett, S. J. (2017). The multiple process model of goal-directed reaching revisited. *Neuroscience & Biobehavioral Reviews*, *72*, 95-110.

Englert, C., & Bertrams, A. (2012). Anxiety, ego depletion, and sports performance. *Journal of Sport and Exercise Psychology*, *34*, 580-599.

Englert, C., & Bertrams, A. (2015a). Integrating attentional control theory and the strength model of self-control. *Frontiers in Psychology*, *6*, 824.

Englert, C., & Bertrams, A. (2015b). Autonomy as a protective factor against the detrimental effects of ego depletion on tennis serve accuracy under pressure. *International Journal of Sport and Exercise Psychology*, *13*, 121-131.

Englert, C., & Bertrams, A. (2016). Active relaxation counteracts the effects of ego depletion on performance under evaluative pressure in a state of ego depletion. *Sportwissenschaft*, *46*, 110-115.

Englert, C., Bertrams, A., Furley, P., & Oudejans, R. R. (2015). Is ego depletion associated with increased distractibility?. Results from a basketball free throw task. *Psychology of Sport and Exercise*, *18*, 26-31.

Englert, C., Zwemmer, K., Bertrams, A., & Oudejans, R. R. (2015c). Ego depletion and attention regulation under pressure: is a temporary loss of self-control strength indeed related to impaired attention regulation?. *Journal of Sport and Exercise Psychology*, *37*, 127-137.

Ericsson, K. A., Krampe, R. T. & Tesche-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review, 100,* 363-406.

Etherton, J. L., Osborne, R., Stephenson, K., Grace, M., Jones, C., & De Nadai, A. S. (2018). Bayesian analysis of multimethod ego-depletion studies favours the null hypothesis. *British Journal of Social Psychology, 57*, 367-385.

Eysenck, M. W. (1982). *Attention and Arorcral: Cognition and Performance.* Berlin: Springer-Verlag.

Eysenck, M. W. (1985). Anxiety and cognitive-task performance. *Personality and Individual Differences*, *6*, 579-586.

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: attentional control theory. *Emotion*, *7*, 336.

Eysenck, M., Payne, S., & Derakshan, N. (2005). Trait anxiety, visuospatial processing, and working memory. *Cognition & Emotion*, *19*, 1214-1228.

Fairclough, S. H., Moores, L. J., Ewing, K. C., & Roberts, J. (2009). Measuring task engagement as an input to physiological computing. In *3rd International Conference on Affective Computing and Intelligent Interaction and Workshops* (pp. 1-9). IEEE.

Fasoli, S. E., Trombly, C. A., Tickle-Degnen, L., & Verfaellie, M. H. (2002). Effect of instructions on functional reach in persons with and without cerebrovascular accident. *American Journal of Occupational Therapy*, *56,* 380-390.

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*, 175-191.

Fazey, J. A. & Hardy, L. (1988). The inverted-U hypothesis: A catastrophe for sport psychology. *British Association of Sports Sciences Monograph no. 1*. Leeds: The National Coaching Foundation.

Fiedler, K. (2011). Voodoo correlations are everywhere - not only in neuroscience. *Perspectives on Psychological Science*, *6*, 163-171.

Fitts, P. M., & Posner, M. I. (1967). Human performance. *Belmont, CA*: Brooks.

Franklin, D. W., & Wolpert, D. M. (2008). Specificity of reflex adaptation for task-relevant variability. *Journal of Neuroscience*, 28, 14165-14175.

Freedman, S. E., Maas, E., Caligiuri, M. P., Wulf, G., & Robin, D. A. (2007). Internal versus external: oral motor performance as a function of attentional focus. *Journal of Speech, Language and Hearing Research, 50,* 131-136.

Fuller, K. A., Karunaratne, N. S., Naidu, S., Exintaris, B., Short, J. L., Wolcott, M. D., ... & White, P. J. (2018). Development of a self-report instrument for measuring in-class student engagement reveals that pretending to engage is a significant unrecognized problem. *PloS One*, *13*-35.

Gailliot, M. T., Baumeister, R. F., DeWall, C. N., Maner, J. K., Plant, E. A., Tice, D. M., ... & Schmeichel, B. J. (2007). Self-control relies on glucose as a limited energy source: willpower is more than a metaphor. *Journal of Personality and Social Psychology*, *92,* 325.

Geukes, K., Mesagno, C., Hanrahan, S. J., & Kellmann, M. (2013). Activation of self-focus and self-presentation traits under private, mixed, and public pressure. *Journal of Sport and Exercise Psychology, 35*, 50-59.

Glover, S., & Dixon, P. (2001). Dynamic illusion effects in a reaching task: evidence for separate visual representations in the planning and control of reaching. *Journal of Experimental Psychology of Human Perception and Performance, 27,* 560–572

Glover, S., & Dixon, P. (2002). Semantics affect the planning but not control of grasping. *Experimental Brain Research*, *146*, 383-387.

Glover, S., Rosenbaum, D. A., Graham, J., & Dixon, P. (2004). Grasping the meaning of words. *Experimental Brain Research, 154,* 103-108.

Goble D. J. (2010). Proprioceptive acuity assessment via joint position matching: from basic science to general practice. *Physical Therapy, 90,* 1176–1184.

Gray, J. A., & McNaughton, N. (2000). *The neuropsychology of anxiety: An enquiry into the functions of the septohippocampal system*. Oxford: Oxford University Press.

Greig, M., & Marchant, D. (2014). Speed dependant influence of attentional focusing instructions on force production and muscular activity during isokinetic elbow flexions. *Human Movement Science, 33*, 135-148.

Gucciardi, D. F., & Dimmock, J. A. (2008). Choking under pressure in sensorimotor skills: Conscious processing or depleted attentional resources?. *Psychology of Sport and Exercise, 9*, 45-59.

Hagger, M. S., & Chatzisarantis, N. L. (2013). The sweet taste of success: The presence of glucose in the oral cavity moderates the depletion of self-control resources. *Personality and Social Psychology Bulletin*, *39*, 28-42.

Hagger, M. S., Wood, C., Stiff, C., & Chatzisarantis, N. L. (2010). Ego depletion and the strength model of self-control: a meta-analysis. *Psychological Bulletin*, *136*, 495.

Halperin, I., Williams, K. J., Martin, D. T., & Chapman, D. W. (2016). The effects of attentional focusing instructions on force production during the isometric midthigh pull. *The Journal of Strength & Conditioning Research*, *30*, 919-923.

Hansen, S., Elliott, D., & Khan, M. A. (2008). Quantifying the variability of three-dimensional aiming movements using ellipsoids. *Motor Control*, *12*, 241-251.

Hansen, S., Glazebrook, C. M., Anson, J. G., Weeks, D. J., & Elliott, D. (2006). The influence of advance information about target location and visual feedback on movement planning and execution. *Canadian Journal of Experimental Psychology*, *60*, 200.

Hardy, L. (1999). Stress, anxiety and performance. *Journal of Science and Medicine in Sport*, *2*, 227-233.

Hardy, L., & Callow, N. (1999). Efficacy of external and internal visual imagery perspectives for the enhancement of performance on tasks in which form is important. *Journal of Sport and Exercise Psychology*, *21*, 95-112.

Hardy, L., & Parfitt, G. (1991). A catastrophe model of anxiety and performance. *British Journal of Psychology*, *82*, 163-178.

Hardy, L., Beattie, S., & Woodman, T. (2007). Anxiety-induced performance catastrophes: Investigating effort required as an asymmetry factor. *British Journal of Psychology*, *98*, 15-31.

Hardy, L., Bell, J., & Beattie, S. (2014). A neuropsychological model of mentally tough behavior. *Journal of Personality, 82*, 69-81.

Hardy, L., Mullen, R., & Jones, G. (1996). Knowledge and conscious control of motor actions under stress. *British Journal of Psychology*, *87*, 621-636.

Hardy, L., Parfitt, G., & Pates, J. (1994). Performance catastrophes in sport: A test of the hysteresis hypothesis. *Journal of Sports Sciences*, *12*, 327-334.

Hardy, L., Woodman, T., & Carrington, S. (2004). Is self-confidence a bias factor in higher-order catastrophe models?. An exploratory analysis. *Journal of Sport and Exercise Psychology*, *26*, 359-368.

Henry, F. M., & Rogers, D. E. (1960). Increased response latency for complicated movements and a "memory drum" theory of neuromotor reaction. *Research Quarterly. American Association for Health, Physical Education and Recreation*, *31*, 448-458.

Hermens, H. J., Freriks, B., Merletti, R., Stegeman, D., Blok, J., Rau, G., ... & Hägg, G. (1999). European recommendations for surface electromyography. *Roessingh Research and Development*, *8*, 13-54.

Hick, W. (1952). On the rate of gain of information. *Quarterly Journal of Experimental Psychology*, 4, 11-26.

Hyman, R. (1953). Stimulus information as a determinant of reaction time. *Journal of Experimental Psychology*, *45*, 188-196.

Jackson, R. C., Ashford, K. J., & Norsworthy, G. (2006). Attentional focus, dispositional reinvestment, and skilled motor performance under pressure. *Journal of Sport and Exercise Psychology*, *28*, 49-68.

Kal, E. C., Van der Kamp, J., & Houdijk, H. (2013). External attentional focus enhances movement automatization: A comprehensive test of the constrained action hypothesis. *Human Movement Science*, *32,* 527-539.

Keele, S. W. (1968). Movement control in skilled motor performance. *Psychological Bulletin*, *70*, 387.

Khan, M. A., & Franks, I. M. (2000). The effect of practice on component submovements is dependent on the availability of visual feedback. *Journal of Motor Behavior*, *32,* 227-240.

Khan, M. A., Elliott, D., Coull, J., Chua, R., & Lyons, J. (2002). Optimal control strategies under different feedback schedules: Kinematic evidence. *Journal of Motor Behavior*, *34*, 45-57.

Khan, M. A., Franks, I. M., Elliott, D., Lawrence, G. P., Chua, R., Bernier, P. M., ... & Weeks, D. J. (2006). Inferring online and offline processing of visual feedback in target-directed movements from kinematic data. *Neuroscience & Biobehavioral Reviews*, *30*, 1106-1121.

Khan, M. A., Lawrence, G. P., Franks, I. M., & Buckolz, E. (2004). The utilization of visual feedback from peripheral and central vision in the control of direction. *Experimental Brain Research*, *158*, 241-251.

Khan, M. A., Lawrence, G. P., Franks, I. M., & Elliott, D. (2003a). The utilization of visual feedback in the control of movement direction: evidence from a video aiming task. *Motor Control*, *7*, 290-303.

Khan, M. A., Lawrence, G., Fourkas, A., Franks, I. M., Elliott, D., & Pembroke, S. (2003b). Online versus offline processing of visual feedback in the control of movement amplitude. *Acta Psychologica*, *113*, 83-97.

Khan, M. A., Lawrence, G., Fourkas, A., Franks, I. M., Elliott, D., & Pembroke, S. (2003). Online versus offline processing of visual feedback in the control of movement amplitude. *Acta Psychologica*, *113*, 83-97.

Khan, M. A, Franks, I. M., Elliott, D., Lawrence, G. P., Chua, R., Bernier, P., Hansen, S., & Weeks, D. J. (2006). Inferring online and offline processing of visual feedback in target-directed movements from kinematic data. *Neuroscience and Biobehavioral Reviews, 30,* 1106-1121.

Khan, M. A., Lawrence, G. P., Fourkas, A., Franks, I. M., Elliott, D., & Pembroke, S. (2003). Online versus offline processing of visual feedback in the production of movement distance. *Acta Psychologica, 113,* 83-97.

Kimble, G. A., & Perlmuter, L. C. (1970). The problem of volition. *Psychological Review*, *77*, 361.

Kinrade, N. P., Jackson, R. C., & Ashford, K. J. (2010). Dispositional reinvestment and skill failure in cognitive and motor tasks. *Psychology of Sport and Exercise*, *11*, 312-319.

Knudsen, E. I. (2007). Fundamental components of attention. *Annual Review of Neuroscience*, 30, 57- 78.

Krane, V. (1994). The mental readiness form as a measure of competitive state anxiety. *The Sport Psychologist*, *8*, 189-202.

Krane, V., Joyce, D., & Rafeld, J. (1994). Competitive anxiety, situation criticality and softball performance. *The Sport Psychologist*, *8*, 58-72.

Kurzban, R., Duckworth, A., Kable, J. W., & Myers, J. (2013). An opportunity cost model of subjective effort and task performance. *Behavioral and Brain Sciences, 36*, 661-679.

Lam, W. K., Maxwell, J. P., & Masters, R. (2009). Analogy learning and the performance of motor skills under pressure. *Journal of Sport and Exercise Psychology*, *31*, 337-357.

Land, W. M., Tenenbaum, G., Ward, P., & Marquardt, C. (2013). Examination of visual information as a mediator of external focus benefits. *Journal of Sport and Exercise Psychology*, *35*, 250-259.

Landers, D. M., & Boutcher, S. H. (1986). Arousal-performance relationships. *Applied sport psychology: Personal Growth to Peak Performance, 4*, 206-228.

Landers, M., Wulf, G., Wallmann, H., & Guadagnoli, M. (2005). An external focus of attention attenuates balance impairment in patients with Parkinson's disease who have a fall history. *Physiotherapy*, *91*, 152-158.

Lange, F., & Eggert, F. (2014). Sweet delusion. Glucose drinks fail to counteract ego depletion. *Appetite*, *75*, 54-63.

Lawrence, G. P., Gottwald, V. M., Hardy, J., & Khan, M. A. (2011). Internal and external focus of attention in a novice form sport. *Research Quarterly for Exercise and Sport*, *82,* 431-441.

Lawrence, G. P., Khan, M. A., & Hardy, L. (2013). The effect of state anxiety on the online and offline control of fast target-directed movements. *Psychological Research*, *77*, 422-433.

Lawrence, G. P., Khan, M. A., Buckolz, E., & Oldham, A. R. (2006). The contribution of peripheral and central vision in the control of movement amplitude. *Human Movement Science*, *25*, 326-338.

Lawrence, G. P., Khan, M. A., Mourton, S., & Bernier, P. M. (2011). The reliance on visual feedback for online and offline processing. *Motor Control*, *15*, 232-246.

Lawrence, G. P., Gottwald, V. M., Hardy, J., & Khan, M. A. (2011). Internal and external focus of attention in a novice form sport. *Research Quarterly for Exercise and Sport, 82,* 431-441.

Lohse, K. R., Sherwood, D. E., & Healy, A. F. (2010). How changing the focus of attention affects performance, kinematics, and electromyography in dart throwing. *Human Movement Science, 29*, 542-555.

Lohse, K. R., Sherwood, D. E., & Healy, A. F. (2011). Neuromuscular effects of shifting the focus of attention in a simple force production task. *Journal of Motor Behavior, 43,* 173-184.

Lohse, K., Sherwood, D., & Healy, A. (2010). How changing the focus of attention affects performance, kinematics, and electromyography in dart throwing. *Human Movement Science, 29,* 542-555.

Lohse, K.R. (2012). The influence of attention on learning and performance: pre-movement time and accuracy in an isometric force production task. *Human Movement Science, 31,* 12-25.

Makaruk, H., Porter, J. M., & Makaruk, B. (2013). Acute effects of attentional focus on shot put performance in elite athletes. *Kinesiology: International Journal of Fundamental and Applied Kinesiology, 45*, 55-62.

Malhotra, N., Poolton, J. M., Wilson, M. R., Uiga, L., & Masters, R. S. (2015). Examining movement-specific reinvestment and performance in demanding contexts. *Journal of Sport and Exercise Psychology*, *37*, 327-338.

Manley, H., Beattie, S., Roberts, R., Lawrence, G. P., & Hardy, L. (2018). The benefit of punishment sensitivity on motor performance under pressure. *Journal of Personality*, *86*, 339-352.

Marchant, D. C., Clough, P. J., & Crawshaw, M. (2007). The effects of attentional focusing strategies on novice dart throwing performance and their task experiences. *International Journal of Sport and Exercise Psychology, 5*, 291-303.

Martens, R., Burton, D., Vealey, R. S., Bump, L. A., & Smith, D. E. (1990). Development and validation of the Competitive State Anxiety Inventory-2. In R. Martens, R. S. Vealey, & D. Burton (Eds.), *Competitive anxiety in sport* (pp. 117-190). Champaign: Human Kinetics.

Masters, R. S. (1992). Knowledge, knerves and know-how: The role of explicit versus implicit knowledge in the breakdown of a complex motor skill under pressure. *British Journal of Psychology*, *83*, 343-358.

Masters, R. S. W., Eves, F. F., & Maxwell, J. (2005). Development of a movement specific Reinvestment Scale. In T. Morris, P. Terry, S. Gordon, S. Hanrahan, L. Ievleva, G. Kolt, & P. Tremayne, (Eds.), *Proceedings of the ISSP 11th World Congress of Sport Psychology*. Sydney, Australia: ISSP.

Masters, R. S. W., Polman, R. C. J., & Hammond, N. V. (1993). 'Reinvestment': a dimension of personality implicated in skill breakdown under pressure. *Personality and Individual Differences*, *14*, 655-666.

Masters, R., & Maxwell, J. (2008). The theory of reinvestment. *International Review of Sport and Exercise Psychology*, *1*, 160-183.

McKay, B., & Wulf, G. (2012). A distal external focus enhances novice dart throwing performance. *International Journal of Sport and Exercise Psychology*, *10*, 149-156.

McNamara, S. W., Becker, K. A., & Silliman-French, L. M. (2017). The differential effects of attentional focus in children with moderate and profound visual impairments. *Frontiers in Psychology*, *8*, 1804.

McNaughton, N., & Corr, P. J. (2004). A two-dimensional neuropsychology of defense: fear/anxiety and defensive distance. *Neuroscience & Biobehavioral Reviews*, *28*, 285-305.

McNevin, N. H., Shea, C. H., & Wulf, G. (2003). Increasing the distance of an external focus of attention enhances learning. *Psychological Research, 67,* 22-29.

Meyer, D. E., Abrams, R. A., Kornblum, S., Wright, C. E., & Smith, J. E. K. (1988). Optimality in human motor performance: Ideal control of rapid aimed movements. *Psychological Review*, 95, 340–370.

Miall, R. C., & Wolpert, D. M. (1996). Forward models for physiological motor control. *Neural Networks*, *9*, 1265-1279.

Mobbs, D., Hagan, C. C., Dalgleish, T., Silston, B., & Prévost, C. (2015). The ecology of human fear: survival optimization and the nervous system. *Frontiers in Neuroscience*, *9*, 55.

Moore, L. J., Wilson, M. R., Vine, S. J., Coussens, A. H., & Freeman, P. (2013). Champ or chump?: Challenge and threat states during pressurized competition. *Journal of Sport and Exercise Psychology*, *35*, 551-562.

Muraven, M., & Baumeister, R. F. (2000). Self-regulation and depletion of limited resources: Does self-control resemble a muscle?. *Psychological Bulletin*, *126*, 247.

Muraven, M., & Slessareva, E. (2003). Mechanisms of self-control failure: Motivation and limited resources. *Personality and Social Psychology Bulletin*, *29*, 894-906.

Muraven, M., Tice, D. M., & Baumeister, R. F. (1998). Self-control as a limited resource: Regulatory depletion patterns. *Journal of Personality and Social Psychology*, *74*, 774.

Murray, N. P., & Janelle, C. M. (2003). Anxiety and performance: A visual search examination of the processing efficiency theory. *Journal of Sport and Exercise psychology*, *25*, 171-187.

Neiss, R. (1988). Reconceptualizing arousal: psychobiological states in motor performance. *Psychological Bulletin*, *103*, 345.

Nieuwenhuys, A., Pijpers, J. R., Oudejans, R. R., & Bakker, F. C. (2008). The influence of anxiety on visual attention in climbing. *Journal of Sport and Exercise Psychology*, *30*, 171-185.

Orrell, A. J., Masters, R. S. W., & Eves, F. F. (2009). Reinvestment and movement disruption following stroke. *Neurorehabilitation and Neural Repair*, *23*, 177-183.

Oxendine, J. B. (1970). Emotional arousal and motor performance. *Quest*, *13*, 23-32.

Payne, K. L., Wilson, M. R., & Vine, S. J. (2019). A systematic review of the anxiety-attention relationship in far-aiming skills. *International Review of Sport and Exercise Psychology*, *12*, 325-355.

Pelleck, V., & Passmore, S. R. (2017). Location versus task relevance: the impact of differing internal focus of attention instructions on motor performance. *Acta Psychologica*, *176*, 23-31.

Perkins-Ceccato, N., Passmore, S. R., & Lee, T. D. (2003). Effects of focus of attention depend on golfers' skill. *Journal of Sports Sciences*, *21*, 593-600.

Pishyar, R., Harris, L. M., & Menzies, R. G. (2004). Attentional bias for words and faces in social anxiety. *Anxiety, Stress & Coping*, *17*, 23-36.

Porter, J. M., Ostrowski, E. J., Nolan, R. P., & Wu, W. F. (2010). Standing long-jump performance is enhanced when using an external focus of attention. *The Journal of Strength & Conditioning Research*, *24*, 1746-1750.

Porter, J. M., Wu, W. F. W., & Partridge, J. A. (2010). Focus of attention and verbal instructions: strategies of elite track and field coaches and athletes. *Sport Science Review*, *XIX*, 77-89.

Prinz, W. (1997). Perception and action planning. *European Journal of Cognitive Psychology*, *9*, 129-154.

Proteau, L. (1992). On the specificity of learning and the role of visual information for movement control. In L. Proteau & D. Elliott (Eds.), *Advances in psychology, vision and motor control* (pp. 67-103). Oxford, England: North-Holland.

Proteau, L., Roujoula, A., & Messier, J. (2009). Evidence for continuous processing of visual information in a manual video-aiming task. *Journal of Motor Behavior*, *41*, 219-231.

Raskin, R., & Terry, H. (1988). A principal-components analysis of the Narcissistic Personality Inventory and further evidence of its construct validity. *Journal of Personality and Social Psychology*, *54*, 890–902.

Reichenbach, A., Franklin, D. W., Zatka-Haas, P., & Diedrichsen, J. (2014). A dedicated binding mechanism for the visual control of movement. *Current Biology*, *24*, 780-785.

Reichenbach, A., Thielscher, A., Peer, A., Bülthoff, H. H., & Bresciani, J. P. (2009). Seeing the hand while reaching speeds up on-line responses to a sudden change in target position. *The Journal of Physiology, 587*, 4605-4616.

Roberts, J. W., Wilson, M. R., Skultety, J. K., & Lyons, J. L. (2018). Examining the effect of state anxiety on compensatory and strategic adjustments in the planning of goal-directed aiming. *Acta Psychologica*, *185*, 33-40.

Roberts, R., Cooke, A., Woodman, T., Hupfeld, H., Barwood, C., & Manley, H. (2019). When the going gets tough, who gets going?. An examination of the relationship between narcissism, effort, and performance. *Sport, Exercise, and Performance Psychology*, *8,* 93.

Roberts, R., Woodman, T., & Sedikides, C. (2018). Pass me the ball: Narcissism in performance settings. *International Review of Sport and Exercise Psychology*, *11*, 190-213.

Roberts, R., Woodman, T., Hardy, L., Davis, L., & Wallace, H. M. (2013). Psychological skills do not always help performance: The moderating role of narcissism. *Journal of Applied Sport Psychology*, *25*, 316-325.

Rosenbaum, D. A., Loukopoulos, L. D., Meulenbroek, R. G., Vaughan, J., & Engelbrecht, S. E. (1995). Planning reaches by evaluating stored postures. *Psychological Review*, *102,* 28.

Russell, R., Porter, J., & Campbell, O. (2014). An external skill focus is necessary to enhance performance. *Journal of Motor Learning and Development*, *2*, 37-46.

Salmon, S. J., Adriaanse, M. A., De Vet, E., Fennis, B. M., & De Ridder, D. T. (2014). "When the going gets tough, who keeps going?" Depletion sensitivity moderates the ego-depletion effect. *Frontiers in Psychology, 5*, 647.

Salmoni, A. W. (1989). Motor skill learning. In D. H. Holding (Eds.), *Human skills* (pp. 97-227). New York: Wiley.

Sarlegna, F. R., & Sainburg, R. L. (2009). The Roles of Vision and Proprioception in the Planning of Reaching Movements. *Progress in Motor Control*, *629*, 317-335.

Schlesinger, M., Porter, J., & Russell, R. (2013). An external focus of attention enhances manual tracking of occluded and visible targets. *Frontiers in Psychology, 3,* 591.

Schmidt, R. A. (1975). A schema theory of discrete motor skill learning. *Psychological Review*, *82*, 225.

Schmidt, R. A., Zelaznik, H., Hawkins, B., Frank, J. S., & Quinn Jr, J. T. (1979). Motor-output variability: a theory for the accuracy of rapid motor acts. *Psychological Review*, *86*, 415-451

Schwenkreis, P., Pleger, B., Höffken, O., Malin, J.P., & Tegenthoff, M. (2001). Repetitive training of a synchronised movement induces short-term plastic changes in the human primary somatosensory cortex. *Neuroscience Letters, 312,* 99–102.

Scott, S. H. (2016). A functional taxonomy of bottom-up sensory feedback processing for motor actions. *Trends in Neurosciences*, *39*, 512-526.

Sherwood, D. E., Lohse, K. R., & Healy, A. F. (2014). Judging joint angles and movement outcome: Shifting the focus of attention in dart-throwing. *Journal of Experimental Psychology: Human Perception and Performance*, *40*, 1903.

Shusterman, R. (2008). *Body consciousness: A philosophy of mindfulness and somaesthetics*. UK: Cambridge University Press.

Shusterman, R. (2011). Somaesthetic awareness, proprioceptive perception, and performance. In E. R. Iñesta, & J. E. Burgos (Eds.), *Consciousness, Perception, and Behavior: Conceptual, Theoretical, and Methodological Issues, Proceedings of the 11th Biannual Symposium on the Science of Behavior*. New Orleans: University Press of the South.

Smith, R. E., Smoll, F. L., Cumming, S. P., & Grossbard, J. R. (2006). Measurement of multidimensional sport performance anxiety in children and adults: The Sport Anxiety Scale-2. *Journal of Sport and Exercise Psychology*, *28*, 479-501.

Sonstroem, R. J., & Bernardo, P. (1982). Intraindividual pregame state anxiety and basketball performance: A re-examination of the inverted-U curve. *Journal of sport psychology*, *4*, 235-245.

Spielberger, C. (1972). *Anxiety: Current trends in research*. London: Academic Press

Spielberger, C., & Charles, D. (1970). *Stress and anxiety in sports, anxiety in sports: An International perspective*. New York: Hemisphere Publishing.

Suprak, D. N., Osternig, L. R., van Donkelaar, P., & Karduna, A. R. (2007). Shoulder joint position sense improves with external load. *Journal of Motor Behavior*, *39*, 517–525.

Sutton, R. S., & Barto, A. G. (1981). Toward a modern theory of adaptive networks: expectation and prediction. *Psychological Review*, *88*, 135.

Tangney, J. P., Baumeister, R. F., & Boone, A. L. (2004). High self-control predicts good adjustment, less pathology, better grades, and interpersonal success. *Journal of Personality*, 72, 271-324.

Tomaka, J., Blascovich, J., Kelsey, R. M., & Leitten, C. L. (1993). Subjective, physiological, and behavioral effects of threat and challenge appraisal. *Journal of Personality and Social Psychology*, 65, 248

Toner, J., & Moran, A. (2011). The effects of conscious processing on golf putting proficiency and kinematics. *Journal of Sports Sciences*, *29*, 673-683.

Toner, J., & Moran, A. (2015). Enhancing performance proficiency at the expert level: Considering the role of 'somaesthetic awareness'. *Psychology of Sport and Exercise*, *16*, 110-117.

Toner, J., & Moran, A. (2016). On the importance of critical thinking: A response to Wulf's (2015) commentary. *Psychology of Sport and Exercise, 22,* 339-340.

Toussaint, L., & Blandin, Y. (2010). On the role of imagery modalities on motor learning. *Journal of Sports Sciences, 28,* 497–504.

Toussaint, L., Meugnot, A., Badets, A., Chesnet, D., & Proteau, L. (2016). The specificity of practice hypothesis in goal-directed movements: visual dominance or proprioception neglect?. *Psychological Research, 81,* 407-414.

Tremblay, L., Crainic, V. A., de Grosbois, J., Bhattacharjee, A., Kennedy, A., Hansen, S., & Welsh, T. N. (2017). An optimal velocity for online limb-target regulation processes?. *Experimental Brain Research*, *235*, 29-40.

Vadillo, M. A., Gold, N., & Osman, M. (2016). The bitter truth about sugar and willpower: The limited evidential value of the glucose model of ego depletion. *Psychological Science, 27*, 1207-1214.

VanVoorhis, C. W., & Morgan, B. L. (2007). Understanding power and rules of thumb for determining sample sizes. *Tutorials in Quantitative Methods for Psychology, 3*, 43-50.

Vealey, R. S. (1990). Advancements in competitive anxiety research: Use of the sport competition anxiety test and the Competitive State Anxiety Inventory-2. *Anxiety Research*, *2*, 243-261.

Veyrat-Masson, M., Brière, J., & Proteau, L. (2010). Automaticity of online control processes in manual aiming. *Journal of Vision*, *10*, 27-27.

Wallace, H. M., & Baumeister, R. F. (2002). The performance of narcissists rises and falls with perceived opportunity for glory. *Journal of Personality and Social Psychology*, *82,* 819-834.

Wallace, S. A. (1981). An impulse-timing theory for reciprocal control of muscular activity in rapid, discrete movements. *Journal of Motor Behavior*, *13,* 144-160.

Welsh, T. N., & Elliott, D. (2004). Movement trajectories in the presence of a distracting stimulus: Evidence for a response activation model of selective reaching. *The Quarterly Journal of Experimental Psychology Section A*, *57,* 1031-1057.

Welsh, T. N., & Elliott, D. (2005). The effects of response priming on the planning and execution of goal-directed movements in the presence of a distracting stimulus. *Acta Psychologica*, *119*, 123-142.

Willingham, D. B. (1998). A neuropsychological theory of motor skill learning. *Psychological Review*, *105*, 558.

Wilson, M. R., Vine, S. J., & Wood, G. (2009). The influence of anxiety on visual attentional control in basketball free throw shooting. *Journal of Sport and Exercise Psychology*, *31*, 152-168.

Wilson, M. R., Wood, G., & Vine, S. J. (2009). Anxiety, attentional control, and performance impairment in penalty kicks. *Journal of Sport and Exercise Psychology*, *31,* 761-775.

Wilson, M., Smith, N. C., & Holmes, P. S. (2007). The role of effort in influencing the effect of anxiety on performance: Testing the conflicting predictions of processing efficiency theory and the conscious processing hypothesis. *British Journal of Psychology, 98*, 411–428.

Wolff, W., Baumann, L., & Englert, C. (2018). Self-reports from behind the scenes: Questionable research practices and rates of replication in ego depletion research. *PloS One*, *13*, e0199554.

Wolff, W., Sieber, V., Bieleke, M., & Englert, C. (2019). Task duration and task order do not matter: no effect on self-control performance. *Psychological Research*, 1-11.

Wolpert, D. M., & Kawato, M. (1998). Multiple paired forward and inverse models for motor control. *Neural Networks*, *11*, 1317-1329.

Wolpert, D. M., Ghahramani, Z., & Jordan, M. I. (1995). An internal model for sensorimotor integration. *Science*, *269*, 1880-1882.

Woodman, T., Roberts, R., Hardy, L., Callow, N., & Rogers, C. H. (2011). There is an "I" in TEAM: Narcissism and social loafing. *Research Quarterly for Exercise and Sport*, *82*, 285-290.

Woodworth, R. S. (1899). Accuracy of voluntary movement. *The Psychological Review: Monograph Supplements, 3,* i.

Wulf, G. (2013). Attentional focus and motor learning: a review of 15 years. *International Review of sport and Exercise psychology*, *6*, 77-104.

Wulf, G. (2015). Why did Tiger Woods shoot 82?. A commentary on Toner and Moran (2015). *Psychology of Sport and Exercise, 22,* 337-338.

Wulf, G., & McNevin, N. (2003). Simply distracting learners is not enough: More evidence for the learning benefits of an external focus of attention. *European Journal of Sport Science, 3,* 1-13.

Wulf, G., & Su, J. (2007). An external focus of attention enhances golf shot accuracy in beginners and experts. *Research Quarterly for Exercise and Sport*, *78*, 384-389.

Wulf, G., & Weigelt, C. (1997). Instructions about physical principles in learning a complex motor skill: To tell or not to tell. *Research Quarterly for Exercise and Sport*, *68*, 362-367.

Wulf, G., Höß, M., & Prinz, W. (1998). Instructions for motor learning: Differential effects of internal versus external focus of attention. *Journal of Motor Behavior*, *30*, 169-179.

Wulf, G., Landers, M., Lewthwaite, R., & Toöllner, T. (2016). External focus instructions reduce postural instability in individuals with Parkinson disease. *Physical Therapy*, *89*, 162-168.

Wulf, G., McNevin, N. H., & Shea, C.H. (2001). The automaticity of complex motor skill learning as a function of attentional focus. *Quarterly Journal of Experimental Psychology*, *54*, 1143–1154.

Wulf, G., Shea, C., & Park, J. H. (2001). Attention and motor performance: Preferences for and advantages of an external focus. *Research Quarterly for Exercise and Sport*, *72*, 335-344.

Xerri C. (2012). Plasticity of cortical maps: multiple triggers for adaptive reorganization following brain damage and spinal cord injury. *Neuroscientist*, *18*, 133–148.

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimuli to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology*, *18*, 459–482.

Zachry, T., Wulf, G., Mercer, J., & Bezodis, N. (2005). Increased movement accuracy and reduced EMG activity as the result of adopting an external focus of attention. *Brain Research Bulletin*, *67*, 304-309.

Zhu, F. F., Poolton, J. M., Wilson, M. R., Maxwell, J. P., & Masters, R. S. W. (2011). Neural co-activation as a yardstick of implicit motor learning and the propensity for conscious control of movement. *Biological Psychology*, *87*, 66-73.

Zijlstra, F. R. H. (1993). *Efficiency in work behavior*. Unpublished doctoral dissertation, Technical University, Delft, The Netherlands.

Zimmerman, B. J., & Kitsantas, A. (1997). Developmental phases in self-regulation: Shifting from process goals to outcome goals. *Journal of Educational Psychology, 89,* 29-36.