The Role of Attentional Control in Sport Performance

Jack Brimmell

Submitted in accordance with the requirements for the degree of Doctor of Philosophy (PhD)

York St John University

School of Education, Language, and Psychology

December 2022

I, Jack Brimmell, confirm that the work submitted is my own, except where work which has formed part of jointly authored publications has been included. The contribution of myself and the other authors to this work has been explicitly indicated below. I confirm that appropriate credit has been given within the thesis where reference has been made to the work of others.

Elements of the work in **Chapter 2** of the thesis has appeared in publication as follows:

Brimmell, J., Edwards, E. J., & Vaughan, R. S. (2022). Executive function and visual attention in sport: A systematic review. *International Review of Sport and Exercise Psychology*, 1-34.

I was responsible for conception, ethical approval, data collection, data analysis, study write-up, peer review edits, and correspondence with journal. The contribution of the other authors was peer review edits and pre-submission editing and proofreading.

Elements of the work in **Chapter 5** of the thesis has appeared in publication as follows:

Brimmell, J., Edwards, E. J., Smith, M., & Vaughan, R. S. (2021). Think, see, do: Executive function, visual attention, and soccer penalty performance. *Sport, Exercise, and Performance Psychology*, *10*(2), 290-309.

I was responsible for conception, ethical approval, data collection, data analysis, study write-up, peer review edits, and correspondence with journal. The contribution of the other authors was peer review edits and pre-submission editing and proofreading.

Table of Contents

Acknowledgements

There are many people that I would like to acknowledge and thank for their very different roles in making my PhD an enjoyable and engrossing experience. First, I would like to thank Drs Rob Vaughan and Liz Edwards for being there every single step of the way over the last 3.5-4 years. Without your expertise, enthusiasm, guidance, and motivating words, none of this would have been possible – you will always have my sincere gratitude. I'd also like to mention Dr Martin Smith for his input earlier on in my PhD and Dr Daniel Madigan for stepping into the supervisory team when needed.

I'd also like to thank my fellow Graduate Teaching Assistants and PhD researchers from the School of Education, Language, and Psychology and the School of Science, Technology, and Health. Without such a group, many moments would have felt much more of a struggle – so thank you, for always providing encouragement and welcome humour when needed. I wish all of you the best in your future endeavours. I'd also like to take a moment to thank the Psychology Technical team for all the support and advice over the years.

Finally, it would be remiss of me not to mention my friends, family, and partner. Despite never really fully understanding exactly what I'm moaning about or what is annoying in the first place, you have all always been there for me – to listen, advise, and remind me that no one is defined by a single piece of work. Special mention to my Mother and Father for their unwavering support in all I do – thank you. Finally, for real this time, the most special thank you goes to my partner, Elly. Everything, not just this PhD, would be so much more difficult without you – so thank you, thank you, thank you, for all that you do for me every day.

Thesis Abstract

Attentional Control Theory-Sport (ACT-S) states that performance under stress or anxiety may be underpinned by attentional processes. The attentional processes outlined in ACT-S are a group of executive functions (EFs) including inhibition, shifting, and updating. However, research grounded within ACT-S has typically assessed attention through visual gaze often captured with an eye-tracker. The key aim of the thesis was to try and better understand how EFs and visual attention (VA) interact to influence sport performance and extend ACT-S. A series of four studies, and one pilot study, were conducted in order to test the idea that EF and VA may indeed work together in successful sport performance. An initial systematic review outlined several research gaps (e.g., a lack of research examining a holistic EF model). Specifically, the review identified that research had often failed to consider EF and VA in the same analyses and rarely considered the distinction between effectiveness and efficiency. After pilot data showed no difference between in-person and online conditions, an online study examined the relationship between tasks of inhibition, shifting, and updating and VA tasks for the first time, and found associations through confirmatory factor analysis. To increase ecological validity, two experimental studies examined the relationship between EF, VA (obtained via eye-trackers), and objective sport performance (i.e., soccer penalty performance). Cross-sectional results suggested the relationship between EF and soccer penalty performance was mediated by VA. Longitudinal results were not completely in line with this finding and suggested that VA alone may be a better influence of soccer penalties over time. However, the search rate and inhibition relationship showed promise. Overall, there appears to be a relationship between EF and VA for sport performance and the components should be considered independent contributors to "attention" within ACT-S, though the long-term relations are not clear.

List of Abbreviations

ACT = Attentional Control Theory

ACT-S = Attentional Control Theory-Sport

A_effectivness = Attentional Breadth Effectiveness

A_effect = Attentional Breadth Effectiveness

A_efficiency = Attentional Breadth Efficiency

A_effic = Attentional Breadth Efficiency

AIC = Akaike Information Criterion

AMOS = Analysis of Moment Structures

ANCOVA = Analysis of Covariance

ANOVA = Analysis of Variance

APA = American Psychological Association

ASL = Applied Science Laboratories

BIC = Bayes Information Criterion

B-S = Between-subjects

C_effectiveness = Category Switch Effectiveness

C_effect = Category Switch Effectiveness

C_efficiency = Category Switch Efficiency

C_effic = Category Switch Efficiency

CFA = Confirmatory Factor Analysis

CFI = Comparative Fit Index

CI = Confidence Interval

CINAHL = Cumulative Index to Nursing and Allied Health Literature

CMIN/DF = Ratio of the Likelihood Statistic to the Degrees of Freedom

COVID-19 = Coronavirus

D_effectiveness = Backward Digit Span Effectiveness

D_effect = Backward Digit Span Effectiveness

D_efficiency = Backward Digit Span Efficiency

D_effic = Backward Digit Span Efficiency

DF = Degrees of Freedom

EE = Elizabeth Edwards

EBSCO = Elton B Stephens Co

F_effectiveness = Modified Flanker Task Effectiveness

F_effect = Modified Flanker Task Effectiveness

F_efficiency = Modified Flanker Task Efficiency

F_effic = Modified Flanker Task Efficiency

FIFA = International Federation of Association Football (English Version)

G_effectiveness = Go/No-Go Task Effectiveness

G_effect = Go/No-Go Task Effectiveness

G_efficiency = Go/No-Go Task Efficiency

G_effic = Go/No-Go Task Efficiency

GFI = Goodness of Fit Index

GK = Goalkeeper

GKMS = Time Fixating the Goalkeeper in MS

GoalMS = Time Fixating the Goal in MS

ID = Identification

I_effect = Inhibition Effectiveness

I_effic = Inhibition Efficiency

IPAQ = International Physical Activity Questionnaire

IPAQ-SF = International Physical Activity Questionnaire-Short Form

JB = Jack Brimmell

MEDLINE = Medical Literature Analysis and Retrieval System Online

MET = Metabolic Equivalent

NAC = NAC Image Technology

N_effectiveness = 2-Back Task Effectiveness

N_effect = 2-Back Task Effectiveness

N_efficiency = 2-Back Task Efficiency

N_effic = 2-Back Task Efficiency

OSPAN = Operation Span Task

PA = Physical Activity

PET = Processing Efficiency Theory

PRISMA = Preferred Reporting Items for Systematic Reviews and Meta-Analyses

QED = Quiet Eye Duration

QEL = Quiet Eye Location

RMSEA = Root Mean Square Error of Approximation

RV = Robert Vaughan

S_effect = Shifting Effectiveness

S_effic = Shifting Efficiency

St_effectiveness = Stop Signal Task Effectiveness

St_effect = Stop Signal Task Effectiveness

St_efficiency = Stop Signal Task Efficiency

St_effic = Stop Signal Task Efficiency

SD = Standard Deviation

SE = Standard Error

SEM = Structural Equational Modelling

SMI = SensoMotoric Instruments

SPSS = Statistical Package for Social Sciences

SR = Search Rate

SRMR = Standardised Root Mean Squaref Residual

SRQ = Stress Rating Questionnaire

STAI = State and Trait Anxiety Inventory

STICSA = State and Trait Inventory for Cognitive and Somatic Anxiety

TLI = Tucker Lewis Index

U_effect = Updating Effectiveness

U_effic = Updating Efficiency

UEFA = The Union of European Football Associations

VA = Visual Attention

V_effectiveness = Visual Search Task Effectiveness

V_effect = Visual Search Task Effectiveness

V_Efficiency = Visual Search Task Efficiency

V_effic = Visual Search Task Efficiency

W-S = Within-subjects

List of Figures

List of Tables

Chapter 1: General Introduction

1.1 Chapter Overview

The aim of this chapter was to provide a critical overview of the literature and methodological concepts associated with attentional control in the domain of sport performance. First, the present chapter uses sporting anecdotes and previous research to establish the relevance of examining attentional control during pressurised sport performance. The potential role of anxiety and interpretations of anxiety are then considered as factors that may influence attentional control during sport performance under pressure before moving to seminal theoretical offerings of anxiety and attentional control. With specific focus on Attentional Control Theory-Sport (ACT-S; Eysenck & Wilson, 2016) and the proposed underpinning of EF said to relate goal-directed attention (i.e., inhibition, shifting, and updating). This chapter will then outline methodological processes that are typically used to examine attentional control in sport and other domains with specific focus on study design, recreating pressure in the laboratory, and indexing attentional control (both visual gaze behaviour and cognitive processes). The focus then shifts to the gaps that the present thesis will address in relation to attentional control. Specifically, the notion that the relationship between EF and VA remains somewhat unclear despite their theoretical connection. Finally, the research aims and hypotheses are outlined.

1.2 Introduction

Effective performance during moments of high pressure is key for success in sport. Pressure is a state whereby the need to perform well is increased and often induces feelings of stress (Baumeister, 1984). Stress is the relationship between an individual and their environment and occurs when the individual believes situational demands exceed personal coping resources (Lazarus, 1966). Theories of anxiety (e.g., Attentional Control Theory [ACT]; Eysenck et a., 2007) suggest that such a situation can lead to feelings of anxiety which can in turn have a negative impact upon attentional control and performance. However, interpretations of anxiety (i.e., how individuals perceive or appraise the stressful situation) are often key (Hanton et al., 2008).

Take for example a penalty kick during an elimination shootout in soccer. A complex but relatively self-paced sporting action with plenty of examples where attentional processes and performance has been different under pressure. At the 1990 FIFA World Cup the English national side had the chance to reach their first World Cup Final in 24 years. Miss the shot, and England would be out. Chris Waddle stepped up and placed his attempt over the bar. The game, the World Cup semi-final, had been lost, all because of one missed kick, in one moment of pressure. Didier Drogba had one kick to win the UEFA Champions League for the first time ever in the history of Chelsea Football Club. Drogba stepped up and calmly dispatched his kick. The game, the Champions League title, had been won, all because of one successful kick, in one moment of pressure.

The anecdotal evidence above shows us that for every poor performance under pressure, you can find an example of successful performance. Empirical evidence supports this performance variability (e.g., Otten, 2009). The present thesis aimed to examine the underlying factors, such as attentional control (consisting of both EF and VA), that may be influenced by stress and anxiety and in turn, cause differences in performance under pressure.

The following chapter will first outline the impact of pressure in sport, and how anxiety and interpretations of anxiety can influence sport performance. Next, this chapter covers relevant theoretical propositions before focusing on ACT-S (Eysenck & Wilson, 2016) and the anxiety-attentional control relationship. The literature review will then cover EF and VA in sport and how EF and VA are often operationalised in the research area. The role of two key proposed covariates (i.e., physical activity and expertise) is also covered. Finally, once the relevant research has been introduced, the review will conclude with the aims of the present thesis, and how this body of work will expand our knowledge in such a novel research area. That is, precisely how the present thesis will contribute to better understanding the joint role of EF and VA during pressurised sport performance.

1.3 Pressure in Sport

The opening sporting examples advocate that pressure is rife in sport and can impact individuals in different ways. Pressurised situations have been said to contain a factor, or combination of factors, that elevate the need to perform well (Baumeister, 1984). Research has reported that performance can both improve under pressure (e.g., Otten, 2009) and drop under pressure (e.g., Lewis & Linder, 1997; Mesagno & Hill, 2013). Theoretical work has purported that performance under pressure may be influenced by the appraisal of the situation (Nicholls & Polman, 2007). Various psychological appraisals exist and differ in their proposed effect on sport performance (e.g., harm/loss, threat, and challenge; Lazarus, 1999). A harm/loss appraisal is concerned with damage that has already occurred. Threat appraisals refer to the situation potentially bringing about future damage and often leads to poorer sport performance (Moore et al., 2013). While challenge appraisals are centred around the potential for success in the situation and have been associated with improved sport performance (Brimmell et al., 2019; Lazarus, 1999).

Researchers have a longstanding interest in whether psychological appraisals influence pressurised sport performance (e.g., Moore et al., 2012). Studies have recreated pressurised tasks in the lab and tried to evoke a stress response. The stress response is often assessed by weighting task demands against personal coping resources and various measures have been used to understand this appraisal in individuals (Brimmell et al., 2019). Turner and colleagues (2012) found that amateur netball players who evaluated an upcoming netball shooting task as more of a challenge also achieved a higher score on the shooting task. Turner and colleagues (2013) then looked to expand on this finding with elite cricketers. However, the results revealed that elite cricketers who appraised the pressurised batting task as a challenge, did not outperform those who appraised the situation as threatening. While these findings may appear contradictory, the appraisal measurement used may not be optimal. The research assessed appraisals with a single item self-report measure (i.e., ‘How challenged or threatened do you feel right now?’) which does not directly address the theoretical propositions in which stress appraisals are grounded (Blascovich, 2008; Lazarus & Folkman, 1984).

Blascovich (2008) suggested that upon initial interaction with a pressured situation, individuals will evaluate the demands of the current situation (i.e., this situation is not very demanding vs this situation is extremely demanding). The individual will then appraise their personal coping resources considering the current situation (e.g., my resources are insufficient for this situation vs my resources meet or exceed the demands of this situation). Research that has utilised this proposition for psychological appraisals under pressure have found support for its application (e.g., Brimmell et al., 2019). Brimmell and colleagues (2019) reported that soccer players who deemed themselves to have sufficient resources to meet the demands of a pressurised soccer penalty task, performed better. In addition, research that evoked either a challenge or threat appraisal in novice golfers found that those who received a challenge manipulation outperformed those who received a threat manipulation on a golf putting task (Moore et al., 2012). These studies showed that a distinct instructional set can influence appraisal (Brimmell et al., 2019; Moore et al., 2012; Turner et al., 2013). Questions remain around the ability to examine psychological appraisals when using measures with one or two self-report items, as well as issues around estimation accuracy (Kline, 2005). It has been suggested that to accurately measure an unobservable latent psychological construct at least four items are needed to ensure the variable is accurately captured (Harvey et al., 1985).

A more apt measurement may be the Stress Rating Questionnaire (SRQ; Edwards et al., 2015). The SRQ utilises five items to measure situational stress responses. Research has found this measure to be effective in determining changes in personal assessments of feelings in pressure and stressful situations (e.g., Edwards et al., 2016). For example, Edwards et al. (2016) obtained SRQs before and after administering manipulation instructions designed to increase stress prior to the completion of an inhibition task. Instructions included manipulating individuals into either a high-pressure (i.e., highlighting poor task performance) or a low-pressure (i.e., highlighting task information) condition. The results revealed that individuals who were manipulated into the high-pressure condition reported significantly higher composite SRQ scores at the post-instruction stage compared to the low-pressure condition. However, this measure remains unexamined in pressure situations within sport.

An often-unconsidered element of the SRQ is the inclusion of anxiety as an explicit item (Edwards et al., 2015). It is widely proposed that anxiety is largely influential within stressful sport performance and responses to pressure (Hanton et al., 2008; Neil et al., 2007; Wilson, 2008). Anxiety has been documented as an adverse evaluation of a situation that may also negatively impact upon one’s self-esteem (Eysenck, 1992). While anxiety is typically reported as a negative emotion, numerous theoretical frameworks have suggested possible adaptive performance under high-pressure (e.g., The Directional Perspective, Jones, 1991; The Transactional Perspective of Stress, Lazarus & Folkman, 1984; and Processing Efficiency Theory, Eysenck & Calvo, 1992). Given that research can account for both performance decrements and enhancement within pressure situations, it is plausible that personal interpretations of anxiety in these situations may be crucial.

1.4 Anxiety in Sport

Research suggests that anxiety, and particularly negative interpretations of anxiety, is one of the main factors behind deficits in sport performance (Hanin, 2010; Lewis & Linder, 1997). Anxiety is commonly delineated into two dimensions. First, trait anxiety which is believed to be relatively stable disposition and second, state anxiety which is a situation dependent and susceptible to mood change (Spielberger, 1983). Pijpers et al. (2003) manipulated anxiety levels by placing novice rock climbers into either a ‘low’ (low situational anxiety) or ‘high’ (high situational anxiety) height climb. Results revealed that rock climbers placed into the ‘high’ height climb group reported greater levels of state anxiety and showed poorer climbing performance (slower completion times and greater movement entropy). It is important to note that the traverse routes were identical, it was only the altitude and degrees of incline that differed between groups (Pijpers et al., 2003). In a study that examined both trait and state anxiety, it was again shown that as anxiety increased, performance suffered (Horikawa & Yagi, 2012). Specifically, Horikawa and Yagi (2012) found that, following the administration of pressure inducing instructions (i.e., manipulation of situational or state anxiety), soccer players with higher levels of trait anxiety also scored higher on a measure of state anxiety and performed poorer on a penalty kick task (i.e., fewer successfully converted penalty kicks).

Anxiety is believed to be the emotional manifestation of stress within sport (Spielberger, 1989). Given the frequency of stressful moments within sport it is important to ensure researchers use valid and reliable assessments of anxiety. There are a number of tried and tested methods for capturing anxiety including cortisol testing, heart rate variability, and self-report measures. Cortisol testing provides a physiological method of recording anxiety levels that are often combined with self-report measures (e.g., Competitive State Anxiety Inventory-2; Filaire et al., 2001). Combined measures are commonplace given that physiological methods are objective (e.g., physical biomarkers in hair cortisol; Gerber et al., 2012) yet are less useful for understanding personal interpretations of stressful situations. For example, "fight or flight" research has outlined that increases in adrenaline prepare the individual for both facing the stressor (i.e., "fight") and avoiding the stressor (i.e., "flight"; Goldstein, 2010). As a result, the increased cortisol, heart rate activity or adrenaline isn't a precise assessment of the situation or of potential compensatory factors used (e.g., effort; Eysenck et al., 2007). Further, physiological measures of anxiety (e.g., cortisol and heart rate variability) lack utility in sport given that they are more invasive, can be more time consuming, and costlier than more readily applied self-report measures. Such individual interpretations of anxiety, therefore are more readily available in self-report measures.

Self-report measures of anxiety have become the most common method of assessment potentially due to ease of administration, less burden placed upon participant, and low cost compared to physiological measures (Balsamo et al., 2018; Dennis et al., 2007). Commonly used self-report measures include the State-Trait Anxiety Inventory (STAI; Spielberger, 1983) and the State-Trait Inventory for Cognitive and Somatic Anxiety (STICSA; Ree et al., 2008). The STICSA measures both cognitive (i.e., thoughts) and somatic (i.e., physical) feelings of anxiety, reporting of state (i.e., situation specific) and trait (i.e., general disposition) factors, and has good validity and reliability (e.g., in clinical samples; Gros et al., 2007, and non-clinical samples; Edwards et al., 2015). Given that both STAI and STICSA are somewhat demanding in terms of length when administered in their full form (STAI: 40

items, STICSA: 42 items) research has examined the effectiveness of shorter measures (e.g., SRQ; Edwards et al., 2015). The SRQ is a 5-item scale that captures aspects of state anxiety, such as how nervous, fearful, anxious, worried, and tense a person feels in a given moment, produced by situational stressors (Edwards et al., 2006).

A positive attribute of self-report measures of anxiety is that there are a number of statistical processes for ascertaining reliability and validity. For example, Carlucci et al. (2018) assessed the dimensionality and convergent validity of the STICSA in a non-clinical non-athlete sample. Confirmatory factor analysis results showed support for the multi-faceted nature of the STICSA (i.e., assesses both state and trait anxiety). Good convergent validity was also found in relation to other anxiety measures for the STICSA (i.e., the STAI and the Beck Anxiety Inventory; Beck et al., 1988). Despite positive psychometric evaluations research has since developed a more sport-centred method of measuring anxiety (i.e., the Competitive State Anxiety Inventory-2; Martens et al., 1990). However, concerns over the accuracy of data obtained from this measure have been raised (e.g., Craft et al., 2003) and questions have been asked of the original validation studies from Martens and colleagues (1990). As a result, recent studies have used domain general self-report measures with high validity and reliability to assess anxiety in sport (e.g., STAI in Ducrocq et al., 2016).

Although measuring trait and state anxiety is useful, state anxiety may be more relevant for competitive sport as many situations involve emotional reactions to competitive stressors (Mellalieu et al., 2009). Given the prevalence of such situations, performance decreases are often associated with somatic and cognitive emotional changes experienced by the individual within that moment of pressure (Mellalieu et al., 2009). It is believed that a performer can either succeed or fail in stressful situations and that the outcome is often dependent on the interpretation of the anxiety felt within the moment (Hanton et al., 2008). It has been theorised that anxiety may impact performance through its effect on attentional control (e.g., ACT-S; Eysenck & Wilson, 2016). Numerous theories have surfaced documenting that performance does not have to suffer in high-pressure situations (e.g., Eysenck & Calvo, 1992; Jones, 1991). That is, theoretical propositions have been made around individuals showing maintained, or increased, performance within these moments (e.g., Processing Efficiency Theory, Eysenck & Calvo, 1992; ACT, Eysenck et al., 2007).

1.5 Theoretical Propositions of Anxiety and Attention

Early theoretical accounts of anxiety and performance often focused on how anxiety would distract an individual by drawing focus away from task-relevant information (Payne et al., 2019). The Inverted “U” hypothesis (Yerkes & Dodson, 1908) proposed that increased arousal was beneficial for sport performance to a point (around 60-70% maximum arousal; Arent & Landers, 2003), after which, continued increases in arousal causes detriments to performance through distraction (Krane, 1992). However, this model has received heavy criticism for a number of reasons (Krane, 1992). Namely, the Inverted “U” inaccurately uses terms like anxiety and arousal interchangeably, doesn’t consider the multidimensionality of anxiety (i.e., cognitive and somatic, nor trait and state), does not establish causal relationships, does not consider personal interpretations, and perhaps most importantly offers no mechanistic understanding of the how and why anxiety can influence performance (Krane, 1992). The Catastrophe theory from Hardy and Parfitt (1991) expanded upon and dealt with some issues present in the Inverted “U” theory (e.g., considered cognitive and somatic symptoms) but ultimately suffered from a lack of understanding around the mechanisms behind the anxiety and sport performance relationship (Payne et al., 2019). These limitations led researchers to create new distraction-based theories that also examined methods through which anxiety could impact performance (e.g., attentional control; Eysenck et al., 2007).

1.5.1 Processing Efficiency Theory

Processing Efficiency Theory (PET; Eysenck & Calvo, 1992) purports that worry and working memory are primary factors influenced by anxiety. In anxiety inducing situations individuals can feel a degree of worry which then can have one of two predominant influences (a more positive and more negative response). First, worry is said to pre-allocate storage and processing resources which leads to inferior performance in tasks high in cognitive demand. It is hypothesised in PET that worrisome thoughts consume large quantities of limited attentional resources in such scenarios limiting resources available for task-relevant processing. Second, and more positively, worry is anticipated to trigger a motivational response. When faced with potential sub-optimal performance, worry can lead to the allocation of additional processing resources (namely effort) in order to maintain task performance (Wilson, 2008). A salient assumption of PET is that there is a distinction between performance effectiveness and efficiency. Where performance effectiveness is solely concerned with the quality or accuracy of task performance, and processing efficiency considers both the effectiveness of performance and the processing resources (e.g., effort, time) invested (Eysenck & Calvo, 1992; Wilson, 2008). It is therefore possible for attention and performance to be maintained, or even improved (i.e., with recruitment of additional effort or more time), under anxiety, though not explicitly outlined in PET.

Processing Efficiency Theory also outlined the important role of working memory during moments of anxiety and borrows the theoretical model proposed by Baddeley (1986). Following theoretical expansion, the proposed model of working memory consists of four components: 1) the central executive, 2) the visuospatial sketchpad, 3) the phonological loop, and 4) the episodic buffer (Baddeley & Hitch, 2001). The model has a main attentional system, the central executive, that is supported by the two short-term operating systems: one centred on visual material (i.e., the visuospatial sketchpad) and one on verbal-acoustic material (i.e., the phonological loop; Baddeley, 2010). The episodic buffer was added following theoretical expansion with the role to hold multi-modal components (i.e., combine visual and auditory information; Baddeley, 2010). The buffer is passive in its role and is believed to be limited in capacity (Baddeley, 2010). It is outlined by PET that anxiety is particularly impactful on the central executive, and as expected, the strength of the effect from anxiety is enhanced during tasks that place more demand on working memory (and the central executive in particular; Eysenck et al., 2007). Numerous empirical examples have tested and found support for these effects proposed by PET (e.g., Wilson & Smith, 2007; Wilson et al., 2007).

Edwards et al. (2002) conducted interviews with elite athletes from various sports and noted that stronger feelings of anxiety were coupled with increased effort to maintain task performance. The results also revealed that perceived effort levels were significantly different before and after a decrease in performance. More precisely, effort levels increased if performance was perceived to be decreasing which concurs with the assumptions of PET (Edwards et al., 2002). Though interview-based research provides good insight into personal interpretations of anxiety experiences under pressure, their retrospective design includes inherent recall and bias discrepancies. Research has since opted to examine state anxiety prior to or during pressurised tasks (Wilson, 2008). For example, Wilson and Smith (2007) examined anxiety, effort, and performance in elite female hockey players at an international competition. After categorising upcoming games based on ‘threat’ level (i.e., perceived difficulty of opponent) the results showed significant increases in self-reported anxiety and effort but no changes in performance (assessed via expert coach ratings). Williams and colleagues (2002) tested the working memory predictions of PET by manipulating working memory demands during a table tennis task. Results showed support for PET in that anxiety negatively impacted effectiveness and efficiency, and the decrements were more distinct when working memory demands were high compared to low.

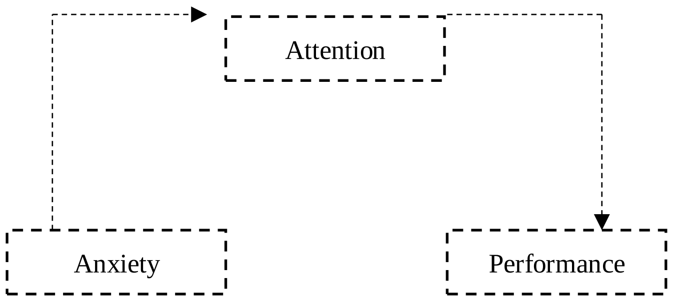
A number of empirical research examples support PET and suggest that anxiety can impact performance effectiveness and efficiency through disruption caused to working memory. Despite this support a number of criticisms and limitations of PET have been outlined. One large issue with PET is that it makes no specific assumptions about which functions within the central executive are impaired by anxiety (Eysenck et al., 2007). Research has noted that the central executive is neurologically located within the pre-frontal cortex of the brain and houses a number of cognitive functions (Miyake et al., 2000). There is a lack of emphasis on how individuals perceive different types of stimuli. Specifically, highly threatening or distracting stimuli most likely exasperates the negative response in anxious individuals. Sport is rife with situations high in emotional valence therefore theoretical application of how individuals respond to these stimuli is key. Finally, PET is limited in consideration that individuals high in anxiety can outperform their low-anxious counterparts, often through compensatory measures addressed in subsequent theory (e.g., effort; Eysenck et al., 2007) or complementary associated variables (e.g., expertise).

1.5.2 Attentional Control Theory

Attentional Control Theory (ACT; Eysenck et al., 2007) was designed to build on the limitations of PET and has become one of the most important theories for understanding anxiety, attention, and performance during moments of pressure (see Figure 1.1). A key expansion of ACT is the specific focus on the attentional mechanisms impacted by anxiety. The inclusion of two neurological attentional systems (i.e., the goal-directed and stimulus-driven systems) that serve different roles within humans offered researchers a better way of understanding the anxiety-attention relationship (Corbetta & Shulman, 2002). The goal-directed system follows a “top-down” approach through conscious control of attention whereby attentional resources are allocated to meet current goals and search for task-relevant stimuli. An example of the goal-directed system in sport could be when the ball-carrier in a game of soccer is actively searching for teammates on the field to pass to. The stimulus-driven system is more concerned with the rapid detection of unexpected and highly salient stimuli (Corbetta & Schulman, 2002). For example, during a soccer penalty kick the taker expects there to be a goalkeeper and a goal. However, goalkeepers often use distracting techniques (e.g., jumping up and down coupled with arm waving) to try and suddenly draw the takers attention away from the task at hand (i.e., placing the ball into the net).

Figure 1.1

The Model of Attentional Control Theory. Anxiety Influences the Attentional Systems (Goal-Directed and Stimulus-Driven Systems) which then Impacts Subsequent Performance (Eysenck et al., 2007).



Both ACT (Eysenck et al., 2007) and Corbetta and Schulman (2002) hypothesise that a balance between the goal-directed and stimulus-driven system is optimal for performance. Balance may be optimal as it is incorrect to consider that goal-directed attention alone is enough for success, especially in situations whereby threatening information (i.e., stimuli or thoughts) pose a genuine threat to the individual achieving a goal. Therefore, the two systems have to interact with one another to monitor potential threat but also achieve the goal. It is when these systems are imbalanced (i.e., over activation of the stimulus-driven system) that performance can suffer during high anxiety or pressurised moments. Specifically, anxiety disrupts the balance between the two attentional systems and causes over-activation of the stimulus-driven system so attention cannot be drawn away from something salient/threatening. Another key expansion within ACT is that it outlines the specific attentional control components within the central executive that are susceptible to anxiety. These constructs include inhibition, shifting, and updating and have been collectively referred to as the lower-order model of EF (Miyake et al., 2000). The relationship between these three EFs has been subjected to confirmatory factor analysis with the results suggesting a complex relationship whereby the constructs are inter-related, yet distinct (Miyake et al., 2000).

These EFs (i.e., inhibition, shifting, and updating) are believed to be distinct in that unique tests can be designed to examine a single function and that each function is somewhat unique in its role within the central executive (Eysenck et al., 2007). Inhibition is the capacity to withhold automatic responses, incorrect responses, and avoid distraction (Friedman & Miyake, 2004). Shifting refers to the ability to switch back and forth between operations or rulesets (Miyake et al., 2000). These two EFs have been outlined as highly pertinent in ensuring effective and efficient goal-directed behaviour. Finally, updating is the ability to manipulate information within working memory replacing task irrelevant information with newer, more relevant information (Miyake et al., 2000). Updating has been outlined as a function more concerned with short-term storage of information than direct interpretation of information within attentional control (Eysenck et al., 2007). As a result, ACT outlines that the effect of anxiety should be greater on inhibition and shifting and to a lesser extent on updating (Eysenck et al., 2007).

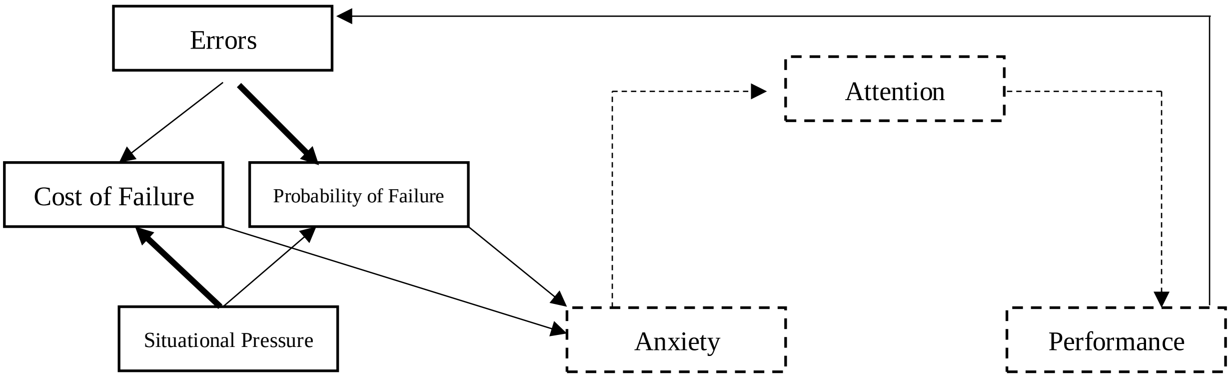
There are a number of theoretical assumptions outlined in ACT. The first assumption is retained from PET and states that performance efficiency is more effected by anxiety than performance effectiveness. Additional assumptions outlined by ACT reflect the expansion into specific attentional control systems (i.e., goal-directed and stimulus-driven) and specific EFs within the central executive (i.e., inhibition, shifting, and updating). The second hypothesis suggests that anxiety impairs attentional control by causing an increase in the influence of the stimulus-driven system. Also, the adverse effects of anxiety on performance increase in parallel as more demands are placed on the central executive. Anxiety is believed to impair the efficiency and effectiveness (effectiveness to a lesser extent) on the shifting, inhibition (especially when threat-related distractors are present), and updating (under stressful situations only) EFs respectively (Eysenck et al., 2007). Despite empirical evidence supporting the assumptions of ACT individuals interested in testing this model in sport have proposed modifications to expand upon ACT and offer greater understanding of how attentional control, anxiety, and sport performance relate.

1.5.3 Attentional Control Theory-Sport

Attentional Control Theory-Sport (ACT-S; Eysenck & Wilson, 2016) retains a number of key elements of ACT including the importance of the two attentional systems (i.e., goal-directed and stimulus-driven) and provides a complimentary, often sport-focused, extension of ACT (see Figure 1.2). One core factor largely reemphasised in ACT-S is how personal levels of anxiety influence subsequent performance. A novel contribution of ACT-S is that it considers the antecedents of anxiety (i.e., how exactly pressure leads to anxiety; Harris et al., 2019). Broadly speaking there are four additional components introduced in ACT-S including: 1) the determinants of anxiety such as potential cognitive biases associated with the perceived probability and cost of failure, 2) how feedback loops from prior experiences can lead to anxiety, 3) that disruptions to attentional control are likely sporadic (i.e., state-like) rather than constant (i.e., trait-like), and 4) that factors like effort or motivation can support performance (Eysenck & Wilson, 2016).

Figure 1.2.

The model of Attentional Control Theory-Sport. More focus is placed on the antecedents of anxiety (solid black lines; Eysenck & Wilson, 2016).



The cognitive biases mentioned within ACT-S are based on the two-phase model of worry from Berenbaum (2010). First, attentional biases are when an individual increases their attention allocation toward threatening stimuli at the expense of neutral stimuli (Bar-Haim et al., 2007). Second, interpretive biases occur when an individual perceives an entire unknown situation as threatening. Both attentional and interpretive biases are associated with increased anxiety and are believed to be the base from which perceptions around the probability and cost of failure stem from in ACT-S (Eysenck & Wilson, 2016). Specifically, anxious individuals may interpret a high-pressure situation as a threat (i.e., interpretation bias) resulting in a higher perceived cost of performance failure and an increased likelihood of negative performance (Baumeister, 1984; Eysenck & Wilson, 2016). The probability of an undesirable outcome (e.g., failure, losing a game, etc.) may become more likely due to continued individual errors. Previous individual errors therefore may lead to increased attentional focus to threatening stimuli that may cause the individual to produce another error (i.e., attentional bias). For example, an individual that has a soccer penalty kick saved by the goalkeeper may pay increased attention to this task threatening stimuli (i.e., the goalkeeper) in subsequent penalty kicks, potentially resulting in more centrally located kicks, thus reducing the likelihood of successful performance (Wilson, Wood, & Vine, 2009).

Commentary on previous errors leading to potential future errors leads nicely to another theoretical edition of ACT-S, namely the inclusion of personal feedback loops (Eysenck & Wilson, 2016). It is hypothesised that in moments of high-pressure individuals that are more anxious will draw upon negative previous situations in which performance was unsuccessful (Harris et al., 2019). The third expansion of ACT-S is that high-pressure situations do not lead to disrupted attentional control at all times but are more sporadic with specific situations impacting attentional control (Eysenck & Wilson, 2016). This may suggest that state measures (i.e., situation specific measures) of anxiety and stress are more suitable to use when research is grounded within ACT-S than trait measures (i.e., more stable long-term measures). A combined look at these three additions of ACT-S highlight the importance of understanding individual interpretations of a pressurised situation in the exact moment it occurs to rigorously test elements of ACT-S.

The fourth, and final, new addition of ACT-S concerns compensatory factors like effort and motivation. Such factors are recruited at varying degrees to help combat the potentially negative effects of anxiety upon performance. It is noted in ACT-S that these factors may indeed help performance effectiveness, but are detrimental to performance efficiency (Eysenck & Wilson, 2016). Performance accuracy is often used to index effectiveness (e.g., Derakshan & Eysenck, 1998) with anxious individuals able to maintain accuracy through the above-mentioned factors. But this often comes at the expense of time and therefore, makes performance inefficient (i.e., extended periods of time needed to achieve similar accuracy levels; Eysenck et al., 2007). This distinction between effectiveness and efficiency is an important component within ACT and ACT-S but has received somewhat limited research attention in sport. However, sport and exercise may be a domain whereby efficiency is particularly important (especially open-skill sports whereby individuals are placed under external time-constraints) and therefore research should look to comment on effectiveness and efficiency as individual performance outcomes.

A number of the theoretical advancements of ACT-S (i.e., cognitive biases, feedback loops, sporadic nature, and compensatory factors; Eysenck & Wilson, 2016) have recently been tested in sport and exercise psychology research, both directly and indirectly. For example, Harris et al. (2019) claimed to provide the first direct test of the basic assumptions of ACT-S seemingly choosing to focus on the feedback loops and sporadic nature of the anxiety-performance relationship. In an analysis of real-world NFL American Football plays, Harris et al. (2019) suggest that failure on a play (i.e., a situation where the offense attempts to gain field territory) leads to an increased likelihood of subsequent failures offering support for this component of ACT-S. Harris et al. (2021a) followed up their own work in a closed sport (i.e., tennis) given complications around different experiences of pressure in more open team sports (i.e., American Football; Harris et al., 2021a). However, the result pattern was similar to Harris et al. (2019) in that errors seem to cause future errors. In a more indirect assessment of the cognitive bias component of ACT-S, Liu et al. (2019) used a Dot Probe Task and found that high state anxiety lead to a negative attentional bias toward further negative stimuli. This early work seems to support the extension offered in ACT-S though more work on the role of compensatory factors is needed.

1.5.4 Combining Executive Function and Visual Attention into Theory

A key hypothesis within ACT is that feelings of anxiety cause disruptions to attentional control and subsequent task performance (Eysenck et al., 2007). This idea was expanded upon in ACT-S, with focus shifting toward the antecedents of anxiety in moments of pressure (e.g., cost and probability of failure; Harris et al., 2019), and the core relationship between situational anxiety, attentional control, and performance remained. Though central to both ACT and ACT-S attentional control has been applied and examined in numerous different contexts. Specifically, research has either examined the theoretically proposed EFs of attentional control (i.e., inhibition, shifting, and updating) or utilised eye-trackers to measure gaze behaviour. It is important to remember that attentional control cannot be summarised through foveal attention alone (i.e., gaze behaviour) but likely works in cooperation with more covert processes of attentional control (i.e., EF). Therefore, research premised on theoretical accounts like ACT-S should include designs capable of examining the multi-faceted nature of attention and robust measures of attentional control.

The present thesis is the first to directly consider both executive and visual sub-components of attentional control in sport and the proposed model is shown in Figure 1.3. Though rarely examined together in sport, there is ample neuroscientific and cognitive psychology research that may allude to a working relationship between EF and VA (e.g., Gaillard & Ben-Hamed, 2022) and one that could transfer to sport. For example, Broadbent (1958) proposed the Attentional Bottleneck Theory of information processing (Bater et al., 2019). According to Attentional Bottleneck Theory, copious visual stimuli reach the sensory buffer (a brain modality for briefly acknowledging stimuli) but limited stimuli reach short term memory and are processed semantically and perceptually (Broadbent, 1958). Thus, creating the “bottleneck” analogy whereby lots of visual stimuli reach the larger base of the bottle, but as the bottle opening begins to narrow, information for processing is reduced (representing a human’s limited processing capacity). It is believed that the initial mass of visual stimuli is cognitively filtered on relevance (i.e., either task relevance or salience) and that only key stimuli passes through the bottleneck (Bater et al., 2019).

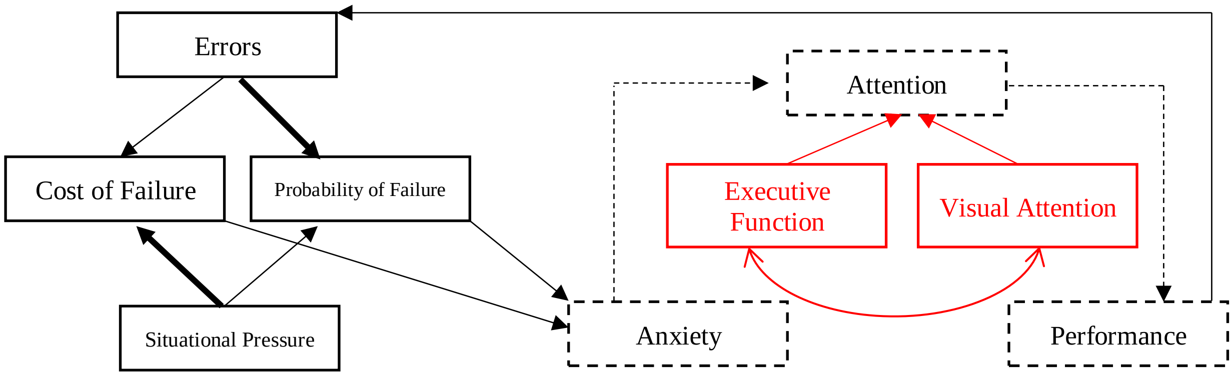
The Attentional Bottleneck Theory, though criticised for over-simplicity (e.g., lack of awareness toward late stimuli processing; Bater et al., 2019), does showcase a relationship between cognitive processing (i.e., EF) and VA. Specifically, this theory outlines that in a world full of visual stimuli there is some kind of cognitive “filter” that selects which stimuli passes through the bottleneck and receives further visual attention. Itti and Koch (2001) expanded upon this theory and outlined in more neuroscientific language the mechanisms that may control both EF and VA. Specifically, all visual stimuli attended to first reaches the visual cortex within the occipital lobe. The visual information then progresses along two neural systems in parallel. These include the dorsal system (including the posterior parietal cortex) which controls top-down goal-directed spatial attention and the ventral system (including the inferotemporal cortex) which controls the recognition of bottom-up stimulus-driven attention (Corbetta & Shulman, 2002). Next, information reaches the pre-frontal cortex which is responsible for modulating the dorsal and ventral streams and finally, directs eye movements based on the information received (Itti & Koch, 2001).

Itti and Koch (2001) provide support for the idea that visual information reaches the pre-frontal cortex, the pre-frontal cortex is then, in part, responsible for directing subsequent eye movements. The interest here lies in the role of the pre-frontal cortex for both visual information processing and directing eye movement and the previously outlined link between the pre-frontal cortex and EF (Miyake et al., 2000). Together this neuroscientific and cognitive psychology research may provide the basis for a working relationship between EF and VA in a sport setting. More specifically, the EF and VA connection may provide a basis for research to understand what visual information individuals attend to, how EF facilitates the processing of this information within the pre-frontal cortex, and how these EFs might relate to subsequent eye movements in sporting situations. For example, in a pressurised sporting scenario (e.g., a soccer penalty kick; Brimmell et al., 2019) individual’s may attend to numerous stimuli (e.g., the goal and goalkeeper). This visual information then reaches the pre-frontal cortex where the EF of inhibition may facilitate subsequent eye movements to goal-directed stimuli (e.g., the goal) and not task threatening stimuli (e.g., the goalkeeper).

Furthermore, the present thesis aimed to extend the limited research in sport examining EF and VA together. Though scant, some research does indicate a potential relationship between EF and VA (e.g., Klostermann, 2020; Scharfen & Memmert, 2021). For example, Wood and colleagues (2016) split participants into a high- and low-working memory capacity groups (based on operation span scores) and found that the high-working memory capacity group showed shorter visual search times and longer quiet eye durations than their low-memory counterparts. Ducrocq et al. (2016) also suggested a link between EF and VA and included a measure of sport performance. Following inhibition training the trained group showed later first target fixations (indicating greater inhibition) and improved tennis serves. Despite this work providing a solid basis for future studies, these examples are not inclusive of all theoretically proposed EFs, and do not directly assess the relationship between EF and VA.

Figure 1.3.

The proposed adapted model of Attentional Control Theory-Sport. The addition the present thesis is making is in red. The proposition is that theoretical depictions of attention should consider the contribution of EF and VA. Additionally, the curved red arrow between EF and VA shows a bidirectional relationship.



One of the main aims of the present thesis was to better understand the joint contribution of EF and VA and expand ACT-S (i.e., through separating attentional control into executive and visual processes; Figure 1.3). There have been a large number of studies trying to validate the hypotheses of ACT and ACT-S. A number of ACT/ACT-S's hypotheses were somewhat dependent on relatively controlled tasks in which particular functions within the central executive are isolated (e.g., inhibition). Despite this, one of the most typical methods for assessing the predictions of ACT and ACT-S is through gaze behaviour obtained through an eye-tracker in laboratory-replicated and/or natural pressurised sport scenarios. Such methods have risen in prominence throughout sport and exercise science due to research claims that measures of attentional control obtained with an eye-tracker are more objective (Ducrocq, 2019; Wilson, 2012). Specifically, lightweight, portable, and highly-accurate mobile eye-trackers allow researchers to capture the true location of foveal attention. However, these measures may lack understanding on the cognitive underpinnings of such processes that can be assessed through EF tasks. As such, it is important to understand procedures for replicating sport under pressure, measuring VA, and measuring EF in the same study.

1.6 Study Design and Materials for Measuring Attentional Control

1.6.1 Manipulating Pressure in a Laboratory

Recreating sporting scenarios in the laboratory provides researchers with a controlled environment to examine and better understand specific processes (e.g., Brimmell et al., 2019). Study design in this area is important given that pressure moments are rife in sport and in these moments, anxiety can negatively impact an individual's attentional control (Hanton et al., 2008). Therefore, study designs have to ensure that sporting tasks reflect, or as close as realistically possible, situations that an athlete may encounter in their natural sporting environment. To achieve this in laboratory-based studies, recreating pressure is key to ensuring ecological validity. Research has a long-standing relationship with manipulating the perceived demands of a task in order to create a feeling of pressure somewhat equivalent to that of "real" sport (see Gropel & Messagno, 2019, for a review). Verbal instructions covering elements such as videotaping (e.g., Balk et al., 2013; Mesagno et al., 2009), rewards and punishment (e.g., Moore et al., 2012; Wood & Wilson, 2011; 2012), perceived competition (e.g., Balk et al., 2013; Moore et al., 2012), and ego relevance (e.g., Moore et al., 2012; Vine & Wilson, 2010; 2011) have been consistently utilised to successfully (most often in combination) enhance feelings of anxiety and create a pressurised scenario in a laboratory experiment.

Of equal importance is ensuring that such manipulations are successful. Specifically, do individuals report higher anxiety or situational stress post- when compared to pre-manipulation. Pre- and post- manipulation analyses have supported the use of instructional sets (e.g., Balk et al., 2013; Moore et al., 2012). For example, participants in Balk and colleagues (2013) work showed significantly higher self-reported perceived pressure and stress when asked to complete golf-putts in a high-pressure condition (i.e., told they would be videotaped, in competition, and potentially rewarded) compared to when asked to complete golf-putts in a low-pressure condition (i.e., standard task instructions focused on completion of the task). Including such instructions and assessing their impact (i.e., a manipulation check) is an effective way in which to recreate pressure in a laboratory setting and thus ensure that the processes behind attentional control (i.e., either EF or visual) are being adequately examined. Indeed, the SRQ may prove a useful tool to assess pressure or stress creation and has been used previously (e.g., Edwards et al., 2015).

1.6.2 Assessing Gaze Behaviour in Laboratory Studies

In sport-related research mobile eye-trackers have become the most utilised instrument for directly measuring gaze behaviour during sensorimotor tasks (Wilson, 2012).

Eye-tracking devices can record both eye-movement and the visual scene before combing the two in a single recording for analysis (Kredel et al., 2017). In such recordings, participant gaze location can be assumed by mapping a superimposed positional cursor that represents current gaze location to stimuli within the visual scene. For example, in a soccer penalty kick the superimposed cursor can indicate which of the key information (i.e., the goal, goalkeeper, ball, or area around the goal; Brimmell et al., 2019) that the individual is looking at before performing an action. These techniques can therefore be used to better understand which factor may be more salient for performance (i.e., where to look, when to look, and for how long; Moran et al., 2019). Eye-trackers have also become a popular method for understanding expert and novice differences (i.e., where do experts look and how does this impact task performance; see Mann et al., 2007, for a review) and, more pertinent to the present thesis, how psychological constructs like anxiety and pressure can impact this facet of attentional control (e.g., Wilson, Vine, & Wood, 2009).

Gaze metrics are commonly calculated from eye-tracking data as they are believed to represent "top-down" attentional control (i.e., eye movements relate to current goals; Ducrocq et al., 2019). Although "top-down" attentional control has been noted to share neural substrates with cognitive shifts of attention (Corbetta, 1998), it remains that visual gaze may be dissociated from the actual focus of attention and therefore, it is unlikely that eye movements alone explain attentional control. Specifically, covert attentional processes (e.g., EF) likely play a role, particularly in situations where deceptive eye movement strategies are required. For example, in soccer penalty kicks various strategies have been outlined (Kuhn, 1988). In a strategy coined "keeper-dependent" the penalty taker focuses visual gaze upon the goalkeeper despite intending to kick the ball elsewhere. In this situation, gaze behaviour is not used to locate, focus on, or specify a target for goal-directed action (Kuhn, 1988). Instead, processes like updating the goalkeeper's location in working memory and inhibiting the impulse to kick toward the moving goalkeeper are used to guide motor action. As a result, examining visual gaze alongside cognitive attentional control (i.e., EF) may be highly informative and allude to a joint role of multiple attentional systems. Moreover, research in sport has previously looked at the distinct role of multiple attentional systems during sport performance. For example, Panchuk et al. (2013) outlined that successful motor performance in ball throwing required the integration of information obtained from two key attentional systems the ventral (i.e., responsible for object recognition) and dorsal (i.e., responsible for sustained action regulation) systems.

A number of popular eye-tracking gaze metrics have been consistently used to index attentional control and potentially the most popular is the quiet eye phenomenon (Mann et al., 2007; Vickers, 2007). The quiet eye variable concerns the duration and location of the final visual fixation before an individual begins a critical movement phase. Specifically, the quiet eye duration refers to the maintenance of gaze within 1° visual angle for a minimum of 120ms before the critical movement (Vickers, 2007). Quiet eye location refers to the spatial location of the final fixation within the visual scene. The quiet eye is believed to be a key phase, particularly in aiming tasks (e.g., soccer penalties), where information related to motor performance is efficiently and effectively planned. The quiet eye itself is a visual gaze metric and its popularity is in large part due to the fact that it reflects a critical period where individuals internally couple perception and action (Vickers, 2007). To do so, cognitive processes are likely utilised alongside gaze to ensure that the quiet eye period is of suitable length to allow optimal information processing and movement planning. One way to extend the quiet eye duration may be through the successful application of the inhibition hypothesis (Klostermann, 2020) which again attests to a potential relationship between EF and VA.

The inhibition hypothesis broadly states that when performing a motor task there are often a large number of approaches that could be used to complete the task (Cisek, 2012). For example, when selecting a single apple from a tree full of apples at some point one apple must be singled out as the target, perception must be coupled with action, and the apple picked from the tree. At the same time the selection of all the other apples must be decoupled from the reaching action (Allport, 1987). In a study examining the inhibition hypothesis in relation to the quiet eye phenomenon, Klostermann et al. (2014) reported that the quiet eye serves a period where the individual inhibits the preparation of sub-optimal solutions in favour of a more suitable solution. This result places less emphasis on the location of visual gaze (e.g., quiet eye location) and emphasises that sustained visual gaze (e.g., quiet eye duration) may facilitate inhibition of inadequate task solutions and enable better performance. It is important to note that this line of research considers only inhibition which is just one of a family of inter-related processes (i.e., EFs; Miyake et al., 2000). The relevant contribution of shifting and updating to VA and subsequent sport performance is less clear.

1.6.3 Assessing Executive Function in Laboratory Studies

Another common method of assessing attentional control in a laboratory is through computerised EF tasks (Derakshan & Eysenck, 2009). Such tasks attempt to isolate specific attentional processes. These processes are typically aligned with the lower-order model proposed by Miyake et al. (2000) and utilised within ACT and ACT-S (e.g., inhibition, shifting, and updating; Eysenck & Wilson, 2016) and examine individual performance. The lower-order model of EF consists of inhibition which refers to the capacity to alter responses based on initial feedback that the original action is no longer task appropriate. Shifting, which involves a “shift” of attention between task instructions or tasks themselves and requires flexible spatial and interpersonal thinking (Diamond, 2013). Finally, updating is closely linked to working memory and involves the processing of new or changing information in relation to previously stored information (Miyake et al., 2000). These lower-order EFs are the same as those theoretically proposed to be fundamental to controlling attention (ACT-S; Eysenck & Wilson, 2016).

Task outcome measures are typically aligned to one of ACT-S's functional distinctions between performance effectiveness and processing efficiency. Specifically, task accuracy (e.g., correct responses, false alarms, probability of success) are performance effectiveness measures are considered as performance quality without consideration of resources used (Derakshan & Eysenck, 2009). Reaction time or response latency, and any computed variable involving time taken to respond (e.g., ratio of accuracy to reaction time score), are considered indicators of processing efficiency. Reaction time measures are indicative of efficiency given the use of additional resources (i.e., time) in order to maintain performance effectiveness (Eysenck et al., 2007). Time is an important resource where increased time to perform an action can be considered poorer efficiency. Though reaction times are only truly reflective of time as a resource, they may also strongly correlate with alternate resources (e.g., effort; Harris et al., 2019).

Computerised tasks of EF allow measurement of covert attentional control in a laboratory and assist with understanding the functional processes that are not easily observed during sensorimotor sporting performance. For example, it is clear that effectively updating content within working memory is important for soccer performance but not easy to measure in-situ. Specifically, to perform optimally in this scenario one must constantly monitor the location of numerous objects (e.g., teammates, opposing players, the ball) and couple action based on this perceptual information. If the information is incorrect (e.g., an opposing player now blocking a passing line is missed) then performance can suffer. However, understanding an individual's ability in this regard is difficult in such a scenario as the construct of interest (e.g., updating) is difficult to isolate hence the use of EF laboratory-tasks. Producing tasks that can isolate a specific EF comes at a detriment to task ecological validity, so this should also be considered when drawing conclusions. For example, the nback task (Jaeggi et al., 201) used to assess updating can isolate updating performance but has no sport-specific context.

Today some of the most common laboratory-based tasks of EF are designed to assess the core model of EF proposed by Miyake and colleagues (2000) and outlined in ACT-S (Eysenck & Wilson, 2016). This model is often referred to as the lower-order model of EF and includes inhibition, shifting, and updating. Earlier work on EFs tended to use more complex and less process-pure tasks, often coined higher-order tasks, some of which are still used today (e.g., Wisconsin Card Sorting Task; Edwards et al., 2015). These tasks were often used in clinical samples to assess impairments in cognitive function as a result of frontal lobe injury (Miyake et al., 2000). These early higher-order tasks helped research develop an understanding of lower-order EF in a number of ways. First, through the study of clinical patients with frontal lobe damage research was able to understand the neurological location of these processes (i.e., pre-frontal/frontal lobe; Verbruggen & Logan, 2008). Second, and in a similar line of work, neurological studies allowed research to understand that participation in regular physical activity led to increased blood flow to the frontal lobes improving EF performance (Weinstein et al., 2012). Finally, given the complexity of the higher-order tasks and the uncertainty surrounding which functions were at work research had to develop the targeted individual lower-order tasks that are used today.

1.7 Summary

Years of anecdotal, theoretical, and empirical evidence has led us to believe that in moments of pressure, anxiety can cause disruptions to attentional control, which in turn can influence subsequent sport performance. Based on theoretical and empirical work, attentional control can broadly be examined in two areas including EF (e.g., inhibition, shifting, and updating; Eysenck et al., 2007) and VA (e.g., the quiet eye; Vickers, 2007). Despite the plethora of tools available to understand both these areas of attentional control in athletes, there is seldom work that has examined these two constructs concurrently. That is, despite a variety of effective EF tasks, tools and variables to measure VA, and useful instructions to validly build pressure within a laboratory, the individual areas remain under-examined in relation to one another. It is most likely that these attentional processes work together for optimal performance (as in Figure 1.3), especially in moments of pressure, yet the literature is void of examples for how these important processes may relate. Specifically, in the creation of a pressurised sport task do EF and VA work together in some way to enhance subsequent sport performance (Figure 1.3).

1.8 Research Aims and Thesis Outline

The main aim of the present thesis was to better understand the direct relationship between two dominant areas of attentional control (i.e., EF and VA). Thus, the thesis aimed to extend seminal theory in this area; namely ACT and ACT-S (Eysenck & Wilson, 2016). Specifically, this thesis examined whether the attentional component of ACT and ACT-S is better reflected as comprising of distinct EF and VA components (Figure 1.3). The thesis outlined elements of research practice that are robust and at the same time addressed research gaps. Specifically, this thesis contains a systematic review of literature that examined both EF and VA in a sport-setting. The focus of this review was to better understand study methodology and association between the attentional components. There was particular effort to note what EF tasks and outcome measures were used, what VA measures were used, and any reported associations between EF and VA.

After outlining common practice, noting research gaps, and ascertaining effective methodology the present thesis sought to directly assess the relationship between EF and VA. An online study was built with two main aims. First, the goal was to replicate the proposed model of EF (i.e., inhibition, shifting, and updating) from Miyake et al. (2000) using confirmatory factor analysis. This model has been widely accepted in sport and exercise psychology without assessment of its structure in a sample of athletes. Second, confirmatory factor analysis was also used to assess the relative contribution of EF upon more visually guided tasks (i.e., VA). Note, for both these aims both performance effectiveness (i.e., accuracy) and efficiency (i.e., accuracy by time) were considered, a distinction present in theory (i.e., ACT; Eysenck et al., 2007) but often omitted from research.

After establishment of the proposed model of EF and examining the initial foundations of a relationship between EF and VA the aim was to solidify the understanding of this relationship. Specifically, this thesis aimed to understand whether EF could predict performance on a sport task (i.e., a soccer penalty kick) through the proposed mediator of VA. A cross-sectional study was deployed whereby established EFs tasks were completed before participants were fitted with a mobile eye-tracker and performed a soccer penalty task. The final aim of the present thesis was to understand the proposed relationship between EF and VA over time. A longitudinal study was designed whereby EF, VA, and sport performance were obtained at three time-points over a 6-month period. In sum, the final thesis structure is as follows: a general introduction, a systematic review of literature, a scoping online study, a cross-sectional laboratory study, and a three-wave longitudinal laboratory study.

Chapter 2: Systematic Review

2.1 Chapter Overview

Attentional control is important in sport performance (e.g., Vestberg et al., 2017). Theory suggests that the cognitive basis of attentional control comprises the lower-order EFs inhibition, shifting, and updating (ACT-S; Eysenck & Wilson, 2016). These lower-order EFs also form the basis of more complex higher-order EFs (e.g., decision-making; Diamond, 2013) and have become popular within sport psychology (e.g., Hagyard et al., 2021). Despite their popularity research often tests ACT-S's assumptions using VA from eye-trackers (e.g., Moore et al., 2013; Wood & Wilson, 2010a). Moreover, despite the theoretical link, limited research has directly examined the relationship between EF and VA. The aim of this chapter was to systematically review literature examining both EF and VA. Specifically, outline sample characteristics, cover which EFs and tasks have been used, outcome variables used to index EF and VA, and reported relationships between EF and VA. The systematic review followed PRISMA protocol (Moher et al., 2009) and yielded 64 experiments across 58 studies. Key results showed large discrepancies in how "experts" and "novices" were labelled, a large focus on higher-order EFs not the lower-order EFs with no consideration of shifting, EF outcomes typically utilised accuracy and reaction time, and common VA measures were the number of and location of fixations. Finally, very few studies included EF and VA in the same analyses but, those that did indicated a relationship. In sum, more assessment of the relationship between EF and VA is needed to understand how the two may influence sport performance.

2.2 Introduction

Successful sport performance requires, in part, a combination of outstanding cognition, perception, and VA (see Furley & Wood, 2016). Recent research supports the importance of EF (i.e., cognitive processes facilitating thoughts and behaviour; Scharfen & Memmert, 2019) and VA (e.g., the quiet eye; Lebeau et al., 2016) in successful sport performance. Studies have focused primarily on group differences and suggest that sporting experts may possess enhanced cognitive and visual abilities (Furley, & Wood, 2016). However, given the theoretical links between EF and VA (Attentional Control Theory-Sport; ACT-S; Eysenck & Wilson, 2016) it is surprising that very few studies have considered the direct and indirect association between these processes. This chapter provides the first systematic review of the literature examining the EF and VA association in sport samples. Research in this area encompasses a range of individual differences, measurement tasks and outcomes, and research designs. Therefore, given such methodological heterogeneity, a qualitative synthesis of relevant studies was conducted.

2.2.1 Executive Function

Executive functions comprise a group of distinct, yet interrelated, top-down (i.e., conscious & goal-directed) processes important for behavioural regulation (Zelazo & Carlson, 2012). Executive functions can be distinguished into lower- and higher-order processes (Diamond, 2013). The lower-order functions of inhibition (i.e., withholding a dominant response), shifting (i.e., switching between or within tasks), and updating (i.e., monitoring information in working memory) are described by ACT (Eysenck et al., 2007) and ACT-S (Eysenck & Wilson, 2016) and are susceptible to feelings of anxiety or stress. By comparison, higher-order functions comprise the co-ordination of lower-order cognitive processes working together (e.g., decision-making, planning, problem-solving; Diamond, 2013). Given its complex, dynamic, and constantly changing environment, sport provides an optimal platform to examine both higher- and lower-order EF. For example, soccer requires the recognition and processing of game-specific situations (i.e., working-memory, updating) in which, the player must select the optimal outcome (i.e., decision-making, planning, anticipation; Huijgen et al., 2015). Also, soccer players often need to cease intended actions (i.e., inhibition) and perform a new action instead (i.e., shifting, problem solving; Sakamoto et al., 2018) based on external cues within the environment.

Higher-order EFs like decision-making, anticipation, and problem solving (often assessed with sport-specific video tasks; Roca et al., 2013) are some of the most researched in sport psychology (e.g., Moore et al., 2019). Decision-making involves selecting the most suitable option from two or more alternatives in both obvious and complex situations (VandenBos, 2006). Anticipation is facilitated by complex knowledge structures which allow for evaluative, predictive, and planning processes (North et al., 2011). Problem solving is involved in overcoming difficulties and achieving goals via higher mental functions (VandenBos, 2006) and may rely upon shifting and updating (Kotsopoulos & Lee, 2012). Research generally indicates those with higher sporting expertise score better on higher-order EF tasks compared to those with lower sporting expertise. For example, experts have outperformed novices in decision-making on both sport-specific (e.g., Moore et al., 2019) and domain-general decision-making tasks (e.g., Vaughan et al., 2019). Anticipation was superior in skilled (professional/semi-professional) compared to less-skilled (recreational) soccer players (Roca et al., 2013) and greater problem solving was shown in athletes compared to non-athletes (Jacobson & Matthaeus, 2014).

Lower-order EFs (i.e., inhibition, shifting, updating) typically assessed via cognitive tasks, have been shown to be important for sport performance and have distinguished between athletic expertise groups. For example, inhibition and shifting abilities (assessed via a Design Fluency task) were higher in 1st division soccer players compared to 2nd and 3rd division soccer players (Vestberg et al., 2012) and inhibition (measured with a Stop Signal Task) significantly predicted self-report and coach rated performance in open-skill sports (Hagyard et al., 2021). Further, Vestberg et al. (2012) and Vestberg et al. (2017) found significant positive correlations between inhibition, shifting, and updating scores and sport performance (i.e., goals and assists), and Furley and Memmert (2012) reported that updating ability facilitated the focus of attention by enabling individuals to avoid distraction (Experiment 1) and resolve interference (Experiment 2) in computerised sport decision-making tasks.

2.2.2 Visual Attention

Sport psychologists have predominantly assessed attentional control through gaze behaviour from eye-trackers as they offer researchers the chance to observe online attention during in-situ sports tasks (e.g., soccer penalty kicks; Brimmell et al., 2019). The number and duration of fixations (sometimes used together to calculate search rate; Brimmell et al., 2019) and the location of fixations have been of interest when attempting to understand which visual stimuli provide athletes with the most information (Wilson, 2008). The quiet eye phenomenon, which encompasses the length and location of the final fixation before initiating a critical movement (Vickers, 2007), is perhaps the most common visual measure in sport-related aiming tasks. A recent review from Klostermann and Moeinrad (2020) attest to the importance of this variable over and above previously applied variables (e.g., number and duration of fixations). Like research exploring EF, studies examining VA have focussed on expert-novice performance differences (see Mann et al., 2007; Lebeau et al., 2016, for reviews). Also, of interest are the effects of training interventions (e.g., Wood & Wilson, 2011) and differences in psychological states (e.g., anxiety/stress manipulations; Wilson, 2012).

2.2.3 Executive Function and Visual Attention

Research considering lower-order EFs and VA in the same study (e.g., Ducrocq et al., 2017; Klosetermann, 2020; Wood et al., 2016) is scant, yet alludes to an association. Scharfen and Memmert (2021) provided one of the few examinations of a complete model of lower-order EF and VA and showed small near-transfer (for inhibition and visual clarity), and no far-transfer effects. Research examining higher-order EFs and VA in athletic samples is more prevalent and typically focuses on athletic group differences (e.g., Moore et al., 2019; Uchida et al., 2014). Focusing on group differences may only allow indirect comments (i.e., not resulting from a single analysis) on the relationship between EF and VA. For example, Uchida et al. (2014) showed "experienced" and "novice" basketball players video footage of free-throws in basketball with eye movements recorded while the participants watched the video. After the video, participants were asked to predict the outcome of the free-throw (i.e., scored or missed). Results showed that "experienced" basketball players made more correct predictions and showed different eye movement patterns.

However, this kind of research design only allows for indirect comments on the EF and VA relationship. This is because when performing tests of differences (e.g., *t*-tests or ANOVA) where expertise group (e.g., "experienced" and "novice"; Uchida et al., 2014) is the predictor and either EF or VA are the outcome variable any relationship between EF and VA is only inferred. Here, and continuing with Uchida et al. (2014) as an example, this means that such an approach allows us only to *assume* that EF and VA are related because "experienced" players outperformed "novice" players on a decision-making task and fixated more on the legs to make these decisions. Without more direct approaches (i.e., relationships inferred based on findings from a single statistical analysis) to confirm this relationship, our understanding of how EF and VA relate will remain limited. As such, a key facet of the present chapter was to synthesise studies that allow researchers to make both direct and indirect comments on the relationship between EF and VA.

Moreover, Natsuhara et al. (2020) found *high-level* soccer players made significantly more correct decisions and fixated certain targets (e.g., free teammates) than middle-level players, but the number and duration of fixations did not differ between groups. This may suggest that certain VA variables are more sensitive to detect between-expertise levels (i.e., fixation location may be more relevant than the number and duration of fixations; Natsuhara et al., 2020) and that focus on training these variables may be optimal. Making these decisions is difficult given the current state of the literature due to differences across sports, tasks, classification of athletes based on potentially unrelated dichotomies (i.e., comparing results of high- vs mid-level athletes in one study to experienced vs novice athletes in another).

2.2.4 Literary Inconsistencies

The aforementioned work is generally concerned with EF and VA in sport but there is considerable variation across studies covering lower- and higher-order EFs (e.g., decision-making studies often use sport-specific videos while inhibition studies use cognitive tasks). Also, disparity is present within EFs as well (e.g., the Design Fluency and Stop Signal task have been used to index inhibition) resulting in various and disperse outcome measures. Research on VA has also produced a vast number of possible outcome measures (e.g., number and duration of fixations, quiet eye, and percentage viewing time to certain locations). It is possible that synthesising the relevant literature may show which variables produce the most informative results in both EF and VA. Likewise, the general study methodology in this area (i.e., study design, sport type, sample type, and association between variables) varies. Research within the field has employed a variety of designs (e.g., expert vs novices), making comparing across studies difficult, and covered a variety of sports limiting generalisability. In systematically reviewing research across sports, this chapter offers interpretations such as whether certain EFs may be more prominent in certain sports and/or whether optimal gaze strategies differ between sports.

2.2.5 The Present Study

There is currently a plethora of literature on EF and VA that is yet to be synthesised making it difficult for researchers to make informed decisions about study design, methodology, and intervention. Although EF and VA are prominent within ACT-S research, little is known about their empirical association, and even less about the direct association. Therefore, this chapter includes a robust systematic review that provided a synthesis of studies that examined EF and VA in athletes both directly and indirectly. Specifically, this chapter aimed to provide the first comprehensive systematic review of the sample characteristics, general methodology (i.e., study design and sport type), and measurement and outcome variables for EF and VA. Although of considerable interest individually, research has made little to no direct comparison between EF and VA. Therefore, this chapter aimed to offer future research a better understanding of how these constructs may relate.

2.3 Method

2.3.1 Search Strategy, Inclusion Criteria, and Screening

An electronic search of Web of Science, Scopus, MEDLINE, APA PsycInfo, PubMed, SPORTDiscus, CINAHL, and Discover EBSCO was conducted. Unpublished dissertations and theses were also searched via ProQuest. Search terms were placed into one of four groups: (a) EF (higher- and lower-order); (b) VA; (c) sport context; and (d) exclusion criteria (as in Scharfen & Memmert, 2019). Specifically, for (a) the terms “executive function” OR “cognition” OR “executive control” OR “inhibition” OR “inhibitory control” OR “shifting” OR “cognitive flexibility” OR “updating” OR “working-memory” OR “planning” OR “decision-making” OR “problem solving” were used. For (b) the terms “visual attention” OR “gaze behaviour” OR “eye-tracking” OR “eye movement” OR “visual search" were used. Regarding (c), the terms "athlete" OR "sport" OR "sport performance" were used. For (d) the terms (searched using the "NOT" function) "concussion" OR "disability" OR "cognitive impairment" OR "clinical" were used. A backward search and search of reference lists for already to-be-included studies was conducted for further relevant titles and abstracts by the first author. The search was not restricted by year of publication. Researchers followed procedures outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009).

Inclusion criteria were established to ensure relevant studies were identified; articles had to meet the following criteria: 1) published in English, 2) contained original empirical data, 3) quantitatively measured EF in sport, or simulated sport, 4) had a full-text available at the time of search, and 5) quantitatively measured VA with an eye-tracker in sport, or simulated sport-settings. Study title and abstracts were initially screened by the first author before being verified in two stages. First, RV independently screened titles and abstracts with discrepancies discussed between JB and RV. Next, EE screened a random 30% of all abstracts. Inter-rater reliability between the JB and EE was assessed via the percentage agreement rates (95.15%) and Cohen's Kappa ($\kappa = .87$). Studies selected for full-text screening underwent a similar two stage verification. First, JB and RV independently assessed full-texts for inclusion with discrepancies discussed until consensus was reached. Next, EE assessed a random 30% of full-text articles and assessed the suitability for inclusion. Once again, inter-rater reliability was assessed via percentage agreement rates (95.23%) and Cohen's Kappa ($\kappa = .77$) between the first author and EE.

2.3.2 Quality Assessment and Data Extraction

Quality assessment can ensure a review is systematic, rather than narrative with little methodological focus (Gopalakrishnan & Ganeshkumar, 2013) and may indicate adequate scientific standards (Borenstein et al., 2011). Payne et al. (2019) outlined that a standardised quality assessment instrument is yet to be established for laboratory-based observational studies. As such, study quality was assessed using items from The Appraisal Instrument (Genaidy et al., 2007), The Quality Index (Downs & Black, 1998), and The Evaluation of Research Articles Checklist (DuRant, 1994). As in Payne et al. (2019), the current study included an additional item to assess adherence to ethical procedures. The maximum possible score for study quality was 23 (see Table 2.1 for items used in the present review) and scores for identified studies are shown in Table 2.2. The quality assessment was completed by JB and checked by EE.

Data extraction for included studies was performed by JB. As in previous literature reviews (e.g., Harris et al., 2021b) the following study characteristics were obtained: authors, date of publication, sample characteristics (sample size, mean age, female percentage, and sport), sport type (open- or closed-skill; Singer, 2000), expertise level, design (between- or within-subjects), EF measured, task used, EF outcome measured, the VA outcome measured, eye-tracker used, key findings, and relationships between EF and VA, where possible.

Table 2.1.

Quality Assessment Items.

Item number	Item description
1	Is/are the hypothesis/aim/objective(s) of the study clearly described?
2	Are the main outcomes to be measured clearly described?
3	Have the authors established a theoretical framework for the study?
4	Is the study design clearly described and appropriate to test the hypothesis?
5	Are the characteristics of participants in the study clearly described?
6	Is there evidence of attention to ethical issues?
7	Are the main findings of the study clearly described?
8	Does the study provide estimates of the statistical parameters?
9	Have actual probability values been reported for the main outcomes, except where the probability value is less than .001?
10	Are conclusions substantiated by the data that are presented in the results?
11	Are results adequately compared to previous studies and in relation to theoretical frameworks?
12	Are the subjects asked to participate in the study representative of the entire population from which they were recruited?
13	Are those subjects who were prepared to participate, representative of the entire population from which they were recruited?
14	Were the statistical tests used to assess the main outcomes appropriate?
15	Do the operational definitions of the variables match the theoretical definitions?
16	Are the methods of assessing the outcome variables valid?
17	Is the control group/condition comparable to the exposed group/condition?
18	Are the methods of assessing the exposure variables valid?
19	Is the manipulation of the exposure variable successful?
20	Are the methods of assessing the outcome variables direct measurement?
21	Are the outcome data reported by levels of exposure?
22	Can the study results be applied to the eligible population?
23	Can the study results be applied to other relevant populations?

Note. Items were taken from The Appraisal Instrument (Genaidy et al., 2007), The Evaluation of Research Checklist (DuRant, 1994), and The Quality Index (Downs & Black, 1998). Item 6 was an additional item intended to assess attention to ethics as in Payne et al. (2019).

Table 2.2.

Quality assessment scores

Article	Items																						Total	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Raw	%
Afonso & Mesquita (2013)	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	22	95.7
Afonso et al. (2012)	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	22	95.7
Alder et al. (2014) exp. 2	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21	91.3
Barton (2013) study 3	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	22	95.7
Bishop (2016)	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	1	1	1	1	21	91.3
Bishop et al. (2014) exp 1	1	1	1	1	1	1	1	1	0	1	1	0	0	1	1	1	1	1	1	1	1	0	0	18	78.3
Bishop et al. (2014) exp 2	1	1	1	1	1	1	1	1	0	1	1	0	0	1	1	1	1	1	1	1	1	0	0	18	78.3
Buszard et al. (2013)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23	100
Castro et al. (2016)	1	0	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21	91.3
Catteeuw et al. (2009)	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	22	95.7
Crespi et al. (2012)	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	20	87
del Campo & Gracia (2018)	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	19	82.6
del Campo et al. (2018)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	22	95.7
Dicks et al. (2010)	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21	91.3

Ducrocq et al. (2016) exp 1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	19	82.6
Ducrocq et al. (2016) exp 3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23	100
Ducrocq et al. (2017)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23	100
Fortin-Guichard et al. (2020)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	22	95.7
Frank et al. (2016)	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	19	82.6
Gorman et al. (2015)	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	22	95.7
Gredin et al. (2018)	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	22	95.7
Hagemann et al. (2010)	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	22	95.7
Hancock & Ste-Marie (2013)	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21	91.3
Harris et al. (2020) exp 2	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	0	20	87
Klostermann (2019)	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	19	82.6
Klostermann (2020) exp 1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	19	82.6
Klostermann (2020) exp 2	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	19	82.6
Klostermann et al. (2015)	1	1	1	1	1	1	1	1	0	1	1	0	0	1	1	1	1	1	1	1	1	0	0	18	78.3
Lex et al. (2015)	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21	91.3
Lorains et al. (2014)	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	21	91.3
Luo et al. (2017) exp 1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	19	82.6
Luo et al. (2017) exp 2	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	19	82.6

McRobert et al. (2011)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23	100
Milazzo et al. (2016)	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	22	95.7
Moore et al. (2019)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23	100
Mori & Shimada (2013)	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21	91.3
Natsuhara et al. (2020)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23	100
North et al. (2009)	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	22	95.7
Page (2009) exp 2	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	21	91.3
Page (2009) exp 4	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	22	95.7
Piras et al. (2014)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23	100
Pizzera et al. (2018)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23	100
Roca et al. (2011)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23	100
Roca et al. (2013)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23	100
Roca et al. (2018)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	22	95.7
Roca et al. (2020)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	22	95.7
Ryu et al. (2013)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23	100
Ryu et al. (2016)	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	0	20	87
Saez-Gallego et al. (2018)	1	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	21	91.3
Savelsbergh et al. (2002)	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21	91.3

Savelsbergh et al. (2005)	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21	91.3
Spitz et al. (2016)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23	100
Takeuchi & Inomata (2009)	1	1	1	1	1	0	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	20	87
Uchida et al. (2014)	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	87
Vaeyens et al. (2007a)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23	100
Vaeyens et al. (2007b)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23	100
van Maarseveen et al. (2018a)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23	100
van Maarseveen et al. (2018b)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23	100
Vater et al. (2016)	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	0	20	87
Vila-Maldonado et al. (2019)	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21	91.3
Williams & Davids (1998) exp 1a	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21	91.3
Williams & Davids (1998) exp 1b	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21	91.3
Williams, Vickers, & Rodrigues, (2002)	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21	91.3
Wood et al. (2016)	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	19	82.6
Total item score	62	61	61	64	63	53	59	64	41	60	64	49	49	64	64	64	61	62	64	64	64	52	48		Avg. %
Total item percentage	96.9	95.3	95.3	100	98.4	82.8	92.2	100	64.1	93.8	100	76.6	76.6	100	100	100	95.3	96.9	100	100	100	81.3	75.0		92.2

Note. 0 = no/unclear, 1 = yes

2.4 Results

2.4.1 Search Results

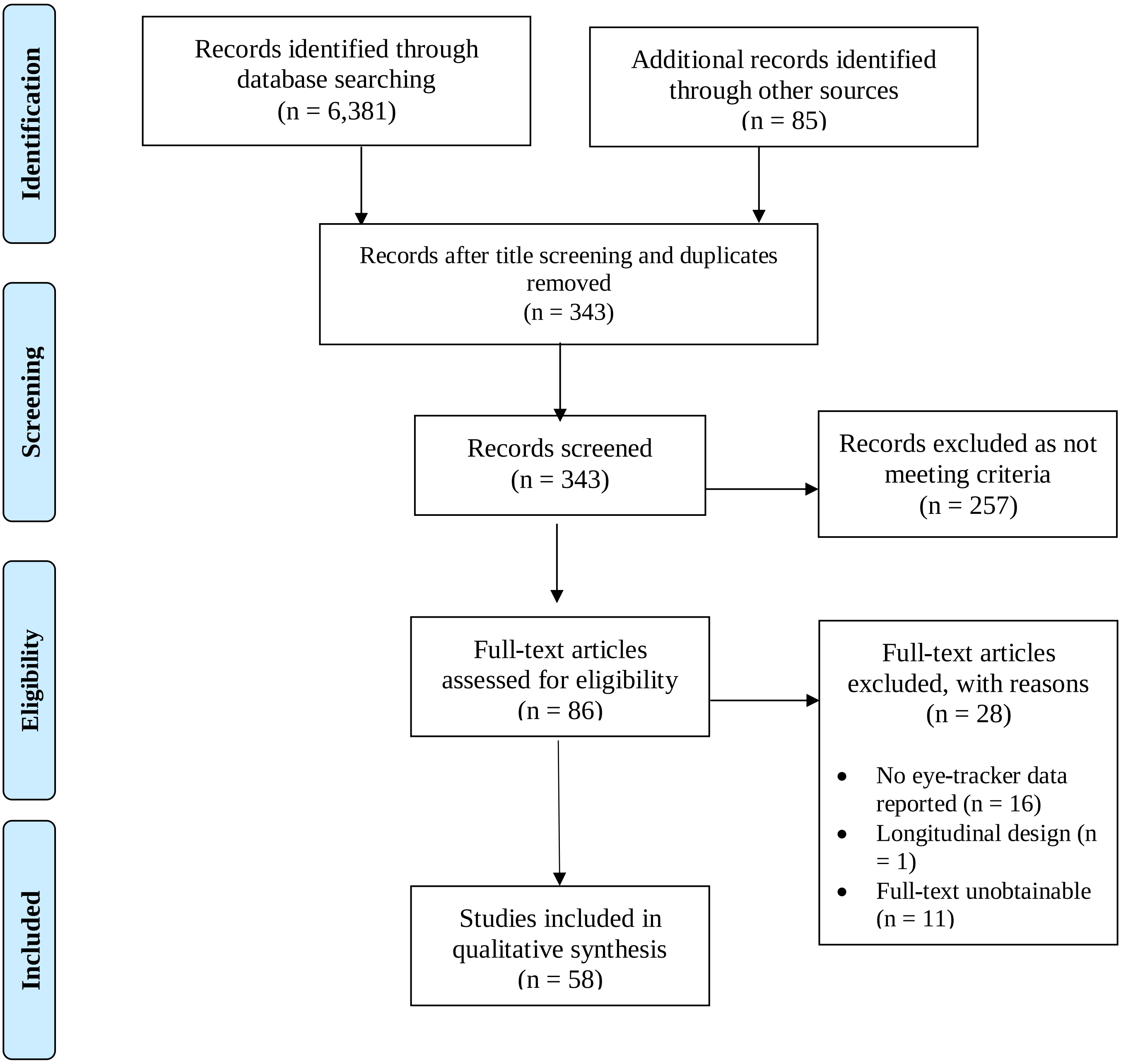
An initial database search resulted in 6,381 papers for further inspection. After initial title screening and duplicate removal, 343 titles were identified for abstract screening. Eighty-six papers met the eligibility criteria and received full-text review. Full-text papers were assessed against predefined criteria aligned to the aims of the present study. Backward searches and reference list checks led to the inclusion of 10 additional studies. A search of ProQuest revealed 12 studies suitable for further review, with two suitable for inclusion. A final total of 58 studies, with 64 experiments, were identified as appropriate for systematic review (see Figure 2.1 for a full breakdown).

2.4.2 Quality Assessment

Quality assessment scores for the 64 experiments ranged from 78.3%-100%, (mean = 92.2%; see Table 2.2). Quality assessment revealed three experiments high (scores between 61%-80%) and 61 experiments very high (scores between 81%-100%) in methodological quality (Payne et al., 2019) with 16 experiments achieving a maximum score in methodological quality. Certain individual items were met in all of the included experiments (i.e., items 4, 8, 11, 14, 15, 16, 19, 20, and 21). Specifically, factors aligned to experimental design, statistical parameters and tests, comparison of results, term definitions, manipulation of exposure variables, direct and suitable measurement of outcome variables, and suitable of outcome variables were present in all included experiments within the systematic review. Lowest scoring (i.e., under 80%) items included item nine, 12, 13, and 23. Coverage of precise probability values (item nine) was only reported in 41 experiments (64.1%). Intended samples (item 12) and actual samples (item 13) that sufficiently represented the general population of athletes was only present in 49 experiments (76.6%) for both items. Finally, whether findings were applicable to other relevant populations (item 23) was present in only 48 experiments (75.0%).

Figure 2.1.

Stages and results of the search process having followed PRISMA guidelines (adapted from Moher et al., 2009)



2.4.3 Study Characteristics

2.4.3.1 Sample Characteristics, Sport Type, and Design

Key information regarding sample characteristics, sport type, and design can be found in Table 2.3. The total number of participants in the reviewed experiments was 1,901 with an age range of 14.50-52.00 years (mean 23.44 ± 6.05 years). If an experiment reported age information for a training and a control group both were included here in the range and in calculation of the mean. Only one experiment did not report mean age information and instead provided the age range (Crespi et al., 2012). Sample size varied between experiments with sample sizes ranging from 3-87 (mean = 29.76 ± 16.89). Gender information was reported in 50 of 64 experiments and not stated in the remaining 14. Representation from female participants ranged from 0-100% (mean = 36.80% ± 38.28%).

The experiments covered numerous sports including: soccer (*n* = 23), volleyball (*n* = 7), basketball (*n* = 5), gymnastics (*n* = 4), tennis (*n* = 3), rugby (*n* = 2), Australian football (*n* = 2), netball (*n* = 1), baseball (*n* = 1), badminton (*n* = 1), billiards (*n* = 1), shooting (*n* = 1), golf (*n* = 1), fencing (*n* = 1), ice hockey (*n* = 1), table tennis (*n* = 1), cricket (*n* = 1), and karate (*n* = 1), multiple sports (*n* = 5), and non-athletes (*n* = 2). Following Singer's (2000) recommendations 14 sports were classified as open-sports while four could be classed as closed-sports. More recent work (e.g., Krenn et al., 2018) further breaks down sport type into static (i.e., predominantly self-paced in consistent environments), interceptive (i.e., require dynamic coordination between body and implement), and strategic (i.e., highly varying situations involving teammates, opponents, and objects). Based on these classifications research in this area involves three static sports, six interceptive sports, and nine strategic sports.

Table 2.3.

Summary of reviewed studies that measured executive function and visual attention in a sporting context

Article	Sample characteristics	Sport	Study design	Female %	Executive function measured: Executive task	Executive function measured: Outcome variable	Eye-tracker	Visual attention measured	Findings	Notes
					Decision-making					
Afonso & Mesquita (2013)	9 skilled elite (16.10 ± 2.00) and 6 less-skilled elite (16.80 ± 2.00) players	Volleyball	B-S	100	Sport-specific video	Verbal responses	ASL 3000	No. fixations, fixation duration, search rate, no. fixation location, % time to key locations	Skilled elites had a significantly longer fixation duration, but no differences were found for no. fixations and fixation location. Skilled elites spent significantly more time viewing ball receiver and space between players. Skilled elites reported higher total, and more sophisticated, verbal responses	Skilled elites made significantly more verbal responses about team mates than less-skilled elite. No differences were found for verbal responses about opponents
					Decision-making					
Afonso et al. (2012)	15 high-skilled elite (19.10 ± 8.30) and 12 skilled elite (17.30 ± 4.20) players	Volleyball	B-S	100	In-situ	Verbal responses	ASL 3000	No. fixations, fixation duration, no. fixation location, % time to key locations	High-skilled elites had a significantly higher no. fixations and significantly more fixation locations. High-skilled elites spent significantly more time viewing the ball receiver and open space. High-skilled elites had significantly more, and more sophisticated, verbal reports	High-skilled elites made significantly more verbal reports about opposing players
					Anticipation					
Alder et al. (2014) exp. 2	8 expert (28.90 ± 3.10) and 8 novice (18.50 ± 1.10) players	Badminton	B-S	NS	Sport-specific video	Response accuracy	ASL	No. fixations, fixation duration, final fixation duration, % time to key locations	Experts had significantly longer fixation durations and final fixation durations. Experts showed significantly higher response accuracy. Experts fixated on the racket more when responding correct than novices. Novices fixated on the wrist more when responding incorrectly than experts. Novices fixated the shuttle more in correct and incorrect conditions	Included various video occlusion points (pre-contact, contact, post-contact). Assessed type of error (depth, direction, or both). Looked at a preparation and execution phase

Barton (2013) study 3	15 high-skilled (21.50 ± 2.30) and 15 low-skilled (23.30 ± 3.10) players	Soccer	B-S	NS	Anticipation	Sport-specific video	Response accuracy	Scene Camera Viewpoint	No. fixations, fixation duration, no. fixation locations, % time to key locations	Significantly lower no. fixations and no. fixation locations, and longer fixation durations in high-skilled group. Low-skilled group fixated the knees and feet while the high-skilled group fixated the shoulders, trunk, and hips more. The novice group's final fixation was directed to the left foot, right foot, and ball significantly more while the expert groups final fixation was directed to the shoulders, trunk, and hips. The expert group began their final fixation earlier and showed greater response accuracy	Used deceptive and non-deceptive trials, two occlusion conditions (0ms and +80ms), and three probability levels (50:50%, 66:33%, 83:17%)
Bishop (2016)	13 international (20.40 ± 2.70) players	Netball	W-S	100	Decision-making	Sport-specific photos	Response accuracy and response time	SR Research Eyelink 1000	No. fixations, % dwell time, initial saccade latency	Response accuracy and time were not significantly correlated. No interaction of semantic or spatial cue on response accuracy or time. But, semantic cue significantly impacted accuracy and spatial cue significantly impacted time. No correlation or interactions between three VA variables. Significant effects for target location on initial saccade latency (shorter to right vs left)	Used auditory semantic and spatial cues. Examined hemifield asymmetry
	26 male (21.00 ± 1.70) and 14	Soccer	W-S	35	Decision-making			SR Research	No. fixations, % dwell time,	Overall participants were highly accurate (88.70 ± 0.10%). Despite 19 predictors (including no.	N/A

Bishop et al. (2014) exp. 1	female (21.40 ± 2.00) novice to semi-professional players				Sport-specific photos	Response accuracy and response time (combined to create efficiency scores)	Eyelink 1000	fixation duration, 1st fixation time, saccadic amplitude, saccadic latency, peak saccadic velocity	fixations to 4 locations, % dwell time to 4 locations, time to first fixate 4 locations, mean fixation duration, mean saccade amplitude, mean peak saccade velocity, initial saccade latency, and 3 soccer participation items), the model accounted for 67% of the variance in efficiency scores. The only individual significant predictor was time to 1st fixate the ball	
Bishop et al. (2014) exp 2	46 non-athlete (19.50 ± 1.20) undergraduate students	Soccer	B-S	56.52	Decision-making Sport-specific photo	Response accuracy and response time (combined to create efficiency scores)	SR Research Eyelink 1000	Time to 1st saccade	No differences between the groups in efficiency scores. "Ball" and control group were significantly faster to saccade to the ball compared to the "head" group. "Ball" group spent more time looking at the ball vs the "head" group. "Head" group were faster than the other two to saccade to the head. Results suggest that the groups did follow instructions	Used three different instructional sets (no instructions [control], ball [told fixate ball], and head [told to fixate head]) to examine impact on decision-making
Buszard et al. (2013)		Australian football	B-S	NS	Decision-making		ASL	No. fixations, fixation duration,	"Loose" instructions led to significantly better response accuracy vs the "take the first"	Split participants into three instructional groups (take the first [give first option only],

	46 professional players (23.40 ± 4.20)				Sport-specific video	Response accuracy and response time		search rate, % time to key locations	instruction group in the even player display. Neither instructional group had significantly greater accuracy than the control group. In the extra loose player display, no group differences were found for response accuracy, response time, or no. fixations but significantly more fixations in extra loose vs even display. No difference between groups in mean duration but significantly longer duration in even vs extra loose display. No difference between groups in search rate but significantly lower search rate in even vs extra loose display. No group difference in fixation locations in the even display condition. Significant group x location interaction for fixation location in the extra loose display (loose group fixated extra loose more than take the first)	loose head [must keep the ball away from loose defender], and control [no instructions]). Used two displays (even player display and extra loose player display). Looked at the effect of player experience on decision-making accuracy
Castro et al. (2016)	25 state/national/international players (16.90 ± 1.00) and 23 "other" school/regional level sportspeople (17.60 ± 1.70)	Volleyball	B-S	0	Decision-making Sport-specific video	Response accuracy	SMI RED500	No. fixations, fixation duration	No differences in no. fixations between volleyball players and other sportspeople in any video situation. Other sportspeople had significantly longer mean duration fixations compared to volleyball players in the central attack condition. Volleyball players had significantly higher response accuracy in extreme attack and central attack situations compared to other sportspeople	Used 4 video situations (extreme attack, central attack, setting, and blocking)
Catteeuw et al. (2009)	5 International (40.00 ± 2.70) and	Soccer	B-S	NS	Decision-making		Tobii T120	No. fixations, fixation duration,	Internationals had significantly better response accuracy than nationals when the player was	Split response accuracy into "flag" (correct = giving offside when the player was

	5 national (39.40 ± 5.10) assistant referees				Sport-specific video	Response accuracy, sensitivity index (signal detection theory)		% time to key locations	onside. No significance when the player was offside. Both performed above chance level. No significance in sensitivity index. Internationals showed no bias toward flag errors, but the nationals did (i.e., flag errors > non-flag errors). Both groups made most errors when attacking player was on the offside line. No difference between the groups in no. fixations or mean fixation duration (participants spent most time fixating the offside line). Internationals fixated on the offside line less and more on the receiving attacker compared to nationals after the pass	offside and incorrect = giving offside when the player was onside) and "no-flag" (correct = no-offside decision when the player was onside and incorrect = no-offside decision when the player was offside). Two areas of interest (passer and offside line). Examined gaze at three times (before pass, at pass, and after pass)
Crespi et al. (2012)	21 expert and 21 novice players (aged between 27-70)	Billiards	B-S	2.38	Decision-making Sport-specific video	 Response accuracy and response time	Eyegaze System	No. fixations, fixation duration, % time to key locations	Higher response accuracy in experts. The group x shot difficulty interaction was non-significant. Experts had faster response times, especially on long shots. Fixation spatial distribution was similar for groups. Novices had broad fixation distributions and experts looked more at the cushion. Novices extrapolated more than experts post occlusion. For post occlusion trajectory, no. fixations and mean fixation duration were significantly higher in novices than experts with no difference before occlusion	Occlusion, different shot types (two cushion [short shot] and five cushion shots [long shots]). Include raw eye position data
	1 expert judge (36.00), 1 expert	Gymnastics	B-S	0	Decision-making		ASL SE5000	No. fixations, fixation duration,	Significant differences in no. fixations and fixation duration to the hips and the near legs. Post	Videos of three different gymnastics skills (vault, uneven bars, and floor).

del Campo & Gracia (2018)	coach (38.00), and 1 expert gymnast (22.00)				Sport-specific video	Response accuracy		% time to key locations	hoc showed the gymnast had the highest no. fixations and fixation durations and there were no differences between the coach and judge. No significant differences in response accuracy, judge performed marginally better. Correlation showed the gymnast improved decision-making when no. fixation and fixation duration near the shoulders increased, but the opposite was found for the judge. The coach showed greatest decision-making when no. fixations and fixation duration to the trunk increased	Include some individual difference data (i.e., gymnast had higher mean no. fixations and fixation duration to hips vs trunk). Included different gymnastic movements in video
del Campo et al. (2018)	11 amateur assistant referees (36.75 ± 4.26) and 11 amateur players (24.37 ± 1.76)	Soccer	B-S	NS	Decision-making Sport-specific video	Response accuracy, sensitivity index (signal detection theory)	ASL SE5000	No. fixations, fixation duration, % time to key locations	Assistant referees showed significantly higher no. fixations, fixation duration, and % time on the last defender. Players spent significantly more time fixating areas deemed task-irrelevant. Regardless of location, assistant referees had significantly longer fixation durations, and players had significantly higher no. fixations. No difference between groups in regard to accuracy or sensitivity on correct decisions. But, type of error significantly differed. Players made more flag errors, and assistant referees made more miss errors. Only players showed a flag error bias	Two areas of interest were the ball carrier and the offside line. Filmed video at different distances (near, medium, and far). Split response accuracy into “flag” (correct = giving offside when the player was offside and incorrect = giving offside when the player was onside) and “no-flag” (correct = no-offside decision when the player was onside and incorrect = no-offside decision when the player was offside). Two areas of interest (passer and offside line)
Dicks et al. (2010)		Soccer	W-S	NS	Anticipation and decision-making		ASL	No. fixations, fixation duration,	Response accuracy was better for in-situ and interceptive response conditions vs other conditions.	Across in-situ and video conditions there were a total of 5 experimental conditions:

	8 experienced goalkeepers (22.80 ± 4.10)				Sport-specific video and in-situ	Response accuracy and response time		no. fixation locations, % time to key locations	Response time did not differ amongst conditions. No differences in no. fixations. Fixation duration was longer in in-situ verbal condition vs in-situ movement condition. Significantly fewer locations were fixated in the in-situ interceptive condition vs video verbal and movement conditions. During run-up the most fixated areas were head, torso, lower kicking leg, lower non-kicking leg and ball. More time fixating the torso in the video movement compared to all in-situ conditions. GKs fixated non-kicking leg in the video and in-situ verbal compared to in situ intercept. More time fixating the ball in the in-situ intercept vs other conditions	verbal responses to video, movement responses to video, verbal responses to in-situ, movement responses to in-situ, and interceptive responses to in-situ. Also, provide first 500ms and final 500ms data. Gaze was most commonly directed to head or torso in 1st 500ms. GKs commonly fixated the ball in the final 500ms of run up in the video verbal and movement conditions and in-situ verbal condition. GKs fixated the ball as early as 500ms in the in situ intercept and even earlier in the in situ movement but gaze was still directed to the ball less in this condition
Ducrocq et al. (2016) exp. 1	33 participants (27.13 ± 4.86)	Tennis	B-S	66.66	Inhibition Visual search inhibition task	Distractor costs	SR Research Eyelink 1000	Saccade latency (anti and pro saccade)	Inhibition improved across training (indicated by distractor costs). Antisaccade and prosaccade performance improved pre to post intervention. Antisaccade latencies were slower than prosaccade latencies. Groups did not differ from each other on saccadic latencies. The task x group and time x group interactions were non-significant. There was a trend for the group x task and the time x group x task interaction to be significant. Follow up showed that improvements were largely driven by the training groups decrease in response latency in the antisaccade task. For prosaccade there were no significant pre to post changes for either group	Participants were split into training and control groups. Pre, intervention, and post design

Ducrocq et al. (2016) exp. 3	22 recreational tennis players (27.84 ± 5.63)	Tennis	B-S	50	Inhibition		SR Research Eyelink 1000	Time to 1st target fixation	Distractor costs were lower post-training for the training group, indicating improved inhibition. Condition was significant, showing that first target fixation was significantly earlier in the high-pressure compared to low-pressure. A significant condition x group interaction was found. The control group had earlier first target fixations at high-pressure while the training group had later first target fixations (indicating greater attention)	Used cognitive anxiety measures to assess hypothesised differences between the high-pressure and low-pressure conditions. Also, included a physical tennis task. For performance, only the training group decreased the number of target misses. Participants were split into training and control groups. Pre, intervention, and post design. Regression showed that first target fixation predicted 13% of the variance in the tennis task
					Visual search inhibition task	Distractor costs				
Ducrocq et al. (2017)	30 recreational tennis players (33.00)	Tennis	B-S	16.66	Working memory		Pupil Labs	Quiet eye duration, quiet eye onset, quiet eye offset	Training group performed significantly better post-training vs pre-training on the nback task. In the near-transfer change detection task only the training group showed improvement from pre-training to post-training. Quiet eye duration was longer in the high-pressure condition, but not significant between groups. All quiet eye onset analyses were non-significant. Quiet eye offset was later in the high-pressure condition. The training group had a later quiet eye offset than the control group indicating improved inhibition	Included a physical tennis task. Participants were split into training and control groups. Pre, intervention, and post design. Anxiety measures showed that the high- and low-pressure conditions were distinct. Only the training group improved on the tennis task from pre-training to post-training
					Nback and change detection task	Average level of difficulty in the nback and hits and false alarms in CDT				
Frank et al. (2016)	15 combined practice group	Golf	B-S	60	Mental representation and working memory			Quiet eye duration	The combined practice group increased functional clusters in regard to the putting action.	Measured performance on a golf-putting task. Placed participants into three groups

	(24.38), 15 physical practice group (25.73), and 15 no training group (27.00) university students				Structural dimension analysis of mental representation	Adjusted rand index	SMI iViewX HED		Adjusted rand index increased in similarity to that of the expert. Physical practice group also improved, and no practice group showed no improvements in adjusted rand index scores. Only combined practice group showed improved quiet eye durations compared to the no practice group. A small positive correlation between the cognitive representations (adjusted rand index) and quiet eye duration was found	(combined practice, physical practice, and no practice). Both types of practice (i.e., combined and physical) improved putting accuracy compared to no practice at a retention test. Assessed imagery ability to be sure it did not influence results
					Anticipation					
Fortin-Guichard et al. (2020)	26 volleyball setters (19.46 ± 1.39), 36 volleyball players (non-setters; 19.75 ± 2.00) and 20 active controls (23.85 ± 2.35)	Volleyball	B-S	45.12	Sport-specific video	Response accuracy	Tobii X3-120	No. fixations, fixation duration, number of key locations fixated, moment of fixation on key locations	No response accuracy differences between setters and non-setters. Both player groups had better response accuracy on sets, attacks, and blocks, but not bumps and services, vs controls. Significantly lower no. fixations for non-setters vs control. Setters fixated more than non-setters on services, bumps, and sets. Setters fixated less than controls on services, sets, and blocks, but not bumps. No differences on attacks nor between setters and non-setters on blocks. Fixation duration was longest for non-setters than other groups for all situations. Setters and control only differed on attacks. No differences in the number of key locations fixated in services, bumps, sets, attacks, or blocks	Training task involved soccer videos, rather than volleyball. Video scenes contained sets, services, bumps, attacks, and blocks. Also, examined predicted probability that a key location was fixated according to time
					Decision-making and pattern recall					
Gorman et al. (2015)	16 expert (20.06 ± 5.99) and 16	Basketball	B-S	0				No. fixations, fixation duration,	Experts had greater response accuracy. Experts had smaller distance error in least squares in	Used moving-image and static-image conditions. Used

	novice (24.19 ± 3.54) players				Sport-specific video and computer based draw task	Response accuracy and distance error in least squares	ASL Eye-Trac 6000	% time to key locations	the pattern recall. Experts and novices did not differ in no. fixations or fixation duration. Experts fixated the attacker second closest to the ball carrier in moving-image condition. Novices fixated the 1st defender more in static-image condition. Experts viewed outer key regions more than novices	both defensive and offensive patterns
Gredin et al. (2018)	16 expert (20.00 ± 2.00) and 15 novice (21.00 ± 3.00) players	Soccer	B-S	0	Anticipation and decision-making		ASL	% dwell time	Experts were more efficient (higher accuracy lower response time). Only expert players improved expectation accuracy when given contextual priors (indicating they were more able to utilise the information). % dwell time only changed following contextual priors for the experts	Had conditions where they provided and did not provide contextual priors. Presented congruent and incongruent trials. Also measured cognitive effort
					Sport-specific video	Response accuracy, response time (combined to create efficiency scores), and expectation accuracy				
Hagemann et al. (2010)	15 expert (20.36 ± 4.63), 15 advanced (24.25 ± 7.18), and 32 novice (24.70 ± 2.66) fencers	Fencing	B-S	37.10	Anticipation		Eyelink II	No. fixations, fixation duration, % time to key locations	Expert and advanced groups had higher response accuracy than novices. No differences in no. fixations and fixation duration. Experts fixated the upper trunk for longer than the advanced and novice groups. Novices fixated the upper legs more than the expert and advanced groups. Results from general, no-occlusion no-cue condition	Also included an occlusion condition and a cue condition
					Sport-specific video	Response accuracy				
	15 higher-level (27.20) and 15	Ice Hockey	B-S	0	Decision-making		Eyelink SR II	No. fixations, fixation duration	Higher-level referees had higher response accuracy and greater decision sensitivity. No	Included additional analyses with only clips that were more sensitive to differences

Hancock & Ste-Marie (2013)	lower-level (31.70) referees				Sport-specific video	Response accuracy and sensitivity index			differences in no. fixation or fixation duration between groups	between the groups. Also, examined differences between penalty and no-penalty decision clips
Harris et al. (2020) exp. 2	36 university students (22.50 ± 3.70)	Non-athletes	B-S	61.11	Working memory		SMI ETG 2.0	Gaze time toward centroid, target, and switches between centroid and target	Only those in the training group improved in MOT task from pre- to post-intervention. No differences in gaze toward target, centroid, or switches at any test point between groups. Training group only showed improvement in nback response accuracy from pre- to post-intervention	Training vs control design. Used a multiple object tracking (MOT) task and examined how working memory and gaze influenced MOT performance
					Nback task	Response accuracy				
Klostermann (2019)	40 undergraduate students (20.30 ± 1.30)	Non-athletes	B-S	45	Inhibition		EyeSeeCam	Quiet eye duration, quiet eye onset, quiet eye offset	Quiet eye duration was longer and quiet eye onset was earlier when inhibition demands were high v low. No difference in quiet eye offset	The study manipulated inhibition demands and placed participants in one of two groups (i.e., high-response and low-response selection demands). Measured throwing performance as well between the conditions. Finally, they measured ball flight and throwing movement differences between the groups
					In-situ/Manipulation	None				
Klostermann (2020) exp. 1	14 male (24.00 ± 3.60) and 12 female (20.90 ± 3.60) sport science university students	Various/unspecified	W-S	46.15	Inhibition		EyeSeeCam	Quiet eye duration, quiet eye onset, quiet eye offset,	Quiet eye duration was longer and quiet eye onset was earlier when inhibition demands were high vs low and when discriminability was low vs high. No differences of quiet eye offset	Manipulated inhibition demands via response demands (i.e., high and low) and discriminability (i.e., high and low). Measured throwing performance as well between the conditions. Used a quiet eye median split and assessed throwing accuracy as well
					In-situ/Manipulation	None				
	22 male (20.70 ± 1.20) and 4	Various/unspecified	W-S	15.38	Inhibition		EyeSeeCam	Quiet eye duration, quiet	Quiet eye duration was longer and quiet eye onset was earlier when throwing to 1 of 4 targets than	Manipulated inhibition demands, but this time continued to manipulate the

Klostermann (2020) exp. 2	female (20.00 ± 1.20) sport science university students				In-situ/Manipulation	None		eye onset, quiet eye offset,	when throwing to a single target and when discriminability was low vs high. No differences of quiet eye offset	demands during the throwing action. Measured throwing performance as well between the conditions. Used a quiet eye median split and assessed throwing accuracy as well
Klostermann et al. (2015)	23 female (21.40 ± 1.50) and 22 male (22.10 ± 1.50) sport science university students	Various/unspecified	B-S	51.11	Decision-making Sport-specific video	Response accuracy	EyeSeeCam	Gaze path index	Gaze path index was similar at pre-test. The functional cue and control groups did not change gaze behaviour following intervention. The dysfunctional group did negatively adapt gaze behaviour. Largest improvements in decision-making were for the control group, followed by functional then dysfunctional. Only the control outperformed the dysfunctional at post- and retention-test	Used a pre-, post-, and retention-task design. Split participants into 3 groups (functional cue, dysfunctional cue, and control). Had 3 types of attack (cross-court, line-, or cut-shot) and 2 occlusion points (280ms and 40ms before contact)
Lex et al. (2015) exp. 2	10 experienced (25.00 ± 3.80) and 10 less-experienced (22.70 ± 2.00) players	Soccer	B-S	NS	Decision-making Choice reaction task	Response time	Eyelink SR II	No. fixations, fixation duration, no. pixels observed	Experienced players had faster response times on correct answers. No group effect on fixation duration. Experts had a lower no. fixations and lower no. pixels observed	Included different tactical decisions (counter attacked, change sides, pressing, and back to defence) and compared response time and gaze behaviour across these tactics
Lorains et al. (2014)	6 professional players (24.10 ± 2.30)	Australian football	B-S	0	Decision-making Sport-specific video	Response accuracy	The Mobile Eye by ASL	No. fixations, fixation duration, % time to key locations	No differences in response accuracy from pre- to retention-test. No change in no. fixations from pre- to retention-test. Fixation duration changed from pre- to retention-test. Above real time spent less time fixating player in possession than normal and control. At retention above-real time spent more time fixating best option vs normal and control	Allocated participants into 3 groups (above-real time, normal, and control) and examined impact of training on response accuracy and gaze. Used a pre-, intervention-, and post-test design
Luo et al. (2017a)	56 undergraduate and graduate sport	Various/unspecified	B-S	76.79	Working memory		Tobii T120	Latency of 1st correct saccade,	Working memory significantly effected the latency of 1st saccade,	Participants were placed into two groups based on OSPAN scores. Participants completed

	university students (21.34 ± 2.41)				OSPAN	Response accuracy		% incorrect saccades	but not the % of incorrect saccades	low- and high-anxiety conditions. Successful creation of high-anxiety was checked. Also, assessed effect of anxiety conditions on gaze
Luo et al. (2017b)	32 undergraduate and graduate sport university students (21.00 ± 1.48)	Various/unspecified	B-S	71.88	Working memory Nback and OSPAN	Response accuracy and achieved difficulty level	Tobii T120	Latency of 1st correct saccade, % incorrect saccades	Only the training group showed improvements in training (indicated by nback scores). Working memory trained group showed improvements in similar OSPAN task and also shorter latency of the 1st saccade. No effect of % of incorrect saccades. Working memory group had better attentional control following training	Training study where participants were in either a training or control group. Also, assessed effect of anxiety conditions on gaze and perceived difficulty and attention levels of participants
McRobert et al. (2011)	10 skilled (25.20 ± 6.80) and 10 less-skilled (23.70 ± 4.10) batters	Cricket	B-S	NS	Anticipation Sport-specific video	Mean radial error and verbal responses	ASL 5001	No. fixations, fixation duration, search rate, no. fixation location, % time to key locations	Skilled batters had lower mean radial errors. Skilled batters spent more time fixating proximal predictive cues while less-skilled batters spent more time fixating distal cues. Skilled batters reduced fixation duration in high-context scenes. Skilled batters viewed more fixation locations. No. fixations was not significant. Skilled batters made more anticipatory statements about evaluation, deep-planning, and prediction	Also assessed participants across two different contexts (i.e., high and low)
Milazzo et al. (2016)	18 highly skilled karate performers (15.70 ± 1.20)	Karate	B-S	100	Decision-making Sport-specific video and in-situ	Response accuracy	ASL	No. fixations, fixation duration, no. fixation locations, % time to key locations	Implicit-motor group showed higher response accuracy vs motor-only and control at post-test. Implicit-motor group showed lengthened fixation durations and fewer no. fixations only. No improvements in any group for the on-mat task from pre- to post-test	Participants were allocated to either an implicit-motor training, motor-only training, or control group. Participants completed a video-based and on-mat decision task. Study followed a pre- and post-test design. Examined coupled (motor) and uncoupled (verbal) responses in participants. Also, assessed changes in decision accuracy across training

Moore et al. (2019)	9 elite (30.00 ± 6.00) and 9 trainee (20.00 ± 1.00) referees and 9 players (33.00 ± 5.00)	Rugby	B-S	NS	Decision-making Sport-specific video	Response accuracy	SMI	Search rate, entropy, % time to key locations	Elite and trainee referees had higher response accuracy than players, no differences between elites and trainees. Players and trainees had higher search rate than elites. Players fixated the central pack less and the outer pack and the non-pack areas more. Collegiate players showed greater entropy (deviation from “ideal” gaze path)	Assessed experience differences to check groups. Also used regression to assess whether gaze predicted decision-making response accuracy
Mori & Shimada (2013) exp. 1	10 collegiate (23.20 ± 1.10) and 10 novice (22.30 ± 0.50) players	Rugby	B-S	0	Anticipation Sport-specific video	Response accuracy and response time	NAC EMR-8B	% time to key locations	Collegiate players had faster response times in all conditions. No group differences in response accuracy. Collegiate players fixated the hips and legs more while novices fixated the chest more	Assessed 3 actions in the videos (no sidestep, 1 sidestep, and 2 sidesteps) to 2 directions (left or right)
Natsuhara et al. (2020)	18 high-level (19.70 ± 1.10) and 18 middle-level (20.10 ± 1.10) players	Soccer	B-S	NS	Decision-making Sport-specific video	Response accuracy and response replication	NAC EMR-8B	No. fixations, fixation duration, no. fixation locations, % time to key locations	High-level players had higher response accuracy, reproducibility, and fixated more locations. No differences in no. fixations and fixation duration. Group by fixation location interaction was significant. High-level players maintained gaze on free attacker, defender, and best-choice player more than middle-level players. While Middle-levels players fixated on the closely marked attacker and open space more	Examined two viewing phases (video presentation to ball ejection phase and ball ejection to participant ball kick phase)
North et al. (2009)	11 skilled (20.60 ± 3.10) and 15 less-skilled (25.80 ± 4.70) players	Soccer	B-S	0	Anticipation Sport-specific video	Response accuracy, recognition time	ASL 5000	No. fixations, fixation duration, no. fixation locations, % time to key locations	The skilled group had higher response accuracy. No differences in recognition time. Skilled participants were more sensitive in distinguishing previously seen scenes from novel scenes. No correlation between response accuracy and recognition time. No differences in no. fixations,	Used two structured trial types (normal video and point-light display). Also looked at fixation transitions

									fixation duration, or % time to key locations. However, skilled participants fixated more locations	
Page (2009) study 2	12 novice (32.30) and 8 expert (52.00) coaches/judges	Gymnastics	B-S	55	Decision-making		ASL 501	No. fixations, fixation duration, no. fixation locations, % time to key locations, scan paths	No differences in outcome judgements. Experts had more fixations (no. fixations) of longer durations (fixation duration) to fewer areas (no. fixation locations). Experts had less "random" scan paths and spent more time fixating the head, shoulders, and torso	
					Sport-specific video	Outcome judgements				
Page (2009) study 4	5 novice coaches/judges (30.80 ± 12.69)	Gymnastics	B-S	60	Decision-making		ASL 501	No. fixations, fixation duration, no. fixation locations	No differences in outcome judgment. Only at retention-test were no. fixations different where the training group showed less "error". Only at post-test was fixation duration different where the training group showed less "error". No differences in no. fixation locations	Allocated participants to either a training or control group. The study followed a baseline-, intervention, post-, and retention-test design. Compare groups across baseline x post-test, baseline x retention-test, post-test x retention-test.
					Sport-specific video	Outcome judgements				
Piras et al. (2014)	15 expert (24.87 ± 1.92) and 15 novice (24.07 ± 0.88) players	Volleyball	B-S	NS	Anticipation		Eyelink II	No. fixations, fixation duration, search rate, % time to key locations	Experts had higher response accuracy, faster response times, showed longer response times when making correct vs incorrect decisions, had a lower no. fixations, and shorter fixation duration. Experts had a correlation between fixation duration and response time on correct responses. When incorrect, experts fixated longer on legs and hands vs novices. Only experts differed in % time to key locations from correct to incorrect trials. Experts spent more time fixating legs and hand area when correct	
					Sport-specific video	Response accuracy and response time				

Pizzera et al. (2018)	35 judges (24.03 ± 8.24)	Gymnastics	B-S	97.14	Decision-making	Sport-specific video	Response accuracy	Tobii Tx300	No. fixations, fixation duration, % time to key locations	Judges with more judging experience had higher response accuracy, more fixations on the gymnast during the whole skill and landing phase. Judges with more judging experience spent more time fixating the head and arms of the gymnast. No differences in fixation duration. When split on specific motor experience there was no difference in response accuracy. Judges with specific motor experience had more fixations on the gymnast, longer fixation durations, and showed more fixations to the legs	Judges were grouped on two variables for analyses. First, on judging experience (in years) and second, in specific motor experience (individual experience completing the action being performed)
Roca et al. (2011) exp. 1	10 skilled (23.60 ± 3.80) and 10 less-skilled (24.30 ± 2.40) players	Soccer	B-S	0	Anticipation and decision-making	Sport-specific video	Response accuracy	ASL	No. fixations, fixation duration, search rate, no. fixation locations, % time to key locations, fixation order	Skilled players had higher response accuracy on the decision-making task and showed greater anticipation. Skilled players reported shorter fixation duration to a higher number of fixation locations. Overall, participants fixated the player in possession with the less-skilled group fixating the player in possession the most. Alternatively, the skilled players fixated attackers and areas of space more. Skilled participants alternated their gaze more (fixation order)	
Roca et al. (2013) exp. 1	12 skilled (23.10 ± 3.70) and 12 less-skilled (24.10 ± 2.20) players	Soccer	B-S	0	Anticipation and decision-making	Sport-specific video	Response accuracy	ASL	No. fixations, fixation duration, search rate, no. fixation locations, % time to key locations	Skilled participants had greater response accuracy in both the anticipation and decision-making tasks. Skilled participants showed more fixations of a shorter duration to more locations. Overall participants fixated the player in possession the most. Skilled participants fixated the opponents and areas of free space	Utilised both a near (close viewing position) and far transfer (far viewing position) task

									more while less-skilled participants fixated the ball and the player in possession more	
Roca et al. (2018)	44 skilled players (20.80 ± 2.20)	Soccer	B-S	0	Decision-making Sport-specific video	Creativity z score	ASL	No. fixations, fixation duration, search rate, no. fixation locations, % time to key locations, 1st fixation to opposing attacker	Highly creative individuals had more creative decision-making (z scores) and gave more original first and final decisions. Highly creative participants also had more appropriate and flexible decisions. Players with high creativity had more fixations of a shorter duration to more locations. Overall, the player in possession was the most fixated. Highly creative players fixated players in a threatening position the most and identified a 1st and 2nd attacker in a threatening position earlier than low creativity players	Participants were placed into two groups based on creativity score
Roca et al. (2020)	40 professional and semi-professional players (21.00 ± 2.00)	Soccer	B-S	0	Decision-making Sport-specific video	Creativity z score	ASL	No. fixations, fixation duration, search rate, no. fixation locations, % time to key locations, 1st fixation to opposing attacker	Highly creative individuals had more creative decision-making (z scores) and gave more original first and final decisions. Highly creative participants also had more appropriate and flexible decisions. Players with high creativity had more fixations of a shorter duration to more locations. Overall, the player in possession was the most fixated. Players high in creativity fixated attackers moving to or already in an attacking position. Highly creative participants identified a 1st and 2nd attacker moving to or in an attacking position faster	Also measured verbal reports. Results identical to those in Roca et al. (2018).

Ryu et al. (2013)	11 skilled (25.20 ± 4.50) and 11 less-skilled (25.70 ± 5.00) players	Basketball	B-S	0	Decision-making Sport-specific video	Response accuracy and response time	Eyelink II	No. fixations, search rate, no. fixation locations, % time to key locations, fixation transitions, saccadic amplitude, no. of saccadic amplitudes	Skilled participants had higher response accuracy and faster response times irrespective of the viewing condition. No differences in search rate. Most fixated regions were the player in possession and the nearest defender to this player. No main effect group differences in no. fixations, % time to key locations, fixation transitions, saccadic amplitude, or no. of saccadic amplitudes	Used a variety of video types (full image, moving window, and moving mask) and analysed skill differences across them. Also assessed impact of repeated exposure to same stimuli
Ryu et al. (2016)	50 recreational players (24.20 ± 3.10)	Basketball	B-S	42	Decision-making Sport-specific video	Response accuracy and response time	Eyelink II	Fixation duration, saccadic amplitude, % time to key locations, breadth of search, spatiotemporal gaze pattern, entropy	Moving-window had highest response accuracy. Moving-window group was the only to improve pre- to post-test and post- to retention-test (full-vision and moving-mask improved pre- to post-test only, no improvement for control). No differences between groups at post-test, only at retention-test. No differences at any stage in response time. All training groups improved duration across the tests, but type of training didn't influence fixation duration. No effect of training group on saccadic amplitude, % time to key locations, breadth of search, spatiotemporal gaze pattern, or entropy	Allocated participants to 1 of 4 groups (moving-window, moving-mask, full-vision, and control). Followed a pre-, post-, and retention-test design. Assessed changes and effects across each stage between groups
Saez-Gallego et al. (2018)	16 players (17.13 ± 0.89)	Volleyball	B-S	100	Decision-making Sport-specific video, in-situ	Response accuracy and response time	ASL	% time to key locations	No group differences in response accuracy. Only mixed training led to improved response time. No group differences in % time to key locations	Allocated participants to either a mixed-training (video and physical), video-training, or control group and followed a pre- and post-test design. Utilised a video and field (in-situ) task. Also measured motor behaviour and

										execution differences in the field task
Savelsbergh et al. (2002)	7 expert (29.90 ± 7.10) and 7 novice (21.30 ± 1.40) goalkeepers	Soccer	B-S	NS	Anticipation Sport-specific video	Response accuracy and response time	ASL 4000SU	No. fixations, fixation duration, search rate, no. fixation locations, % time to key locations	No group differences in penalties saved but experts were better at anticipating side and height information (all under response accuracy). Experts made fewer corrective movements and initiated responses closer to foot-ball contact. Experts had fewer fixations of longer durations to fewer areas. Novices fixated the trunk, arm, and hips more while experts fixated the kicking leg, non-kicking leg, and ball. Early in the trial experts tended to fixate the head while novices fixated "unspecified" areas	Assessed differences on successful and unsuccessful trials as well
Savelsbergh et al. (2005)	16 expert goalkeepers (25.70 ± 7.10)	Soccer	B-S	NS	Anticipation Sport-specific video	Response accuracy	ASL 4000SU	No. fixations, fixation duration, search rate, no. fixation locations, % time to key locations	The successful group had higher overall response accuracy, and greater anticipation of kick side and kick height. The successful group initiated movement closer to foot-ball contact. No group differences on no. fixations, fixation duration, or no. fixation locations. The successful group fixated the non-kicking leg more, while the unsuccessful group fixated the head more. The successful group fixated the "unspecified" region more	2 groups were created based on no. penalties saved (an unsuccessful and successful group)
Spitz et al. (2016)	20 elite (33.10 ± 1.40) and 19 sub-	Soccer	B-S	NS	Decision-making		Tobii T120	No. fixations, fixation duration,	Elite players showed higher response accuracy. Elite players outperformed sub-elite on	Looked at open play and corner kicker scenes. Looked at decision type as well

	elite (32.80 ± 1.80) referees				Sport-specific video	Response accuracy		search rate, % time to key locations	disciplinary decisions only. During open play scenes there were no differences in no. fixations or fixation duration. The elite group fixated the contact area of the attacker more with no differences in the contact area of the defender. During corner kick scenes there were no differences in no. fixations, fixation duration or fixations to the contact areas	(technical or disciplinary). When grouping was not considered there was higher accuracy on corner scenes. The attacker was fixated more than the defender in open scenes and contact zone was more fixated than non-contact zone in corner scenes
Takeuchi & Inomata (2009)	7 experts (19.40 ± 1.70) and 7 non-experts (22.40 ± 2.80)	Baseball	B-S	0	Decision-making Sport-specific video	Response accuracy and response time	NAC EMR-8	No. fixations, search rate, no. fixation locations, % time to key locations, time of pitchers motion	No. fixations and no. fixation locations differed between the groups. No effect of time on pitcher's motion. Experts fixated the pitching arm and release point while the novices fixated the head and face more in the final phase only, with no differences in % time to key locations in the initial and middle phases. Experts had better response accuracy and faster response times	Looked at three phases of the complete action (initial, middle, and final)
Uchida et al. (2014)	8 "players" (21.80 ± 0.40) and 8 novices (22.30 ± 2.30)	Basketball	B-S	0	Decision-making Sport-specific video	Response accuracy and response time	Eyelink II	Fixation rate	Only players showed above chance response accuracy and faster response time at normal speed. No differences at slow or fast speed. At normal speed, players had a higher fixation rate to the lower body, while novices had a higher fixation rate to the upper body. No differences in fixation rate to the ball. Only players showed comparable rates across the three areas	Used normal speed, slow speed, and fast speed video conditions. Authors also present results for modified video conditions (i.e., slow and fast speed)
Vaeyens et al. (2007a)	21 elite (14.70 ± 0.50), 21 sub-elite	Soccer	B-S	0	Decision-making		ASL 5000	No. fixations, fixation duration,	Successful players had faster response times across all video scenarios. Response time	Videos scenarios varied in the number of players present (2v1, 3v1, 3v2, 4v3, and 5v3

	(14.60 ± 0.30), and 23 regional (14.60 ± 0.60) players				Sport-specific video	Response accuracy and response time		search rate, % time to key locations, interfixation rate, fixation order	generally increased as the number of players increased. Successful group had higher response accuracy in all bar one condition (2v1). Successful players had a higher number of fixations per second (search rate). No differences in fixation duration. No differences in interfixation between groups. Successful group alternated gaze more between the player in possession and other areas of the display more (fixation order). The groups differed in % time to key locations in two conditions (3v2 and 4v3) with successful players fixating the ball, player in possession, and attacker closely marked more. Overall, successful players spent more time fixating the player in possession	scenarios). Participants were not compared across expertise level but rather split into "successful" and "unsuccessful" groups. Allocation was based on response accuracy. Authors offer more specific findings for differences between video scenarios
Vaeyens et al. (2007b)	21 elite (14.70 ± 0.50), 21 sub-elite (14.60 ± 0.30), 23 regional (14.60 ± 0.60) players and 22 control individuals (14.50 ± 0.40)	Soccer	B-S	0	Decision-making Sport-specific video	Response accuracy and response time	ASL 5000	No. fixations, fixation duration, search rate, % time to key locations, interfixation rate, fixation order	No differences in choice reaction time. Playing groups had faster response times than control group in all video scenarios. Elite and sub-elite were faster than regional players in all conditions bar 2v1. Response time generally increased as the number of players increased. All player groups had higher response accuracy on 3v1 and 4v3 vs control group. Only elite and sub-elite had higher response accuracy in 5v3 than control. No differences between groups in no. fixations or fixation durations. No differences between groups in interfixation rate. Elite players altered fixations between the player in possession and other areas of the visual field (fixation	Videos scenarios varied in the number of players present (2v1, 3v1, 3v2, 4v3, and 5v3 scenarios). Authors offer more specific findings for differences between video scenarios

									order) more than any other group. Overall, successful players spent more time fixating the player in possession. More skilled players fixated the player in possession more. In addition, the elite players fixated the defensive and unmarked attacking players less and the attacker closely marked more	
van Maarseveen et al. (2018a)	22 highly talented players (16.30. ± 1.10)	Soccer	B-S + W-S	100	Anticipation, decision-making, and pattern recall		SMI	No. fixations, fixation duration, search rate, % time to key locations, fixation order, entropy	There was no relationship between in-situ performance and anticipation, decision-making, or pattern recall. A median split analysis using best and worst performers from both in-situ and perceptual-cognitive tasks, in separate analyses, revealed the same results. Better performance on the in-situ task was only associated with less time fixating the ball in the decision-making task, no other VA measures.	Used manipulation checks to assess the effect of different occlusion times (-100ms, 0ms, and 100ms) and whether repeated exposure to the same stimuli inadvertently facilitated learning effects. Also examined gaze differences across the three perceptual-cognitive (video) tasks
					Sport-specific video and in-situ	Response accuracy and anticipatory recall score				
van Maarseveen et al. (2018b)	13 skilled players (16.90 ± 1.30)	Basketball	W-S	100	Decision-making		SMI	First fixation on selection, final fixation on selection, % time to key locations, scan paths, no. fixations to correct option when an incorrect choice was made	No differences based on defensive movement (“under”, “over”, “hedge”) or court side (left/right) in response accuracy. Decisions were noted as different based on the side of the play. No differences in response time. Participants often fixated upon their final decision. 95 of 188 final fixations were toward their final decision. The option players chose was not influenced by the % time to key locations. A higher response accuracy was associated with lower % time viewing the	Used a manipulation check to assess the impact of wearing an eye-tracker during an in-situ task. The defender in the in-situ task was given one of three instructions (“under”, “over” and “hedge”). Also analysed potential performance differences based on the side of the court the action was performed (i.e., left and right). Looked at whether the side influenced preferences. Looked at the gaze behaviour across the
					In-situ	Response accuracy and response time				

									free outer space. Scan paths were different, and more diverse, when selecting to pass to teammate rather than drive to basket or shoot. Different scan paths for correct and incorrect decisions were found. When incorrect, gaze was only directed to the optimal outcome in 12 of 56 trials	different decisions made (drive to basket, shoot, pass to teammate, or pass to corner)
Vater et al. (2016)	11 high-skilled (18.55 ± 2.80) and 11 lower-skilled (22.91 ± 4.51) players	Soccer	B-S	0	Anticipation		ASL	No. fixations, fixation duration, no. fixation locations, % time to key locations	The high-skilled group had significantly higher response accuracy and faster response times compared to lower-skilled players. For accuracy, there was no effect of anxiety, task constraints, nor interaction. For time, participants took longer at high anxiety, under different task constraints. Also, interactions were significant. High-skilled group had a significantly higher no. fixation locations only. For % time to key locations, higher skilled players fixated the opponents, teammates, and free space more while lower skilled players fixated the ball significantly more	Task constraints included near and far video footage. Successfully manipulated anxiety across all players. Used rating scale of mental effort which was significant across anxiety conditions, between groups, and across task constraints. A large number of VA interactions are reported between groups and some additional main effects also.
					Sport-specific videos	Response accuracy and response time				
Vila-Maldonado et al. (2019)	38 players (23.90 ± 4.20)	Volleyball	W-S	100	Decision-making		ASL	No. fixations, fixation duration, % time to key locations	Regression showed that longer fixation durations to the shoulders and head negatively affected total response accuracy (with similar results for “zone 3” and “zone 4” accuracy). Total response accuracy was positively impacted by no. fixations to the ball-wrist and negatively impacted by no. fixations to the head.	Divide their response accuracy variable into three (“zone 3” accuracy, “zone 4” accuracy, and total accuracy). Zones refer to areas on the court
					Sport-specific video and in-situ	Response accuracy				

Williams & Davids (1998) exp 1a	12 experienced (24.00 ± 4.10) and 12 less-experienced (23.30 ± 4.00) players	Soccer	B-S	0	Anticipation		ASL 4000SU	No. fixations, fixation duration, search rate, fixation order, % time to key locations	Experienced players showed greater response accuracy than less-experienced. Initiation time was the greatest distinguishing factor between the groups (better than response time, response accuracy, and movement time). No differences in fixation order, fixation location, no. fixations or fixation duration	Used 3v3 scenarios. Across the whole sample (combined experienced and less-experienced) the lower-body of the player in possession of the ball, players upper body, and the right side of the screen were most fixated
					Sport-specific video	Response accuracy, response time, initiation time, and movement time				
Williams & Davids (1998) exp 1b	12 experienced (24.00 ± 4.10) and 12 less-experienced (23.30 ± 4.00) players	Soccer	B-S	0	Anticipation		ASL 4000SU	No. fixations, fixation duration, search rate, fixation order, % time to key locations	Experienced players showed greater performance on the anticipation test. Initiation time was the greatest distinguishing factor between the groups (better than response time, response accuracy, and movement time). No differences in fixation order, % time to key locations but effect sizes showed a meaningful differences in % time fixating the area between the knees and shoulders, where experienced players fixated here for longer. Experienced players had shorter fixation durations and higher no. fixations.	Used 1v1 scenarios
					Sport-specific video	Response accuracy and response time				
Williams, Vickers, & Rodrigues (2002)	10 recreational players (28.90 ± 8.20)	Table tennis	W-S	20	Working memory		ASL 501	No. fixations, fixation duration, search rate, % time to key locations	Performance was better under low-anxiety conditions vs high-anxiety and better when working memory demands were low vs high. Anxiety impacted frequency of gaze. Participants fixated "other" areas of the display less vs the ball when anxiety was high in the high working memory condition. No differences in fixation duration.	Used a manipulation check to assess the effectiveness of their anxiety manipulation (used high- and low-anxiety conditions). Manipulated the task to have low- and high-demands on working memory. Also obtained mental effort scores. Obtained some kinematic measures (ball velocity, arm velocity at
					In-situ/manipulation	None				

										contact, peak velocity, and initial position)
Wood et al. (2016)	12 low working memory (20.30 ± 2.11) and 12 high working memory (20.00 ± 1.70) undergraduate students	Shooting	B-S	29.17	Working memory OSPAN	Response accuracy	ASL XG	Quiet eye duration, visual search	Low working memory individuals had slower visual search times and shorter quiet eye durations when the target was incongruent (marginally non-significant to congruent targets)	Manipulated situation to create a high threat (high-anxiety) and low threat (low-anxiety). Task targets were congruent (word matches ink colour) and incongruent (word does not match ink colour). Also measured performance on the shooting task

Note. all sample ages are shown in parentheses in “Sample Characteristics”. B-S = between-subjects, NS = not specified, and W-S = within-subjects.

Fifty-five experiments used a between-subjects design while eight used a within-subjects design and one experiment applied a dual between- and within-subjects design (van Maarseveen et al., 2018a). Between-subject experiments could be further broken down into sporting expertise differences (*n* = 34), randomised control trials/training experiments (*n* = 11), performance differences (*n* = 6), task/instructional differences (*n* = 4). Large variation in the labelling of expertise groups was found across the 34 experiments where claims to assess experts and novices, high-skilled and low-skilled, high-level and mid-level, skilled elite and less-skilled elite, high-skilled elite and skilled elite, skilled and less-skilled, international and national, higher-level and lower-level, experienced and less-experienced, officials and players, task-relevant sportspeople and alternate sportspeople were reported. Within-subject experiments were either manipulation (*n* = 4) or exploratory (*n* = 4) experiments. Manipulation experiments involved manipulating auditory stimuli, inhibition demands, and anxiety. Exploratory experiments involved understanding which gaze strategies led to optimal decisions and comparing performance in-situ and video scenarios.

2.4.3.2 Executive Function

See Table 2.3 for a full breakdown of results relating to EF. Fifty-two experiments examined a higher-order EF and 12 examined a lower-order EF. Higher-order EF experiments covered decision-making (*n* = 33), anticipation (*n* = 13), decision-making and anticipation (*n* = 4), decision-making and pattern recall (*n* = 1), and decision-making, anticipation and pattern recall (*n* = 1). Lower-order EF experiments assessed inhibition (*n* = 5) and updating/working memory (*n* = 7) with no experimental examination of shifting.

Eleven tasks were used to assess EF including: sport-specific video, sport in-situ, sport-specific photo, visual search, nback, Operation Span Task (OSPAN), change detection, structural dimension analysis of mental representation, recall, choice reaction, and in-situ manipulation. Some experiments also used a combination of tasks (e.g., sport-specific video and sport in-situ tasks; Dicks et al., 2010). Sport-specific video tasks were used in 24 decision-making experiments, 13 anticipation experiments, and three decision-making and anticipation experiments. Two decision making experiments used a sport in-situ task, three decision-making experiments used sport-specific photo tasks, and one decision-making experiment used a choice reaction time task. Three decision-making experiments, one decision-making and anticipation experiment, and one decision-making, anticipation, and pattern recall experiment used a combination of sport-specific video and in-situ tasks. One decision-making and pattern recall experiment used a combination of sport-specific video and recall tasks. Three inhibition experiments used an in-situ task where inhibition demands were manipulated and one working memory experiment used an in-situ task where working memory demands were manipulated. Two inhibition experiments used a visual search task and one working memory task used a structural dimension analysis of mental representation. For remaining working memory experiments, one used an nback task, two used the OSPAN task, one used a combination of nback and OSPAN tasks, and one used a combination of nback and change detection tasks.

Various outcome measures of the examined EF were reported across experiments. A total of twenty outcome measures, including combinations[1] of the following outcome measures, were reported across the 11 tasks. Outcome measures included verbal responses, response accuracy, response time, efficiency score, sensitivity index, error in least squares, difficulty level achieved, replication ability, recognition time, anticipatory recall scores, initiation time, movement time, expectation accuracy, outcome judgements, creativity scores,

[1] Combined outcome measures included the following: response accuracy and response time, response accuracy and efficiency score, response accuracy and sensitivity index, response accuracy and distance error in least squares, response accuracy and difficulty level achieved, response accuracy and replication ability, response accuracy and recognition time, response accuracy and anticipatory recall scores, response accuracy, response time, initiation time, and movement time, and response accuracy, response time, efficiency score, and expectation accuracy.

radial error, distractor costs, hits and false alarms, adjusted rand index, and none (i.e., the study did not have an outcome measure associated with EF).

For decision-making experiments, 11 used response accuracy and response time, nine used response accuracy, three used response accuracy and a sensitivity index, two used verbal responses, two used response accuracy, response time, and efficiency scores, two used outcome judgements, two used creativity scores, one used response time, and one used response accuracy and replication. For anticipation experiments, five used response accuracy, five used response accuracy and response time, one used radial error and verbal responses, one used response accuracy and recognition time, and one used response accuracy, response time, initiation time, and movement time. Experiments examining decision-making and anticipation used response accuracy (*n* = 2), response accuracy and response time (*n* = 1), and response accuracy, response time, efficiency scores, and expectations (*n* = 1). The sole decision-making and pattern recall experiment used response accuracy and distance error in least squares. The only decision-making, anticipation, and pattern recall experiment used response accuracy and anticipatory recall scores. For inhibition experiments, three had no outcome measure at all and two used distractor costs. Regarding working memory, three used response accuracy, one used an adjusted rand index, one used difficulty level achieved and hits and false alarms, one used difficulty level achieved and response accuracy and one used no outcome measure at all.

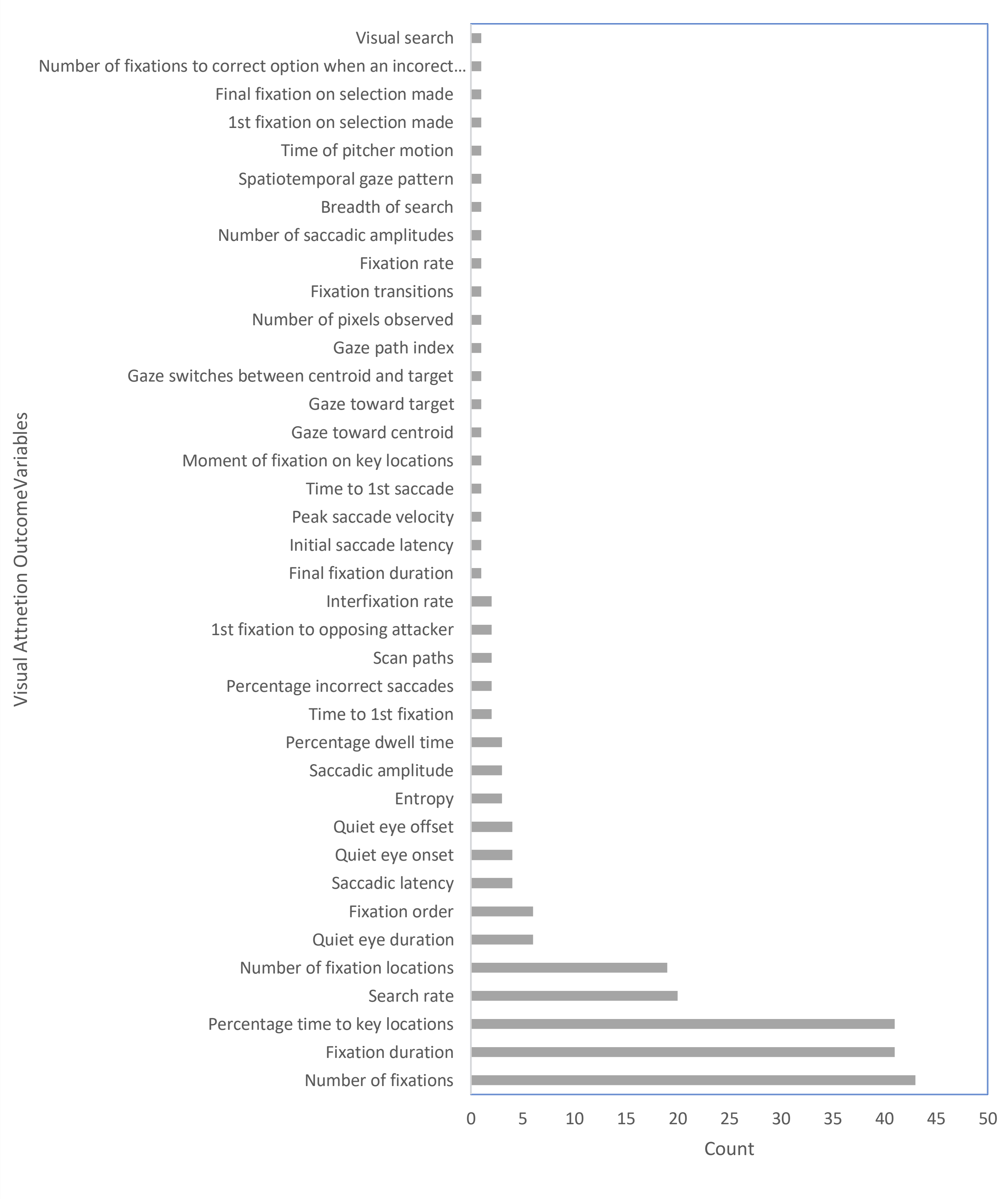
2.4.3.3 Visual Attention

See Table 2.3 for a full breakdown of VA results. There was large variance in the mobile eye-tracker used: Applied Science Laboratories (ASL; *n* =30), SR Research (*n* = 12), SensoMotoric Instruments (SMI; *n* = 6), Tobii (*n* = 6), EyeSeeCam (*n* = 4), NAC Image Technology (*n* = 3), Pupil Labs (*n* = 1), Scene Camera Viewpoint (*n* = 1), and EyeGaze System (*n* = 1). A number of specific models were also outlined across experiments. Eighteen specific ASL Models were outlined and included: 4000SU (*n* = 4), 501 (*n* = 3), 5000 (*n* = 3), 3000 (*n* = 2), SE5000 (*n* = 2), 5001 (*n* = 1), Eye-Trac 6000 (*n* = 1), The Mobile Eye (*n* = 1), and XG (*n* = 1). Twelve specific SR Research models were reported including: Eyelink 1000 (*n* = 5), Eyelink II (*n* = 5), and Eyelink SR II (*n* = 2). Three specific SMI models were outlined: RED500 (*n* = 1), iViewX HED (*n* = 1), and ETG 2.0 (*n* = 1). Reported Tobii models included: T120 (*n* =4), X3-1201 (*n* = 1), and Tx300 (*n* = 1). Three NAC models were reported and included: EMR-8B (*n* = 2) and EMR-8 (*n* = 1). Remaining experiments did not clarify their specific eye-tracker model (ASL = 12, EyeSeeCam = 4, SMI = 3, Scene Camera Viewpoint = 1, Eyegaze system = 1, Pupil Labs = 1).

Thirty-eight different outcome measures were reported (see Figure 2.2). Nine experiments used a single outcome measure for VA and 55 used at least two outcome measures (range 2-7). Outcome measures that appeared in at least two experiments include: number of fixations (*n* = 44), fixation duration (*n* = 42), percentage time spent viewing key locations (*n* = 42), search rate (*n* = 20), number of fixation locations (*n* = 20), fixation order (*n* = 6), quiet eye duration (*n* = 6), quiet eye onset (*n* = 4), quiet eye offset (*n* = 4), saccadic latency (*n* = 4), percentage dwell time (*n* = 3), saccadic amplitude (*n* =3), entropy (*n* = 3), first fixation time (*n* =2), percentage of incorrect saccades (*n* =2), scan paths (*n* =2), first fixation to an opposing attacker (*n* =2), and interfixation rate (*n* =2). Twenty additional VA outcome measures were also used (see Figure 2.2).

Figure 2.2.

Count of visual attention outcome variables across the included experiments



2.4.3.4 Executive Function and Visual Attention

The present review seems to suggest an association between EF and VA and that this relationship is positive (i.e., improved EF is associated with improved VA). Research from the neuroscientific literature may explain this relationship (Corbetta & Shulman, 2002; Gaillard & Ben Hamed, 2022). Specifically, key areas within the fronto-parietal areas of the brain (i.e., dorsal and ventral streams; Itti & Koch, 2001) are proposed to facilitate both VA and cognitive information processing. Though an underexamined area in sport, this neuroscientific explanation may suggest that outcome measures to do with EF and VA yield positive relationships because they are influenced by similar regions of the brain. Therefore, the positive associated found in the present review may, in part at least, support the idea that this neurological basis is also responsible for the EF and VA relationship in sport.

Fifty-three experiments had outcome measures of EF and VA reported in separate analyses. This is potentially due to study designs favoured measuring EF and VA before comparing group differences. Despite not appearing in the same analyses, 52 experiments contained a significant finding in relation to both EF and VA. Response accuracy (EF outcome measure) and percentage time fixating key locations (VA outcome measure) were the most common and both appeared significant in 20 experiments. However, the association between these variables remains speculative given the research design (i.e., group differences). Specifically, these studies often assessed EF and VA differences between expertise groups independently with no direct comparison. Eleven experiments contained some kind of direct comparison between EF and VA (e.g., Piras et al., 2014). Ten were focused on higher-order EFs (e.g., decision making) and one focused on lower-order EF (e.g., updating; Frank et al., 2016). Only one experiment that directly compared EF and VA found no significant association (i.e., Savelsbergh et al., 2002).

2.5 Discussion

The present review examined the relationship between EF (higher- or lower-order) and VA in sport. One key focus was on obtaining a greater understanding of how these two facets of attention (executive and visual processes) may relate despite research often omitting direct comparisons. Identified studies included a range of sample characteristics, research designs, sport types, EF measures and VA tasks, and outcomes. The findings and specific comparisons and contrasts across experiments are discussed in detail below. The present study provided the first narrative and comprehensive explanation of research examining the association between both higher- and lower-order EFs and VA in sport, thus further informing our understanding of ACT and ACT-S (Eysenck & Wilson, 2016). Overall, the present review provides valuable insights into the apparent relationship between EF and VA within sport and could guide future research and practice.

2.5.1 Quality Assessment

The quality assessment results raised a number of issues with the included studies. The worst performing was item 9 which concerned the reporting of actual *p* values. Reporting actual *p* values, rather than whether a value is greater or lesser than a standardised alpha value (e.g., $p < .05$), allows for greater transparency and for readers to interpret the findings themselves (Payne et al., 2019). However, in instances where the *p* value is less than .001, reporting $p < .001$ is suitable. Reporting exact *p* values is important but research has noted that best practice may be to prioritise effect sizes, rather than *p* values, given that large sample sizes can lead to a significant *p* value though statistical effects may actually be arbitrary (Sullivan & Feinn, 2012). Therefore, it is recommended that future work reports exact *p* values and the effect size in all relevant statistical analyses.

Various experiments were deemed to not meet item 12 (i.e., have a targeted sample that is fully representative of the larger population) nor item 13 (i.e., have an actual sample that is fully representative of the larger population). This was typically due to issues around generalising results of low sample size experiments (average sample size = 30.71) and experiments examining athletes from a single sport (e.g., an experiment on basketball players is not likely representative of all athletes/sports; Gorman et al., 2015). It is recommended that future experiments opt for larger and more sport-type diverse samples (to allow more definitive inferences). Perhaps more important is to include power calculations that justify sample size to help avoid missing real effects (i.e., underpowered experiments) or over-spending on experimental resources (i.e., overpowered experiments; Green & MacLeod, 2015). Recommended methods for power calculations include G*Power (Faul et al., 2009) or using R (e.g., the "simr" package; Green & MacLeod, 2015).

Item 23 assessed whether the results could be applied to other relevant populations. As the present review outlined that results were not applicable to all individuals within the target sport, they are therefore unlikely to represent athletes, or other relevant populations, as a whole. It is important to consider that a large number of experiments used lab-settings where ecological validity can be low and transferring results to the "real-world" is difficult. A small number of experiments utilised in-situ tasks which may yield higher ecological validity and show that the design is possible. Only higher-order EF experiments considered outcome measures within in-situ tasks. Whereas lower-order EF experiments opted instead to manipulate task demands and not use an outcome measure (e.g., Klostermann, 2020).

All experiments were deemed to meet item 20 (i.e., directly measured outcome variables) and item 16 (i.e., validly assessed outcome variables). Despite all experiments included a direct and valid outcome for VA, not all experiments did so for EF. This only occurred in experiments examining lower-order EFs where demands were manipulated in-situ for updating (Williams, Vickers, & Rodrigues, 2002) and inhibition (Klostermann, 2020, Experiment 1 and 2). While the use of in-situ tasks may increase ecological validity (i.e., the situation is more reflective of the "real-world"), it can make capturing outcome measures difficult and subsequently reduces understanding of how an individual's EF and VA relate. As there are a number of standardised lower-order EF tasks that allow for response accuracy, response time, or combined measures to be captured (e.g., Stop Signal Task; Verbruggen et al., 2019) it is recommended that future work consider applying in-situ and standard tasks together. The reason for this recommendation is that, even with it being reasonable to assume that individuals with greater EF perform better on an in-situ task designed to place high demands on EF should outperform those with lower EF, the inclusion of task-related outcome measures (e.g., combined response accuracy and time) should only strengthen and consolidate this assumption.

2.5.2 Discussion of Findings

2.5.2.1 Sample Characteristics, Sport Type, and Design

Age, sample size, and gender provided some interesting points of discussion. Age varied across studies. Given that EF develops with age (Diamond, 2013) caution should be taken when reconciling findings using samples with different ages and therefore, disparate cognitive development. Sample size was generally small so researchers are encouraged to use larger samples (so as to produce more generalisable results) and utilise a priori power calculators (e.g., G*Power or R). Indeed, Abt et al. (2020) note that many papers submitted to the Journal of Sport Sciences were without sample size justification and recommend future work includes such calculations. Though it is acknowledged that when working with elite groups obtaining a larger sample can be difficult (Koch & Krenn, 2021). Female representation was low with the average representation around one third. Increased female representation in high-quality experiments may help alleviate issues around the misapplication of previous findings from male samples to female samples (Emmonds et al., 2019). Such work may also allude to any gender differences in the development and utilisation of EF and VA.

Open-skill sports were predominant amongst the reviewed literature and may have been selected due to the increased attentional (executive and visual) demands (e.g., the need to efficiently and effectively process complex stimuli; Mann et al., 2007). Interestingly, ultra-marathon runners (e.g., closed-skill sport) have shown to be higher in motivation (Hammer & Podlog, 2016) and resilience (Roebuck et al., 2020) compared to other sports-people and non-athletes. Future research could examine how EFs allow individuals to maintain motivation and/or resilience rather than directly impact closed-skill sport performance (e.g., finish time in elite running). In the case of an ultra-marathon runner, EF may not directly impact performance outcomes but work with other psychological qualities for success (e.g., motivation) thus, suggesting an interaction effect. This suggestion, however, remains hypothetical and yet to be tested. In terms of research design, the most commonly examined differences were between groups of experts and novices (between-subjects design).

2.5.2.2 Expertise

There were consistent discrepancies in the labelling of athletic expertise that could lead to non-generalisable findings (Polman, 2012). McRobert et al. (2011) considered professional/national level as *skilled* and local club as *less-skilled* while Afonso and Mesquita (2013) asked independent coaches to subjectively assign *skilled* and *less-skilled* groups. Comparisons across studies therefore are difficult as groups potentially share a label yet differ greatly in expertise. McRobert et al. (2011) and Gorman et al. (2015) used different group labels but similar group definitions. Specifically, both included national level in their *expert* definition but labelled the group as *skilled* (McRobert et al., 2011) and *expert* (Gorman et al., 2015). While both studies included local-level performers for their *novice* group but McRobert et al. (2011) used the label *less-skilled* while Gorman et al. (2015) use the term *novice*. The issue here is that researchers may not compare these experiments due to labels used, when really the experiments are comparable. The problem around defining expertise groups is not new (see Swann et al., 2015, a review). Swann et al. (2015) provided a taxonomy for rating expertise on a continuum, rather than using dichotomous groups, which may be pertinent for future research. This method has been successfully applied in previous work in this research area (e.g., Hagyard et al., 2021).

2.5.2.3 Executive Function, Tasks, and Outcomes

Higher-order EFs (e.g., decision-making) are dominant within the EF, VA, and sport literature. Focus on higher-order processes is not surprising given the importance of such complex processes in many sports, particularly open-skill sports (e.g., soccer; Roca et al., 2013). Where, and for how long, experts direct gaze when making correct decisions or anticipating opponent movement may be of specific interest in open-skill sports due to potential trainability. For example, training young or novice athletes on where to look, and for how long to look at key stimuli, in order to be successful appears to be beneficial (Moore et al., 2019). It is important to consider that higher-order EFs are inherently more complex (i.e., driven by multiple simpler or lower-order attentional processes), and as such it may be difficult to isolate specific functions and maximise intervention training. Lower-order EFs have been reported as important factors for sport performance (Vestberg et al., 2012; 2017) and may compliment sport-training regimes as they are more easily isolated within a task. No experiments have examined a direct interaction between lower-order EF and VA in sport (e.g., do lower-order EF facilitate VA during sport performance).

Higher-order processes have predominately been examined using sport-specific video tasks whereas lower-order EFs are often assessed with domain-general cognitive tasks or EF demands are manipulated within the task. Such tasks have been questioned regarding their ecological validity and transferability to real word sport contexts (van der Kamp et al., 2008). Specifically, sport-specific videos are sport-relevant but often lack sensory feedback while domain-general cognitive tasks assess the underlying cognitive procedures but lack sport-specific context. Research suggests that domain-general inhibition training can lead to significantly improved VA (i.e., time to first fixation) and real-world tennis performance (Ducrocq et al., 2016). Therefore, future work may wish to focus on how performance on domain-general lower-order EF tasks can influence subsequent sport performance (with sensory input) rather than simply examining group differences. Another note for future research concerns using multiple tasks to assess a single EF. Miyake et al. (2000), and the present review, note that experiments examining lower-order EFs often utilise a single task which may be a problem and only allow researchers to comment on task-specific performance. Therefore, this thesis calls for more studies to use multiple measures of the same EF to better understand the latent construct over task-specific performance.

Response accuracy appears to be somewhat consistently measured despite the EF (i.e., higher- or lower-order) and task under investigation and response time is more popular when measuring higher-order EFs. It is important to add that accuracy measures should include errors in their calculation to avoid participant effects (e.g., speed-accuracy trade-offs; Vaughan & Laborde, 2021). Somewhat surprisingly, few experiments combined time and accuracy (often termed efficiency score; Bishop et al., 2014; Edwards et al., 2016) with experiments showing a tendency to report response accuracy only (effectiveness). Future research may wish to consider combined accuracy and time measures as success in sport often requires rapid and accurate decision-making under externally driven time constraints. Second, ACT-S outlines that response accuracy is usually an indicator of effectiveness only (i.e., performance quality) and does not consider performance efficiency (i.e., the relationship between effectiveness and resources used; Eysenck & Wilson, 2016). To better reflect genuine sporting situations and theoretical assumptions, it is recommended that future work include both indices of effectiveness (accuracy) and efficiency (ratio of accuracy to time).

Finally, a number of experiments examining lower-order EFs recorded no outcome measure. Instead such experiments opted to manipulate task demands and attribute subsequent performance differences across conditions to the executive demands placed on the individual (e.g., Klostermann, 2020). Klostermann (2020) built a target-throwing paradigm with four conditions each of which placed different demands on inhibition. Klostermann (2020) then assessed VA (quiet eye duration) differences across the conditions and assumed differences were due to varying inhibitory demands across conditions. However, this task also placed demands on peripheral attention (participants were asked to fixate centrally) and working memory (targets were shown only for a short time-period). Without any specific outcome measure of inhibition or updating it is difficult to understand the varying contributions of such factors. It is suggested for future work to first include a direct outcome measure when examining lower-order EF and second to directly compare such outcome measures to VA and sport performance.

2.5.2.4 Visual Attention

The reviewed experiments tended to use similar eye-tracker brands with 30/64 experiments opting for the ASL brand. The experimental results showed that, despite the eye-tracker used, the reported significance of VA variables was most often mixed (i.e., some variables significantly related to sport while others did not; 45/64 experiments). It has become common to use multiple outcome measures when assessing VA (56/64 experiments used multiple) as single measures may not be sensitive enough to capture the complex visual processes involved in sport performance. Outcome measures like the number of fixations, fixation duration, fixation location, and the quiet eye have featured heavily in review work which may explain these decisions (Mann et al., 2007). An updated review from Klostermann and Moeinirad (2020) suggested that the number and duration of fixations may not be as meaningful as previously stated and that quiet eye variables and gaze location may be more informative. Interestingly, Klostermann and Moeinirad (2020) also suggest that VA outcome measures may be dependent on the operational task utilised (i.e., decision-making or aiming task).

Rather than explicitly state the advantages of certain VA outcomes, more emphasise could be placed on the relevance of variables in certain tasks. The present review suggests that the importance of VA variables may fluctuate across sports and tasks. For example, Lex et al. (2015) found soccer experts showed fewer fixations when responding to soccer tactical displays while Takeuchi and Inomata (2009) reported baseball experts reported more fixations during a sport-specific video decision-making task. Brams et al. (2019) may support this point in their systematic review on decision-making and anticipation (i.e., higher-order EFs). A medium-large effect size for fixation duration, fixations to key locations, and scan patterns was noted in experiments comparing experts and novices which supports the importance of such outcomes in higher-order tasks. This chapter argues that researchers should carefully consider the sport and task being used when ascertaining the relevance of VA outcomes rather than using a generic approach. Finally, an interesting avenue for future work might be time course analysis (Vansteenkiste et al., 2014). Time course analysis focuses on the time at which performers fixated certain stimuli for successful performance, rather than using cumulative gaze behaviour. Such methods may help show the importance of measures like fixation duration and number and address Klostermann and Moeinirad's (2020) concerns.

2.5.2.5 Executive Function and Visual Attention

A key purpose of the present review was to better understand the association between EF and VA. After reviewing relevant literature, it became clear that making a direct assessment between these two is difficult due to differences in experimental designs and because most studies assess EF and VA across groups without direct comparison. Though not directly assessed, there appears to be a positive association between EF (higher- and lower-order) and VA with 51 from 64 (80%) experiments reporting significance in at least one outcome measure of both EF and VA. An initial informative narrative is possible but results must be interpreted cautiously until there is more research that allows for a direct comparison of EF and VA within the same analyses. Some research has examined EF and cognitive attention (e.g., Vaughan & Laborde, 2021) and other work has begun to demonstrate an association between EF, VA and sport performance (e.g., Ducrocq et al., 2016; 2017), yet more research is needed to better understand the interplay of these processes in sport. A quantitative meta-analysis would then be appropriate to corroborate the current findings.

Given that response accuracy was reported far more than response time for EF outcomes, more is known about the relationship between response accuracy (rather than response time) and VA. This is surprising given the volume of experiments examining sports where the time to respond is pivotal (e.g., soccer; Roca et al., 2018) and given that theoretical accounts suggest the importance of effectiveness (i.e., accuracy) and efficiency (i.e., accuracy by time; ACT-S; Eysenck & Wilson, 2016). Combined accuracy and time measures (i.e., efficiency scores; as in Bishop et al., 2014) are optimal for understanding accurate performance under time constraints and in turn the drawing conclusions about time-pressured performance and visual cues for successful performance. Piras et al. (2014) reported that greater expertise was associated with longer fixation durations (i.e., more stable gaze) and faster response times on correct decisions. This may suggest a positive relationship between stable gaze (i.e., VA) and subsequent response times (i.e., EF) in sport-related higher-order tasks. However, confirming the direction of this association is not easy (i.e., does VA influence EF, or vice versa) as results are often unequivocal. Klostermann (2020) reported that manipulating inhibitory demands (a lower-order EF) led to changes in VA (i.e., quiet eye), more work is needed to understand the direction of this relationship.

Twelve experiments in the present review made direct comments about the association between EF and VA with the majority (10/12) concerned with higher-order EFs (e.g., decision-making). Future work is encouraged to focus on understanding the association between lower-order EFs and VA to comprehend more precisely the cognitive processes that underpin gaze behaviour. The general interpretation of results from identified studies suggest that higher- and lower-order EFs relate to VA positively. Interestingly, only one experiment that examined a lower-order EF explicitly analysed outcome measures of both EF and VA and demonstrated their relationship (i.e., Frank et al., 2016). Frank and colleagues (2016) showed a small significant positive correlation between performance on the structural dimension of mental representation within a memory task and quiet eye duration. More research is needed to better understand how holistic lower-order models of EF (i.e., those proposed by Miyake et al., 2000, and ACT-S; Eysenck & Wilson, 2016) are linked to VA in sport.

Despite forming part of a theoretical model of attention (i.e., ACT-S; Eysenck & Wilson, 2016) zero experiments examined shifting in relation to VA. This is surprising as ACT-S predicts that whenever demands are high on inhibition and updating, they should also impair shifting. Shifting has been outlined as important for attention, representation, and perception related processes (Ionescu, 2012) and has been positively related to sport performance (e.g., Vestberg et al., 2017). Future work is encouraged to first examine the role of shifting for sports performance but also, understand how shifting ability may interact with VA in order to guide motor control during sports performance.

Of the experiments that outlined a relationship between EF and VA only one found no significant relationship (albeit higher-order EF). Savelsbergh et al. (2002) compared VA across successful and unsuccessful anticipation trials and found no differences in performance attributable to gaze behaviour. This experiment is the only one to consider VA and anticipation ability directly and may indicate that other perceptual processes are more important for anticipation than VA. In addition, the authors suggested that individuals may be able to extract and process information effectively during fixations (hypothetically through enhanced quiet eye periods) and make better use of peripheral vision (i.e., use anchor points and/or visual pivots; Vater et al., 2020). Although it should be noted that Savelsbergh et al. (2002) created their groups based on successful penalty performance and was likely underpowered with seven participants in each group. Future work should look to better understand how quiet eye variables relate to both lower- and higher-order EFs and consider the role of peripheral vision.

2.5.3 Implications

The present review has a number of implications for future applied and theoretical work. Perhaps the largest implication is that, despite very little in the way of explicit examination, there appears to be a positive association between EF and VA in sport. More work is needed to better understand the precise manner in which the two relate (e.g., longitudinal work where EF and VA are tracked over time). The present review highlights an issue with unstandardised expertise labels and suggests a unified method for labelling athletic expertise. Future studies could consider using Swann et al.'s (2015) framework for creating a continuous measure of expertise that does not require the artificial categorisation of participants into groups. Also, given the link between expertise and EF it would be important to consider other known covariates like physical activity and age (see Diamond, 2013) even when not explicitly looking for such differences between athletic groups.

The present review found that there is generally a lack of research examining lower-order EFs and VA together. Lower-order EFs comprise the fundamental processes used in perceptual-cognition and likely underpin more complex higher-order EFs (e.g., decision-making). Tasks designed to assess lower-order EFs are also more likely to tap only the targeted function providing a more sensitive examination of the underlying processes at work during gaze. The present review recommends that future work should deploy EF tasks that assess both response time and accuracy together (i.e., efficiency scores) and VA tasks that assess some or all of fixation number and duration, fixation percentage to key locations, and quiet eye (despite concerns from Klostermann & Moeinirad, 2020). The key may be deciding on the relevance of certain outcome variables based on the sport and task being examined.

2.5.4 Limitations

The present review is an informative resource for understanding the current state of EF and VA literature in sport. However, there are some weaknesses. Despite following PRISMA guidelines (Moher et al., 2009) and adopting similar criteria to previous reviews (e.g., Payne et al., 2019) the items used for quality assessment were not specific to all the identified studies. Items were adapted from relevant previous works (Downs & Black, 1998; DuRant, 1994; Genaidy et al., 2007; Payne et al., 2019) yet the lack of general agreement in how to assess experiment quality can lead to differences in opinion (Payne et al., 2019). Until a list is psychometrically tested the criteria may be considered somewhat hypothetical. Further, the review included many experiments covering a variety of sports, EFs, VA measures, and sample characteristics, and this may raise questions around comparing and drawing conclusions from very different works. However, it’s hoped that this review provides a critique of the necessary ‘ingredients’ for future studies and becomes the catalyst for further work in EF and VA in sport.

2.5.5 Conclusion

The examination of EF and VA in sport is an exciting and growing area for researchers and sports coaches alike. The present review highlighted differences in tasks with sport-specific video tasks utilised for examining higher-order EFs and domain-general or manipulation tasks used for investigating lower-order EFs. A number of experiments examining lower-order EFs were limited by their outcome variables (i.e., some including no outcome measures and not all measured both effectiveness and efficiency) and the representation of lower-order EFs in relation to VA in the literature was limited (especially shifting). For athletic expertise there is an issue around definition with large discrepancies in how labels are used and a unified method of operationalising expertise is required. In sum, despite very limited direct research, it seems that EF and VA are positively associated and more focus on how this relationship impacts sport performance is needed.

Chapter 3: Moving online: Comparing executive function and visual attention performance online and in the laboratory – A pilot study

3.1 Chapter Overview

Amidst the global Coronavirus pandemic (2019-2020) behavioural researchers had to look for alternatives to the more traditional laboratory-based method of collecting data. One method gaining popularity in behavioural research was online studies. This is in part because online methods offer researchers a platform to build, recruit, administer, and track experiments remotely. Though beneficial in a number of ways there remains historical concerns over whether online research technology can accurately measure human responses (e.g., whether a button pressed thousands of miles away is accurately recorded by the host server) and replicate a laboratory environment. Therefore, the aim of this brief chapter was to compare effectiveness and efficiency performance on a number of cognitive behavioural tasks measuring EF and VA across an online and laboratory sample. A sample of 21 laboratory participants were matched against a sub-sample of 21 online participants (from Chapter 4) for age, physical activity, and expertise. All participants completed six EF tasks (two for inhibition, shifting, and updating, respectively) and two tasks of VA. Independent samples *t*-tests showed no significant differences in age, physical activity and expertise suggesting appropriate group matching. Also, *t*-test results suggested no significant differences in effectiveness of efficiency performance for any inhibition, shifting, or VA tasks. Significant differences were found in Backward Digit Span Task (i.e., updating) efficiency. Overall, the results support the use of online methods when using cognitive behavioural tasks and suggest such results are accurate representations of individual ability.

3.2 Introduction

Experimental psychology and research examining behavioural processes has increasingly shifted to online data collection methods to reach more participants (Adjerid & Kelley, 2018; Anwyl -Irvine et al., 2020) and obtain more diverse research samples (Casler et al., 2013). The recent global pandemic, (COVID-19), increased the number of researchers using online data collection methods given an inability to conduct laboratory-based research. In the shift from laboratory-based research to online research there are several technological factors to consider that could have an impact upon task performance. These include; different servers (i.e., the experiment host), internet provider (i.e., data delivery method), the browser (i.e., how the experiment is presented and responses recorded), and the content itself (i.e., varying media methods; Anwyl-Irvine et al., 2020). Online environments may also be lacking in experimental control when compared to laboratory settings (i.e., standardised equipment in a standardised location vs. some variety in equipment in a remote setting selected by the participant). As a result, it was important to ascertain whether statistical effects found are real or a methodological consequence. For example, is the variance accounted for in a dependent variable due to the manipulation of independent variable or an artefact of different testing and measurement conditions.

Studies examining behavioural processes like EF and VA often utilise cognitive paradigms to assess differences in individual performance. Such cognitive paradigms are typically built and performed on computers in controlled lab-settings (Morrison et al., 2015). One of the most commonly voiced arguments for using a laboratory over an online-setting, concerns accuracy of participant responses (Hilbig, 2016). Specifically, the above listed technological and control factors have been identified as potential inflators of unexplained error variance in web-based response time studies (Hilbig, 2016). Consequently, questions are asked as to whether data derived from online platforms are a reliable and valid reflection of individual performance and doubt is raised over conclusions reached (e.g., Bulger et al., 2021).

Response time variables are a key component of the tasks used to assess EF and VA as such measures are often used to indicate individual performance, especially in scenarios concerned with performance efficiency (i.e., accuracy in consideration of time; Eysenck & Wilson, 2016). Therefore, the aim of this chapter was to conduct pilot work to test for differences in anxiety and performance effectiveness (i.e., accuracy) and efficiency (i.e., accuracy divided by time) in tasks of EF (i.e., inhibition, shifting, and updating) and VA (i.e., attentional breadth and visual Search), based on method of study completion (i.e., laboratory or online). This chapter hypothesised that, due to technological advances in the task administration tool used (i.e., Gorilla Experiment Builder; Gorilla.sc) and the relatively low anxiety inducing situation, anxiety and task effectiveness and efficiency would not differ between the online or laboratory data collection methods.

3.3 Method

3.3.1 Participants

A total of 42 participants (Female = 66.66%; M_{age} = 24.93 years ± 10.37 years) completed the pilot study. Twenty-one participants were in the lab-based group (M_{age} = 25.00 years ± 10.89 years) and 21 participants were in the online group (M_{age} = 24.86 years ± 10.09 years). Groups were matched on age, physical activity, and sport expertise as these are known influencers of EF and VA and the study wanted to isolate the effect of collection method (i.e., laboratory or online). The study received institutional ethical approval from the York St John University School Research Ethics Committee for the School of Education, Language, and Psychology (see Appendix 1A).

3.3.2 Design

The pilot study adopted a between-subjects design where collection method was the independent variable (i.e., laboratory or online) and the dependent variables were anxiety and effectiveness and efficiency measures for EF tasks of inhibition, assessed by a Go/No-Go Task (Gordon & Caramazza, 1982) and a Stop Signal Task (Verbruggen et al., 2019), shifting indexed by a Colour-Shape Switch Task (Friedman et al., 2008) and a Modified Flanker Task (Krenn et al., 2018), updating measured by the 2-Back Task (Jaeggi et al., 2003) and a Backward Digit Span Task (Reynolds, 1997), and VA using a Attentional Breadth Task (Grol & Raedy, 2014) and a Visual Search Task (Motter & Simoni, 2008). Full task configuration and outcome measures are described in the Measures section in Chapter 4.

3.3.3 Procedure

There were two procedural difference between the two groups (i.e., laboratory and online groups). First, the recruitment process differed and second, the method in which data was collected was different (i.e., laboratory or online). The lab-based group were a volunteer sample that completed the study in a standardised experimental laboratory setting at an English university Psychology Department and received partial course credit for remuneration. The online group were also volunteering and comprised a sub-sample of a larger study (see Chapter 4). Specifically, the online group were recruited through sharing of the study link on social media and through email invitation (e.g., through lead authors network), and Prolific (i.e., an online participant recruitment platform). Participants using the study link were remunerated via an optional prize draw entry while Prolific participants were paid (£7.50 per hour/£8.75 total). The laboratory group completed the study exclusively in a controlled laboratory setting at a university campus while the online group completed the study anywhere with an internet connection.

All participants, irrespective of group, read the information sheet, provided informed consent, and created a pseudonym ID for anonymous data storage. Participants then provided demographic information (e.g., age), reported known vision impairments, and completed questions on physical activity and sport participation levels for calculation of expertise. Next, anxiety measures were completed including the STICSA (Ree et al., 2008), SRQ (Edwards et al., 2015), and STAI (Spielberger et al., 1983). Finally, participants completed the six EF tasks and two VA tasks. The order of task completion was randomised for each participant.

3.3.4 Data Analysis

All analyses were conducted in SPSS version 28. Descriptive statistics were conducted first and consisted of means and standard deviations for matching variables (i.e., age, physical activity, and expertise) and test variables (i.e., anxiety, effectiveness and efficiency scores for EF and VA tasks; see Table 3.1). Independent samples *t*-tests were used to examine differences in the dependent variables (i.e., anxiety, effectiveness and efficiency scores for EF and VA tasks) based on the independent variable (i.e., laboratory vs online groups). Significance was assessed against the alpha value of $p < .05$.

3.4 Results

3.4.1 Independent Samples *T*-test

Separate independent samples *t*-tests revealed there were no significant differences between the laboratory and online groups in age ($t(40) = .04$, $p = .965$), physical activity ($t(40) = .95$, $p = .350$), and expertise ($t(40) = -.63$, $p = .534$). Therefore, the groups were successfully matched based on age, physical activity, and expertise supporting the idea that any subsequent differences in dependent variable were more likely due to an effect of the independent variable. Independent groups *t*-tests comparing anxiety between the laboratory and online groups were not significant for the STICSA ($t(40) = .05$, $p = .963$), SRQ ($t(40) = -.23$, $p = .817$), and STAI ($t(40) = .13$, $p = .895$). As such, the data collection method showed no significant differences between groups in anxiety, offering support for the notion that participation in the laboratory setting does not induce additional anxiety over online research.

Table 3.1.

Means and Standard Deviations for matched variables and dependent variables overall and per collection method

Variable	Overall (Mean ± SD)	Collection Method	
		Laboratory (Mean ± SD)	Online (Mean ± SD)
Age	24.93 ± 10.37	25.00 ± 10.89	24.86 ± 10.09
Physical Activity	114.52 ± 106.39	130.05 ± 116.10	98.99 ± 96.01
Expertise	2.24 ± 1.85	2.10 ± 2.07	2.46 ± 1.63
STICSA	39.62 ± 13.15	39.71 ± 11.45	39.52 ± 14.94
SRQ	17.14 ± 6.55	16.90 ± 5.86	17.38 ± 7.32
STAI	41.33 ± 11.43	41.57 ±10.15	41.10 ±12.83
A_effectiveness	16.02 ± 48.50	19.99 ± 48.34	12.06 ± 49.52
A_efficiency	2.11 ± 4.98	2.37 ± 4.50	1.87 ± 5.51
V_effectiveness	43.38 ± 4.54	43.90 ± 4.67	42.86 ± 4.45
V_efficiency	4.14 ± 1.01	3.88 ± 1.09	4.40 ± .87
G_effectiveness	133.32 ± 11.51	134.71 ± 7.93	131.59 ± 14.90
G_efficiency	39.57 ± 5.08	39.47 ± 4.23	39.68 ± 6.10
St_effectiveness	-5.85 ± 13.19	-4.00 ± 13.01	-7.80 ± 13.42
St_efficiency	294.73 ± 104.03	313.07 ± 122.72	275.48 ± 78.55
D_effectiveness	-6.22 ± 6.69	-7.48 ± 5.47	-4.90 ± 7.69
D_efficiency	1247.16 ± 631.95	1049.93 ± 589.68	1454.25 ± 621.77
N_effectiveness	7.64 ± 6.13	6.83 ± 6.20	8.59 ± 6.08
N_efficiency	3.31 ± 2.83	3.17 ± 3.11	3.48 ± 2.55
C_effectiveness	79.99 ± 20.88	79.20 ± 25.05	80.82 ± 15.99
C_efficiency	3.69 ± 50.86	1.37 ± 71.69	6.12 ± 6.20
F_effectiveness	56.39 ± 15.47	58.95 ± 12.32	53.70 ± 18.15
F_efficiency	15.18 ± 27.07	17.34 ± 11.34	12.92 ± 37.37

Note. A_ = Attentional Breadth Task, C_ = Colour-Shape Switch Task, D_ = Backward Digit Span Task, F_ = Modified Flanker Task, G_ = Go/No-Go Task, N_ = 2-Back Task, SRQ = Stress Rating Questionnaire, STAI = State-Trait Anxiety Inventory, STICSA = State-Trait Inventory for Cognitive and Somatic Anxiety, S_ = Stop Signal Task, V_ = Visual Search Task.

The independent samples *t*-tests showed no significant group differences in Go/No-Go effectiveness ($t(36) = .83$, $p = .413$) and efficiency ($t(40) = -.13$, $p = .901$), Stop Signal Task effectiveness ($t(39) = .92$, $p = .363$) and efficiency $t(39) = 1.16$, $p = .253$), Colour-Shape Switch Task effectiveness ($t(39) = -.25$, $p = .807$) and efficiency ($t(39) = -.30$, $p = .770$), Modified Flanker Task effectiveness ($t(39) = 1.09$, $p = .283$) and efficiency ($t(39) = .52$, $p = .608$), 2-Back Task effectiveness ($t(37) = -.90$, $p = .376$) and efficiency ($t(37) = -.34$, $p = .734$), Backward Digit Span Task effectiveness ($t(39) = -1.24$, $p = .222$), Attentional Breadth Task effectiveness ($t(40) = .53$, $p = .602$) and efficiency ($t(40) = .32$, $p = .748$), and Visual Search Task effectiveness ($t(40) = .74$, $p = .461$) and efficiency ($t(40) = -1.72$, $p = .093$). The only significant group difference was in Backward Digit Span Task efficiency ($t(39) = -2.14$, $p = .039$) with the laboratory group showing significantly greater Digi Span Task efficiency than the online group. Together, results suggested that there were no convincing differences in performance effectiveness and efficiency between the method of data collection supporting the appropriateness of online research for measurement of behavioural processes like EF and VA.

3.5 Discussion

The aim of this pilot study was to understand whether different data collection methods (i.e., laboratory or online) produced equivalent anxiety responses and performance effectiveness and efficiency on six EF and two VA tasks. Reasons for completing such a pilot study was due to previous concerns over reaction time differences online that might arise due to extraneous variables such as internet connections, browser differences, and server factors. This is in addition to online research offering a less controlled environment (i.e., performed at the participants convenience) by comparison to laboratory settings which may induce anxiety due to attending an experimental laboratory testing session. After matching the laboratory group with online counterparts on measures age, physical activity, and expertise there were no significant differences on any of the anxiety measures (i.e., STICAS, SRQ, and STAI). This may suggest that performing a behavioural study in the laboratory is no more anxiety inducing than performing the study online. Also, the results generally supported the idea that there are no differences in performance effectiveness (i.e., accuracy) or efficiency (i.e., accuracy divided by time) between laboratory and online data collection methods as 15 of 16 separate *t*-tests using the behavioural outcome variables showed no significant group differences. The results offer support for using an online experimental builder for the use of cognitive paradigms and tasks assessing anxiety and measuring behavioural processes like EF and VA.

Though the majority of results (15/16) suggested no group differences in the present pilot study, it is important to unpack the single significant group difference. There was a significant difference in Backward Digit Span Task efficiency between the groups whereby individuals were significantly more efficient in the laboratory than online. Given that reaction time data is used to calculate the efficiency score it could be argued that there is indeed an impact of either technological or environmental factors, or both. However, this is unlikely as 1) if true, other significant differences on efficiency measures would have emerged and 2) differences are more likely due to the online sub-sample not being as efficient rather than this group suffering technological issues (i.e., increased latency of responses). This point can be somewhat corroborated by examining how reaction time is used in the Backward Digit Span Task and historical concerns regarding online reaction times (e.g., “lag” between actual and recorded button press; Anwyl-Irvine et al., 2020). Specifically, the Backward Digit Span Task does not require an early rapid response to stimuli (like a Stop Signal Task), a response which may be susceptible to technological issues (e.g., “lag”). Despite some focus being on speed in the Backward Digit Span Task, the manner of responding to the task is different whereby participants see all relevant stimuli before entering their answer on a separate screen. Thus, reaction time is likely longer and reflective of continuous cognitive processing rather than reflective of rapid motor responses. Finally, this pilot study concurs with other work that supports online research (Anwyl-Irvine et al, 2020).

3.6 Conclusion

In sum, recently some research has shifted from the laboratory to online methods because of technological advances and the COVID-19 pandemic. As a result, researchers must assess the suitability of cognitive tasks hosted via online methods to ensure confidence in conclusions drawn from this work. This pilot study is part of a growing number of research endeavours that support the use of online data collection methods, specifically using Gorilla Experiment Builder (Anwyl-Irvine et al., 2020), when measuring anxiety and performance effectiveness and efficiency of computerised EF and VA tasks.

Chapter 4: Understanding executive function and visual attention in sport: A latent variable analysis

4.1 Chapter Overview

Independently, EF and VA have become popular areas of study for sport psychology researchers given that examination of these constructs can shed light on the perceptual-cognitive processes underpinning sport performance. However, given the theoretical link (i.e., ACT-S; Eysenck & Wilson, 2016) between EF and VA it is plausible that they are both discrete and work in conjunction to aid sport performance - a sentiment that often remains untested in empirical studies (see Chapter 2). Before examining whether a relationship exists between EF and VA the present chapter first sought to ascertain whether the model proposed by Miyake et al. (2000) is relevant in an athletic sample. Tasks of inhibition, shifting, and updating have often been adopted from cognitive psychology, used in sport without applying sport-specific context and shown mixed results (see Voss et al., 2010, for a review). Issues have been raised about the transferability of such tasks due to their domain-general nature. Therefore, the first aim of this chapter was to assess Miyake et al.'s (2000) model of EF in athletes and better understand its applicability in sport. The second aim of the present chapter was to model the relationship between EF and VA. A sample of 135 participants completed an online study comprising six EF and two VA tasks with effectiveness and efficiency scores obtained for each task. The results suggested that Miyake et al.'s (2000) model is suitable for athletic samples for both effectiveness and efficiency. Furthermore, EF and VA appear to be related whereby EF may influence VA. In sum, the present chapter supports the use of the lower-order EF model of inhibition, shifting, and updating in athletes and proposed that future works should look to assess the joint contribution of EF and VA upon sport performance.

4.2 Introduction

The importance of perceptual-cognition (i.e., the ability to identify, understand, and utilise environmental cues for optimal outcome selection; Marteniuk, 1976) in expert sport performance has become apparent (see Chapter 2 and Klostermann & Moeinirad, 2020, for a recent review). Particularly important for perceptual-cognition is a set of processes that regulate thoughts and behaviour known as EF (Miyake et al., 2000). Common lower-order EFs include inhibition, shifting, and updating and have been theorised as the primary functions of attentional control (ACT-S; Eysenck & Wilson, 2016). Miyake and colleagues' (2000) framework provided a latent variable analysis of the structure of these EFs suggesting a hierarchical structure (i.e., lower order processes were subsumed into more complex abilities). Despite unequivocal representation of this theoretical model of EF no research has offered replication, extension, or viability of the model in the sport and exercise context. This is an important gap as Miyake et al.'s (2000) model provides the theoretical foundation of much of the early work examining EF in athletes. Despite the theoretical link between EF and VA proposed by ACT-S, little work has examined the association between these processes in the same study. That is, empirical examination of the link between EF and VA is lacking. Therefore, determining the overarching structure of these processes in a single study is important and can inform future experimental examining EF and VA in athletes.

4.2.1 Perceptual-Cognition and Attentional Control Theory-Sport

Perceptual-cognitive processes, such as being able to know when and where to look, are crucial for making the best decisions within complex sporting scenarios (Mann et al., 2007). Optimal decision making, anticipation, planning, and problem solving are all partial products of being able to identify, direct sufficient attention to, and extract meaning from goal-directed stimuli in information rich areas (Williams et al., 1999). Numerous accounts suggest that experts possess greater perceptual-cognitive skills and enhanced maintenance of goal-directed behaviour than novices (see Mann et al., 2007, for a review). The expert advantage seemingly allows for faster and more accurate responses to sport-specific decision making, anticipation, and spatial memory tasks alongside enhanced visual search capabilities (e.g., elongated quiet eye durations; Vickers, 2007). The expert advantage also extends to general cognitive tasks void of sporting context (e.g., Anzeneder & Bosel, 1998), though these results must be interpreted cautiously as equivocal results have been reported elsewhere (see Voss et al., 2010). Specific processes for the maintenance of goal-directed behaviour have become the central focus for researchers and comprise the EFs inhibition, shifting, and updating. As noted, theoretical accounts also support the role of these EFs for the maintenance of attentional control (e.g., ACT-S; Eysenck & Wilson, 2016).

4.2.2 Executive Function and Sport

Miyake and colleagues (2000) assessed whether inhibition, shifting, and updating were distinct or unified constructs at the latent level (through multiple tasks per EF) using Confirmatory Factor Analysis (CFA). Results supported the notion that while there is overlap between these EFs (i.e., moderate intercorrelations) they are also independent factors that contribute differentially in more complex tasks (Miyake et al., 2000). Despite this, it is still common however for studies to use discrete task measures for a single EF in sport with the hypothesised model remaining untested in sporting samples. Further, precisely how this model relates to tasks of VA in sport has not been empirically tested.

A growing number of studies have explored the link between lower-order EFs and sports performance. For example, Vestberg et al. (2017) reported greater shifting ability (indexed via a colour-word interference task) in high-division youth soccer players compared to low-division youth soccer players. Inhibition (measured via a Stop Signal Task) has been cross-sectionally and longitudinally linked to self-report and coach rated sport performance (Hagyard et al., 2021). In a study of working-memory, of which updating is a key component, Furley and Memmert (2012) found athletes with superior working-memory showed greater goal-directed attention (better task-specific decision making despite distracting audio stimuli). It is important to note that these research examples all utilised a single task as an indicator of the target EF. Issues here may arise in that outcome variables may be task specific, rather than a function of the underlying EF of interest. Also, this literature often advocates that expert athletes show better EF than novices on domain-general measures of EF, a phenomenon termed the cognitive component skill approach (see Scharfen & Memmert, 2019; Voss et al., 2010 for meta-analytic reviews), supporting the inclusion of expertise as a covariate in future work.

In addition to expertise, EF appears to be somewhat responsive to individual levels of physical activity and age, topics often studied following initial concerns that differences in athletes were simply examples of more active individuals showing greater EF (Tomporowski et al., 2008) or improvements associated with age (Diamond, 2013). Huijggen et al. (2015) found significant differences in physical activity levels and inhibition, shifting, and updating in favour of elite over sub-elite youth soccer players. The results were found when expertise was not considered, and then were found to be reduced in magnitude when expertise was added into the analysis supporting the notion that physical activity was in part responsible for group differences. Regarding age, it has been reported that EF and age may follow a Gaussian distribution (Moffitt et al., 2011). Specifically, EF begins to form and is developed from a young age right through adolescence before a natural decline at older age (Diamond, 2013). Therefore, such research shows the importance of including age and physical activity in the analyses of studies in this area.

4.2.3 Visual Attention and Sport

Advances in eye-tracking technology have allowed researchers to assess direct "online" VA at varying levels of anxiety or across expertise, a technique that has become common within the literature (Payne et al., 2019). Metrics such as the quiet eye, number and duration of fixations, and gaze locations have appeared in over 100 studies since 1976 (Klostermann & Moeinirad, 2020). Clear expertise differences in the length of the quiet eye duration (i.e., longer durations in athletes of greater expertise; Chapter 2; Klostermann & Moeinirad, 2020) and positive moderate effect sizes of quiet eye duration on successful performance have been found (Lebeau et al., 2016). Similar results have been reported for the number and duration of fixations and gaze location (see Mann et al., 2007 for a review). However, Klostermann and Moeinirad (2020) noted that the effect of the number and duration of fixations and fixation location may not be as relevant as they once were and that perhaps alternate perceptual processes are more crucial (Klostermann & Moeinirad, 2020). Computerised tasks of VA are also popular within the literature (e.g., Scharfen & Memmert, 2021) and may offer additional understanding of the underlying attentional processes lost with typical foveal vision studies.

Such tasks suggest that athletes with enhanced domain-general visual functioning (e.g., depth perception) have higher success rates in team sports (Burris et al., 2020). Scharfen and Memmert (2021) utilised a computerised Attention Window Task (Huttermann & Memmert, 2017) to assess VA breadth. Also popular are Visual Search Tasks (Motter & Simoni, 2008) which require efficient "top down" visual processing (Radvansky & Ashcraft, 2016) and are often used to understand the functional visual field (a bounded area around a fixation point within which we can select, identify, and scrutinise features; Motter & Simoni, 2008). While speculative, Moore et al. (2019) suggested that their gaze results may be indicative of a "visual pivot", whereby rugby union referees fixated a central cue and used peripheral vision to locate other potentially relevant cues within their functional visual field. Although Moore et al. (2019) do caveat that central cues may have simply been more information rich, hence foveal attention. Overall, measuring gaze behaviour with an eye-tracker in isolation may leave the cognitive underpinnings unclear.

4.2.4 Executive Function and Visual Attention

While limited, work examining both domain-general EF and VA found significant effects on working-memory capacity, quiet eye offset, and tennis performance under pressure following working-memory training (Ducrocq et al., 2017). However, this research often does not consider the direct relationship between EF and VA and instead assesses group differences following training of specific EF (Ducrocq et al., 2016) or VA (Scharfen & Memmert, 2021) or examination of a single theoretical EF (Ducrocq et al., 2017). This is surprising as research in this field supports a latent approach (i.e., scores across tasks) over single-task performance when examining the role and organisation of EF (Miyake et al., 2000). Issues may also arise using higher-order EF tasks ("global" tasks which require multiple lower-order EFs) such as the Design-fluency Task (Vestberg et al., 2017). Such tasks do not allow for precise estimation of which processes (i.e., inhibition, shifting, and updating) are most utilised by athletes. Whereas, process-pure tasks (i.e., tasks assessing inhibition, shifting, and updating specifically) can determine the contribution of each function when structurally modelled (see Miyake et al., 2000).

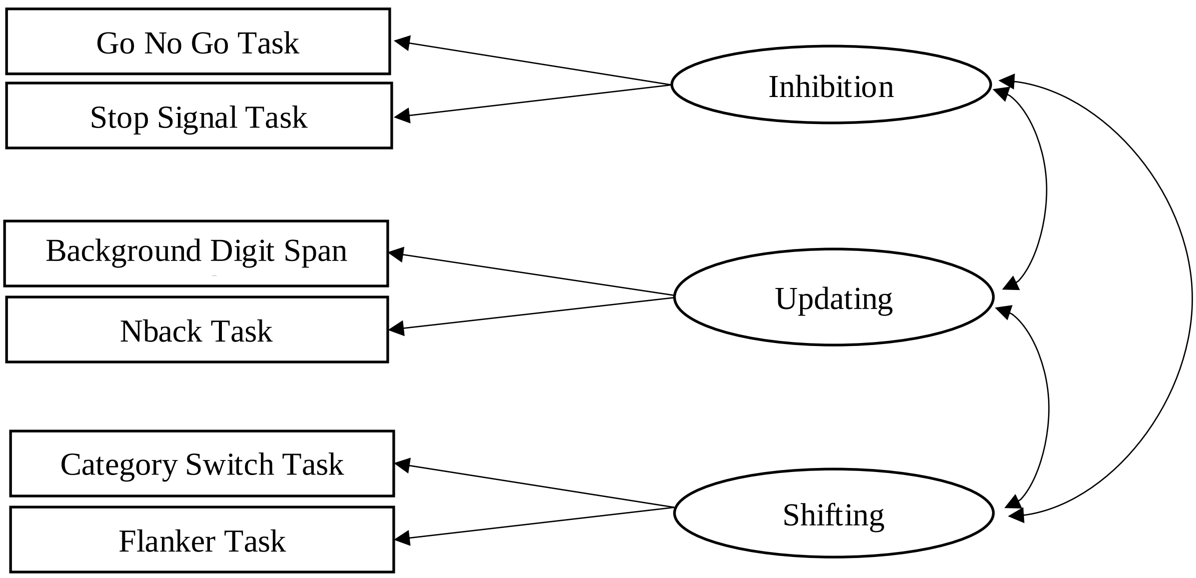
4.2.5 The Present Study

The first goal of the present study was to replicate the EF model from Miyake et al. (2000) in the sport context but for performance effectiveness and efficiency independently using CFA (see Figure. 4.1A). Moreover, the aim was to assess the proposed model in a sample of athletes while controlling for covariates (i.e., age, expertise, physical activity, and anxiety). While Miyake et al. (2000) did not differentiate the type of output, their results demonstrated that variation in EF task outcomes is important and that task performance produces two broad types of output – effectiveness (i.e., accuracy) and efficiency (i.e., accuracy/time). Following Miyake et al.'s (2000) recommendations the present chapter adopted a latent variable approach based on these distinctions in order to provide a rigorous observation of these specific EF processes. It was hypothesised that the model proposed by Miyake et al. (2000) of inhibition, shifting, and updating would replicate for both performance effectiveness and efficiency, separately. Second, this chapter aimed to directly model the relative contributions of EF to the VA tasks using Structural Equation Modelling (i.e., CFA) for the first time in a sporting sample. The model was similar to the original CFA model from Figure 4.1A with the addition of another latent construct consisting of two manifest variables of VA (see Figure 4.1B). This chapter hypothesised that the proposed model of EF predicting VA would show acceptable fit for both effectiveness and efficiency of each discrete process.

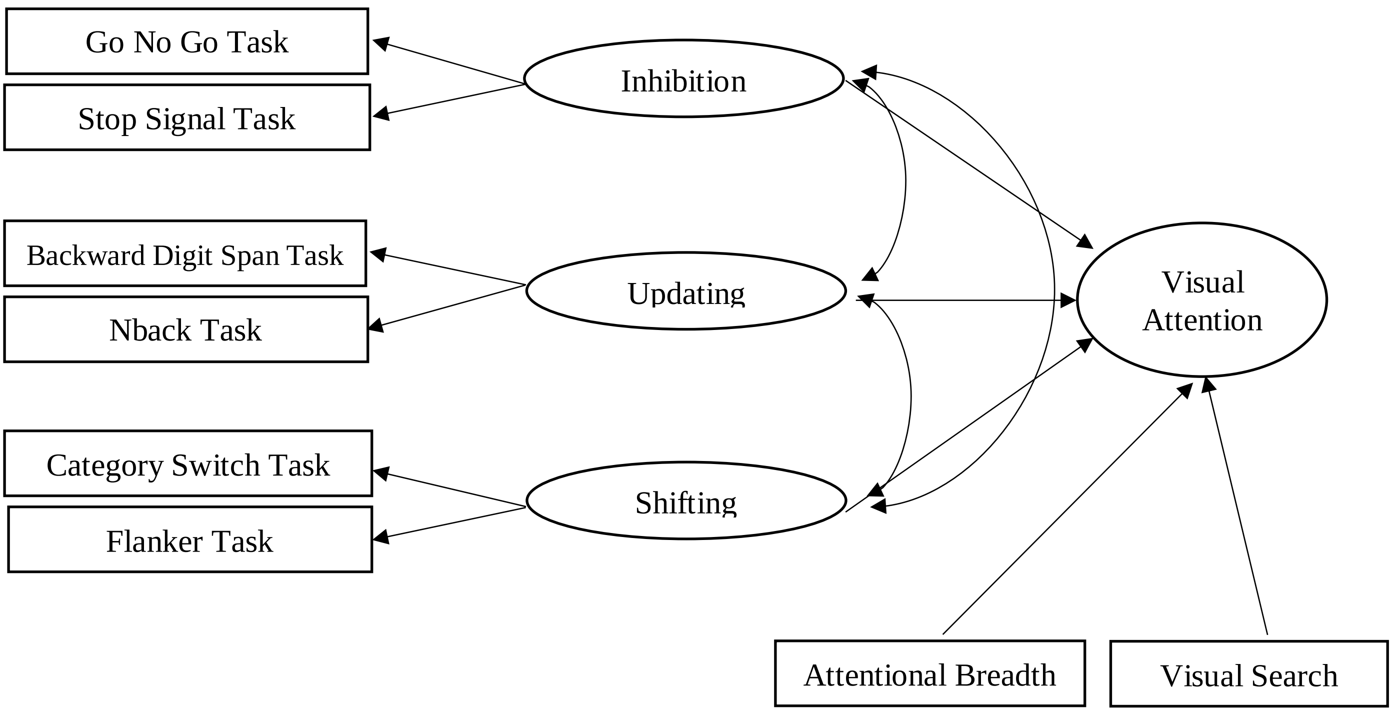
Figure 4.1.

A) The theorised three factor model of executive function and B) the model proposed in the current paper including visual attention

A)



B)



4.3 Method

4.3.1 Design

The current study was conducted via a cloud-based experimental platform (i.e., Gorilla; Anwyl-Irvine et al., 2020) given findings from Chapter 3 (i.e., that such a platform is suitable for delivering EF and VA tasks). This online platform facilitated the administration of the experiment remotely and allowed participants to be directed to other psychological testing software providers (e.g., Millisecond by Inqusit; https://www.millisecond.com/). Individuals participated using their own computer. Online platforms have been successfully utilised in previous work within the closely related field of attentional focus (Ziv & Lidor, 2021). Outcome measures in the present study involved response time and accuracy, and both time and accuracy values have been noted as comparable across web-based and lab-based measurements (e.g., Crump et al., 2013; Hilbig, 2016; see also Chapter 3).

4.3.2 Participants

One hundred and thirty-five participants (71 male, 63 female, and one non-binary) with a mean age of 27.23 years (*SD* = 10.52 years) and a range of sporting expertise (i.e., non-athlete = 4, novice = 49, amateur = 56, elite = 23, and super-elite = 3; see *Expertise* in methods for details) completed the online study. Participants were recruited through both a volunteer sampling method strategy and through Prolific – an online recruitment platform that allows individuals meeting researcher set criteria to complete online studies for monetary reward (Ziv & Lidor, 2021). Participants recruited via Prolific were remunerated £8.75 for full-completion of the study while volunteers were remunerated with optional entry into a prize draw. Note, there was no difference in scores between recruitment methods (i.e., all outcome variable mean differences between groups were not statistically significant [$p > .05$]). The present sample size was utilised based on analytical recommendations (Muthen & Muthen, 2002) and previous research with similar methodology (i.e., $n = 137$; Miyake et al., 2000). The study received institutional ethical approval from the York St John University School Research Ethics Committee for the School of Education, Language, and Psychology (see Appendix 1A).

4.3.3 Measures

4.3.3.1 Physical Activity

The IPAQ-SF (Booth, 2000) was used to measure physical activity over the preceding seven days (see Appendix 3). The IPAQ-SF consists of seven questions, two for vigorous activity, two for moderate activity, two for walking activity, and one for sitting activity. For vigorous, moderate, and walking activity, one question concerned frequency (i.e., number of days spent performing that activity) and one duration (i.e., average minutes spent completing that activity). Activity based elements (i.e., vigorous, moderate, and walking) were given a score based on the energy requirements in metabolic equivalent units (METs) before summing all elements to create METs-minutes per week score that was entered as a covariate in subsequent analyses. Nigg et al. (2020) found high external and construct validity for the IPAQ-SF compared to the original IPAQ.

4.3.3.2 Expertise

Expertise was calculated based on classification recommendations in Swann et al. (2015; see Appendix 2). Classification involved creating a composite score based on A) individual highest performance standard (e.g., professional athlete), B) success at highest standard (e.g., league titles won), C) experience at that standard (e.g., years at the highest performance level), D) competitiveness of selected sport in residing country (e.g., national sport with high participation levels), and E) global competitiveness of selected sport (e.g., globally recognised sport with high participation levels). Each individual factor (e.g., highest performance level) is assigned a score between zero and four based on criteria outlined in Swann et al. (2015). These scores are then entered into the equation; expertise = [(A + B + C

/2) /3] x [(D + E) /2]. The outcome composite score is then used to assign an expertise level (e.g., elite). The framework has been successfully used to distinguish between expertise levels in previous research (Hagyard et al., 2021; Vaughan & Edwards, 2020).

4.3.3.3 Anxiety and Situational Stress

Three measures of anxiety were used to establish situational state-like anxiety and stress symptoms in participants. This chapter used multiple measures to obtain a more reliable assessment and utilised only state measures given the relevance of "in the moment" situation-specific anxiety and stress within an often complex and evolving field, like sport. The included measures of anxiety were: state anxiety items from the STICSA (Ree et al., 2008; see Appendix 5) and state anxiety items from the STAI (Spielberger et al., 1983; see Appendix 6), while situational stress was measured with the SRQ (Edwards et al., 2015; see Appendix 4). The STICSA consisted of 21-items measuring cognitive and somatic state anxiety. For each item, participants were asked to provide responses to self-descriptive statements. Responses for each participant were rated on a 4-point Likert scale ranging from 1-Almost Never to 4-Almost Always with total STICSA scores ranging from 21-84. Higher scores on the STICSA indicated greater state anxiety. The STICSA has shown good internal consistency scores in previous research (α = .87-.88; Gros et al., 2007).

The STAI is made up of 20-items with participants asked to provide self-descriptive responses to each statement. Each item was rated on a 4-point Likert scale ranging 1-Not At All to 4-Very Much So with total STAI scores ranging from 20-80. Higher scores on the STAI suggested greater state anxiety. The STAI has been reported to have appropriate criterion, discriminant, and predictive validity supporting the use of the STAI as a measure of state anxiety (Meades & Ayers, 2011). The SRQ (Edwards et al., 2015) was used to capture situational stress as a pressure manipulation check (see also Brugnera et al., 2017). Responses to five bipolar dimensions (e.g., calm to nervous) are given on a 7-point Likert scale with scores ranging from 1 (e.g., very calm) to 7 (e.g., very nervous). Composite scores on the SRQ are calculated by summing responses on each dimension, such that higher composite scores reflect higher situational stress. The SRQ was used to determine the efficacy of the pressure instructions where differences in SRQ composite scores from baseline to post-manipulation were compared. Composite scores at baseline have been found to significantly correlate with the State-Cognitive Anxiety scale on the STICSA (r = .48; Edwards et al., 2015; Ree et al., 2008) supporting its utility as a valid measure of situational stress. Furthermore, the SRQ has demonstrated satisfactory internal consistency with Cronbach's α ranging from .87 to .89 (Brugnera et al., 2017).

4.3.3.4 Inhibition

4.3.3.4.1 The Stop Signal Task. The Stop Signal Task was designed and delivered based on the recommendations of Verbruggen et al. (2019; see Appendix 9). This task required key press responses to the direction of a central target arrow stimuli presented within a white circle. Participants pressed the "F" key when the arrow faced left and the "J" key when the arrow faced right. However, on 25% of the trials the presentation of the target arrow was followed by a "stop" signal (a distinct change of colour from white to red on the presentation circle). The stop signal was the indicator for participants to withhold their response and wait for the next trial to automatically begin. Participants were instructed to respond as quickly and accurately as possible on all trials and not wait for the circle to change colour. To avoid participants being able to predict when the circle colour would change adaptive stop-signal delays were used. Specifically, when participants successfully withheld their response the stop-signal delay increased by 50ms and when incorrect the delay dropped by 50ms. The task involved a block of 10 practice trials and two blocks of 100 trial with short breaks allowed between blocks. (Verbruggen et al., 2019).

4.3.3.4.2 The Go/No-Go Task. The Go/No-Go task (Gordon & Caramazza, 1982) included the presentation of a continuous stream of letter stimuli that required participants to provide either a "Go" or "No-Go" response. Two letter stimuli were used including "K", which was associated with the "Go" response, and "L", which was associated with the "No-Go" response. When "K" was presented, participants were instructed to press the spacebar key and when "L" was presented participants were to withhold a response. Participants were informed throughout (via on-screen instructions) to respond as quickly and accurately as possible. The task was comprised of one practice block of eight trials and two blocks of 100 trials with an opportunity for a break between blocks. "Go" stimuli were presented 75% of the time with "No-Go" targets appearing 25% of the time (see Appendix 9).

4.3.3.5 Shifting

4.3.3.5.1 Colour-Shape Switch Task. Participants were presented with one of four target visual stimuli in the centre of their screen (Friedman et al., 2008; Miyake & Friedman, 2012). The target visual stimuli consisted of four different colour-shape combinations including: green square, blue square, green rectangle, and blue rectangle. Above the presented target stimuli was a cue word (either "colour" or "shape") that informed the participant on which criteria to categorise the stimuli on. Participants role was to respond to the presented target stimuli based on the visible cue word with one of two response keys. When assessing the target stimuli based on colour participants used the "J" key for green and "F" key for blue when assessing colour and the "J" key for square and the "F" key for rectangle when assessing shape. Random presentation of cue words, though equal in total number within a block, meant participants were constantly shifting between categorisation rules. Participants were informed at the start and reminded throughout to respond as quickly and accurately as possible. A single block of four practice trials were completed before two blocks of 48 trials with opportunity for rest between blocks (see Appendix 9).

4.3.3.5.2 Modified Flanker Task. This task was based on the work of Krenn et al. (2018; see Appendix 9). Participants were informed the goal was to successful identify the direction a black central target arrow amidst distractor "flanker" arrows. Flanking arrows were either congruent (i.e., facing the same direction as the target arrow) or incongruent (i.e., facing the opposite direction to the target arrow). For left facing target arrows the "Z" key was correct and for right facing target arrows the "M" key was correct. However, when the target arrow was presented in red participants had to respond with the opposite key (i.e., with "Z" for right facing arrows and "M" for left facing arrows), whereas when the target arrow was presented in green, participants followed the same rules for responding to black target arrows. Thus, participants had to shift their responses based on the colour of the central target arrow. A final shifting element was added through the inclusion of "up" facing arrows that required no response (as in Krenn et al., 2018). Participants were informed to respond as quickly and accurately as possible. Participants completed four practice blocks (one for black targets, one for red targets, one for green and "up" targets, and one final block with all possible targets), two blocks of 126 trials with optional rest between blocks.

4.3.3.6 Updating

4.3.3.6.1 2-back Task. In the 2-back Task (Jaeggi et al., 2003) a continuous stream of alphabetical letters is presented to which the participant must recall whether the current letter was the same as the one presented two trials before or not (see Appendix 9). If the current target matched the one two trials before participants pressed the "F" key while if the current target did not match the one two trials before participants pressed the "J" key. Participants were told to respond as quickly and accurately as possible throughout. First, a single block of six practice trials were completed, before three blocks of 20 trials with an opportunity for rests between blocks.

4.3.3.6.2 Backward Digit Span Task. Participants were presented with a sequential string of numerical digits, ranging from three digits to nine digits, located in the centre of their screen (see Appendix 9). Following the presentation of the final digit of that string the participants role was to recall the complete list of presented digits in reverse order. Participants entered their complete digit string onto an onscreen box using their numeric keypad before submitting. Only the reverse Backward Digit Span was utilised as it relies more upon updating and working memory while the Forward Digit Dpan has been deemed a simpler attention measure more associated with short-term memory (Reynolds, 1997). Participants were informed to recall the numeric digit string as quickly and accurately as possible. One block of two-digit strings was performed for practice (including a 3-digit and a 4-digit string) before completing three blocks of seven-digit strings (ranging from 3-digit to 9-digit strings) with chances for rest between blocks.

4.3.3.7 Visual Attention

4.3.3.7.1 The Attentional Breadth Task. The Attentional Breadth Task (Grol & Raedy, 2014; see Appendix 9) was used to assess an individual's ability to identify a peripheral stimulus while fixating and accurately recalling a central stimulus. This task was adapted from Millisecond (https://www.millisecond.com/) where an online version has been used to assess the impact of mood on attentional breadth and used highly-emotional human face stimuli (Grol & Raedt, 2014). As the present study was not designed to assess the impact of mood, facial biases caused by mood state were removed by using less emotionally-laden Emoji-face stimuli. The inclusion of a central target remained paramount to ensure participants fixated centrally and used peripheral vision to locate target stimuli. As a result, participants had to first identify, and respond with a mouse click, whether the expression of the Emoji-face was positive, neutral, or negative to ensure centrally located foveal vision. Presented simultaneously with the central Emoji-face were 16 grey-filled circles displayed in two concentric circles (one 4.5cm at 10° visual angle and one 11.2cm at 25° visual angle from the central face; Grol & Raedt, 2014). These grey circles were presented in pairs (one near and one far) on one of eight indiscernible axes. Simultaneously presented with the central Emoji-face and grey circle stimuli was the smaller target black dot (1.3cm). The black target dot was presented within a grey circle and appeared within any of the 16 grey circles across both concentric circles at random.

Total presentation time for all stimuli was 68ms to avoid confounds associated with saccadic eye movements in search of a peripherally located target (Ball et al., 1988). Participants completed two blocks of eight practice trials. The first block presented all stimuli for 250ms to familiarise participants with the protocol and the second block utilised presented all stimuli for 68ms similar to the test phase. This was followed by a test phase of two blocks of 48 trials with rest breaks afforded between blocks. Only trials in which the participant was able to correctly identify the emotion of the central Emoji-face were included in the outcome measure. This was done to ensure foveal attention was directed at the centre of the screen and that target stimuli were picked up via peripheral vision. Participants were informed to respond as quickly and accurately as possible.

4.3.3.7.2 The Visual Search Task. This task assessed an individual's functional visual field (Motter & Simoni, 2008; see Appendix 9). Participants searched a visual array for a prespecified target stimuli (a single orange "L" letter stimulus) located amongst distractor stimuli (orange "F" and blue "L" letter stimuli). Target stimuli shared one feature with both the different distractor stimuli (i.e., sharing a colour with one and a letter with the other). The number of stimuli within each array was either nine (with either nine distractor stimuli and no target or eight distractor stimuli and one target) or 16 stimuli (with either 16 distractor stimuli and no target or 15 distractor stimuli and one target). Participants were required to press the "J" key when they located the target and to press the "F" key when they believed the target to not be present, therefore all trials required a key-press response. The task involved one block of three practice trials and two blocks of 24 trials with opportunity for rest between blocks. In each block of 24 trials there were 16 trials with a target and eight without. Participants were informed to decide whether the target stimuli were present or not as quickly and accurately as possible.

4.3.4 Outcome Measures

The primary indicators of performance across all tasks (six EF and two VA) were effectiveness and efficiency as outlined in theoretical accounts of attentional control (i.e., ACT-S; Eysenck & Wilson, 2016). Effectiveness is typically indexed through accuracy whereby correct responses are indicative of performance (e.g., Scharfen & Memmert, 2021). Such measures sometimes fail to consider errors (i.e., do not consider how incorrect responses may also influence accuracy) allowing non-compliant participants to incorrectly appear more accurate. For example, participants randomly responding with “go” on every single trial would appear highly accurate as “go” trials have a 100% success rate but “no-go” trials would yield a 0% success rate. Also, effectiveness often does not consider the time requirements required for an individual to respond, hence the importance of efficiency measures. Efficiency scores are indexed as a product of accuracy divided by time whereby more efficient individuals perform correctly without requiring additional processing resources (e.g., time; Eysenck et al., 2007). The present study reported effectiveness for each task as the number of correct responses minus incorrect responses and an efficiency measure that incorporate response time.

Specifically, for the Attentional Breadth Task effectiveness was correct minus incorrect responses to near and far targets and efficiency was effectiveness divided by correct trial average reaction time (Grol & Raedt, 2014). For the Visual Search Task, the number of correct minus incorrect responses within nine and 16 stimuli arrays was effectiveness and efficiency was effectiveness divided by correct trial average reaction time. Go/No-Go Task effectiveness was indexed as the number of correct hits minus false alarms and efficiency was outlined as effectiveness divided by average correct “go” trial reaction time. For the Stop Signal Task correct minus incorrect responses on “stop” trials was effectiveness and the Stop Signal Reaction Time was the measure of efficiency (as in Verbruggen et al., 2019). Backward Digit Span Task effectiveness was correct minus incorrect responses and efficiency was outlined as average correct reaction time divided by correct responses. For the 2-back task effectiveness was indexed as correct minus incorrect responses divided by the number of blocks (Jaeggi et al., 2010) and efficiency was outlined as effectiveness divided by average correct reaction time. For the Category Switch Task effectiveness was correct minus incorrect responses on “switch” trials and efficiency was the difference between congruent (i.e., non-switch trials) and incongruent (i.e., switch trials) trials in correct average reaction time divided by effectiveness. In the Flanker Task, effectiveness was outlined as correct minus incorrect responses on “switch” trials and efficiency was the difference between congruent (i.e., red arrows) and incongruent (i.e., black arrows) in correct average reaction time divided by effectiveness (as in Krenn et al., 2018).

4.3.5 Procedure

Participants were recruited online via either Prolific or email invitation (e.g., through lead authors network). After opening the online Gorilla study link participants were asked to create a pseudonym to protect anonymity (i.e., initial letter from first and surname, numerical day of birth, and numerical month of birth combined). Participants then read the online information sheet and provided informed consent before reporting any known visual impairments (e.g., colour blindness) on Qualtrics (https://www.qualtrics.com/uk/). Demographic information including age, gender identification, and ethnicity were also obtained (see Appendix 2). Next, participants completed questions around sport participation (for expertise calculation) and physical activity levels.

After redirection back to Gorilla for testing participants completed the three measures of state anxiety (i.e., STICSA, SRQ, STAI) before completing the eight online tasks (Attentional Breadth Task, Visual Search Task, Go/No-Go Task, Stop Signal Task, Backward Digit Span Task, 2-back Task, Category Switch Task , Flanker Task). Each participant completed the tasks in a counter-balanced order using the Latin Square feature in Gorilla. The procedure ended with a brief thank you, debrief, and the opportunity to enter a voluntary prize draw. The draw was voluntary as it required participants to provide an email address to send an electric voucher allowing those wishing to remain anonymous the chance to do so. Participants recruited through Prolific were not granted the opportunity of the prize draw as they had received payment for participation (see Participants section for details).

4.3.6 Data Analysis

All analyses were conducted using SPSS and AMOS versions 28. Data were screened for missing values, tested against CFA assumptions (Miyake et al., 2000), and examined for multivariate outliers. Means, standard deviations, and bivariate correlations were conducted. Correlations were used to a) outline whether the proposed covariates (i.e., age, expertise, physical activity, and anxiety) warranted inclusion (i.e., significantly correlated with EF and VA outcome measures) and b) examine the bivariate correlations within and between the theoretically proposed EF and VA outcome measures.

Next, following the analytical procedures outlined by Miyake et al. (2000), CFA was used to understand the goodness of fit across four proposed models using maximum likelihood estimators (Lee et al., 1990). First, this chapter assessed effectiveness and efficiency performance for the theoretically proposed EF outcome measures alone (see Figure 4.1A; as in Miyake et al., 2000). Second, two models were constructed that included VA outcome measures for effectiveness and efficiency (see Figure 4.1B) in a hierarchical CFA framework (i.e., VA as the second order factor). To assess model fit this chapter utilised a number of common indices based on recommendations from the literature (Hu & Bentler, 1999; Marsh et al., 2004). First, absolute fit was assessed using Chi Square (χ^2) with *p* values greater than .05 indicating good absolute fit (Hu & Bentler, 1999). Relative fit was deemed suitable when the ratio of the likelihood statistic to the degrees of freedom (CMIN/DF) was three or less; each of the goodness-of-fit index (GFI), comparative fit index (CFI), and Tucker-Lewis index (TLI) was .90 or greater; the root mean square error of approximation (RMSEA) was .10 or less; and the standardised root mean square (SRMR) was smaller than .08. The Bayes Information Criteria (BIC) was used to assess model simplicity whereby smaller numbers reflect parsimonious models.

4.4 Results

4.4.1 Data Screening – Missing Values and Outliers

Initial variable screening of missing values revealed 3% missing data (89 cases from a possible 2,970). As total missing data was less than 5% all missing values were replaced using the ipsatised item mean (Tabachnick & Fidell, 2007). As CFA and SEM are susceptible to extreme outliers (Kline, 1998) bivariate within-construct (e.g., across both inhibition tasks) analyses for the six tasks that assessed EF and the two tasks that assessed VA were performed to understand a) the influence of single observations on the overall results (as in Miyake et al., 2000) and b) whether outliers were present. Specifically, single observations that may have been overly influential on the results were examined using Cook's distance and leverage values (Cook, 1977). While outliers were determined through examination of the Mahalanobis' distance for each EF and VA task.

Data were excluded if following the removal of extreme observations using Cook's distance greater than 4/number of observations, leverage values greater than .05, and

Mahalanobis distances with *p* values less than .001, the results were significantly changed in magnitude. Through the combined examination of these techniques 13 participants across all eight tasks were noted as either a potential overly strong influencer of results or an outlier in at least one task (Miyake et al., 2000). However, following the inspection of each within-construct correlation after the removal of participants violating any one of Cook's distance, leverage values, or Mahalanobis distance resulted in non-significant changes of the correlations. Therefore, all participants were retained for analysis. Such an approach may be preferred over typical methods of removing extreme/outlier values (i.e., values two *SD* greater than the mean) as when dealing with reaction time data these methods can introduce a bias whereby the true mean is underestimated (Miller, 1991).

4.4.2 Descriptive Statistics and Correlations

Means and *SD* were calculated for the proposed covariates (i.e., age, expertise, physical activity, and anxiety measures), EF and VA (see Table 4.1). Table 4.2 shows bivariate correlations between the proposed covariates, the outcome measures of EF (i.e., effectiveness and efficiency for inhibition, shifting, and updating tasks), and the outcome measures of VA (i.e., effectiveness and efficiency for Attentional Breadth Task and Visual Search Task). As shown in Table 4.2, age was significantly negatively correlated with expertise, Attentional Breadth Task effectiveness and efficiency and Visual Search Task efficiency. Expertise was significantly positively correlated with physical activity and significantly negatively correlated with the STICSA, SRQ, and STAI. Physical activity was significantly negatively correlated with Go/No-Go Task effectiveness and efficiency and Flanker Task efficiency. The STICSA was significantly positively correlated with the SRQ and STAI. The STICSA also significantly negatively correlated with Visual Search Task efficiency, Go/No-Go Task effectiveness and efficiency and positively correlated with Category Switch Task effectiveness. The SRQ was significantly negatively correlated with the STAI, Attentional Breadth Task effectiveness, and Go/No-Go Task efficiency. Finally, the STAI was significantly negatively correlated with Visual Search Task efficiency, Go/No-Go Task effectiveness and efficiency, and 2-back Task efficiency. Overall, these correlations support the inclusion of age, expertise, physical activity, and anxiety as covariates.

Table 4.1.

Means and Standard Deviations for all Variables

Variable	*M*	*SD*
Age (years)	27.23	10.52
Expertise	3.99	2.47
Physical Activity	99.85	86.60
STICSA	35.12	10.12
SRQ	15.67	6.89
STAI	38.64	12.31
Attentional Breadth-Effectiveness	18.91	54.02
Attentional Breadth-Efficiency	2.65	6.06
Visual Search-Effectiveness	43.04	6.95
Visual Search-Efficiency	4.29	1.30
Go/No-Go-Effectiveness	130.25	20.58
Go/No-Go-Efficiency	39.02	7.23
Stop Signal-Effectiveness	-7.63	14.11
Stop Signal-Efficiency	296.74	135.83
Backward Digit Span-Effectiveness	-3.70	8.53
Backward Digit Span-Efficiency	1545.07	1279.99
2-Back-Effectiveness	7.02	6.12
2-Back-Efficiency	2.96	27.2
Category Switch-Effectiveness	78.91	21.25
Category Switch-Efficiency	15.68	68.96
Flanker-Effectiveness	50.61	27.62
Flanker-Efficiency	3.51	77.05

Note. SRQ = Stress Rating Questionnaire, STAI = State-Trait Anxiety Inventory, STICSA = State-Trait Inventory for Cognitive and Somatic Anxiety

Table 4.2.

Correlations Between Proposed Covariates (top) and Outcome Measures (side) of Executive Function and Visual Attention

Variable	1. Age	2. Expertise	3. Physical Activity	4. STICSA	5. SRQ	6. STAI
1	1	-.203*	.074	-.070	-.001	-.118
2		1	.222**	-.301**	-.263**	-.353**
3			1	-.045	-.041	-.073
4				1	.708**	.770**
5					1	.872**
6						1
Attentional Breadth-Effectiveness	-.333**	.082	-.013	-.073	-.174*	-.146
Attentional Breadth-Efficiency	-.284**	.062	-.051	-.060	-.129	-.109
Visual Search-Effectiveness	.066	-.020	.004	-.129	-.011	-.005
Visual Search-Efficiency	-.198*	.166	.027	-.174*	-.161	-.170*
Go/No-Go-Effectiveness	-.010	-.018	-.287**	-.254**	-.137	-.184*
Go/No-Go-Efficiency	-.159	.051	-.261**	-.267**	-.197*	-.215*
Stop Signal-Effectiveness	.085	-.085	-.067	-.117	-.128	-.068
Stop-Signal-Efficiency	.135	-.003	.114	.103	.076	.060
Backward Digit Span-Effectiveness	.037	.054	.021	-.066	.057	.037
Backward Digit Span-Efficiency	.062	.019	-.012	.015	-.092	-.071
2-Back-Effectiveness	-.153	-.009	-.129	-.156	-.117	-.159
2-Back-Efficiency	-.136	.072	-.125	-.167	-.131	-.180*
Category Switch-Effectiveness	-.126	-.050	.145	.209*	.004	.019
Category Switch-Efficiency	.153	.150	.161	.140	.059	.004
Flanker-Effectiveness	.056	-.033	-.014	.032	.113	045
Flanker-Efficiency	.149	-.120	-.189*	.140	.061	.044

Note. SRQ = Stress Rating Questionnaire, STAI = State-Trait Anxiety Inventory, STICSA = State-Trait Inventory for Cognitive and Somatic Anxiety

Correlations between the main outcome variables of EF and VA are presented in Table 4.3. Attentional Breadth Task effectiveness was significantly positively correlated with the effectiveness scores on the Go/No-Go Task, Stop Signal Task, Backward Digit Span Task, 2-back Task and the Category Switch Task, and efficiency scores on the Attentional Breadth Task, Visual Search Task, Go/No-Go Task, and 2-back Task. Also, Attentional Breadth Task effectiveness was significantly negatively correlated with efficiency scores on Stop Signal Task, Backward Digit Span Task, and the Category Switch Task. Attentional Breadth Task efficiency was significantly positively correlated with Visual Search Task efficiency, Go/No-Go Task effectiveness and efficiency, Stop Signal Task effectiveness, Backward Digit Span Task effectiveness, 2-back Task effectiveness and efficiency, and Category Switch Task effectiveness.

Attentional Breadth Task efficiency was significantly negatively correlated with Stop Signal Task efficiency, Backward Digit Span Task efficiency, and Category Switch Task efficiency. Visual Search Task effectiveness was significantly positively correlated with Visual Search Task efficiency, Go/No-Go Task effectiveness and efficiency, Stop Signal Task effectiveness, 2-back Task effectiveness and efficiency, Category Switch Task effectiveness, and Flanker Task effectiveness while significantly negatively with Stop Signal Task efficiency and Category Switch Task efficiency. Visual Search Task efficiency was significantly positively correlated with Go/No-Go Task effectiveness and efficiency, Backward Digit Span Task effectiveness, 2-back Task effectiveness and efficiency, Category Switch Task effectiveness, and Flanker Task effectiveness. Visual Search Task efficiency was significantly negatively correlated with Stop Signal Task efficiency, Backward Digit Span Task efficiency, and Category Switch Task efficiency.

Go/No-Go Task effectiveness was significantly positively correlated with Go/No-Go Task efficiency, Stop Signal Task effectiveness, Backward Digit Span Task effectiveness, 2-

back Task effectiveness and efficiency, Category Switch Task effectiveness, and Flanker Task effectiveness and significantly negatively correlated Stop Signal Task efficiency, Backward Digit Span Task efficiency, and Category Switch Task efficiency. Go/No-Go Task efficiency was significantly positively correlated with Stop Signal Task effectiveness, Backward Digit Span Task effectiveness, 2-back Task effectiveness and efficiency, Category Switch Task effectiveness, and Flanker Task effectiveness. Go/No-Go Task efficiency was significantly negatively correlated with Stop Signal Task efficiency, Backward Digit Span Task efficiency, and Category Switch Task efficiency.

Stop Signal Task effectiveness was significantly negatively correlated with Stop Signal Task efficiency, Backward Digit Span Task efficiency, and Category Switch Task efficiency and positively correlated with Backward Digit Span Task effectiveness, 2-back Task effectiveness and efficiency, and Category Switch Task effectiveness. Stop Signal Task efficiency was significantly negatively correlated with Backward Digit Span Task effectiveness, 2-back Task effectiveness and efficiency, and Category Switch Task effectiveness while was significantly positively correlated with Backward Digit Span Task efficiency and Category Switch Task efficiency.

Backward Digit Span Task effectiveness was significantly negatively correlated with Backward Digit Span Task efficiency and Category Switch Task efficiency and positively correlated with Category Switch Task effectiveness and Flanker Task effectiveness. Backward Digit Span Task efficiency was significantly negatively correlated with Category Switch Task effectiveness and Flanker Task effectiveness and significantly positively correlated with Category Switch Task efficiency.

2-back Task effectiveness was significantly positive correlated with 2-back Task efficiency, Category Switch Task effectiveness, and Flanker Task effectiveness and was significantly negatively correlated with Category Switch Task efficiency. 2-back Task efficiency was significantly positively correlated with Category Switch Task effectiveness and Flanker Task effectiveness and was significantly negatively correlated with Category Switch Task efficiency. Category Switch Task effectiveness was significantly negatively correlated with Category Switch Task efficiency and Flanker Task efficiency and was significantly positively correlated with Flanker Task effectiveness. Category Switch Task efficiency was significantly negatively correlated with Flanker Task effectiveness.

Table 4.3.

Correlations Between Outcome Measures of Executive Function and Visual Attention

Variable	1. A_effect	2. A_effic	3. V_effect	4. V_effic	5. G_effect	6. G_effic	7. St_effect	8. St_effic	9. D_effect	10. D_effic	11. N_effect	12. N_effic	13. C_effect	14. C_effic	15. F_effect	16. F_effic
1	1	.953**	.121	.394**	.252**	.433**	.233**	-.255**	.172*	-.248**	.434**	.440**	.289**	-.181*	.144	-.038
2		1	.105	.373**	.263**	.426**	.237**	-.281**	.184*	-.247**	.448**	.459**	.280**	-.164	.135	-.034
3			1	.517**	.386**	.349**	.201*	-.207*	.152	-.050	.337**	.321**	.276**	-.511**	.190*	.047
4				1	.286**	.468**	.128	-.229**	.191*	-.177*	.487**	.508**	.274**	-.352**	.299**	.043
5					1	.792**	.322**	-.329**	.194*	-.169	.392**	.365**	.466**	-.594**	.249**	-.001
6						1	.243**	-.405**	.221*	-.230**	.426**	.440**	.399**	-.502**	.203*	.004
7							1	-.516**	.218*	-.194*	.236**	.200*	.356**	-.180*	.128	.043
8								1	-.233**	.235**	-.134	-.101	-.313**	.182*	-.069	-.048
9									1	-.696**	.029	.060	.364**	-.201*	.220*	-.014
10										1	-.164	-.147	-.479**	.284**	-.313**	-.004
11											1	.946**	.381**	-.258**	.332**	.002
12												1	.338**	-.221**	.296**	-.007
13													1	-.528**	.351**	-.256**
14														1	-.258**	.138
15															1	.125
16																1

Note. A_effect = Attentional Breadth effectiveness, A_effic = Attentional Breadth efficiency, C_effect = Category Switch effectiveness, C_effic = Category Switch efficiency, D_effect = Digit Span effectiveness, D_effic = Digit Span efficiency, F_effect = Flanker effectiveness, F_effic = Flanker efficiency, G_effect = Go/No-Go effectiveness, G_effic = Go/No-Go efficiency, N_effect = 2-back effectiveness, N_effic = 2-back efficiency, St_effect = Stop Signal effectiveness, St_effic = Stop Signal efficiency, V_effect = Visual Search effectiveness, V_effic = Visual Search efficiency.

4.4.3 Structural Equational Modelling

Table 4.4 shows the CFA relative fit indices for all models. The initial constrained (i.e., a single fixed regression coefficient per latent variable) CFA model on effectiveness performance showed good absolute fit with a non-significant $\chi^2(6) = 5.859$, $p = .439$. Also, relative fit indices support the proposed EF structure: CMIN/DF = .976, GFI = .993, CFI = .999, TLI = .999, RMSEA = .001, SRMR = .016, and BIC = 359.038 (see Figure 4.2A). However, the initial constrained CFA model on efficiency performance showed unacceptable fit to the proposed EF structure. Inspection of the modification indices indicated that acceptable model fit could be achieved through five additional constraints and modifications. These included constraining regression coefficients between the updating and shifting latent constructs and through correlating the error terms between Go/No-Go Task efficiency and Category Switch Task efficiency, Stop Signal Task efficiency and Backward Digit Span Task efficiency, Backward Digit Span Task efficiency and Category Switch Task efficiency, and Backward Digit Span Task efficiency and Inhibition. As a result, the model reached good absolute fit ($\chi^2(4) = 5.611$, $p = .230$) and good relative fit: CMIN/DF = 1.403, GFI = .993, CFI = .997, TLI = .944, RMSEA = .055, SRMR = .023, and BIC = 368.602 (see Figure 4.2B).

Table 4.4.

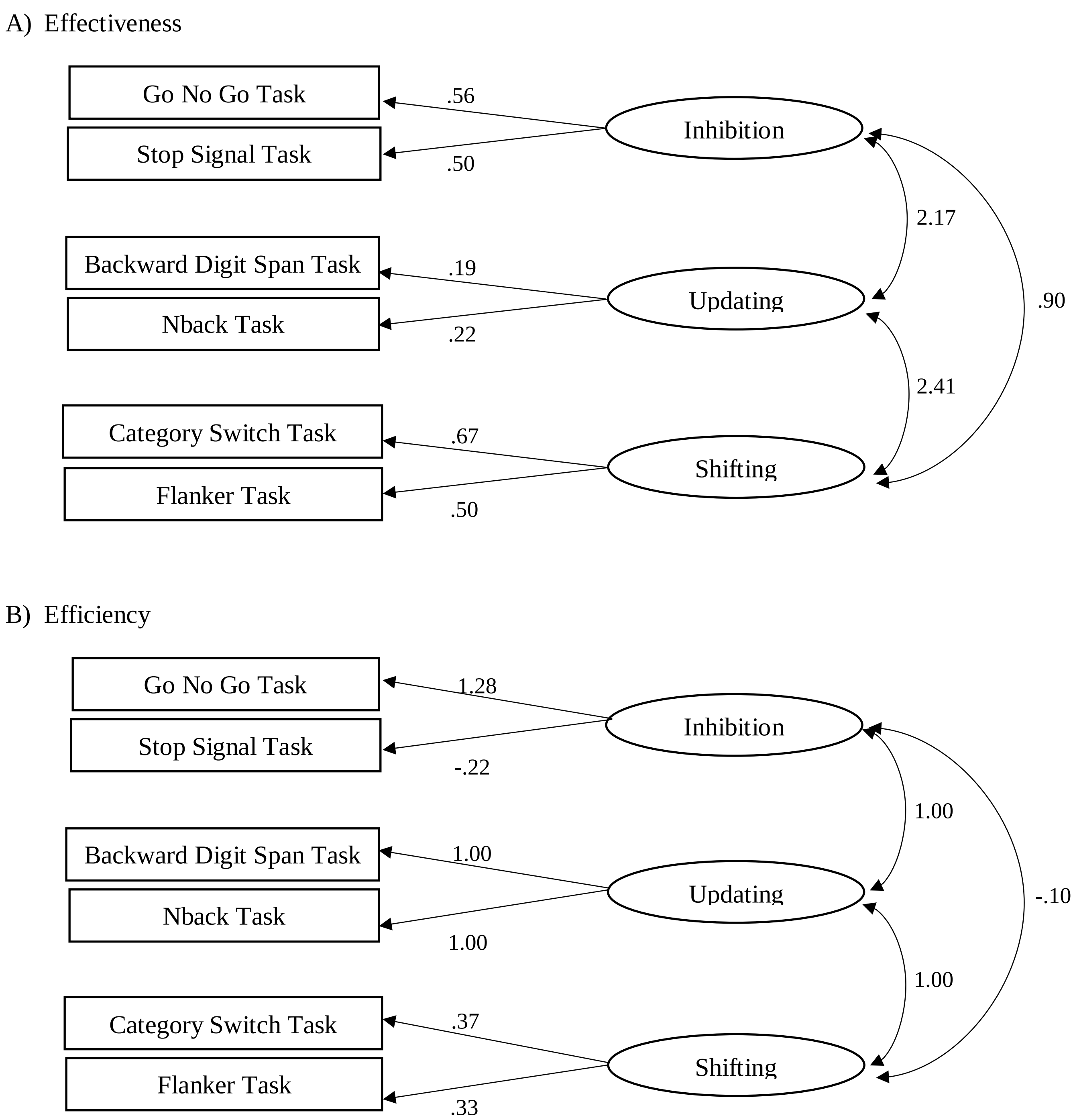
Confirmatory Factor Analysis outcomes with relative model fit indices

Model	CMIN/DF	GFI	CFI	TLI	RMSEA	SRMR	BIC
ModelA-Effectiveness	.976	.993	.999	.999	.001	.0159	359.038
ModelA-Efficiency	1.403	.993	.997	.944	.055	.0228	368.602
ModelB-Effectiveness	.945	.986	.999	.999	.000	.0212	459.667
ModelB-Efficiency	1.466	.982	.989	.927	.059	.0272	466.900

Note. BIC = Bayesian information criterion, CFI = comparative fit index, CMIN/DF = ratio of the likelihood statistic to the degrees of freedom, GFI = goodness-of-fit index, ModelA-Effectiveness = effectiveness fit values for Model A, ModelA-Efficiency = efficiency fit values for Model A, ModelB-Effectiveness = effectiveness fit values for Model B, ModelB-Efficiency = efficiency fit values for Model B, RMSEA = root mean square error of approximation, SRMR = standardised root mean square, TLI = Tucker-Lewis index

Figure 4.2.

A) The theorised three-factor model of executive function for performance effectiveness and B) The theorised three-factor model of executive function for performance efficiency. Single headed arrows show standardised regression coefficients (beta weights) with maximum likelihood estimation. Curved double-headed arrows show standardised correlation coefficients between the latent constructs

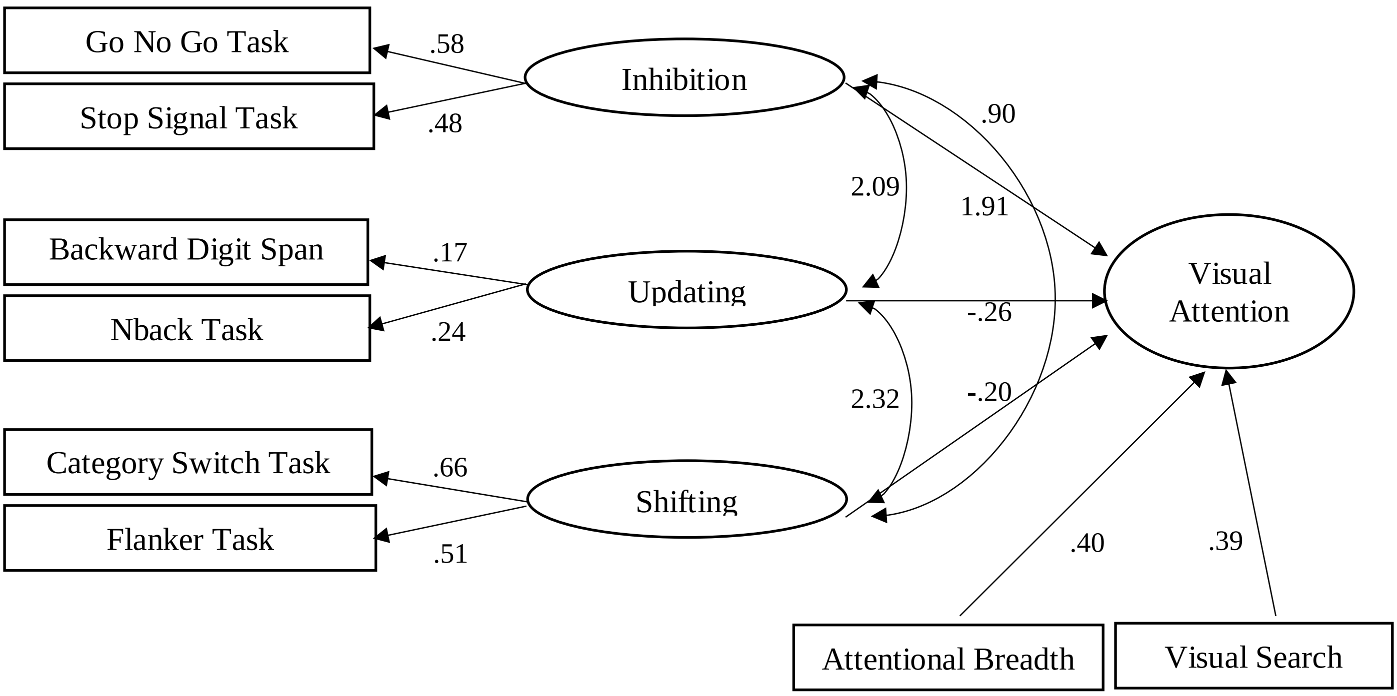


When VA was added to the model, the initial constrained model for effectiveness showed good absolute model fit ($\chi^2(14) = 13.287$, p .504). Relative fit indices also suggested good fit: CMIN/DF = .945, GFI = .986, CFI = .999, TLI = .999, RMSEA = .001, SRMR = .021, and BIC = 459.667 (see Figure 4.3A). However, the proposed EF and VA model for efficiency performance yielded unacceptable fit. Modification indices suggested four edits to improve model fit including constraining the inhibition and shifting and updating and shifting variables as well as correlating errors terms between VA and Go/No-Go Task efficiency, and Stop Signal Task efficiency and Backward Digit Span Task efficiency. Following these four modifications and constraints the model yielded good absolute fit ($\chi^2(14) = 20.520$, $p = .115$) and relative fit: CMIN/DF = 1.466, GFI = .982, CFI = .989, TLI = .927, RMSEA = .059, SRMR = .027, and BIC = 466.900 (see Figure 4.3B).

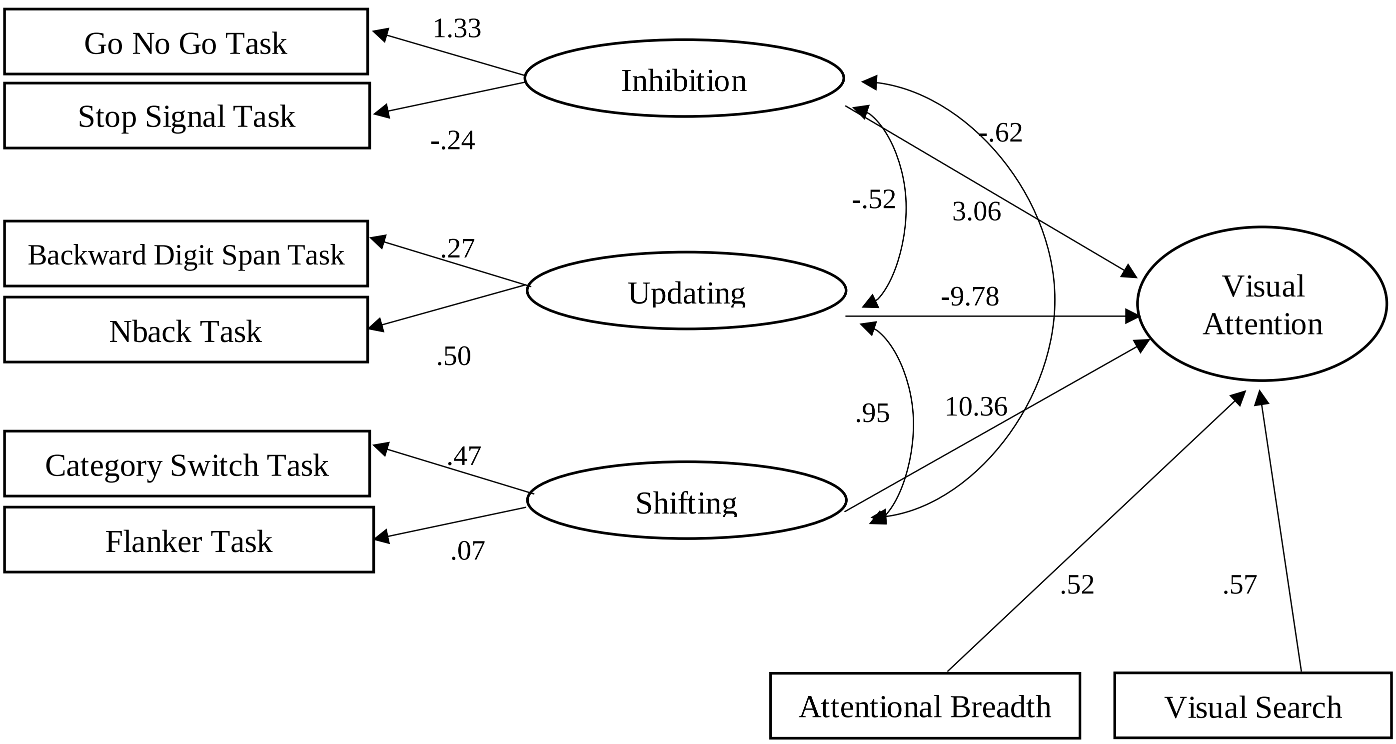
Figure 4.3.

A) The performance effectiveness path diagram for executive function and visual attention and B) the performance efficiency path diagram for executive function and visual attention. Single headed arrows show standardised regression coefficients (beta weights) with maximum likelihood estimation. Curved double-headed arrows show standardised correlation coefficients between the latent constructs

A) Effectiveness



B) Efficiency



4.5 Discussion

The first aim of the present study was to replicate the EF model proposed by Miyake and colleagues (2000) in a sport sample where the structure of EF is examined at the latent level (i.e., across multiple tasks) rather than a manifest level (i.e., single tasks only; Miyake et al., 2000). This chapter expanded upon this by separating manifest outcomes into effectiveness and efficiency as proposed in ACT-S (Eysenck & Wilson, 2016) and utilised an athletic sample. The results showed good model fit for effectiveness when controlling for hypothesised covariates. For efficiency the model showed acceptable model fit following modification. The second, and main goal, was to use SEM to provide the first direct assessment of the relationships between multiple tasks of EF and VA, while controlling for important covariates (i.e., age, physical activity and expertise). The results for VA followed a similar pattern to EFs that the effectiveness model showed good fit and the efficiency model required modification before acceptable fit could be achieved. Finally, the BIC supported the idea that effectiveness models were lower in complexity potentially suggesting outcomes associated with efficiency are more compounded.

4.5.1 Correlations

The results of the correlation analyses regarding the proposed covariates provided a number of expected and unexpected findings. Results tended to support the inclusion of the proposed covariates, but not in a straightforward manner. All proposed measures of state anxiety were highly positively correlated (as expected) suggesting an ability to assess a similar underlying construct. Notably, the SRQ, a fewer item and easy to administer questionnaire, performed similar to the more established STICSA and STAI scales. This finding supports previous work and suggests the SRQ may be a shorter and equally reliable alternative for future research (Edwards et al., 2016). The only other significant correlations between the covariates included expertise and physical activity and expertise and age. The expertise-physical activity correlation was not surprising and supports previous research stating elite youth soccer players show higher levels of physical activity as well as elite status compared to sub-elite youth soccer players (Huijgen et al., 2015). It is likely those engaging at a higher-level of sport are completing more training or games thus reporting higher physical activity scores (i.e., more time engaged in vigorous, moderate, and walking time; Booth, 2000).

To assess whether the proposed covariates (i.e., age, physical activity, and expertise) warranted inclusion, the correlations between the covariates and the manifest outcomes of EF and VA were examined. Overall, the correlations showed that at least one covariate significantly correlated with a task of inhibition, shifting, updating, and/or VA. It is interesting that the number of significant correlations was less than anticipated. Age was significantly negatively correlated with performance on VA tasks only. Specifically, younger participants tended to show greater attentional breadth effectiveness and efficiency and greater visual search efficiency. This may initially suggest a greater impact of age upon vision over cognition. A lack of correlation between age and measures of EF is reported elsewhere. Vaughan and Edwards (2020) found that age did not correlate with measures of inhibition, shifting, and updating. Additional reasoning could be that the Pearson's correlation assesses the linear relationship between two variables (Hauke & Kossowski, 2011) where the relationship between age and EF is suggested to following a Gaussian distribution (Diamond, 2013). That is, EF and age does not follow a linear path (e.g., as age increases so does EF) but rather starts relatively low, develops throughout adolescence and early adulthood, before declining in older age (Diamond, 2013).

Huijgen et al. (2015) suggested that physical activity was an influential factor in differences between elite and sub-elite athletes in inhibition, shifting, and updating. The present study somewhat supports this as physical activity was significantly negatively correlated with inhibition (Go/No-Go effectiveness and efficiency) and shifting (Flanker efficiency), but not with updating. As physical activity increases cerebral blood flow to the pre-frontal cortex, where EFs are housed, thus activation of these functions based on physical activity levels is to be expected. Generally speaking, anxiety was correlated with EF, but the consistency in these correlations was lacking. The only EF that all three individual measures of anxiety (i.e., STICSA, SRQ, and STAI) correlated with was inhibition (Go/No-Go task). This may suggest that the element of attentional control that anxiety impacts the most is inhibition. Theoretically, ACT-S posits that anxiety disrupts attentional control by increasing the vigilance of the stimulus-driven system to potential sources of threat (Eysenck & Wilson, 2016). It may be this affect is greater upon inhibition (withholding dominant responses) compared to shifting (altering mental sets or spatial attention) and updating (monitoring information within working memory). Albeit hypothetical, one explanation may be that inhibition ability is strongly driven by external cues (to protect oneself from danger; Eysenck et al., 2007).

Also unusual was that anxiety, namely the STICSA, was unexpectedly positively correlated with category switch effectiveness. This could be explained through the ACT-S prediction that effectiveness can be maintained through the recruitment of additional resources (Eysenck & Wilson, 2016). Interestingly though if this additional resource was time, you would expect a negative correlation between the STICSA and category switch efficiency. Given that this did not emerge, it may be that alternate resources were recruited that did not impact time taken. One potential resource also outlined in ACT-S that may have been recruited is effort (Eysenck & Wilson, 2016). Increased focus on behavioural or motivational effort has been associated with coping during distracting/stressful scenarios (Wilson, 2012). Moreover, individuals consistently exposed to anxiety in training are more able to effectively and efficiently invest their increased effort (Oudejans & Nieuwenhuys, 2009). Individuals' previous exposure to anxiety was not obtained in the present study and thus could potentially explain this unusual finding.

Finally, expertise did not significantly correlate with the manifest variables for EF or VA which was unexpected. The posited relationship between EF and expertise is unclear and has arguments for (e.g., Hagyard et al., 2021) and against (e.g., Furley & Memmert, 2013) greater expert performance. The present data may support the idea that sporting expertise does not allow for greater performance on domain general EF tasks. Or rather, that expertise is relevant but perhaps requires some level of "activation" (i.e., performance in a field or lab setting with a tangible measure of sport performance) that is missed through online remote testing, as was conducted here. Likewise, it is possible that individual differences in other factors may interact to facilitate the EF and sport performance relationship in athletes (e.g., personality; Vaughan & Edwards, 2020).

There were a number of expected correlations both within and between the latent constructs of EF and VA. Within construct correlations can be split into two categories. There are correlations between measures of effectiveness and efficiency per task and there are correlations between the two tasks that assess the same latent construct for both effectiveness and efficiency. Given that effectiveness and efficiency share similarities in their calculation (i.e., both consider accuracy) it is not surprising the strongest correlation in most instances was between the effectiveness and efficiency score for particular tasks. The only instance the two did not correlate was the Flanker task. The efficiency variable for the Flanker task was adopted from Krenn et al. (2018) who successfully utilised this variable in an athletic sample and followed a similar calculation as the other measures of efficiency. Specifically, Flanker efficiency involved differences in accuracy and reaction time between both incongruent (i.e., red arrow trials that require opposite key responses) and congruent (i.e., black arrow trials that require simple key responses) whereas the effectiveness score were calculated based on correct and incorrect responses on incongruent trials only. The sole difference between the Category Switch Task and the Flanker Task was that certain trials are not pre-allocated as congruent and incongruent but rather such “switch” trials are more covertly worked within the task (as in Friedman et al., 2016). These analyses highlight that seemingly small nuances in how researchers calculate variables can have a large impact that must not be understated.

Regarding correlations between the two tasks designed to measure the same latent construct (e.g., Go/No Go and Stop Signal both captured inhibition) a large number of correlations were as expected. The only construct to have both measures of effectiveness and efficiency significantly correlate for both tasks was inhibition. Though not as complete as inhibition, VA, and shifting tasks showed high levels of correlation. Interestingly, there were no significant correlations between any outcome measure for the updating tasks (i.e., the nback and Backward Digit Span tasks). This may have arisen due to the difficulty of the Backward Digit Span task that were apparent when examining effectiveness. The mean score on this task was surprisingly low and indicated that for the most part participants were getting more responses incorrect than correct (i.e., potentially indicated floor effects). As utilised in Woods et al. (2011) it may be more optimal for future works to utilise an adaptive measure of performance effectiveness in this task. This may remove floor effects because individuals who may struggle with lower string backward digit spans will not have to face seemingly impossible longer spans. Finally, there were a vast number of significant correlations between the various manifest outcomes designed to measure different EFs and VA. These results support the idea to use CFA to test both the theoretical model (Miyake et al., 2000) and hypothesised model in the current study (i.e., relationships between EF and VA).

4.5.2 Structural Equation Modelling

Within the present study, CFA which was the inferential statistical approach used to (a) replicate the EF model proposed in Miyake et al. (2000) and (b) examine the relative contributions of each EF to VA task performance in a sample of athletes. The present study was also the first to examine this relationship for both effectiveness and efficiency performance separately. Previous works using CFA to model the relationship between a hypothesised model of EF used a combination of effectiveness and efficiency measures in the same model (Miyake et al., 2000). While such work used legitimate outcome measures for each EF the method used may not consider the somewhat distinct nature of effectiveness and efficiency as outlined in ACT-S (Eysenck & Wilson, 2016). The present study supports both the proposed model of EF from Miyake et al. (2000) and the importance of examining both effectiveness and efficiency as per ACT-S (Eysenck & Wilson, 2016) in athletes.

Specifically, both models of effectiveness and efficiency reached acceptable levels but required different levels of modification. The BIC is a metric that penalises model complexity with lower values indicating greater parsimony (Burnham & Anderson, 2002). Here, the effectiveness models are seemingly simpler and a "better" fit compared to efficiency models (Neath & Cavanaugh, 2012). This is not a surprising finding as efficiency measures often contain more complex calculation (i.e., accuracy and reaction time) and are not all interpreted in the same direction (i.e., sometimes lower scores are optimal and sometimes higher scores are optimal). For example, Stop Signal Reaction Time, one of the most utilised outcome measures of the Stop Signal Task (Verbruggen et al., 2019), is inherently complex as it involves computing a reaction time when no reaction is given. Such a variable is calculated from the average stop signal delay achieved (i.e., the mean length between "go" and "stop" stimulus presentation), the probability of responding (i.e., the likelihood someone will incorrectly press following presentation of the "stop" signal), and the corresponding *n*th value from the reaction time distribution (Verbruggen et al., 2019). In sum, lower scores are optimal as they are indicative of smaller discrepancies between “stop” signal presentation and the *n*th reaction time.

Consider this against the Go/No-Go Task which has a simpler outcome measure for efficiency (i.e., an outcome less complex in calculation). Here, efficiency is calculated in the same manner as effectiveness but the end product is divided by mean reaction time. In addition, this variable is considered better when scores are higher (i.e., higher values represent both greater Go/No-Go Task effectiveness and efficiency). For example, an individual with eight hits, two false alarms, and an average reaction time of 300ms, and an individual with eight hits, two false alarms, and an average reaction time of 500ms score the same regarding effectiveness. However, they would differ on efficiency with the individual with the average reaction time of 300ms proving more efficient ([8-2]/300 = .020) compared to the individual with the average reaction time of 500ms ([8-2]/500 = .012). Overall, future work may opt to consider outcome measures that are derived in similar ways, though this may not be easy, in order to obtain more parsimonious EF models of efficiency.

A number of other absolute and relative fit indices for model suitability were examined and generally suggested that the data supported our hypotheses. Often outlined as a test of absolute fit the Chi-Square value (χ^2; Sun, 2005) was non-significant for all proposed hypothesised models. Non-significant χ^2 values support the null hypothesis (i.e., the predicted model and observed model are equivalent; Arbuckle & Wothke, 2004). However, using a single measure such as the χ^2 value is not a holistic way of assessing fit and additional relative indices sensitive to sample size and model complexity should be used (Kline, 2005). Therefore, the CMIN/DF, RMSEA, and SRMR values found in the present study supplement the non-significant χ^2 values. The CMIN/DF is also based on the χ^2 value (where CMIN represents χ^2 and DF refers to the degrees of freedom). Issues with the χ^2 value alone are centred around sample size where, as sample size increases, the likelihood of a significant χ^2

increases (Yaslioglu & Yaslioglu, 2020). The CMIN/DF is considerate of this issue and the values found here further support that there is acceptable fit between the hypothesised and observed models in the present study (Moss et al., 2015).

Both the RMSEA and SRMR are also based on comparisons between the observed model (i.e., based on data obtained) and a hypothesised model (e.g., independent model). In the present study RMSEA was acceptable (i.e., values < .10) for the hypothesised effectiveness models. This indicated that differences in the observed model were substantially different from the most restrictive model, where correlations are set to zero (i.e., the independent model in AMOS). A potential reason for this could be the somewhat low degrees of freedom for each model in the present study. Degrees of freedom are used within the calculation for RMSEA whereby they are pivotal in how discrepancies are assessed between models (Maydeu-Olivares et al., 2018). It has also been noted that there is greater sampling error in the RMSEA when degrees of freedom are lower, creating potential question about this measure here (Kenny, 2015). Based on this, alternative accounts suggest that values below .05 indicate excellent fit, with .05 and .10 representative of good and acceptable fit (MacCallum et al., 1996). On this basis the present results would suggest that the efficiency models show good RMSEA and therefore meaningful difference from the independent model.

The RMSEA is an unstandardised measure that does not regulate measurement scales before calculating outcome variables. The SRMR is standardised and examination of the SRMR for all models within the present study suggest good fit for the observed model compared to the independent model (i.e., values considerably below .08; Hu & Bentler, 1999). However, as with all relative fit indices, caution is paramount when using the SRMR as it too is susceptible to sample size and degrees of freedom though in this instance the effect is a false positive (i.e., SRMR appears better in smaller samples with low degrees of freedom). Therefore, the present study retains the use of both indices and in combination the results support that the observed data shows meaningful discrepancy from the independent model. The additional measures of fit reported here (i.e., GFI, CFI, and TLI) support this claim. That is, effectiveness showed better scores (i.e., values closer to 1; Hu & Bentler, 1999) compared to efficiency, despite efficiency also reaching good levels. Therefore, all observed models again show meaningful deviations from the independent model supporting the hypotheses of the present study.

One goal of the present study was to assess how the proposed manifest variables of EF measured the latent constructs of inhibition, shifting, and updating as in Miyake et al. (2000; Figure 4.1A) in a sample with varying athletic expertise. The above fit indices support the model proposed by Miyake et al. (2000) and the application of such a model in an athletic sample. For effectiveness the present analyses showed strong similarities to those proposed by Miyake et al. (2000). Specifically, the regression coefficients for inhibition and shifting show fair-very good weighting whereby 20-40% of the variance in performance on the relevant tasks were accountable to the latent construct (Comrey & Lee, 1992). However, the regression weights between the updating latent construct and manifest tasks (i.e., 2-back and Backward Digit Span Tasks) were weaker than in previous research. Initial reasoning could again stem from the difficulty over the Backward Digit Span Task. As the group appeared to exhibit floor effects, therefore updating ability may not have sufficiently captured.

The counterpoint to this is given that the 2-back regression coefficient was also low, this may suggest the 2-back task was too difficult. When combined, the pattern of results found here might indicate that updating information within working memory is less relevant for athletes than the general population (as in Miyake et al., 2000), though this seems unlikely as other research supports the relevance of working memory (Furely & Memmert, 2012; Vaughan & Laborde, 2021). Future work could clarify this by comparing expertise or sport-related differences in latent updating constructs rather than control for differences as was done here. As the efficiency model for EF required additional constraints and modifications the path structure differed a little despite also reaching suitable model fit. The reason for a divergent path structure could be due to the complexity of these outcome variables which can influence the model (Neath & Cavanaugh, 2012).

The correlations between the latent EF constructs were similar to previous work (e.g., Miyake et al., 2000), though the stronger relationships between constructs edge towards a more unified model for effectiveness. As in previous work the weakest correlation, though still a strong correlation, between EFs was inhibition and shifting with stronger correlations between inhibition and updating, and updating and shifting. This increased strength in correlation between these latent EF variables may be based on how manifest variables were calculated. Specifically, in Miyake et al. (2000) outcome variables comprised reaction time and accuracy which were intertwined within the same model. This does not necessarily present an issue with Miyake et al.'s (2000) model, but highlight that when EF outcomes are similar, greater correlations can be expected. Also, stronger correlations may have occurred because athletes get more exposure to scenarios that place demands on these functions (Faubert & Sidebottom, 2021). Indeed, many studies support the idea that athletes possess greater EF than non-athletic counterparts (e.g., Hagyard et al., 2021) therefore, it may be that with improved function greater correlations between EFs are present. The efficiency model followed a similar pattern but again correlations were weaker because of additional constraints and modifications placed on the model.

Another important goal of the present study was to extend the proposed model of EF and assess the relative contribution of latent EF measures upon a latent hierarchical VA variable. Again, model fit generally supports the hypothesised model outlining a relationship between EF and VA. The manifest tasks designed to measure the latent construct of VA (i.e., the Attentional Breadth and Visual Search task) showed fair-good regression coefficients (Comrey & Lee, 1992). Regarding effectiveness (i.e., correct – incorrect responses) it appears that inhibition has a greater influence on VA than shifting and updating. Importantly, because the present study used numerous measures to adequately capture a latent inhibition factor these results strengthen the association between inhibition and VA above studies using single task measures (e.g., Ducrocq et al., 2016). Inhibition appears to be important for visually guided attention. This result is not surprising as withholding the want to visually attend to distracting goal directed stimuli leads to more optimally directed attention. For example, Furley et al. (2017) found that individuals who spent longer fixating on the less-relevant and task-threatening goalkeeper in soccer penalty kicks were more likely to have their attempt saved. Future work should examine how inhibition relates to commonly used VA measures (e.g., quiet eye; Vickers, 2007).

The efficiency model (i.e., effectiveness by reaction time) of EF and VA appeared to show a different pattern of results. Specifically, the latent shifting construct appeared to influence the VA construct the most and considerably more than inhibition. Inhibition in this model appears to have the least impact upon VA which is unusual given its influence upon performance effectiveness. These results do however somewhat support the theoretical assumptions of ACT-S in that effectiveness and efficiency are different and may be uniquely effected by EF (Eysenck & Wilson, 2016). When reaction time was included in the model shifting became the dominant EF in performance of VA tasks where quicker “shifters” showed more efficient VA. Therefore, it might be that being able to quickly alter between mental sets, patterns, or tasks facilitates optimal visual information pick up (evidenced through enhanced performance on visual tasks). Specifically, detaching from no longer relevant information to more relevant means optimal visual cues can be identified and acted upon earlier. Research from Huijgen et al. (2015) reported greater shifting performance in elite compared to sub-elite soccer players. Though this does not necessarily suggest that shifting leads to someone becoming elite nor that being elite improves shifting, but rather the present results and Huijgen et al. (2015) support the important role of shifting in sport.

4.5.3 Limitations and Future Recommendations

The present study provides researchers with a better understanding of how two often separate areas (i.e., EF and VA) may relate while considering theoretical frameworks (e.g., ACT & ACT-S). Despite this, a number of limitations are present. Although each statistical model in this study is fairly simple (i.e., low number of latent and manifest variables) and the outcomes are based on sound assumptions that each manifest task (e.g., Stop Signal Task) tap the desired latent construct (e.g., inhibition) it may be that equivocal model fit can be found when entering the manifest tasks in any number of combinations (e.g., Stop Signal Task as measures of shifting rather than inhibition). But, as Miyake et al. (2000) note, it would be difficult, and unwise, to test every single combination. It should also be noted that future work in this area should look to include at least a single manifest variable of each element of the lower-order model (i.e., inhibition, shifting, and updating; Miyake et al., 2000). In doing so a more complete understanding of the individual contribution of such functions is possible. A number of cases of overfit were observed. Sample size was ample and general rules of thumb were followed (e.g., 10 cases per indicator variable; MacCallum et al., 2001) yet it could be that sample size may have been restrictive, and thus caused overfit, especially in models with low degrees of freedom (MacCallum et al., 2001).

Regarding the tasks themselves, the attentional breadth has been linked to emotion (Grol & Raedt, 2014). Where positive emotions are linked to a broadened attentional scope (Rowe et al., 2007) and negative emotions and depressive symptoms have been associated with a more narrowed attentional scope (Derryberry & Tucker, 1994). While the present study attempted to remove this effect by replacing typically used human faces, with Emoji faces. Despite this the results may still have been driven by the emotional valence of faces as research has reported links between EF and emotional intelligence in athletes (Vaughan et al., 2021). The Background Digit Span Task proved to be too difficult resulting in a potential floor effect. Perhaps an adaptive format would be better where the task begins with a two-string span, after each successful digit recall the length is increased by one digit and every unsuccessful digit recall the length is decreased by one digit (Woods et al., 2011).

4.5.4 Conclusion

The goal of the present study was twofold. First, to replicate and extend the original model of EF proposed by Miyake et al. (2000) in a sample of athletes. Second, to extend this model further by examining the relative contribution of latent EF constructs upon a latent VA construct. The EF model was replicated in the present sample suggesting that inhibition, shifting, and updating are relevant to athletes. Particularly, strong was the association with performance effectiveness (i.e., correct – incorrect responses) rather than efficiency (i.e., effectiveness by reaction time). The results of this chapter propose that sport and exercise psychology researchers interested in EF can utilise Miyake et al.'s (2000) model in sport. It also appears that EF has a meaningful impact upon VA. Note, this effect appears to be relevant at the latent level (i.e., when multiple tasks are used to measure a construct) and not just task specific as previous single-task studies may have outlined. However, further work is needed to examine how EF may relate to objectively measures VA (i.e., obtained via an eye-tracker) and how EF and VA may interact to influence objective sport performance.

Chapter 5: Think, see, do: Executive function, visual attention, and soccer penalty performance – A cross-sectional examination

5.1 Chapter Overview

The results of Chapter 4 suggested that EF and VA relate but without consideration of objective sport performance. As a result, the interaction between EF and VA is not fully understood during actual sport performance. Despite theoretical links (i.e., ACT-S; Eysenck & Wilson, 2016), there is surprisingly little information on whether VA (i.e., quiet eye, search rate, and fixations to key locations) could mediate the relationship between EF (i.e., shifting, inhibition, and updating) and soccer penalty performance under pressure. An experimental between-subjects design with random assignment to low- and high-pressure conditions was used. Ninety-five participants with a range of competitive soccer experience, completed measures of situational stress, physical activity, athletic expertise, and tasks of EF, before completing a soccer penalty task while VA was recorded via a mobile eye-tracker. Between-subjects ANCOVA showed no significant differences between the pressure conditions in VA or soccer penalty performance, so subsequent analyses were collapsed across all participants. Mediation revealed that the effect of inhibition on soccer penalty performance was significantly mediated by quiet eye duration, search rate, and the number of fixations toward the goal. Also, the effect of updating on soccer penalty performance was significantly mediated by quiet eye duration and location, and the number of fixations toward the goal. These results are the first to suggest that EF (inhibition and updating) and VA (quiet eye duration and location, fixations toward the goal, and search rate) combine to enhance soccer penalty performance.

5.2 Introduction

Sport provides an optimal environment for examining divergent performance under pressure. Pressure can be defined as any situation containing a factor(s) that enhances the need to perform well (e.g., audience presence, competition, performance-contingent rewards and punishments, and ego relevance; Baumeister & Showers, 1986). Attentional Control Theory (Eysenck et al., 2007) suggests attention suffers under pressure due to heightened anxiety or stress, resulting in poorer performance. However, in a recent sport-specific theoretical update, Attentional Control Theory-Sport (ACT-S; Eysenck & Wilson, 2016), suggested personal interpretations of a pressurised situation govern individual stress responses (i.e., positive or negative). Theoretically, ACT-S adopts the cognitive attention measures (i.e., shifting, inhibition, and updating) proposed by Attentional Control Theory, but contextualises these processes to sport performance (see Figure 1.2). It has become commonplace to test ACT-S assumptions using VA measures (e.g., the quiet eye; Vickers, 2007), leaving the cognitive processes under-examined. Despite Chapter 4 showcasing that EF and VA may relate through latent modelling, little is known about how EF, VA, and subsequent sport performance may relate. The present study is the first to examine the potential mediating role of VA on the EF and sport performance relationship.

5.2.1 Role of Pressure in Attentional Control Theory-Sport

One theoretical assumption of ACT-S, and a focus of the present study, is that negative task performance under pressure may arise due to inefficiency of EFs (i.e., inhibition, shifting, and updating; Miyake et al., 2000) and subsequently poor gaze (i.e., VA). It is also outlined in ACT-S that performance under pressure is contingent on personal interpretations of the situation and how pressure is perceived (often in light of previous and optimal performance; Eysenck & Wilson, 2016). This personal assessment in turn effects the perception of threat, and subsequent feelings of anxiety (Harris et al., 2019). It has been proposed that our assessment of stress or pressure is influenced by several feedback loops that include personal cognitive biases, perceptions of the cost, probability of failure, and motivation levels (Eysenck & Wilson, 2016). Positive interpretations of a pressurised situation may facilitate a balance between the attentional systems (i.e., goal-directed and stimulus-driven systems) allowing attention to be directed to task-related stimuli and potential threatening stimuli simultaneously. As a result, it is plausible that EFs (i.e., shifting, inhibition, and updating) may operate more efficiently, combatting the potentially negative effect of anxiety and stress experienced under pressure, allowing for subsequent VA and performance to be optimised.

5.2.2 Executive Function Under Pressure

Both ACT and ACT-S refer to a lower-order model of EFs (i.e., shifting, inhibition, and updating) which are interrelated, yet distinct (Miyake et al., 2000). It has been shown outside of sport that this lower-order model can be influenced to stress or pressure. For example, Edwards et al. (2015) found that the relationship between cognitive trait anxiety and shifting efficiency (i.e., accuracy divided by time) was only significantly influenced in the “high-stress” condition. More specifically, when individuals were given instructions designed to elicit greater situational stress those with reported higher levels of cognitive trait anxiety showed poorer shifting efficiency. Though research in sport has examined the role of EF upon performance (as evidenced in Chapter 2), there has been little focus on how stress or pressure influence the relationship in this specific context. The limited evidence we do have does however suggest the relationship may be similar (i.e., EFs are negatively influenced by stress/pressure unless compensated for). For example, poorer shifting, inhibition, and updating performance has been associated with increased distractibility (Eysenck & Wilson, 2016). Indeed, elite athlete accounts have indicated that 25.9% of thoughts under high-pressure relate to distraction (Oudejans et al., 2011), which may relate to inhibition as research has noted that resisting distractor interference is reliant upon the inhibition function (Friedman & Miyake, 2004).

Research suggests that the relationship between EF and sport performance may highly relate to expertise (e.g., Verburgh et al., 2014; Vestberg et al., 2017). For example, Hagyard et al. (2021) reported that expertise was related to inhibition (measured via a Stop Signal Task) both cross-sectionally and longitudinally over a 16-week period. Therefore, expertise should be controlled for in any analyses not explicitly examining group differences (i.e., elite vs. novice groups) in order to ensure that results are not attributable to expertise differences. Physical activity can also influence EF (e.g., via increases in brain plasticity; Erickson et al., 2015). Elite athletes undergo intense and extensive training in which they often exhibit high levels of physical fitness, motor control, and cognitive ability (Diamond & Ling, 2016). This may suggest differences in EF may have been in part driven by physical training, supporting the inclusion of physical activity as a covariate. Despite EF being linked to expertise and physical activity, research rarely controls for the influence of these variables.

5.2.3 Visual Attention Under Pressure

Visual attention, obtained using a mobile eye-tracking device, is commonly used to examine the assumptions of ACT-S (e.g., Ducrocq et al., 2016). It has also become common, unlike with EF, to place individuals in a controlled environment where pressure can be manipulated. The point here being to understand how VA may be different between low- and high-pressure conditions. From a theoretical standpoint, ACT-S suggests that negative interpretations of pressure induce anxiety or stress and subsequently increase attention allocation toward threatening stimuli at the expense of goal-directed stimuli (Eysenck & Wilson 2016). In Wood and Wilson (2010a; 2011) noted that, during soccer penalty performance, anxiety related disruptions to attentional control occur far more during the aiming phase (a phase where critical information is extracted for accurate kicks) compared to the execution phase (where attention is typically focused on ensuring adequate foot-ball contact). This suggests that the aiming phase may be more important than the execution phase when studying the impact of anxiety or pressure on VA in soccer penalty kicks. Timmis et al. (2018) corroborated this idea reporting that during the final approach to the ball fixations were primarily located toward the ground at an area just in front of the ball (a phenomenon deemed the “anticipatory fixation”), supporting the idea that during execution gaze is located away from the intended striking target.

Recording visual attention in soccer penalties is useful as they contain clear goal-directed (e.g., the goal) and potentially threatening (e.g., the goalkeeper) stimuli which allows researchers to comment on whether individuals focus on the goal or threat during the sporting action. Previous research examining psychophysiological responses (i.e., challenge and threat states) within a soccer penalty task reported that a positive physiological response (i.e., a challenge state) lead to more fixations toward the goal (Brimmell et al., 2019). Also, under low-anxiety conditions, fixations were more distally located within the goal area potentially representing greater goal-directed attention (Wilson, Wood, & Vine, 2009). Finally, Binsch et al. (2010) found that individuals who fixated on the goalkeeper despite being explicitly informed not to look at the goalkeeper (i.e., the “ironic” effect) displayed significantly shorter final fixations (i.e., quiet eye duration) and significantly more centrally located soccer penalty kicks in the “not-keeper” condition when compared to “accurate” and “open-space” conditions. Regarding fixations toward the goalkeeper, research has been less definitive. Wilson, Wood, and Vine (2009) found participants made significantly more fixations to the goalkeeper in a high-anxiety condition compared to a low-anxiety condition. However, a negative psychological response to a high-pressure soccer penalty task did not lead to significantly more fixations toward the goalkeeper (Brimmell et al., 2019). More research is needed to further explore this relationship and to test whether interactions between VA (i.e., gaze behaviour) and EF (i.e., shifting, inhibition, and updating) explain soccer penalty performance.

5.2.4 Executive Function, Visual Attention, and Sport

Research has begun to examine the interplay between EF, VA, and sport performance (e.g., Ducrocq et al., 2017; Wood et al., 2016). Ducrocq et al. (2016) used an inhibition training paradigm to improve VA (i.e., first target fixation) and tennis-specific sport performance. Those who underwent inhibition training showed significantly later first target fixation (indicating superior inhibition and VA) and greater tennis performance under pressure. Ducrocq et al. (2017) implemented a working-memory training paradigm that, for those within the training group, lead to significantly later quiet eye offset times and improved tennis performance under pressure. Given that EF has been linked to sport performance (e.g., Vestberg et al., 2017), that training elements of EF can lead to subsequent improvements in VA (e.g., Ducrocq et al., 2016; 2017), and that improved VA relates to better soccer penalty kick performance (e.g., Wood & Wilson, 2011), it may be that VA mediates the EF and sport performance relationship (i.e., EF first impacts VA before subsequently affecting sport performance). However, this hypothesis is yet to be examined.

5.2.5 The Present Study

Research has typically utilised VA metrics (i.e., quiet eye duration and location, search rate, and fixations to key locations) to empirically test the predictions of ACT-S at different pressure levels. The lack of focus on the EFs proposed by ACT-S is surprising given their importance within sport performance (e.g., Vestberg et al., 2017). To fill this gap, the present study aimed to replicate whether different pressure instructions (i.e., low- and high-pressure) lead to differences in VA and sport performance (Wilson, Wood, & Vine, 2009). Second, this study examined the extent to which VA (i.e., quiet eye duration and location, search rate, and fixations to key locations) mediated the EF (i.e., shifting, inhibition, and updating) and sport performance (i.e., soccer penalty) relationship, after controlling for covariates (i.e., physical activity and expertise).

This chapter offered the first direct test of the relationship between the theoretically proposed EFs of ACT-S and the typically used VA measures in a pressurised sport task. While having theoretical importance for ACT-S, this relationship may also be of interest for sport coaches and practitioners. Specifically, by characterising precisely which EF and/or VA factors are important for sport performance under pressure, findings from the present study can provide target markers for interventions. Based on theory and evidence (e.g., Wilson, Wood, & Vine, 2009), it was hypothesised that those in the high-pressure condition would display poorer VA, and soccer penalty performance compared to the low-pressure condition. Lastly, guided by prior findings (e.g., Ducrocq et al., 2016; 2017) it was hypothesised that EF (i.e., inhibition, shifting, and updating) would predict soccer penalty performance through the mediator of VA (i.e., quiet eye duration and location, search rate, and fixations to key locations).

5.3 Method

5.3.1 Participants

Ninety-five participants (58 male; M_{age} = 25.07 ± 7.50 years) with a range of sporting expertise took part in the study (i.e., non-athlete: *n* = 47, novice: *n* = 16, amateur: *n* = 18, and elite: *n* = 14; based on Swann et al., 2015). Participants received verbal and written study instructions and were tested individually. Participants were allocated randomly to receive either low-pressure or high-pressure instructions (see Procedure for details). Power analysis indicated a sample of 89 participants were needed to detect a moderate indirect effect (per Vaughan & Laborde, 2020) where partial r for all paths = .33, alpha = .05, and power = .80 (MedPower; Kenny 2017). The study received institutional ethical approval from the York St

John University Cross-School Research Ethics Committee for the School of Education, Language, and Psychology (see Appendix 1B).

5.3.2 Design

The study used an experimental between-subjects design with random allocation to low- and high-pressure conditions (allocation conducted using Qualtrics). For more details on low- and high-pressure conditions see "Procedure" section of Chapter 5.

5.3.3 Measures

5.3.3.1 Situational Stress

The SRQ (Edwards et al., 2015; see Appendix 4) was used to capture situational stress and used to assess the efficacy of the pressure manipulation instructions (see also Brugnera et al., 2017). A full description of the SRQ can be found in Chapter 4 (see section 4.3.3.3). Finally, in the present study, the SRQ showed satisfactory internal consistency (α = .92).

5.3.3.2 Physical Activity

The IPAQ-SF (Booth, 2000; see Appendix 3) was used to index physical activity over the preceding seven days. A full description of the IPAQ-SF can be found in Chapter 4 of the present thesis (see section 4.3.3.1).

5.3.3.3 Expertise

Expertise was classified following Swann et al.'s (2015) recommendations (see Appendix 2). A full description is provided in Chapter 4 (see section 4.3.3.2).

5.3.3.4 Executive Function

5.3.3.4.1 Shifting. The Flanker task (Ridderinkhof et al., 1997; see Appendix 9) involved identifying the direction of a centralised arrow (displayed for 1750ms before timeout) that is 'flanked' by distractor arrows that are either congruent (i.e., arrows face the same direction as the target arrow) or incongruent (i.e., arrows face the opposing direction to the target arrow). Participants selected the direction they feel the arrow is facing as quickly and accurately as possible. The outcome measure was based on switch cost (i.e., difference between reaction time on correct congruent trials and correct incongruent trials; Hughes et al., 2014) reflecting performance efficiency. As switch costs often don't capture latency and accuracy (Hughes et al., 2014) an inverse efficiency score was calculated to incorporate both latency and accuracy by dividing mean reaction time by mean accuracy for both congruent and incongruent trials. The difference between these scores was then indexed as shifting ability (i.e., incongruent inverse efficiency - congruent inverse efficiency; Hughes et al., 2014). The Flanker task has acceptable intraclass-correlations (r = .66-.74; Hedge et al., 2018).

5.3.3.4.2 Inhibition. The Parametric Go/No-Go task (Langenecker et al., 2007; see Appendix 9) involved a continuous stream of letters, each displayed for 500ms, a small number of which are targets (i.e., "r" and "s") while other letters acted as distractor stimuli. This task utilised two levels to assess response inhibition. The first level aimed to build a response tendency and requires participants to respond to all target letters, while ignoring distractor stimuli. The second level assessed inhibition ability based on a contextual rule. The rule being that participants must respond to target stimuli in a non-repeating order (i.e., respond to the "r" target only if the previous target was "s"), while still ignoring distractor stimuli. An inhibition efficiency score was calculated using the following equation, ({[(5 x PCTT) + PCIT]/6} /RT) x 100; Votruba & Langenecker, 2013). Where Percentage Correct Target Trials (PCTT) is correct target responses divided by the total possible correct target responses. Percentage Correct Inhibitory Trials (PCIT) is correct inhibitory trials divided by the total possible inhibitory trials and Response Time (RT) is mean response time on correct target trials. This task has previously shown acceptable construct and discriminant validity

(Votruba & Langenecker, 2013) and test-retest reliability (*r* = .57-.83; Langenecker et al., 2007).

5.3.3.4.3 Updating. The nback task (Jaeggi et al., 2010; see Appendix 9) involved the sequential presentation of eight unfamiliar yellow shapes against a black background for 500ms, followed by a 2,500ms interstimulus interval. The nback task comprised three experimental conditions, each of which were completed twice (e.g., 2 × 2-back). In the 2-back task participants responded to the stimuli if it were the same as the one presented two trials before. The 3-back task required participants to respond if the stimuli were the same as the one presented three trials before. Finally, in the 4-back task participants responded to the stimuli if it were the same as the one presented four trials before. An outcome measure was calculated through hits minus false alarms averaged over all levels of the task (Jaeggi et al., 2010). This task has shown acceptable construct validity (*r* = .33-.45; Shelton et al., 2009).

5.3.3.5 Visual Attention

Visual attention was measured via a lightweight (76 g) binocular mobile eye-tracking device, recording at a spatial resolution of .5˚ and a temporal resolution of 30 Hz (SensoMotoric Instruments PLC., Boston, Massachusetts), connected to a mobile recording device (ETG recording unit 2.0, Samsung Galaxy S4, Samsung Electronics LTD., Surrey, United Kingdom). Before completing the soccer penalty task, a 3-point calibration process was completed to ensure adequate tracking of gaze. Calibration points included a near target (i.e., a soccer ball .5 m from the participant) and a far target (i.e., a researcher 5 m from the participant). Quiet Eye Solutions software was used for offline frame-by-frame analysis (www.quieteyesolutions.com). A fixation was defined as maintenance of gaze within 1˚ of visual angle for at least 120 ms (Vickers, 2007). Five gaze measures were calculated for the aiming phase (i.e., pre-run-up; as in Wood & Wilson, 2011) and included: 1) quiet eye duration, 2) quiet eye location, 3) search rate, 4) number of fixations to the goal, and 5) number of fixations to the goalkeeper.

5.3.3.5.1 The Quiet Eye. The quiet eye duration was defined as the final fixation in ms that began before the initiation of the critical movement (i.e., the run-up; Vickers, 2007). The onset of the quiet eye occurred before initiating this critical movement while the offset occurred when gaze deviated from the fixation location by 1° of visual angle (Vickers, 2007). Despite the quiet eye duration beginning before the initiation of the critical movement (i.e., quiet eye onset), the duration can carry on through the remainder of the movement process. In this case the quiet eye duration could carry on from the pre-run up, throughout the run-up, foot-ball contact, and even beyond. Quiet eye location was based on the spatial location of the final fixation (i.e., quiet eye) during the aiming phase (as in Wood et al., 2017). This method involved separating the goal into 12-zones (6-zones in each half of the goal) ranging from 0cm at the centre to 180cm at each post. The location was determined using frame-by-frame analysis in Quiet Eye Solutions to deduce the distance of the final fixation from the centre of the goal in cm (i.e., higher scores represent distally located quiet eye fixations whereas lower scores represent centrally located quiet eye fixations; as in Wood et al., 2017).

5.3.3.5.2 Fixation data. Search rate involved dividing the total number of fixations by the total duration (in seconds) of fixations (as in Brimmell et al., 2019). The number of fixations to the goal (i.e., goal-directed gaze) and goalkeeper (i.e., stimulus-driven gaze; Brimmell et al., 2019) referred to the sum of fixations toward the goal and goalkeeper, respectively. This thesis opted to record the number of fixations only and not the total or mean duration of fixations as previous research has indicated these variables are highly inter-related. Brimmell et al. (2019) reported a strong correlation between the number of and total duration of fixations to the goal ($r = .89$; $p < .01$) and between the number of and total duration of fixations to the goalkeeper ($r = .80$; $p < .01$). Likewise, mean fixation duration was not included as Wilson, Vine, and Wood (2009) reported that both the number of fixations and mean fixation duration were near identical in their influence on performance accuracy and may overlap.

5.3.3.6 Performance

Frame-by-frame videos from the mobile eye-tracking device’s scene camera were used to assess performance in Quiet Eye Solutions software. Performance was based on a single kick of a standard soccer ball (20.57 cm diameter) from a pre-defined penalty spot 5.0 m away from a traditional indoor soccer goal (3.6 m × 1.2 m; B.G. Sports International Ltd., Lancashire, United Kingdom). Each soccer penalty kick was assigned a horizontal ‘x’ coordinate to determine distance from the centre of the goal and accuracy (in cm; Brimmell et al., 2019). The centre of the goal was defined as the ‘origin’, with six 30 cm zones either side reaching a maximum 180 cm at either post. Higher scores reflected a more accurate penalty kick placed further away from the goalkeeper (van der Kamp, 2006). Goalkeeper movement (i.e., static), positioning (i.e., central), and posture (i.e., knees bent, and arms out to either side) were all standardised (van der Kamp & Masters, 2008), and the goalkeeper was unfamiliar to participants. Penalties that missed the goal (either over the cross-bar or wide of the goal; $n = 13$), hit the post ($n = 3$), the cross-bar ($n = 2$), or the goalkeeper (where the ball hit the goalkeeper stood at the ‘origin’; $n = 4$), scored zero.

5.3.4 Procedure

Participants provided informed consent, demographic information (e.g., age, sex; see Appendix 2), and sport participation details for expertise calculation. Participants then completed the baseline SRQ and the IPAQ-SF. Three EF tasks were then completed in a counterbalanced order (administered via Inquisit-5 by Millisecond, Millisecond Software LLC., Seattle, Washington) on a MacBook Air 13inch laptop with a 1440 x 900 resolution. Next, participants received verbal task-instructions, based on their experimental condition (i.e., low- or high-pressure manipulation), adapted from previous research (e.g., Brimmell et al., 2019; Moore et al., 2013). All participants were informed that the task would comprise a single soccer penalty kick and that a goalkeeper would be present. The high-pressure group were also informed that the goalkeeper would be attempting to save the penalty, that there would be a leader board, prizes for top performers, interviews for the poorest performers, and that the soccer penalty was the most important part of the study. Participants then completed their post-manipulation SRQ and were fitted with the mobile eye-tracking device, underwent the calibration procedure, and took a single soccer penalty kick. All elements of the procedure were completed in a specialist sport-laboratory and lasted approximately 45 minutes. Finally, participants were thanked and debriefed upon completion.

5.3.5 Data Analysis

Data was screened for missing data and multivariate outliers. Means, standard deviations, and zero-order correlations were calculated. Prior to the main analyses, normality was assessed via skewness and kurtosis with all values falling within acceptable range of parametric analyses (i.e., between -2 and 2). The effectiveness of the pressure manipulation instructions at increasing situational stress was assessed using a 2 x 2 mixed ANOVA. A one-way ANCOVA was used to examine whether the low- and high-pressure groups differed in EF, VA, or soccer penalty performance according to the ACT-S, with physical activity and expertise entered as covariates. Non-significant differences on EF ensures comparability between groups at baseline. To test for mediation (i.e., EF → VA → sport performance) PROCESS custom dialog was used (Hayes, 2018). Fifteen mediation models were completed to satisfy all combinations of the independent variable (i.e., shifting, inhibition, and updating), mediator (i.e., quiet eye duration and location, search rate, number of fixations to the goal, and number of fixations to the goalkeeper), and dependent variable (i.e., performance) with physical activity and expertise entered as covariates. PROCESS custom dialog allows inferences regarding mediation based on the indirect effects shown when using percentile bootstrapped confidence intervals (e.g., a default 5000 bootstrap resampling). When the confidence intervals do not contain zero, mediation can be inferred (Preacher & Hayes, 2008). All statistical analyses were conducted using IBM SPSS statistical software version 25 with an *a priori* alpha level set at $\alpha = .05$ for all relevant analyses (Field, 2013).

5.4 Results

5.4.1 Preliminary Analyses

Missing data, which comprised < 1%, was replaced with the item mean using ipsatised item replacement (Tabachnick & Fidell, 2007). Multivariate outliers were determined through examination of the Mahalanobis distance and revealed one multivariate outlier which was removed from subsequent analyses. Means, and standard deviations were then calculated (see Table 5.1). Zero-order correlations showed that baseline SRQ scores were significantly positively correlated with SRQ post-manipulation scores, and significantly negatively correlated with physical activity and expertise. Post-manipulation SRQ scores were significantly negatively correlated with physical activity, expertise, inhibition, quiet eye duration, and soccer penalty performance, while significantly positively correlated with search rate. Also, physical activity and expertise were significantly positively correlated with quiet eye duration and soccer penalty performance, and significantly negatively correlated with search rate, supporting their inclusion as covariates (see Table 5.1).

Regarding soccer penalty performance, the only EF that significantly positively correlated was inhibition. Inhibition was only significantly correlated with updating regarding the EFs. Shifting was significantly negatively correlated with number of fixations to the goalkeeper. Inhibition was significantly positively correlated with quiet eye duration, number of fixations to the goal, and was significantly negatively correlated with search rate. Updating was significantly positively correlated with number of fixations to the goal and quiet eye location. Quiet eye duration, quiet eye location, and number of fixations to the goal were significantly positively correlated. Search rate was significantly negatively correlated with quiet eye duration, quiet eye location, number of fixations to the goal, and number of fixations to the goalkeeper. Finally, quiet eye duration, quiet eye location, and number of fixations to the goal were significantly positively correlated, while search rate and number of fixations to the goalkeeper were significantly negatively correlated, with soccer penalty performance (see Table 5.1).

Table 5.1.

Means, Standard Deviations, and Zero-Order Correlations for all variables

Variable	Total (*N* = 95) M(SD)	High-Pressure (*N* = 48)	Low-Pressure (*N* = 47)	Zero-Order Correlations (*N* = 95)												
		M(SD)	M(SD)	1	2	3	4	5	6	7	8	9	10	11	12	13
1. SRQ baseline	12.91(6.35)	12.92(6.21)	12.89(6.55)	1	.64**	-.47**	-.50**	-.05	-.18	-.01	-.19	-.09	.16	-.06	.01	-.16
2. SRQ post-instruction	15.54(7.44)	16.52(7.76)	14.53(7.03)		1	-.40**	-.35**	-.08	-.25*	.01	-.22*	-.04	.23*	-.08	.06	-.20*
3. IPAQ-SF	5803.04(3813.01)	5919.77(3775.58)	5683.83(3888.01)			1	.53**	.20	.07	.04	.30**	.05	-.26*	.01	.02	.21*
4. Expertise	2.78(3.28)	2.51(3.12)	3.07(3.45)				1	-.03	.15	.16	.25*	.17	-.31**	.04	-.04	.33**
5. Shifting	7.37(5.46)	7.83(5.88)	6.90(5.04)					1	.02	-.10	.14	-.16	-.04	-.04	-.21*	.11
6. Inhibition	15.45(4.79)	15.35(5.08)	15.55(4.52)						1	.25**	.27**	.19	-.29**	.28**	-.07	.22*
7. Updating	.18(1.58)	.12(1.54)	.23(1.65)							1	.20	.31**	-.19	.27**	.03	.16
8. Quiet Eye Duration	184.90(59.04)	189.96(68.52)	179.85(47.95)								1	.31**	-.67**	.33**	.01	.49**
9. Quiet Eye Location	50.59(46.96)	51.25(49.64)	49.89(45.21)									1	-.23*	.55**	-.21	.47**
10. Search Rate	5.73(1.26)	5.72(1.28)	5.74(1.27)										1	-.28**	-.29**	-.48**
11. Goal Fixations	1.70(1.76)	1.65(1.76)	1.76(1.79)											1	-.05	.28**
12. GK Fixations	1.68(1.50)	1.60(1.57)	1.76(1.45)												1	-.23*
13. Performance	76.53(60.12)	69.79(63.96)	83.40(55.78)													1

Note. GK = Goalkeeper; IPAQ-SF = International Physical Activity Questionnaire-Short Form; SRQ = Stress Rating Questionnaire.

5.4.2 Differences in Low- and High-Pressure

The effect of the pressure manipulation on the dependent variable SRQ differences (i.e., SRQ post-manipulation minus SRQ baseline) was measured using a 2 x 2 mixed ANOVA with Time (baseline vs. post-manipulation) as the within-subject factor and Group (low- vs. high-pressure) as the between-subject factor. There was a significant main effect of Time ($F(1, 93) = 18.66$, $p < .001$, $\eta_p^2 = .17$), however there was no statistically significant main effect of Group ($F(1, 93) = .62$, $p = .435$, $\eta_p^2 = .01$) nor a statistically significant Time x Group interaction ($F(1, 93) = 2.62$, $p = .109$, $\eta_p^2 = .03$). The main effect of time suggested that SRQ scores were significantly higher post manipulation (low-pressure $M = 14.53 \pm 7.03$; high-pressure $M = 16.52 \pm 7.76$) compared to baseline (low-pressure $M = 12.89 \pm 6.55$; high-pressure $M = 12.92 \pm 6.21$) across both low- and high-pressure groups. Despite the non-significant interaction, ANCOVA was conducted to examine whether differences between the pressure conditions manifested in EF, VA, or soccer penalty performance.

The results of the ANCOVA revealed no significant differences between the groups (i.e., low- and high-pressure) in inhibition ($F(1, 91) = .01$, $p = .951$, $\eta_p^2 = .00$), shifting ($F(1, 90) = .34$, $p = .559$, $\eta_p^2 = .01$), or updating ($F(1, 91) = .02$, $p = .878$, $\eta_p^2 = .00$), when controlling for physical activity and expertise. This finding confirmed that that the groups were comparable in EF. The ANCOVA revealed no significant differences between the groups (i.e., low- and high-pressure), when controlling for physical activity and expertise, on measures of quiet eye duration ($F(1, 90) = .90$, $p = .346$, $\eta_p^2 = .01$), quiet eye location ($F(1, 90) = .10$, $p = .749$, $\eta_p^2 = .01$), search rate ($F(1, 91) = .06$, $p = .808$, $\eta_p^2 = .01$), number of fixations to the goal ($F(1, 90) = .07$, $p = .798$, $\eta_p^2 = .01$), number of fixations to the goalkeeper ($F(1, 89) = .14$, $p = .707$, $\eta_p^2 = .01$), and soccer penalty performance ($F(1, 91) = .84$, $p = .364$, $\eta_p^2 = .01$), suggesting that VA and soccer penalty performance did not differ between the unique pressure conditions. The ANCOVA revealed no significant differences between the groups (i.e., low- and high-pressure) which suggested that all participants had a similar increase in stress levels from baseline to post-instruction despite the different pressure instructions. Therefore, as groups did not emerge, mediation analyses were collapsed across all participants.

5.4.3 Mediation Analyses

Six significant mediation effects were found (see Tables 5.2 to 5.6 for all mediation analyses). Quiet eye duration significantly mediated the inhibition and performance relationship (B = 1.32, 95% CI [0.10, 2.63]). This suggested that greater inhibition may lead to superior soccer penalty performance by facilitating longer quiet eye durations. Search rate significantly mediated the inhibition and performance relationship (B = 1.27, 95% CI [0.26, 2.54]). This indicated that greater inhibition may lead to a lower search rate, in turn enhancing soccer penalty performance. The number of fixations to the goal significantly mediated the inhibition and performance relationship (B = .82, 95% CI [0.03, 1.73]). This suggested that greater inhibition performance may allow individuals to direct more fixations toward the goal leading to subsequently greater soccer penalty performance. Quiet eye duration significantly mediated the updating and performance relationship (B = 3.58, 95% CI [0.66, 7.39]). This implied that greater updating may allow for longer quiet eye durations and superior soccer penalty performance. Quiet eye location significantly mediated the updating and performance relationship (B = 4.64, 95% CI [1.63, 8.59]). This suggested that greater updating may allow for more distally located quiet eye locations, in turn allowing for superior soccer penalty kick performance. The number of fixations to the goal significantly mediated the updating and performance relationship (B = 2.45, 95% CI [0.32, 5.69]). This suggested that superior updating may allow individuals to direct more fixations toward the goal leading to subsequently greater soccer penalty performance.

Table 5.2.

Summary of Mediation Analyses for Quiet Eye Duration

Effect	Coefficient	SE	Bootstrapping 95% CI	
X = Shifting	Y = Performance		Lower	Upper
Total effect (c)	1.39	1.19	-0.97	3.76
Direct effect (c′)	.55	1.05	-1.53	2.63
Indirect effects				
Total indirect effects	.85	.69	-0.36	2.39
a (X – M)	1.57	1.11	-0.63	3.78
b (M- Y)	.54	.10	0.34	0.74
X = Inhibition	Y = Performance		Lower	Upper
Total effect (c)	2.42	1.25	-0.07	4.90
Direct effect (c′)	1.09	1.12	-1.14	3.33
Indirect effects				
Total indirect effects	1.32	.63	0.10	2.63
a (X – M)	2.49	1.16	0.19	4.80
b (M- Y)	.53	.10	0.33	0.73
X = Updating	Y = Performance		Lower	Upper
Total effect (c)	4.05	3.87	-3.65	11.75
Direct effect (c’)	.47	3.42	-6.34	7.27
Indirect effects				
Total indirect effects	3.58	1.73	0.66	7.39
a (X – M)	6.51	3.56	-0.57	13.60
b (M- Y)	.55	.10	0.35	0.75

Note. CI = Confidence Interval, M = Mediator, SE = Standard Error, X = Predictor, Y = Outcome.

Table 5.3.

Summary of Mediation Analyses for Quiet Eye Location

Effect	Coefficient	SE	Bootstrapping 95% CI	
X = Shifting	Y = Performance		Lower	Upper
Total effect (c)	1.05	1.14	-1.22	3.33
Direct effect (c′)	1.79	1.03	-.26	3.84
Indirect effects				
Total indirect effects	-.74	.52	-1.76	.30
a (X – M)	-1.30	.93	-3.15	.55
b (M- Y)	.57	.12	.34	.80
X = Inhibition	Y = Performance		Lower	Upper
Total effect (c)	2.28	1.24	-.18	4.73
Direct effect (c′)	1.49	1.14	-.82	3.72
Indirect effects				
Total indirect effects	.83	.52	-.16	1.90
a (X – M)	1.60	1.01	-.42	3.61
b (M- Y)	.52	.11	.29	.75
X = Updating	Y = Performance		Lower	Upper
Total effect (c)	4.56	3.79	-2.97	12.09
Direct effect (c’)	-.08	3.60	-7.23	7.07
Indirect effects				
Total indirect effects	4.64	1.77	1.63	8.59
a (X – M)	8.54	2.98	2.62	14.46
b (M- Y)	.54	.12	.30	.79

Note. CI = Confidence Interval, M = Mediator, SE = Standard Error, X = Predictor, Y = Outcome.

Table 5.4.

Summary of Mediation Analyses for Search Rate

Effect	Coefficient	SE	Bootstrapping 95% CI	
X = Shifting	Y = Performance		Lower	Upper
Total effect (c)	1.17	1.13	-1.07	3.41
Direct effect (c′)	1.04	1.02	-0.99	3.07
Indirect effects				
Total indirect effects	.13	.52	-0.84	1.21
a (X – M)	-.01	.02	-0.05	0.04
b (M- Y)	-20.53	4.56	-29.59	-11.48
X = Inhibition	Y = Performance		Lower	Upper
Total effect (c)	2.40	1.24	-0.07	4.87
Direct effect (c′)	1.13	1.18	-1.21	3.46
Indirect effects				
Total indirect effects	1.27	.58	0.26	2.54
a (X – M)	-.06	.03	-0.12	-0.01
b (M- Y)	-19.88	4.65	-29.12	-10.65
X = Updating	Y = Performance		Lower	Upper
Total effect (c)	4.09	3.78	-3.42	11.61
Direct effect (c’)	1.58	3.48	-5.33	8.49
Indirect effects				
Total indirect effects	2.51	1.73	-0.58	6.26
a (X – M)	-.12	.08	-0.28	0.04
b (M- Y)	-20.67	4.57	-29.76	-11.59

Note. CI = Confidence Interval, M = Mediator, SE = Standard Error, X = Predictor, Y = Outcome.

Table 5.5.

Summary of Mediation Analyses for the Number of Fixations to the Goal Area

Effect	Coefficient	SE	Bootstrapping 95% CI	
X = Shifting	Y = Performance		Lower	Upper
Total effect (c)	1.16	1.13	-1.09	3.41
Direct effect (c′)	1.28	1.10	-0.90	3.47
Indirect effects				
Total indirect effects	-.12	.33	-0.79	0.56
a (X – M)	-.01	.04	-0.08	0.06
b (M- Y)	8.66	3.32	2.05	15.26
X = Inhibition	Y = Performance		Lower	Upper
Total effect (c)	2.51	1.26	0.01	5.01
Direct effect (c′)	1.68	1.29	-0.88	4.25
Indirect effects				
Total indirect effects	.82	.44	0.03	1.73
a (X – M)	.11	.04	0.04	0.19
b (M- Y)	7.44	3.45	0.59	14.29
X = Updating	Y = Performance		Lower	Upper
Total effect (c)	4.32	3.83	-3.29	11.93
Direct effect (c’)	1.87	3.86	-5.80	9.55
Indirect effects				
Total indirect effects	2.45	1.38	0.32	5.69
a (X – M)	.29	.11	0.07	0.52
b (M- Y)	8.33	3.44	1.49	15.17

Note. CI = Confidence Interval, M = Mediator, SE = Standard Error, X = Predictor, Y = Outcome.

Table 5.6.

Summary of Mediation Analyses for the Number of Fixations to the Goalkeeper

Effect	Coefficient	SE	Bootstrapping 95% CI	
X = Shifting	Y = Performance		Lower	Upper
Total effect (c)	1.02	1.14	-1.24	3.28
Direct effect (c′)	.52	1.15	-1.76	2.79
Indirect effects				
Total indirect effects	.50	.32	-0.03	1.22
a (X – M)	-.06	.03	-0.12	-0.01
b (M- Y)	-8.10	4.07	-16.19	-0.01
X = Inhibition	Y = Performance		Lower	Upper
Total effect (c)	2.48	1.25	-0.02	4.97
Direct effect (c′)	2.26	1.24	-0.20	4.73
Indirect effects				
Total indirect effects	.22	30	-0.30	0.92
a (X – M)	-.03	.03	-0.09	0.04
b (M- Y)	-7.64	3.92	-15.43	0.15
X = Updating	Y = Performance		Lower	Upper
Total effect (c)	4.72	3.82	-2.86	12.31
Direct effect (c’)	4.95	3.74	-2.49	12.39
Indirect effects				
Total indirect effects	-.23	.94	-1.94	1.94
a (X – M)	.03	.10	-0.17	0.23
b (M- Y)	-8.43	3.94	-16.26	-0.60

Note. CI = Confidence Interval, M = Mediator, SE = Standard Error, X = Predictor, Y = Outcome.

5.5 Discussion

The current study had two aims. First, to determine whether different pressure instructions (i.e., low- and high-pressure conditions) evoked differences in VA and soccer penalty performance as previously found (e.g., Wilson, Wood, & Vine, 2009). Results indicated non-significant differences in reported situational stress between low- and high-pressure groups. This pattern continued as no differences between groups in VA or soccer penalty performance emerged. Moreover, EF scores were comparable between groups at baseline. As a result, subsequent analyses were collapsed across groups. The second aim of the study was to examine whether EF (i.e., shifting, inhibition, and updating) predicted soccer penalty performance through the mediator of VA (i.e., quiet eye duration and location, search rate, and fixations to key locations), while controlling for important covariates (i.e., physical activity and expertise). Results showed numerous significant mediations highlighting the important interaction between EF and VA and the subsequent impact upon sport performance.

The results of the manipulation check provided mixed findings. A significant effect of pressure instructions on situational stress across all participants, independent of group (i.e., low- and high-pressure) was found. However, despite different pressure instructions (following Brimmell et al., 2019) the high-pressure group did not report greater situational stress compared to their low-pressure counterparts. It is possible that informing both groups about the presence of a goalkeeper, albeit only the high-pressure group were explicitly informed that the goalkeeper would try to save their soccer penalty, was enough to evoke situational stress. In terms of ACT-S, the mere presence and mention of a threat to performance (i.e., a goalkeeper) could have been enough to bring about changes in situational stress, yet the additional instructions in the high-pressure group were unable to evoke any additional pressure/stress in the soccer penalty task. Though traditional indoor soccer goals have been frequently used by studies looking at attention in soccer penalties (e.g., Brimmell et al., 2019), it may be the case that the smaller goal (i.e., 5-a-side vs. 11-a-side) had an effect. Specifically, in proportion to the goal, the goalkeeper will occupy more space in a 5-a-side goal therefore, appearing bigger to the penalty taker. It may be that this perception of a larger goalkeeper elicited changes in situational stress in all participants.

In addition, ACT-S makes some specific predictions about potential determinants of anxiety that may have impacted these data and that were beyond the scope of the current study. Namely, that cognitive biases in performance monitoring (i.e., a bias toward physical and mental errors), perception of failure (i.e., the cost and likelihood of failure), and motivation (i.e., highly motivated individuals are more likely to maintain goal-directed attention, potentially through increased effort) could have affected the situational stress response (Eysenck & Wilson, 2016). As such, it may be that more distinct instructions were needed or additional measurement of these determinants (e.g., motivation) were warranted. Wood and Wilson (2010a) used different instructional sets to successfully create different pressure conditions by informing one group that the task aims were to check the reliability of an eye-tracker while another group received instructions similar to the high-pressure group in the present study (e.g., prizes and leader boards). This thesis concluded that both our pressure instructions were sufficient to increase situational stress, yet our data suggested that self-reported situational stress was not significantly different between the conditions, nor were any of our other test variables. As such, it is suggested that the data represented performance within a general pressurised situation only, and not performance across two pressure conditions (i.e., high- and low-pressure).

The present study supports limited research that has proposed a link between inhibition, VA, and sport performance (e.g., Ducrocq et al., 2016). Ducrocq et al. (2016) found that, following inhibition training, participants first fixation to a task-relevant target was significantly later (indicating superior inhibition and VA) and performance on a tennis task was significantly improved. Here, quiet eye duration significantly mediated the inhibition-soccer penalty performance relationship. This may expand upon previous work (i.e., Ducrocq et al., 2016) in that, not only is superior inhibition (an ability to withhold prepotent responses) associated with delayed first fixations to task-relevant targets, but also associated with a lengthened quiet eye duration. It may be possible that an ability to 'ignore' distracting stimuli increases the time for processing task-relevant information (i.e., the quiet eye period; Vickers, 2007), which in turn allows for more distally placed kicks and superior soccer penalty performance.

One assumption of ACT-S is that anxious or stress-prone individuals are hypervigilant to stimuli that can 'threaten' goal attainment (Eysenck & Wilson, 2016). While research examining VA and sport performance has included both threatening (e.g., a goalkeeper) and goal-directed (i.e., the goal) stimuli (e.g., Binsch et al., 2010), previous work on EF, VA, and sport performance has often only included stimuli that is task-relevant (i.e., a tennis target; Ducrocq et al., 2016) and not stimuli that may 'threaten' task success. The inclusion of specific goal-directed (i.e., the goal) and threatening (i.e., the goalkeeper) stimuli in the present study allowed for a direct test of this ACT-S assumption and thus, greater ecological validity. Mediation revealed that greater inhibition led to more fixations to goal-directed stimuli (i.e., the goal), and improved subsequent soccer penalty performance. This may support ACT-S in that greater inhibition appears to lead to superior goal-directed attention. Search rate also mediated the inhibition-soccer penalty performance relationship, with the present work being the first to examine this relationship. Research has suggested search rate can influence performance (e.g., Vine et al., 2015), however the cognitive underpinnings have not yet been considered. Search rate may derive from inhibition, with poor inhibition (i.e., failure to resist distraction) causing high search rate due to an inability to maintain gaze upon goal-related stimuli (e.g., the goal), and instead gaze 'jumps' between visual locations resulting in inefficient information pick-up and poorer subsequent performance (Eysenck & Wilson, 2016).

The updating-soccer penalty performance relationship was significantly mediated by quiet eye duration which suggested that an ability to maintain goal-directed attention (via superior updating) may allow for longer quiet eye durations and better soccer penalty performance under stressful conditions. This supports limited research reporting a relationship between updating, quiet eye duration, and sport performance (e.g., Ducrocq et al., 2017). Quiet eye location also significantly mediated the updating-soccer penalty performance relationship further supporting a link between the cognitive process of updating and the quiet eye phenomenon. This result suggests that an enhanced ability to update information within working-memory not only allows for one to extend the period of critical information processing, but also for more goal-directed final fixation locations (i.e., more distal quiet eye locations).

This chapter expanded upon previous research by showing that, as well as affecting the quiet eye duration and location, updating may affect the number of fixations to goal-directed stimuli. Greater updating may result in more fixations to task-relevant areas of the visual field (i.e., the goal) indicating more optimal goal-directed attention. This result showed that not only does superior updating facilitate more goal-directed final fixations (i.e., distal quiet eye locations) but may also allow for an increased number of fixations to goal-directed stimuli (i.e., the goal) which positively impacts subsequent soccer penalty performance. Moreover, it is possible that the control element of working-memory, tapped by updating, facilitates interaction between attentional and cognitive processes which in turn improve performance (i.e., updating acts as control mechanism between processing facilities; Vaughan & Laborde, 2020).

The number of fixations to the goalkeeper did not mediate any EF-soccer penalty performance relationships. This is somewhat surprising as the goalkeeper may have represented threatening stimuli within the current task and has been previously shown to operate as a distractor during soccer penalty kicks (Wood & Wilson, 2010a). However, ACT-S states that optimal performance stems from a balance between the two attentional systems

(Eysenck & Wilson, 2016). To achieve balance, some attention must be paid to potentially task-threatening stimuli (i.e., the goalkeeper), but superior attentional control comes when individuals are also able to direct more attention to goal-directed stimuli (i.e., the goal). Wood and Wilson (2010a) note that gaze is typically directed toward the ball during a run-up, while hypothetical, it could be that participants with poorer EF may have directed attention toward the ball during the pre-run-up as well (to ensure accurate contact; Wood & Wilson, 2010b) rather than directing gaze to goal-directed areas likely to lead to success (i.e., the goal) or the stimuli that may 'threaten' their success (i.e., the goalkeeper).

Shifting did not appear in any significant mediation models and the use of the Flanker task offers a potential explanation for this. This task was selected as it requires visuospatial shifts away from distracting 'flanker' stimuli (Posner, 2016), potentially increasing the relevance to objective VA measures, but this did not emerge. Miyake et al. (2000), and indeed ACT-S, do not explicitly refer to visuospatial shifting, but rather an ability to shift between tasks, operations, or mental sets. Therefore, a task involving switching between rule sets (e.g., the category switch task; Friedman et al., 2008) may be more theoretically suitable. Moreover, Miyake et al. (2000) suggest that, although distinct, inhibition, shifting, and updating do correlate with one another. While updating and inhibition correlated in the present study shifting did not correlate with either of these EFs, which suggested that the task may not tap an appropriate theoretical shifting ability (unlike the category switch task that requires alternating between two rulesets based on cue word; Friedman et al., 2008). Interestingly, shifting did correlate with the number of fixations to the goalkeeper, which suggested that, while perhaps not a theoretically suitable task, visual shifting, and the ability to divert attention from threatening stimuli (e.g., the goalkeeper) may relate.

The present study offered important implications for ACT-S (Eysenck & Wilson, 2016). Limited work has shown that after training the EFs proposed by ACT-S, VA and sport performance are improved in a subsequent task (e.g., Ducrocq et al., 2016; 2017). Here, this thesis strengthens the theoretical association by showing that inhibition and updating have a direct impact upon VA (i.e., quiet eye duration, search rate, and fixations to the goal area), which together influence soccer penalty performance. This finding may also be of interest to coaches and practitioners. More specifically, being the first study to demonstrate a direct relationship between the inhibition, updating and VA, this thesis offers preliminary support for the potential advantages of training these separate components. Further work is needed to confirm such benefits.

5.5.1 Limitations and Future Directions

While novel, the present study was not without limitation. First, many aspects of the study could be enhanced through the use of multiple measures such as that tested in Chapter 4 (due to the complexity and time-demand already placed on participants we opted for one measure per EF in the present chapter). For example, different cognitive paradigms may require different cognitive abilities. The Stop Signal and Go/No-Go paradigms require different inhibition abilities (i.e., controlled and automatic). Therefore, it may be optimal to administer multiple tests of each EF (i.e., inhibition, shifting, and updating) to ensure numerous relevant abilities are captured and reliability between tasks. This may be particularly relevant for shifting in the current study and to rule out that effects are task specific. Also, it may be optimal for future work to use multiple measures of situational anxiety (i.e., a more direct assessment of anxiety such as the Mental Readiness Form; Krane, 1994) to better detect differences between conditions.

The present study was unable to create two distinct pressure conditions (i.e., low- and high-pressure) therefore future research may wish to use more distinct instructional sets (Wood & Wilson, 2010a). Also, the between-subjects design may mean that individual differences in interpretation of the situation may unknowingly reduce the effects of the pressure instructions. Future research could use a within-subjects design allowing for comparisons between individual performance at low- and high-pressure levels. Also, a within-subjects design could allow for further understanding of how these EFs affect performance at varying levels of pressure. Finally, the cross-sectional design limits causality and direction, thus, future research should examine this relationship longitudinally to increase confidence in the observed effects. Specifically, obtaining EF, VA, and sport performance data over multiple timepoints, or across a playing season (cf. Hagyard et al., 2021), would enable researchers to examine whether changes in scores impact performance and better ascertain direction of effects.

5.5.2 Conclusion

Chapter 4 outlined that EF and VA may relate and be relevant in sports performers. However, the present chapter is the first to offer an explanatory pathway between EF and soccer penalty performance under pressure via VA. Greater inhibition and updating ability allowed for longer quiet eye durations, more distal quiet eye locations, more fixations toward the goal (i.e., goal-directed stimuli), and, for inhibition only, lower search rate which in turn led to improved soccer penalty kicks. In sum, better EF and VA can lead to superior soccer penalty performance though the longitudinal relationship between these variables remains unclear.

Chapter 6: A longitudinal examination of executive function, visual attention, and soccer penalty performance

6.1 Chapter Overview

The present chapter aimed to extend the relationship established (Chapter 4) and empirically tested (Chapter 5) between EF, VA, and performance on a soccer penalty task. Specifically, the aim of this chapter was to longitudinally assess the robustness and consistency of the relationship between EF, VA, and performance on a soccer penalty task across a 24-week period. A sample of 22 participants first completed covariate measures including: anxiety, stress, physical activity, expertise, and commitment. Next tasks of EF (measuring inhibition, shifting, and updating) were performed before completing a soccer penalty task (i.e., as utilised in Chapter 5) while VA was recorded. This process was then repeated at timepoint 2 (12-weeks later) and timepoint 3 (a further 12-weeks later). Bayesian mixed-effect models were used to assess the individual contribution of each key variable (e.g., covariates, EF, and VA) and interactions between EF and VA variables. Compared to the baseline model (i.e., timepoint as a single fixed-effect) only the VA variables of quiet eye duration, quiet eye location, search rate, and time fixating on the goalkeeper significantly improved model fit, explained more variance, and differed from the baseline model. These results suggested that VA may be the most important predictor of soccer penalty performance over time. The only interaction effect was between search rate and inhibition which suggested that these variables may be the most relevant for the soccer penalty and training protocols and interventions should look to target these in athletes.

6.2 Introduction

Substantial research contributions have highlighted that an important component of sports performance is effective attentional control processes such as perceptual-cognition and EF (Scharfen & Memmert, 2019). The ability of such attentional components to perform optimally is influenced by perceptions of the sporting situation. Specifically, personal perceptions of factors like anxiety can have an impact upon EF (Eysenck & Wilson, 2016). Attentional Control Theory-Sport (ACT-S; Eysenck & Wilson, 2016) outlined three key EFs (i.e., inhibition, shifting, and updating) that control individual attentional capacity. However, despite this theoretical account research in this area has typically assessed the assumptions of ACT-S through objective VA measures, often captured with an eye-tracker, alone. That is, until recent work that has expressed that the areas of EF and VA may relate and work together (see Chapter 4; Chapter 5). There is still limited knowledge around the long-term relationship between EF and VA. Therefore, the present study aimed to address limitations from Chapter 5 by examining how objective soccer penalty performance changes across a 24-week period were influenced by EF, VA, and a combination of the two.

6.2.1 Attentional Control Theory-Sport

One of the most prominent theoretical accounts of EF and attentional processes is ACT-S (Eysenck & Wilson, 2016). Despite attention being a fundamental component of ACT-S, there has been surprisingly little investigation into how numerous forms of attention (i.e., EF and VA) may operate together to facilitate optimal performance in athletes (see Chapter 2). For example, it is almost certain that athletes will use multiple perceptual-cognitive processes at any one moment to be successful in a sporting situation (e.g., attend to visual cues in the environment and use working memory and decision-making to select a suitable outcome). The findings of Chapter 4 provided some of the first evidence that the attention component of ACT-S may be made up of two independent, yet related, constructs (i.e., EF and VA). Chapter 5 extended these findings, and ACT-S, with results that suggested EF could predict soccer penalty performance through VA as a mediator. The aforementioned results of the present thesis may indeed further our understanding of attentional theory and even expand ACT-S itself (see Figure 1.3.).

6.2.2 Executive Function and Visual Attention

Executive functions are a family of inter-related, yet distinct, cognitive constructs that help facilitate thoughts and behaviour (Miyake et al., 2000). Two of the most popular strands of EF comprise higher-order and lower-order constructs. Higher-order processes consist of complex functions like planning and problem-solving and usually require numerous lower-order EFs (Diamond, 2013). One of the most popular models of lower-order EF was proposed by Miyake and colleagues (2000) and is utilised within ACT-S (Eysenck & Wilson, 2016). This model is made up of inhibition (i.e., withholding dominant/prepotent responses), shifting (i.e., altering between mental sets/instructions), and updating (i.e., manipulating information within working memory; Miyake et al., 2000) and was found to replicate and work in an athletic sample in Chapter 4. Though also concerned with attentional control overt and covert movements of VA may be controlled by very different neural circuits than EF (i.e., the parietal lobe rather than frontal lobe; Posner & Raichle, 1994). As such researchers have measured key variables like the quiet eye (i.e., the duration and location of the final fixation before initiating a critical movement; Vickers, 2007) and fixation data (i.e., the number of individual fixations to a key target of interest within a visual scene) with objective eye-trackers instead (e.g., Wilson, Vine, & Wood, 2009).

There is currently a gap in our understanding of how the areas of EF and VA directly relate to one another (see Chapter 2). That being said, recent research is moving toward at least incorporating both measures within the same study. The issue with such studies is that they often focus on differences between two or more groups (e.g., trained vs control) and rarely, if ever, examine the variables together. Rather any potential relationship is only suggested rather than explicitly tested. For example, Wood et al. (2016) found individuals with poorer functioning working memory also showed longer visual search times, reduced quiet eye durations, and poorer shooting performance. When examining differences in working memory, quiet eye, and tennis performance between trained and untrained individuals Ducrocq et al. (2017) found the trained individuals performed significantly better in facets of all areas in a pressurised tennis volley task. More recent works have brought the research areas even closer. Scharfen and Memmert (2021) found training on a perceptual-cognitive task (3D-multiple object tracking) lead to small but negligible improvements in a single inhibition task. Chapter 4 and 5 showed a stronger and more thorough association between EF and VA. Whether this relationship is stable over an extended period of time is still unknown.

6.2.3 Longitudinal and Training Studies

There is long-standing evidence that EF develops substantially throughout childhood and adolescence and remains important during adulthood (Anderson, 2002). This suggests that such processes may not be static, but rather alter and adapt based on circumstance within our lives. There is also longitudinal evidence that physical activity level can have a prolonged influence upon EF (Howell et al., 2013; Ishihara & Mizuno, 2018). Increased tennis play over a 12-month training period was associated with improvements in EF (Ishihara & Mizuno, 2018). Hagyard et al. (2021) expanded upon this by showing that long-term participation (i.e., a 16-week period) in any sport lead to improved inhibitory control, with gains stronger for those with greater expertise. However, there is still very limited knowledge on how EF changes could implicate increases or decreases in other constructs (e.g., VA) over a longitudinal period.

Albeit not explicitly longitudinal in design the trainability of VA measures such as the quiet eye has become of interest in sport science. Within their review, Lebeau et al. (2016) summarised that the results of quiet eye training studies generally support the notion for such training to become commonplace within the sporting environment. Quiet eye training typically involved pre-assessment, a training period, and post-assessment (e.g., Vine et al., 2011) with some studies also including a follow-up session (e.g., Vine & Wilson, 2011). The results of these studies typically indicated a positive effect of training the quiet eye (i.e., to lengthen the quiet eye duration) upon subsequent sport performance in golf (Vine et al., 2011) and basketball (Vine & Wilson, 2011). A notable point to draw here is that, much like EF, facets of VA appear malleable. In general, results across EF and VA over extended periods of time suggest adaptation is possible. Therefore, given that research has shown us these two facets directly relate (Chapter 4; Chapter 5) it is plausible to suggest adaptations in one area (e.g., EF) may facilitate growth in another (e.g., VA).

6.2.4 Confounds of Executive Function and Visual Attention

Various extraneous variables can influence EF, VA, or both. Higher physical activity has been associated with increased cerebral blood flood to the pre-frontal cortex (i.e., the home of EF; Chen et al., 2019) and Huijgen and colleagues (2015) reported significantly greater EF in elite youth soccer players compared to sub-elite youth soccer players while considering physical activity. Physical activity was also included as a covariate in Chapter's 4 and 5 and was significantly correlated with measures of EF (e.g., Go/No-Go effectiveness and efficiency and Flanker efficiency in Chapter 4) and VA (quiet eye duration and search rate in Chapter 5). These significant correlations may further support the inclusion of physical activity in the present study. Expertise can influence EF and VA whereby individuals operating at a higher expertise level tend to outperform athletes at a lower level (e.g., Klostermann & Moeinirad, 2020; Mann et al., 2007). Hagyard et al. (2021) reported a significant effect of sporting expertise level upon inhibition ability both cross-sectionally and longitudinally. While expertise level also appears to distinguish between individual's VA during real-world sport tasks (Memmert et al., 2009). The present thesis supports expertise as a covariate given the significant correlation reported between expertise and quiet eye duration and search rate in Chapter 5. Finally, the potential implications of stress and anxiety on attentional control were highlighted in ACT-S (Eysenck & Wilson, 2016) and studies assessing ACT-S's assumptions (e.g., Ducrocq et al., 2017). One potential way that individuals can combat the effects of anxiety or stress is through increased effort or commitment (Edwards et al., 2015; Swann et al., 2021).

6.2.5 The Present Study

Recent work (i.e., Chapter 4; Chapter 5) has established a direct relationship between EF and VA in sport. It seems EF and VA may be related and malleable and therefore, susceptible to similar changes over time (e.g., changes in EF may mirror changes in VA). However, the longitudinal relationship between EF and VA and how these variables may combine to influence soccer penalty performance is unclear. Cross-sectional designs have shown that EF and VA are linked to sport performance (e.g., Chapter 5) yet it remains to be seen whether fluctuations in these variables over time translate into similar changes in the other variable (i.e., if EF increases over time does this also lead to improvements in VA, and vice versa) and does this impact subsequent sport performance. The aim of the present study was to address this gap. Specifically, this chapter aimed to model the EF, VA, and soccer penalty performance relationship at three times across a 24-week period while also considering key variables (state anxiety, stress, physical activity, expertise, and commitment). It was hypothesised that changes in soccer penalty performance over time could be explained by subtle changes in EF and VA. Additionally, that an interaction between EF and VA variables will explain more performance variance than EF or VA alone.

6.3 Method

6.3.1 Participants

The present study comprised 22 participants (16 male; M_{age} = 21.27 ± 3.43) varying in athletic expertise (i.e., non-athlete: *n* = 2, novice: *n* = 5, amateur: *n* = 5, elite: *n* = 10). All participants received verbal and written study instructions, provided online informed consent, and were tested individually. Power analysis in RStudio 4.0.2 (R Core Team, 2022) suggested that for large within-subject effects (.70), alpha = .05, and .80 power, a sample of 21 participants was needed at three timepoints. The study received institutional ethical approval from the York St John University Cross-School Research Ethics Committee for the School of Education, Language, and Psychology (see Appendix 1C).

6.3.2 Design

A longitudinal design was adopted in the present study whereby participants completed three individual testing sessions over a 24-week period. The initial testing point (0-weeks) was followed by timepoint-2 12-weeks later, before returning for timepoint-3 a further 12-weeks later.

6.3.3 Measures

6.3.3.1 Mood and Seasonal Changes

To assess mood and seasonal changes components from the Seasonal Pattern Assessment Questionnaire (SPAQ; Magnusson, 1996) were used (see Appendix 7). The SPAQ was comprised of two sections. First, participants evaluated their self-assessed seasonal changes across six dimensions (i.e., sleep length, social activity, mood [overall feeling of well-being], weight, appetite, and energy level). Participant responses were provided on 4-point Likert scales ranging from 0-No Change to 4-Extremely Marked Change with seasonal change scores ranging from zero-24. In the second section of the SPAQ, participants crucially stated whether changes in the above mood and behaviour states caused any perceived or actual problems. If participants outlined such changes as problematic, participants were asked to clarify the severity (i.e., whether the problem was mild, moderate, marked, severe, or disabling). As all outlined changes were low (i.e., responses rarely above moderate) and no individuals reported problems due to these changes this variable was not entered as a covariate in subsequent analysis. Participants only completed the SPAQ at timepoint one.

6.3.3.2 Anxiety

State anxiety was measured using the STICSA (Ree et al., 20008; see Appendix 5). See Chapter 4 for a full description (see section 4.3.3.3).

6.3.3.3 Situational Stress

Situational stress was measured using the SRQ (Edwards et al., 2015; see Appendix 4). For a full description, please see Chapter 4 (see section 4.3.3.3).

6.3.3.4 Physical Activity

Physical activity over the preceding seven days was measured using the the IPAQ-SF (Booth, 2000; see Appendix 3). A full description of the IPAQ-SF can be found in Chapter 4 of the present thesis (see section 4.3.3.1).

6.3.3.5 Expertise

Expertise was classified following Swann et al.'s (2015) recommendations (see Appendix 2. A full description is provided in Chapter 4 (see section 4.3.3.2).

6.3.3.6 Goal Commitment

Goal commitment was obtained to better understand individual effort levels for the upcoming soccer penalty task and was based on recommendations from Klein et al. (2001; see Appendix 8). Goal commitment was assessed via 5-items marked on a 5-point Likert scale ranging from 1-Strongly Disagree to 5-Strongly Agree. The 5 items were selected from the original scale from Hollenbeck et al. (1989) following suggested revisions outlined in

Klein et al. (2001). Items 1, 2, and 4 are reversed scored and higher total scores reflect greater goal commitment. The scale has shown acceptable internal consistency with α = .74 (Klein et al., 2001).

6.3.3.7 Executive Function

All tasks of EF were taken from Inquisit-5 by Millisecond (www.millisecond.com) and were chosen to measure the lower-order model of shifting, inhibition, and updating from Miyake et al. (2000) and ACT-S (Eysenck & Wilson, 2016). See Appendix 9 for more information on all EF tasks.

6.3.3.7.1 Shifting. To assess shifting ability the present chapter used the Colour-Shape task (Friedman et al., 2008). The Colour-Shape task requires participants to respond to one of four stimuli (green square, blue square, green rectangle, and blue rectangle) with one of two key press responses (“J” and “F” keys). Participants were presented with one of the four stimuli and the goal to categorise the stimuli based on the cue word presented above it (i.e., either “colour” or “shape”). For the colour cue word participants were to press “J” for green and “F” for blue and for the shape cue word participants were to press “J” for square and “F” for rectangle. Trials were either congruent (i.e., same cue word back-to-back [e.g., shape-shape] or incongruent (i.e., different cue word followed the previous cue [e.g., shape-colour]). An equal number of each of the four stimuli were presented randomly across a block which meant participants were constantly shifting between categorisation rules.

Participants completed a single practice session of four trials and two blocks of 48 trials in the main test. Both before the task and between all blocks (practice and main) participants were informed to respond as quickly and accurately as possible. The outcome measure of shifting effectiveness was calculated by subtracting the number of incorrect responses on incongruent trials (i.e., switch trials) from the number of correct responses on incongruent trials. For shifting efficiency, the first calculation involved taking the mean correct response time on incongruent trials and dividing it by shifting effectiveness to get an incongruent shifting efficiency. Next, a similar process was performed for congruent trials whereby mean correct response time on congruent trials were divided by congruent shifting effectiveness (which used the same calculation as shifting effectiveness but with congruent trials) to get congruent shifting efficiency. Finally, a shifting efficiency score was calculated by subtracting congruent shifting efficiency from incongruent shifting efficiency.

6.3.3.7.2 Inhibition. Inhibition was assessed using the Stop Signal Task and followed the latest literary recommendations (see Verbruggen et al., 2019). This task is conceptualised as a race between a “go” runner (activated by a go stimulus) and a “stop” runner (activated by a stop stimulus; Logan & Cowan, 1984). The go stimulus consisted of either a centrally located white left-facing (requiring a “D” key response) or white right-facing (requiring a “K” key response) arrow presented against a black background. A stop runner was randomly presented on 25% of the total trials and such stop trials involved the presence of an auditory stop signal after the go stimulus presentation. Following stop signal presentation participants were to withhold their response and wait for the next trial. Inhibition was deemed successful when no response is provided on stop trials (i.e., the “stop” runner finishes before the “go” runner). Time (in ms) between the presentation of the go and stop stimuli was adapted based on individual performance to obtain a variety of stop signal delays (Verbruggen et al., 2019). Specifically, after successful inhibition the delay increased by 50ms whereas the delay decreased by 50ms when unsuccessful.

The task comprised one practice block of 32 trials and three blocks of 72 test trials. Both before the task and between all blocks (practice and main) participants were informed to respond as quickly and accurately as possible. The outcome measure for inhibition effectiveness involved subtracting the number of incorrect responses on “stop” trials from the number of correct responses on “stop” trials. As recommended by Verbruggen et al. (2019)

and utilised in previous sporting samples (e.g., Hagyard et al., 2021), Stop Signal Reaction Time was used to index inhibition efficiency. Stop Signal Reaction Time is the time taken for participants to withhold a motor response (Verbruggen et al., 2019). More specifically, Stop Signal Reaction Time is the *n*th reaction time value minus the mean stop signal delay.

The stop signal delay is the mean delay time across all “stop” trials. Finding the *n*th reaction time involves the total number of “go” trials, the probability of responding on “stop” trials, and the reaction time distribution on “go” trials. The total number of “go” trials is the amount of “go” trials within the task. The probability of responding is the likelihood of the participant providing a response on a “stop” trial (when the correct response is to give no response). The reaction time on “go” trials is the complete distribution of reaction times across all “go” trials with incorrect responses given maximum scores (i.e., 1000ms). To find the *n*th reaction time you multiple the probability of responding by the total number of “go” trials and selecting the corresponding value from the distribution of reaction times to “go” trials. So, for example, if a participant has a probability of responding of 45% (used as .45) on a task with 200 trials, the *n*th reaction time would be the 90th value (Verbruggen et al., 2019). To get Stop Signal Reaction Time, you would then minus the mean stop signal delay from this newly obtained value (Hagyard et al., 2021).

6.3.3.7.3 Updating. The nback task was used to asses updating in the present study (Jaeggi et al., 2010; Ragland et al., 2002). Stimuli within this task comprised white coloured uppercase letters presented against a black background. The task comprised several conditions including: a 0-back where participants responded to a single target letter, a 1-back where participants responded if the currently presented letter matched the letter one trial before it, a 2-back where participants responded if the currently presented letter matched the letter two trials before it, and a 3-back where participants responded if the currently presented letter match the letter three trials before it. In all conditions, participants were informed to press the "A" key when they believe the current letter stimulus matched based on the conditional rule and give no response when the current letter stimulus did not match. Correctly pressing "A" when the stimuli on screen matched the one *n*back was deemed a "hit" and incorrectly pressing "A" when the stimuli on screen did not match the one *n*back was deemed a "false alarm".

Participants completed one practice run of nine trials for each condition before completing three blocks of 15 test trials per condition. Both before the task and between all blocks (practice and main) participants were informed to respond as quickly and accurately as possible. Updating effectiveness was the number of correct responses (i.e., "hits") minus the number of incorrect responses (i.e., "false alarms") across all conditions (i.e., 0-back to 3-back). Updating efficiency was calculated by dividing updating effectiveness by mean reaction time on "hits".

6.3.3.8 Visual Attention

A Pupil Labs Core mobile eye-tracking device (Pupil Labs GmbH, Berlin, Germany) connected to a OnePlus A6003 mobile-phone running Pupil Capture was used to record VA. Eye movements were recorded through corneal reflections at a 200Hz capture rate and .60° gaze accuracy (Kassner et al., 2014). Offline pupil detection, pupil calibration, and fixation detection was performed in Pupil Player. Pupil detection involved running a detection algorithm on the pre-recorded eye videos individually. For offline calibration, a 9-point procedure was performed using the Pupil Labs calibration marker v0.4 (https://docs.pupil-labs/pdfs/v0.4_marker.pdf). The marker was shown in real-time but detected post-hoc using the Gaze from Offline Calibration plug-in which searches the world recording for the calibration marker (i.e., a known fixation location for the participant). Fixations were detected with the Offline Fixation Detector plug-in. This plug-in automatically detects fixations based on prespecified criteria concerning the maximum dispersion (i.e., maximum spatial movement before a fixation is ended), minimum duration (i.e., smallest value that the gaze marker remains within the dispersion range), and maximum duration (i.e., largest value that the gaze marker remains within the dispersion range). The present study applied a maximum dispersion of 1°, minimum duration of 100ms, and no specific maximum duration.

6.3.3.8.1 The Quiet Eye. This variable was broken into duration and location as in Chapter 5. Quiet eye duration was based on the length of the final fixation before movement initiation in ms (where a fixation was the maintenance of gaze within 1° visual angle for a minimum of 100ms; Vickers, 2007). The onset of the quiet eye duration began just before the initiation of the run-up in the current study and the quiet eye duration offset was whenever gaze deviated from the start location by 1° visual angle (Vickers, 2007). Though the quiet eye period had to begin prior to movement initiation the duration could continue through the whole movement process (i.e., the run-up period) and even beyond. Quiet eye location referred to the spatial location of the final fixation from the centre of the soccer goal during the aiming phase (as in Chapter 5 and Wood et al., 2017). To determine the quiet eye location the goal was divided into 12 equal zones (six 30cm zones per half of the goal). This created a minimum score of zero cm (a centrally located quiet eye) and a maximum score of 180cm (a quiet eye location to a post) with higher scores deemed more optimal for performance (Chapter 5; Wood et al., 2017).

6.3.3.8.2 Fixation Data. The present study also obtained common fixation metrics including search rate and the time fixating key locations (i.e., goal and goalkeeper). Search rate calculation involved dividing the total number of fixations to a given target (i.e., goal or goalkeeper) by the total time, in seconds, spent fixating that target and has been noted as a potential measure of visual scanning (Nibbeling et al., 2012). The time fixating the goal and goalkeeper variables were calculated as the sum total of time (in ms) fixating the respective target during the aiming phase (Brimmell et al., 2019). Due to research showing high correlations between the number of fixations and the amount of total time and mean time spent fixating key locations (e.g., Brimmell et al., 2019; Wilson, Vine, & Wood, 2009) this thesis opted for the parsimony of a single measure only here.

6.3.3.9 Sport Performance

Performance on the soccer penalty task was assessed through frame-by-frame analysis of the eye-tracking device's scene camera in Pupil Player. Performance outcomes were based on a single kick of a regulation size-5 soccer ball (20.57cm diameter) from a pre-defined penalty spot 5.00 m toward a standard indoor soccer goal (3.6 m × 1.2 m; B.G. Sports International Ltd., Lancashire, United Kingdom). The outcome measure was based on distance from the centre of the goal in cm (as in Brimmell et al., 2019; Chapter 5). The centre of the goal was allocated as the "origin" with six 30cm zones either side of this origin. Scoring was completed on a continuum based on the spatial location of the ball when it reached the goal-line where the minimum score of zero was given to kicks that missed the goal (either over the cross-bar or wide of the goal; n = 7), hit the post (n = 1), the cross-bar (n = 1), or the goalkeeper (where the ball hit the goalkeeper stood at the "origin"; n = 0) and a maximum score of 180 was given to a kick located in the corner just before the post. Therefore, higher scores reflected a penalty that was more accurately placed into a corner further away from the goalkeeper (Chapter 5; van der Kamp, 2006). Finally, goalkeeper movement (i.e., static), positioning (i.e., central), and posture (i.e., knees bent with arms out to either side) was standardised for all penalty kicks (Chapter 5; van der Kamp & Masters, 2008).

6.3.4 Procedure

Participants were tested at three timepoints spanning a 24-week period (timepoint 1 = 0-week, timepoint 2 = 12-weeks, timepoint 3 = 24-weeks). After arriving for timepoint 1 participants provided informed consent, a contact email address, demographic information (i.e., age and gender identification; see Appendix 2), and sport participation information for subsequent expertise calculations. Participants then completed the mood questionnaire, STICSA, pre-instruction SRQ, and IPAQ before a brief break while instructions regarding the EF tasks were given. The three EFs tasks were then completed in a counterbalanced order and performed on a MacBook Air 13inch laptop with a 1440 x 900 resolution. Next, participants were given soccer penalty instructions that highlighted: 1) that the penalty was the most important part of the task, 2) rewards for best performers, 3) leader board rankings, 4) that performance was filmed, and 5) such film would be scrutinised by a soccer penalty expert (in line with Gropel & Mesagno, 2019). Participants then completed the post-instruction SRQ and the goal commitment scale before being fitted with the mobile eye-tracking device and performing the soccer penalty kick task. Timepoint 2 and 3 followed similar protocol bar a couple of changes: 1) the mood scale was not complete again, 2) the only demographic reported again was age, and 3) sport expertise was asked about again, but participants were only asked to inform researchers of any changes.

6.3.5 Data Analysis

Data was processed and analysed in RStudio 4.0.2 (R Core Team, 2022) and the associated code and data files are available on the York St. John University data-repository RaYDaR (https://yorksj.figshare.com/articles/software/R_Code/20089364). First, descriptive statistics including mean, standard deviation, skew, and kurtosis were calculated for each timepoint (i.e., timepoint 1, 2 and 3). The correlations between key variables were calculated for timepoint 1, timepoint 2, timepoint 3 individually. Boxplots were examined to understand the general trend of key variables across timepoints.

The relationship between EF, VA, and soccer penalty performance over time was assessed using Bayesian mixed-effect models (`blme` R package version 1.0-5; Chung et al., 2013). Bayesian models were preferred given the small sample size (i.e., to allow for individual random intercepts) and because they allow distribution priors. For fixed-effects the Gaussian distribution was specified and for random-effects the Wishart distribution was selected (Wentzell et al., 2017). First, a baseline maximum likelihood model with soccer penalty performance as the dependent variable, timepoint as the fixed-effect, and subject as the random-effect was calculated to ascertain changes over time. Next, an identical experimental model was built but with a variable of interest added as a fixed-effect. The Akaike Information Criterion (AIC) was used to assessed model fit and penalised complex models while conditional R^2 (accounts for fixed- and random-effects; Nakagawa & Schielzeth, 2013) and *p* values were used to assess variance explained and whether the experimental model was significantly better than the baseline model. When an experimental model was superior to the baseline model the variable in question was added to combined model to ascertain the optimal model. Finally, to test for interaction effects between EF and VA on soccer penalty performance interaction-models were examined.

6.4 Results

6.4.1 Descriptives, Correlations, and Plots

Descriptive statistics including the mean, standard deviation, skewness, and kurtosis were calculated for all variables at timepoint 1 (see Table 6.1), timepoint 2 (see Table 6.2), and timepoint 3 (see Table 6.3). Correlation coefficients between key variables were calculated for timepoint 1, timepoint 2, and timepoint 3 and can be found in Tables 6.4, 6.5, and 6.6, respectively with significant correlations shown in Figure 6.1. Mean changes for key variables across time were first visualised using boxplots and are presented in Figure 6.2. Boxplots suggested changes in soccer penalty performance over time, but such changes were often not mirrored in other key variables of EF and VA. Only expertise, quiet eye duration, and inhibition efficiency showed a similar trajectory over time to soccer penalty performance. That is, there was a similar drop in magnitude from timepoint 1 to 2, and a similar increase in magnitude from timepoint 2 to 3. Unexpected but notable results included: little to no changes in state anxiety and situational stress and stable shifting and updating efficiency across time despite subtle improvements in effectiveness.

Table 6.1.

Means, standard deviation, skewness and kurtosis for variables at timepoint 1

Var	Age	Anx	SRQ	PA	Expert	Commit	I_effect	I_effic	S_effect	S_effic	U_effect	U_effic	QED	QEL	SR	GoalMS	GKMS	Pen
Mean	21.59	27.68	.73	100.62	6.51	19.32	-25.36	386.26	21.18	44.63	35.86	6.76	158.32	84.50	1.96	440.69	361.69	85.25
SD	4.49	5.10	3.78	66.69	4.62	3.27	26.50	358.26	5.71	96.69	17.42	3.52	60.37	61.64	.60	523.68	391.46	54.64
Skewness	3.32	1.03	.52	1.21	-.20	.11	.38	.67	-.29	3.91	-1.18	-.76	.92	.30	.09	1.81	.91	-.21
Kurtosis	14.19	4.04	3.12	3.86	1.38	1.89	1.25	2.74	2.29	17.44	3.14	2.47	2.59	1.77	1.87	6.22	2.19	1.93

Note. Anx = state anxiety, Commit = goal commitment, Expert = expertise, GKMS = time fixating the goalkeeper, GoalMS = time fixating the goal, I_effect = inhibition effectiveness, I_effic = inhibition efficiency, PA = physical activity, Pen = soccer penalty performance, QED = quiet eye duration, QEL = quiet eye location, SD = standard deviation, S_effect = shifting effectiveness, S_effic = shifting efficiency, SR = search rate, SRQ = stress rating questionnaire, U_effect = updating effectiveness, U_effic = updating efficiency.

Table 6.2.

Means, standard deviation, skewness and kurtosis for variables at timepoint 2

Var	Age	Anx	SRQ	PA	Expert	Commit	I_effect	I_effic	S_effect	S_effic	U_effect	U_effic	QED	QEL	SR	GoalMS	GKMS	Pen
Mean	21.86	28.33	1.33	129.58	6.32	18.29	-4.38	228.62	23.33	31.88	39.90	7.42	155.66	87.89	2.09	407.66	318.74	72.37
SD	4.79	7.25	2.78	90.43	4.55	3.99	20.49	255.94	6.70	74.14	16.13	3.34	66.30	63.86	.53	338.95	292.27	66.88
Skewness	3.22	.96	.90	1.39	-.10	.49	-1.25	1.98	-2.05	4.07	-1.13	-0.51	1.02	.06	.12	.64	.65	.14

Kurtosis	13.50	2.88	3.40	4.21	1.36	1.96	3.30	7.56	6.51	18.09	3.17	2.51	2.51	1.61	1.62	2.40	2.10	1.38

Note. Anx = state anxiety, Commit = goal commitment, Expert = expertise, GKMS = time fixating the goalkeeper, GoalMS = time fixating the goal, I_effect = inhibition effectiveness, I_effic = inhibition efficiency, PA = physical activity, Pen = soccer penalty performance, QED = quiet eye duration, QEL = quiet eye location, SD = standard deviation, S_effect = shifting effectiveness, S_effic = shifting efficiency, SR = search rate, SRQ = stress rating questionnaire, U_effect = updating effectiveness, U_effic = updating efficiency.

Table 6.3.

Means, standard deviation, skewness and kurtosis for variables at timepoint 3

Var	Age	Anx	SRQ	PA	Expert	Commit	I_effect	I_effic	S_effect	S_effic	U_effect	U_effic	QED	QEL	SR	GoalMS	GKMS	Pen
Mean	20.36	28.55	1.45	130.60	7.92	17.55	-9.45	350.51	23.45	7.84	36.36	6.60	197.59	93.33	2.34	377.88	336.72	130.00
SD	1.12	11.79	5.59	89.46	4.50	2.11	21.22	234.92	7.54	38.10	22.79	4.19	73.67	73.91	.39	288.68	330.45	21.21
Skewness	-.76	2.30	.64	.76	-.84	.17	-1.08	1.47	-.86	-1.98	-.62	-.50	-.25	.13	1.61	.56	1.19	-.55
Kurtosis	2.99	7.20	3.10	3.03	1.94	1.35	2.67	3.93	2.51	6.54	1.78	1.81	2.73	1.27	4.31	1.96	3.80	2.45

Note. Anx = state anxiety, Commit = goal commitment, Expert = expertise, GKMS = time fixating the goalkeeper, GoalMS = time fixating the goal, I_effect = inhibition effectiveness, I_effic = inhibition efficiency, PA = physical activity, Pen = soccer penalty performance, QED = quiet eye duration, QEL = quiet eye location, SD = standard deviation, S_effect = shifting effectiveness, S_effic = shifting efficiency, SR = search rate, SRQ = stress rating questionnaire, U_effect = updating effectiveness, U_effic = updating efficiency.

Table 6.4.

Correlations between variables at timepoint 1

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. AvgMood	1.00																			
2. TotMood	.99	1.00																		
3. age	.14	.14	1.00																	
4. SRQ	-.37	-.37	.30	1.00																
5. S_Anx	.05	.05	.16	-.15	1.00															
6. PA	-.20	-.20	.04	.12	.31	1.00														
7. Expert	.06	.06	-.11	-.20	-.37	-.33	1.00													
8. Commit	-.30	-.30	-.05	.06	-.33	-.20	.35	1.00												
9. I_Effect	.10	.10	.35	.50	.15	.20	-.32	.03	1.00											
10. I_Effic	-.22	-.22	-.33	-.34	-.15	-.11	.22	.04	-.81	1.00										
11. S_Effect	-.13	-.13	.14	-.35	.10	-.08	-.13	-.17	-.24	.26	1.00									
12. S_Effic	.16	.16	-.22	.14	-.06	-.01	.19	-.27	-.12	.17	-.54	1.00								
13. U_Effect	.39	.39	.17	.13	-.01	-.54	.06	.14	.27	-.40	-.02	-.02	1.00							
14. U_Effic	.42	.42	-.03	-.01	-.04	-.50	.25	.02	.17	-.33	-.03	.07	.92	1.00						
15. QED	.27	.27	-.20	-.49	.24	-.09	-.23	-.31	.00	-.13	.16	-.22	-.10	.05	1.00					
16. QEL	.03	.03	-.06	-.01	.10	.37	.05	.22	.08	-.30	-.41	.18	-.05	-.02	.05	1.00				
17. SR	.41	.41	-.32	-.52	.54	.16	.09	-.33	-.11	-.08	-.18	.22	-.10	.06	.37	.05	1.00			
18. GoalMS	.08	.08	-.26	-.06	.29	.65	-.29	-.40	.10	-.28	-.37	.27	-.34	-.21	.31	.51	.46	1.00		
19. GKMS	-.50	-.50	-.21	.01	-.11	.30	-.02	.13	-.27	.39	.00	-.14	-.53	-.50	.09	-.29	.06	.18	1.00	
20. Pen	.25	.25	-.01	-.02	.32	.16	-.24	-.18	.18	-.42	-.05	.10	.28	.29	.21	.41	.25	.27	-.42	1.00

Note. AvgMood = average mood, Commit = goal commitment, Expert = expertise level, GKMS = time fixating the goalkeeper, GoalMS = time fixating the goal area, I_Effect = inhibition effectiveness, I_Effic = inhibition efficiency, PA = physical activity, Pen = soccer penalty performance, QED = quiet eye duration, QEL = quiet eye location, S_Anx = state anxiety, S_Effect = shifting effectiveness, S_Effic = shifting efficiency, SR = search rate, SRQ = stress rating, TotMood = total mood score, U_Effect = updating effectiveness, U_Effic = updating efficiency.

Table 6.5.

Correlations between variable at timepoint 2

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. age	1.00																	
2. SRQ	.05	1.00																
3. S_Anx	.00	-.07	1.00															
4. PA	-.22	-.30	-.03	1.00														
5. Expert	-.06	.11	-.30	.20	1.00													
6. Commit	-.03	.53	-.51	-.23	.43	1.00												
7. I_Effect	.28	.08	-.04	-.27	-.22	.19	1.00											
8. I_Effic	-.30	-.33	.08	.18	.22	-.24	-.83	1.00										
9. S_Effect	.16	-.11	.32	.00	-.15	-.23	-.02	.05	1.00									
10. S_Effic	.16	-.10	-.13	.19	.00	.00	.21	-.32	-.64	1.00								
11. U_Effect	.03	-.10	.00	.48	-.14	-.03	.40	-.28	.00	.08	1.00							
12. U_Effic	-.18	-.20	-.06	.37	-.10	-.05	.42	-.28	-.17	.18	.86	1.00						
13. QED	.17	-.19	-.03	.17	.30	.01	-.06	.15	-.13	.17	.40	.37	1.00					
14. QEL	-.28	.39	-.26	.28	.42	.44	-.05	-.11	-.10	.02	.10	.06	.19	1.00				
15. SR	.09	-.28	.23	-.25	.20	.06	.11	.28	.15	-.09	-.15	-.17	.21	-.24	1.00			
16. GoalMS	-.20	-.40	-.10	.28	.19	-.12	.04	-.02	.03	.03	-.07	.05	-.06	.30	-.06	1.00		
17. GKMS	-.01	-.18	.37	-.08	-.21	-.41	-.58	.57	.12	-.06	-.51	-.61	-.14	-.20	.14	-.09	1.00	
18. Pen	-.02	.27	-.19	.18	.61	.55	.23	-.10	.06	-.11	.36	.21	.49	.64	.34	.03	-.39	1.00

Note. Commit = goal commitment, Expert = expertise level, GKMS = time fixating the goalkeeper, GoalMS = time fixating the goal area, I_Effect = inhibition effectiveness, I_Effic = inhibition efficiency, PA = physical activity, Pen = soccer penalty performance, QED = quiet eye duration, QEL = quiet eye location, S_Anx = state anxiety, S_Effect = shifting effectiveness, S_Effic = shifting efficiency, SR = search rate, SRQ = stress rating, , U_Effect = updating effectiveness, U_Effic = updating efficiency.

Table 6.6.

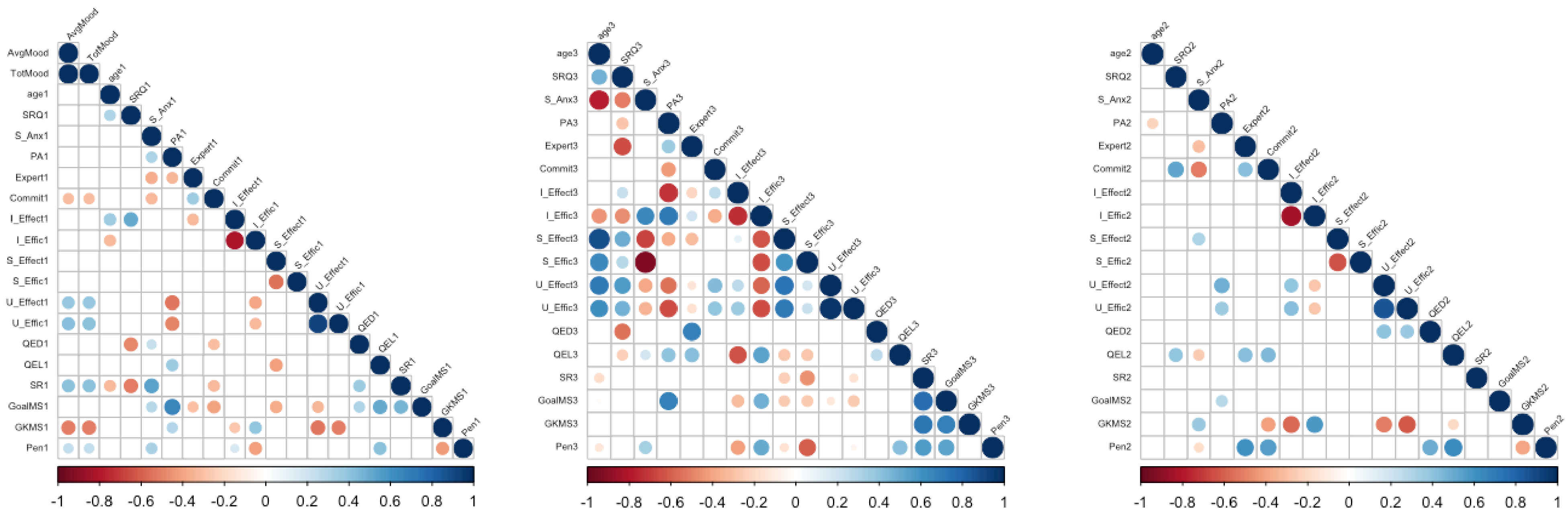
Correlations between variables at timepoint 3

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. age	1.00																	
2. SRQ	.47	1.00																
3. S_Anx	-.78	-.51	1.00															
4. PA	-.04	-.29	.03	1.00														
5. Expert	-.02	-.65	.05	.37	1.00													
6. Commit	.11	.15	-.21	-.43	.39	1.00												
7. I_Effect	-.18	.23	-.03	-.71	-.22	.26	1.00											
8. I_Effic	-.45	-.46	.64	.71	.21	-.38	-.73	1.00										
9. S_Effect	.88	.50	-.68	-.37	-.31	.03	.10	-.63	1.00									
10. S_Effic	.65	.28	-.92	-.01	-.03	-.02	.10	-.64	.60	1.00								
11. U_Effect	.70	.56	-.39	-.54	-.14	.44	.27	-.58	.74	.20	1.00							
12. U_Effic	.62	.47	-.34	-.64	-.17	.40	.37	-.65	.71	.22	.97	1.00						
13. QED	.22	-.54	-.09	.30	.67	.12	-.17	.08	.14	.12	.06	.07	1.00					
14. QEL	.02	-.24	.19	.40	.42	.17	-.64	.54	-.28	-.28	.08	.06	.27	1.00				
15. SR	-.18	.25	.19	.17	.10	.33	.12	.20	-.25	-.45	.01	-.15	.05	-.11	1.00			
16. GoalMS	-.03	.06	.08	.67	.27	.01	-.32	.48	-.25	-.27	-.12	-.27	.38	.29	.76	1.00		
17. GKMS	.33	.53	-.43	.35	-.04	.21	-.18	.02	.17	.15	.07	-.14	.00	-.16	.72	.67	1.00	
18. Pen	-.13	.02	.33	.13	.03	.32	-.42	.50	-.15	-.61	.05	-.05	.17	.42	.56	.53	.40	1.00

Note. Commit = goal commitment, Expert = expertise level, GKMS = time fixating the goalkeeper, GoalMS = time fixating the goal area, I_Effect = inhibition effectiveness, I_Effic = inhibition efficiency, PA = physical activity, Pen = soccer penalty performance, QED = quiet eye duration, QEL = quiet eye location, S_Anx = state anxiety, S_Effect = shifting effectiveness, S_Effic = shifting efficiency, SR = search rate, SRQ = stress rating, , U_Effect = updating effectiveness, U_Effic = updating efficiency.

Figure 6.1.

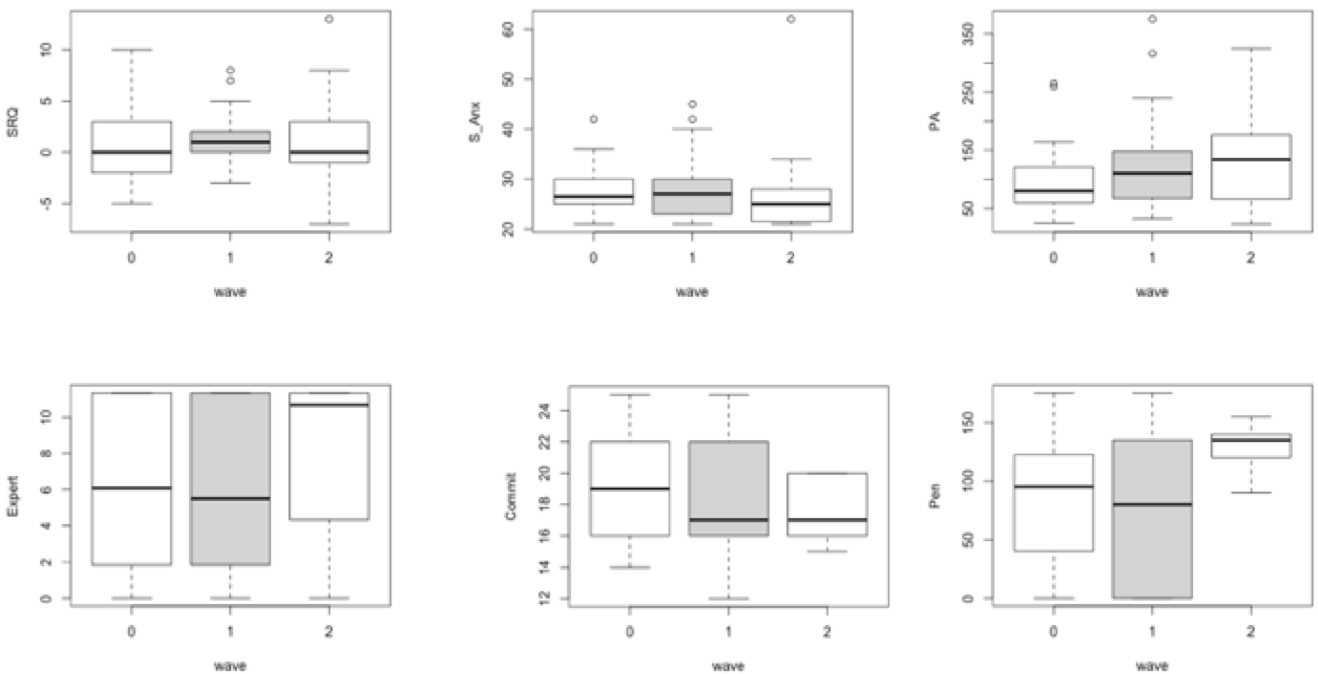
Significant correlations only between variables at timepoint 1 (left), timepoint 2 (right), and timepoint 3 (centre). Circles size indicates strength of the correlation and colour indicates direction (where red = -1.00 and blue = 1.00). 1 = timepoint 1, 2 = timepoint 2, 3 = timepoint 3, AvgMood = average mood, TotMood = total mood, SRQ = stress rating questionnaire, S_Anx = state anxiety, PA = physical activity, Expert = expertise, Commit = commitment, I_Effect = inhibition effectiveness, I_Effic = inhibition

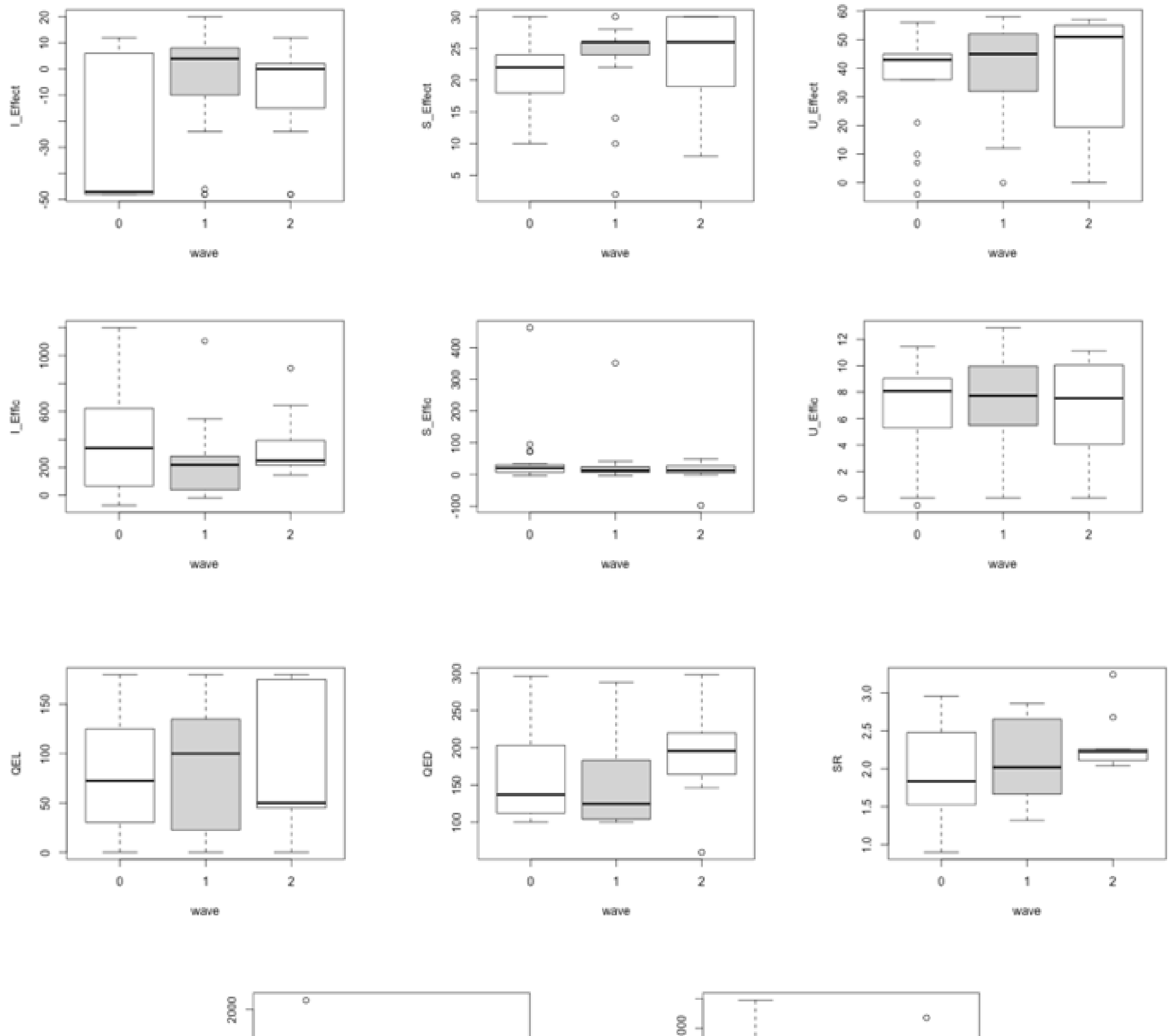


efficiency, S_Effect = shifting effectiveness, S_Effic = shifting efficiency, U_Effect = updating effectiveness, U_Effic = updating efficiency, QED = quiet eye duration, QEL = quiet eye location, SR = search rate, GoalMS = time fixating the goal, GKMS = time fixating the goalkeeper, Pen = soccer penalty performance

Figure 6.2.

Boxplots to show trajectory of key variables over time. SRQ = stress rating questionnaire, S_Anx = state anxiety, PA = physical activity, Expert = expertise, Commit = commitment, I_Effect = inhibition effectiveness, I_Effic = inhibition efficiency, S_Effect = shifting effectiveness, S_Effic = shifting efficiency, U_Effect = updating effectiveness, U_Effic = updating efficiency, QED = quiet eye duration, QEL = quiet eye location, SR = search rate, GoalMS = time fixating the goal, GKMS = time fixating the goalkeeper, Pen = soccer penalty performance




I_Effect
S_Effect
U_Effect
I_Effic
S_Effic
U_Effic
QEL
QED
SR
wave

6.4.2 Bayesian Mixed-Effect Models

To model the relationship of key variables (i.e., state anxiety, situational stress, physical activity, expertise, commitment, EF, VA, and soccer penalty performance) over time Bayesian mixed-effect models were used. The baseline model yielded an AIC of 523.20. R^2 = .17, and suggested an average increase in soccer penalty performance over time of 16.25cm. The experimental models for inhibition effectiveness (AIC = 525.50, R^2 = .18, $p > .05$) shifting effectiveness (AIC = 525.31, R^2 = .17, $p > .05$), updating effectiveness (AIC = 524.13, R^2 = .17, $p > .05$), inhibition efficiency (AIC = 524.90, R^2 = .19, $p > .05$), shifting efficiency (AIC = 525.31, R^2 = .18, $p > .05$), updating efficiency (AIC = 524.73, R^2 = .17, $p > .05$), time fixating the goal (AIC = 523.92, R^2 = .25, $p > .05$), state anxiety (AIC = 525.18, R^2 = .18, $p > .05$), SRQ (AIC = 525.05, R^2 = .19, $p > .05$), and physical activity (AIC = 524.42, R^2 = .22, $p > .05$) all showed inferior model fit and did not explain significantly more variance than the baseline model.

The experimental models for commitment (AIC = 523.13, R^2 = .20, $p > .05$) and expertise (AIC = 522.42, R^2 = .22, $p > .05$) did show superior model fit than the baseline model (through reduced AIC) but did not explain significantly more variance. However, the experimental models for quiet eye duration (AIC = 518.48, R^2 = .36, $p = .009$), quiet eye location (AIC = 513.09, R^2 = .35, $p < .001$), search rate (AIC = 520.87, R^2 = .28, $p = .036$) and time fixating the goalkeeper (AIC = 520.96, R^2 = .24, $p = .038$) all showed superior model fit and explained significantly more variance than the baseline model.

As a result, quiet eye duration, quiet eye location, search rate, and time fixation the goalkeeper were entered into a combined-experimental model. Unsurprisingly, the combined-experimental model was superior to the baseline model (AIC = 514.37, R^2 = .71, $p < .001$). Examination of model estimates suggested the largest contributors to variance explained were quiet eye location (8.14) and the interaction between quiet eye duration, search rate, and time fixating the goalkeeper (8.05) therefore, these factors alone were compared to the combined-experimental model. Results revealed that the quiet eye location only model was a better fit for the data (AIC = 513.09, R^2 = .35), potentially due to fewer parameters within the model, but the combined-experimental model explained significantly more variance (p = .021). The quiet eye duration, search rate, and time fixating the goalkeeper interaction model was a poorer fit for the data (AIC = 516.47, R^2 = .56) and the combined-experimental model explained significantly more variance (p = .020). Therefore, the initial combined-experimental model (with interactions between quiet eye location, quiet eye duration, search rate, and time fixating the goalkeeper) was the best model for explaining additional variance in soccer penalty performance over time, compared to baseline.

Finally, the multiplicative effect of EF and VA upon change in soccer penalty performance over time, were modelled. To test for interaction effects, the experimental model with a single VA variable was compared against an interaction-model i.e., a single VA variable and single EF (e.g., inhibition effectiveness and efficiency). Results showed that the only interaction-model that improved model fit and explained significantly more variance was the search rate and inhibition model. As reported earlier, the experimental model for search rate outperformed the baseline model (AIC = 520.87, R^2 = .28, p = .036). The model depicting an interaction between search rate and inhibition effectiveness and efficiency showed better model fit and explained significantly more variance than the experimental model for search rate alone (AIC = 518.30, R^2 = .49, p = .024).

6.5 Discussion

The aim of Chapter 6 was to ascertain whether variance in soccer penalty performance across a 24-week period could be accounted for by EF and/or VA and known covariates. It was hypothesised that changes in soccer penalty performance over time would be explained by related changes in EF and VA. The results suggested that the EF and the proposed covariates (state anxiety, stress, physical activity, expertise, and commitment) didn't account for significant variance in soccer penalty performance compared to time alone. However, VA explained significantly more variance in soccer penalty performance over time than time as a factor alone. Specifically, quiet eye duration, quiet eye location, search rate, and time fixating the goalkeeper all explained more variance than time as an individual factor. After sequentially removing variables to assess more parsimonious models, the model containing all significant VA variables was the best fit for the data and explained the most variance. Finally, given previously established relationships (Chapter 4; Chapter 5) it was expected that interactions between EF and VA would explain the most variance in soccer penalty performance over time. The only interaction that showed better model fit and explained significantly more variance in soccer penalty performance over time included search rate and inhibition.

While interpretation is subjective, the boxplots show how variables changed over the 24-week period and often suggested that the pattern of movement for predictor variables and soccer penalty performance was not similar. Previous work has outlined that the interaction between updating performance and time fixating the goal (deemed goal-directed attention in a soccer penalty; Brimmell et al., 2019) could influence one-off soccer penalty performance (Chapter 5). However, Chapter 6 suggested that such a relationship (i.e., updating performance and time fixating the goal predicting soccer penalty performance) may not be consistent over time. Though not predicted, this finding is not completely surprising. Wood and Wilson (2010b; 2011) outlined that individuals use multiple visual strategies across soccer penalties to avoid giving information about striking preferences away.

As Chapter 6 examined three penalty kicks per participant against the same goalkeeper, findings may provide more evidence that individuals do indeed use various visual search strategies, some of which are less familiar to the individual and lead to different outcomes. Interestingly, updating effectiveness and time fixating the goal did share similar trajectories over time. A visual interpretation of the present data suggests a stable relationship between these two variables (indicated by subtle but steady increases over time) despite the soccer penalty performance fluctuating.

The boxplots also showed some unanticipated, but interesting, relationships between shifting and updating. Shifting and updating effectiveness gradually improved over time (in some cases very slightly) whereas shifting and updating efficiency was consistent throughout. Research focused on EF training is often mixed. For example, Scharfen and Memmert (2021) noted task-specific and near-transfer (i.e., improvements in trained task and closely related tasks) but no far-transfer (i.e., improvements in unrelated but cognitively similar tasks). However, Scharfen and Memmert's (2021) results and those of similar studies, often fail to distinguish between effectiveness and efficiency. By parsing EF outcomes based on the theoretically proposed effectiveness and efficiency the findings of Chapter 6 may have revealed that effectiveness (i.e., accuracy) is more malleable than efficiency (i.e., accuracy by time) and thus created an exciting new way for research to approach EF training (i.e., focus on effectiveness). It is important to note that this comment is mostly a hypothetical interpretation of boxplots so should be treated with caution and warrants further investigation.

Also interesting was the lack of change in state anxiety or stress measures across time despite soccer penalty performance fluctuating. However, this result could be explained in numerous ways. First, it would be reasonable to expect that on occasions where soccer penalty performance was low, state anxiety and/or stress was high which, in part, caused the reduced performance, but this did not happen. It could be that the instructions weren't distinct enough to evoke additional stress across timepoints one to three despite the study intentions and despite following Gropel and Mesagno's (2019) recommendations (i.e., instructions included reference to videotaping, reward and punishment, perceived competition, and ego relevance). Second, it would also be reasonable to anticipate that when soccer penalty performance improved (as it did from timepoint one to timepoint three), state anxiety and/or stress was low but, this pattern did not emerge. This finding may reinforce the notion that sport performance can be maintained through the recruitment of additional resources during the task (e.g., effort; Eysenck & Wilson, 2016; Harris et al., 2019) despite state anxiety levels remaining similar.

Additionally, the improvement in soccer penalty performance from timepoint one to timepoint three, coupled with the lack of change in state anxiety or stress measure, may be because of the questions included within the respective measures. Specifically, state anxiety and stress directed toward the soccer penalty task could have been reduced across time (which then partially explains why soccer penalty performance improved), but because the items of the state anxiety and stress measures used were not soccer penalty task-specific, additional, unrelated and more general, anxieties or stressors could have influenced the reported scores (e.g., current exam-related anxiety or stress). Future work could look to design or utilise sport-specific state anxiety measures for comparison against more “general” established measures (e.g., STICSA; Ree et al., 2008).

Further examination of the boxplots outlined that quiet eye duration, inhibition efficiency, and expertise followed a similar trajectory to soccer penalty performance over time as expected. However, the direction of this relationship was surprising. Contrary to previous work, inhibition efficiency increases (i.e., maintained accuracy but with longer reaction times on trials in the Stop Signal Task) were associated with lengthened quiet eye durations, higher expertise, and higher soccer penalty scores. Hagyard et al. (2021) showed that decreased inhibition efficiency scores (i.e., accurate and fast responses) were associated with higher expertise and higher self-rated and coach-rated measures of sport performance (i.e., self-reported measures of overall performance across a competitive season). It may be the case that a soccer penalty kick, which, in the present study, placed no explicit time limit on participants, is more effectively executed when the inhibitory action is slower and more calculated (indexed here by increased inhibition efficiency scores) when compared to the more general "season performance" measures applied by Hagyard and colleagues (2021) which may require accuracy and time (i.e., reduced inhibition efficiency scores).

The present study added to previous work that outlined experts outperformed novices in sport (Mann et al., 2007) and that EF (Hagyard et al., 2021) and VA (Wilson, Vine, & Wood, 2009) influenced sport performance by measuring these variables over time. Therefore, the present research can draw conclusions about variables that appear to have an impact across timepoints rather than at a single point in time. As a result, it may be that quiet eye duration, inhibition efficiency and expertise are amongst the strongest perceptual-cognitive influencers of soccer penalty performance. This notion was supported in the main Bayesian mixed-effect models.

Though not as anticipated, several results from the Bayesian mixed-effect models do support hypotheses. A number of interesting results appeared to be related to variables that shared a similar trajectory over time as the dependent variable (i.e., soccer penalty performance). When expertise was entered into the model the AIC indicated an improvement in model fit suggesting that expertise was indeed contributing to performance on the soccer penalty task. However, p values and R^2 indicated that the model was not significantly better than baseline. Rather than a lack of effect of expertise upon sport performance (i.e., soccer penalty kick performance) this pattern of results is likely a consequence of low statistical power (i.e., small sample size). Furthermore, this finding may be exasperated by the attrition rate from timepoint 2 to 3 (57.14%). Whilst the current work represents a significant advance in the literature, it is likely given previous work, that expertise is an indicator of sport performance (as in Mann et al., 2007) and future research should replicate the longitudinal design used here but with a larger sample and minimise attrition to further determine the temporal association between EF, VA, and pressurised sport performance.

A similar pattern of results was found for goal commitment (i.e., motivation to achieve a pre-specified goal). Less research has been conducted in the sport setting but commitment has been outlined as a moderator of general goal-attainment and comparable to motivational effort in sport (Swann et al., 2021). Here, when commitment was entered into the model it appeared a better fit for the data than the baseline model suggesting individual levels of commitment was a factor in soccer penalty performance over time. This result also shared overlap with expertise, whereby higher commitment facilitates expertise. For example, it could be argued that someone willing to dedicate themselves to achieving sporting goals reaps benefits in regard to sport expertise and performance. Commitment has been reported as the extent to which an individual perceives the goal as important (Locke & Latham, 2019). Therefore, it is reasonable to suggest that individuals who perceived the task as more important (i.e., individuals with higher sporting expertise) were also the ones more committed to performing well (Swann et al., 2021).

Visual attention appeared to be a key variable in the performance of a soccer penalty as four of five experimental models showed a better fit for the data, greater R^2 values, and explained significantly more of the variance. This isn't particularly surprising given the abundance of literature that has attested to the importance of visually guided perception in sport (Ducrocq et al., 2017; see Klostermann & Moeinirad, 2020, for a review). Nonetheless, this is a novel insight as Wood and Wilson (2010b) alluded to the complexities of trying to obtain reliable measures of soccer penalty performance and maintain the validity of a penalty setting (i.e., perform enough penalties to understand individual performance levels but also consider that you get one chance in a game-setting). The present study somewhat addressed this issue by using a longitudinal design whereby each participant took a single soccer penalty kick at three timepoints. As a result, the present study builds on previous literature, including Chapter 4 and Chapter 5 from the present thesis, examining involvement of VA in aiming tasks (i.e., the soccer penalty) over time.

More specifically, quiet eye duration and location, search rate, and time spent fixating the goalkeeper appear to individually explain significantly more of the variance in soccer penalty performance than time alone. When searching for a combined model that explained the most variance, was the best fit for the data, and not excessively complex (i.e., high R^2, low number of variables) the experimental model containing all significant VA variables was optimal. This outcome confirmed that the quiet eye duration, quiet eye location, search rate, and time fixating the goalkeeper were making unique contributions to soccer penalty performance and emphasises the relevance of each variable in soccer penalty kicks, and possibly aiming tasks more generally. This conclusion partially supports comments from Klostermann and Moeinirad (2020) outlining that the quiet eye is indeed important in expert performance with the current findings suggest that perfecting the length and location of the quiet eye has benefits for performance in sport. However, the current work also attests to the importance of general fixation variables (e.g., search rate and time fixating the goalkeeper) suggesting they are important for aiming tasks (see Chapter 2, for an overview) therefore also opposing Klostermann and Moeinirad’s (2020) conclusions.

Though significant, the general trend of the search rate data was not expected. Search rate is a variable in which improvements are usually indicated through decreased values. That is, a low search rate is normally indicative of steady gaze to a small number of locations for a longer period of time to draw key information from the stimuli (Brimmell et al., 2019). The present study showed that search rate significantly influenced soccer penalty performance over time and that search rate increased at each timepoint. This is contradictory to previous studies examining search rate which suggested that enhanced performance is associated with lower search rates (e.g., Brimmell et al., 2019; Chapter 5). Instead, the present study suggested that, over time, increases in search rate (i.e., more fixations of a shorter duration) facilitated soccer penalty performance. It may be that improvements in memory, obtained through repeated task exposure, resulted in individuals requiring less time to process specific stimuli (due to familiarity from previous trials) and therefore, increased search rates (i.e., more fixations of shorter duration). This is somewhat corroborated by Wood et al. (2016) who outlined that greater working memory was associated with a reduced visual search time given that time fixating key stimuli is a central part of our calculation of search rate.

The only VA variable to not significantly influence soccer penalty performance over time was time fixating the goal. This is an unanticipated result given the fairly instinctive notion that goal-directed behaviour should lead to goal-success, a finding often reported in sport (Chapter 5; Wilson, Vine, & Wood, 2009). Examination of the time fixating the goal boxplot supports the idea that, over time, time spent fixating the goal was consistent. This finding may suggest that VA overtly directed to stimuli labelled goal-directed is not crucial for successful soccer penalty performance and instead other perceptual-cognitive processes are more important (e.g., quiet eye, search rate). However, it must be noted that the present study utilised a small sample and therefore subtle nuances may not have emerged.

Another surprising finding was that EF had little effect on soccer penalty performance over time. This finding spanned both effectiveness and efficiency scores and generally suggested that changes in soccer penalty performance over time could not be explained by changes in inhibition, shifting, or updating. It is likely that sample size hindered the emergence of any hypothesised relationships. Missing data (i.e., the drop from 21 participants to nine from timepoint 2 to 3) is also likely to have influenced the power of the Bayesian mixed-effect models as well (but not bias parameters; Lohse et al., 2020). Given that previous studies have outlined an association between EF and sport performance (Chapter 5; Ducrocq et al., 2017; Hagyard et al., 2021), it is likely that EF still has a role to play in sport performance.

Chapter 6 contributed to a limited pool that assessed the relationship between EF and VA in sport longitudinally. The present study is not the first to outline little-to-no impact of EF in sport over time. Beavan et al. (2020) found limited evidence that EF developed over time in elite soccer players when considering age and sporting experience. It may be that other perceptual-cognitive abilities (e.g., VA) are more a consistent predictor of aiming task performance as outlined in the present study. Nonetheless, perhaps the best explanation for lack of effects could rest with task selection. Research in VA includes the same consistent measures (e.g., quiet eye, fixations, duration) whereas EF has been indexed by several different tasks for each EF making comparison and consensus difficult (see Chapter 2). For example, inhibition is frequently measured with Stroop, Go/No-Go, Flanker, Antisaccade, and Stop-Signal Tasks (Diamond, 2013). Therefore, more research is needed to further delineate EFs relationship with sport performance over time.

Interaction models were constructed to better understand the joint impact of EF and VA on soccer penalty performance over time as previous cross-sectional studies have alluded to a combined effect (Chapter 4; Chapter 5). The present results showed numerous VA variables were a better fit for the data and explained significantly more of the variance than time alone, as such the interaction models were compared to the experimental models. The inclusion of an EF variable allowed for determination of whether the variance explained through a combination of EF and VA was greater than that of VA alone. Only the models containing search rate and inhibition (both effectiveness and efficiency) were a better fit for the data and explained significantly more variance. Given this result, more optimal training for soccer penalty performance may be targeted toward search rate, inhibition, or pertinently, a combination of both.

It was initially unexpected that no other combination of EF and VA variables expanded upon the VA only models. But, after the experimental models containing EF only showed no improvements from baseline, this finding was not surprising in the current sample. It is possible that if effects were present, but not detected in the experimental models due to low sample size and power, then similar issues effected the combined models. Another possible explanation is that EF is perhaps more stable and given that no real age changes occurred in the present study, EFs have likely not altered much over the 24-week period (i.e., no significant age increase allowing for EF development; Diamond, 2013). This could be supported by the very stable scores of shifting and updating efficiency in the present study which may also suggest that future EF research in sport with adults should opt for an experimental period of longer than 24-weeks to see potential changes in EF. However, it may be the case that soccer penalty kick performance fluctuations occur on a regular basis. Variance may also be exasperated by the idea that at each timepoint individuals only had a single penalty kick (e.g., “flukes” may have occurred). Perhaps an alternative soccer-task that is more consistent and less prone to “fluke” performance would be better for future research (e.g., a soccer penalty task with multiple kicks at each timepoint).

6.5.1 Limitations and Future Directions

Despite Chapter 6 providing novel and interesting insights into the longitudinal relationship between EF, VA, and soccer penalty performance, it is not without limitation. One of the main issues with the present study concerns the sample. First, the sample size was small and the attrition rate from timepoint 2 to timepoint 3 was large. Low statistical power reduces confidence in statistical effects. The present study ran a high number of experimental models on a small dataset and as a result some caution must be taken when interpreting the results of multiple comparisons (i.e., type 2 error; Banerjee et al., 2009). To move forward, research should utilise longitudinal designs with a larger sample, avoid high attrition, perhaps by offering incentives for participants to return (i.e., a reward), and run fewer experimental models (by using the present study to ascertain what may or may not be relevant).

Though the smaller sample size and attrition rate was somewhat dealt with by the selection of Bayesian modelling (Wentzell et al., 2017), however, this technique is not without some shortcomings. van Doorn et al. (2021) outlined that there is ambiguity around the most suitable Bayes factor hypothesis when looking to detect either the presence or absence of an experimental effect. Therefore, and although model priors and models themselves were selected based on best beliefs, it may be the case an alternative model structure could have been selected. Research has outlined that when specifying priors for random-effects, alternates to the Wishart distribution may be appropriate. Ariyo et al. (2019) outlined that a separation approach (where variance covariance matrices are broken down; Barnard et al., 2000) may be more optimal.

6.5.2 Conclusions

In sum, Chapter 6 sought to understand the relationship between EF, VA, and soccer penalty performance across a 24-week period while considering known covariates. There was only partial support for the hypotheses. Appearing to have a greater influence on soccer penalty performance over time, VA was more influential than any other proposed variable (i.e., state anxiety, situational stress, physical activity, expertise, commitment, and EF). Regarding the combined effect of EF and VA on soccer penalty performance the only combination that had meaningful explanatory power was search rate and inhibition effectiveness and efficiency. This finding may suggest that search rate and inhibition effectiveness and efficiency are related and important for success in the soccer penalty. Future work is encouraged to replicate this longitudinal design with a larger sample, incentivise participant engagement to minimise attrition, apply, and utilise alternate statistical modelling techniques to further understand the hypothesised longitudinal relationships.

Chapter 7: General Discussion

7.1 Chapter Overview

The present chapter recaps the general research area and aims of the program of five studies (Chapter 2-6) presented in the current thesis. It focuses on the broad theoretical aims as well as chapter- and study-specific aims and hypotheses. This chapter covers the main findings included within the thesis, specifically, showcasing how each chapter relates to previous work examining the relationship between EF and VA in a sporting context and how each study builds on the next. Implications of the thesis are discussed with specific comments on how the findings extend theory (e.g., ACT; Eysenck et al., 2007; and ACT-S; Eysenck & Wilson, 2016) and experimental research. The present chapter then addresses limitations of the thesis before moving to outline how future research may address such shortcomings. Finally, concluding statements are presented that outline the significance and contribution of the work composing the thesis.

7.2 Thesis Overview and Aims

This thesis set out to explore the relationship between, and joint contribution of, EF and VA during sport performance. There are theoretical accounts (e.g., ACT; Eysenck et al., 2007 and ACT-S; Eysenck & Wilson, 2016) that suggest attentional control is a key factor for sports performers. When individuals perceive a particular sporting situation as anxiety inducing or stressful, they can suffer from disrupted attentional control which can lead to poorer subsequent sports performance (Wilson, Vine, & Wood, 2009). A key tenet of ACT and ACT-S is that attentional control is facilitated by a series of cognitive processes known as EF which are housed within the pre-frontal cortex of the brain (Corbetta & Shulman, 2002). The theoretically proposed EFs comprise the lower-order model of inhibition, shifting, and updating (Miyake et al., 2000). These processes are also believed to form the building blocks of more “complex” processes often examined in sport and exercise psychology (e.g., decision-making; Diamond, 2013). Despite the theoretical tie of these EFs to attentional control, research has typically opted to assess the assumptions of ACT and ACT-S by measuring attentional control through VA obtained with eye-trackers (e.g., Lebeau et al., 2016). As a result, there is currently a lack of research that combines the theoretically proposed EFs and often more utilised VA.

The overarching aim of the present thesis was to better understand the relationship between EF, VA, and sport performance. Specifically, the goal was to see if the attentional control component outlined in ACT-S (Eysenck & Wilson, 2016) could be divided into two sub-components (i.e., EF and VA) that interact in some way to influence pressurised sport performance (i.e., performance on a soccer penalty). Across five programmatic studies (i.e., Chapter 2, Chapter 3, Chapter 4, Chapter 5, and Chapter 6) including a systematic review, online-based, cross-sectional experiment, and longitudinal experiment, this thesis assessed the joint contribution of these attentional processes in sport. The aim of the systematic review was to first get an understanding of how EF and VA may relate by reviewing studies measuring both in a sport setting. A thorough review of previous research allowed the online and experimental studies that followed to include best measures and methods and target and thus address research gaps. Once the review was complete the aims of the following online and experimental (cross-sectional and longitudinal) studies were to empirically test the relationship between EF and VA while considering a number of known covariates (i.e., anxiety, stress, physical activity, expertise, and commitment). The online study used CFA to analyse whether the proposed lower-order model of EF (inhibition, shifting, and updating; Miyake et al., 2000) could be replicated in a sample of athletes and whether EF task performance contributed to VA task performance. Another important aim of this study was to separate EF performance into the more theoretical, but often ignored, outcomes of effectiveness (i.e., accuracy) and efficiency (i.e., accuracy by time).

There have been a large number of experimental studies that have examined either EF or VA in relation to sport performance/performers. However, there is a lack of research that has tried to examine the joint effect between the two variables, which is surprising given their theoretical relation. The series of experimental (i.e., cross-sectional and longitudinal) studies aimed to address this gap. First, this thesis cross-sectionally examined EF, VA, and soccer penalty performance, while controlling for known covariates. Next, this thesis longitudinally (i.e., over a 24-week period) examined how EF, VA, and known covariates influenced soccer penalty performance over time. The next section of this chapter outlines the main findings of these four studies and compares and contrasts the findings with similar research in order to demonstrate the overall contribution of the thesis to the literature.

7.3 Summary and Discussion of Main Findings

7.3.1 A Unified Way of Reporting Expertise

Within sport and exercise psychology the study of expertise is prominent (Moran et al., 2019). Specifically, researchers have often sought to find exactly what characteristics or abilities enable a sportsperson to become an expert (Ericsson et al., 1993). One area that is popular with researchers is perceptual-cognition and within perceptual-cognition fall the constructs of EF and VA (Klostermann & Moeinirad, 2020; Mann et al., 2007; Voss et al., 2010). A key finding within the systematic review of studies examining measures of EF and VA (i.e., Chapter 2) was that there were many different ways individuals were labelled as experts. An issue associated with a lack of consensus on expertise is that it makes compiling and understanding results in this area more complex and as a result, designing suitable training paradigms more complex (e.g., when trying to understand which variables of EF and VA best differentiate between expert performers).

This complexity stems from trying to draw conclusions based on numerous results between groups that appear to be similar (e.g., labelled "skilled" and "less-skilled") but are realistically at very different performance levels (e.g., "skilled" performers with international experience [McRobert et al., 2011] and "skilled" performers based on independent coach ratings [Afonso & Mesquita., 2013]). Consider the situation where a researcher is aiming to design an EF or VA training intervention and is looking to ascertain which key variables to train based on previous works. At a glance, a researcher may use the above studies (Afonso & Mesquita, 2013; McRobert et al., 2011) to potentially, and possibly incorrectly, suggest unequivocal results based on the independent research findings (i.e., "expert" group performed better on the EF task, but VA patterns were different). However, a deeper look at how expertise was defined in each study would show that individuals at very different performance levels were assessed (i.e., the criteria used to define an expert varied). As a result, the present thesis propose that research move toward a unified and more continuous measure of expertise so as to avoid dichotomisation (e.g., Swann et al., 2015). Such a technique was successfully used in the present thesis (Chapter's 3, 4, 5 and 6) and in peer-reviewed work (e.g., Hagyard et al., 2021; Vaughan & Edwards, 2020).

7.3.2 Studies Directly Examining Lower-Order Executive Function and Visual Attention in Sport are Sparse

One key factor outlined in Chapter 2, and then addressed in subsequent chapters (i.e., Chapter 3, 4, 5, and 6), of the present thesis was that research is severely lacking in studies that have examined lower-order EFs (e.g., the model of inhibition, shifting, and updating; Miyake et al., 2000) and VA in sport. This finding is somewhat surprising given that there is ample neuroscientific evidence of a relationship between EF and VA which may well transfer to sport. For example, research has outlined that the neurological home of EF and VA is similar (i.e., the fronto-parietal lobe; Gaillard & Ben Hamed, 2022). Also, neural activity in the pre-frontal cortex, the home of EF, increases in magnitude and frequency when individuals are engaging in goal-directed attention. This neuroscience work may allow inferences around the relationship between EF and VA in sport. Specifically, given the neurological association between areas of the brain, it may be reasonable to suggest that such a relationship exists within sport providing an avenue of exploration for future sport and exercise psychology research in this area.

When a study did contain both an EF and VA there were limited instances where the two were included within the same statistical analyses. This lack of research has meant that understanding any joint role or interaction between these two constructs for sports performance has remained relatively speculative. Speculative in the sense that studies will often use between-subjects designs and ask participants to complete an EF task while wearing an eye-tracker (e.g., Klostermann, 2020). Such researchers then infer that superior performance on the EF task stems from VA without statistically commenting on the relationship between EF and VA. Therefore, it is clear that to better understand the relationship between the theoretical component of attentional control (i.e., EF) and the typically utilised component of attentional control (i.e., VA) more research is needed. This problem is in part addressed by the current thesis (i.e., Chapters 4, 5, and 6) as evidence is provided for a relationship between EF and VA in athletes across numerous study designs. However, whether this EF and VA relationship is present at all levels of EF and/or VA is unclear. That is, does EF impact VA in individuals with high levels of EF and VA and low levels of EF and VA, or both. Wood et al. (2016) found that only individuals low in working memory capacity suffered performance deficits under pressure. It may be the case that such a relationship exists between EF and VA. Finally, cognitive flexibility (i.e., shifting) did not appear at all. Cognitive flexibility is important in everyday life (Diamond, 2013) and sport (e.g., expert soccer players perform better on tasks assessing cognitive flexibility; Vestberg et al., 2017) and therefore also warrants investigation.

7.3.3 Reproducing the Lower-Order Model of Executive Function in Sport

The lower-order model of EF was proposed in 2000 by Miyake and colleagues and consists of inhibition, shifting, and updating. This model has been widely accepted and utilised across a number of domains with researchers in sport often assessing inhibition (e.g., Hagyard et al., 2021), shifting (e.g., Vestberg et al., 2017), and updating (Ducrocq et al., 2017) in athletic samples. However, since it's conception the model has not been tested and is yet to be directly applied to a sporting sample. In Chapter 4 of the present thesis CFA was used to address exactly this gap. The results showed that for the first time the lower-order model is applicable in a sample of sportspeople. This finding has important implications for the use of such measures in existing and future sport and exercise psychology research. This result may suggest that despite research at times not finding any effect of training sportspeople in domain-general tasks of EF (e.g., the NeuroTracker; Scharfen & Memmert, 2021) that the functions themselves are still relevant. As such, researchers are challenged by this result to find novel ways to look to train these EFs. One potentially novel and state-of-the-art method would be through virtual and/or augmented reality (Harris et al., 2020).

7.3.4 Latent Modelling of Executive function and Visual Attention: The Role of Effectiveness and Efficiency

Chapter 4 also modelled the relationship between EF and VA and was unique in a number of ways. First, the hypothesised model examined EF as a latent variable (i.e., multi-task) rather than the typical single-task variable seen in most studies (e.g., Hagyard et al., 2021; Vaughan & Laborde, 2020). Though popular, single-task designs may raise questions as to whether the target EF is being measured or if performance is task-specific (i.e., research may not be able comment on overall inhibition performance but rather a specific component of inhibition). Through including multiple measures of a single EF construct (e.g., the Go/No-Go and Stop Signal Tasks for inhibition; Chapter 4) this thesis was better placed to comment on inhibition performance. For a more reliable measure of the EF of interest, future work may also wish to adopt a latent variable approach. It should be noted that studies often do use valid tasks to assess the target EF and that single-task designs may still be preferred where multiple EFs are measured or the study measures numerous other variables (e.g., to reduce experimental demand on participants). The results of the latent modelling provided support for an associated between EF and VA. This suggests that the two do relate in some way and that empirical work into exactly how the two may work together to influence sport performance is important.

Second, and another key finding, was that effectiveness and efficiency outcome variables were quite different fits for the data. Criteria used to assess model fit (i.e., χ^2, CMIN/DF, GFI, CFI, TLI, RMSEA, SRMR, and BIC) suggested that effectiveness models were a better fit for the obtained data and more parsimonious than the efficiency models for both model A (i.e., EF alone) and model B (i.e., EF and hierarchical VA models). Despite initially showing inferior fit, both models for efficiency (i.e., model A and B) did achieve acceptable model fit after theory guided modifications (e.g., correlated error terms and constrained additional pathways). In doing so this thesis deviated from the theorised model toward a modified model. The issue with this is that the modified model is solely data driven (i.e., relative to the current sample only) and may not be generalisable. As such, the association between the present efficiency models and the theorised model should be interpreted with caution until it can be replicated in additional athlete samples.

Overall, the results suggested that both effectiveness and efficiency outcome variables of latent EF and VA fit the hypothesised model but can be modelled differently. This result supports the theoretical notion that effectiveness and efficiency may be differentially impaired by factors like anxiety or stress (ACT-S; Eysenck & Wilson, 2016) and therefore, should be considered and examined as independent outcome variables. Future work is therefore implored to outline whether outcome variables of EF and visual tasks represent a measure of accuracy only (i.e., effectiveness) or accuracy and time (i.e., efficiency) a limitation of Miyake and colleagues (2000) seminal work. Regarding VA, this result may be more relevant to computerised tasks used to track VA like those used in Chapter 4 (i.e., the Visual Search and Attentional Breadth Tasks) and may be more complex when using eye-trackers to assess visual behaviour.

7.3.5 Executive Function and Visual Attention Work Together to Influence Soccer Penalty Performance

One of the key aims of the present thesis was to better understand how the areas of EF and VA may interact to influence pressurised sport performance. Chapter 4 outlined that EF and VA may relate to one another, but the study was void of a typical measure of VA (i.e., an eye-tracker; Ducrocq et al. 2016; 2017) and did not include an objective measure of sport performance. Without these two factors it is difficult to comment on whether there is any joint effect and exactly how the variables work together in sporting scenarios. Chapter 5 addressed this issue and found that there was indeed a direct association between EF, VA, and sport performance (i.e., soccer penalty performance). The included EFs predicted performance on the soccer penalty task through the mediator of VA. In a phenomenon coined the “think-see-do” concept (Boyd et al., 2022) the reported results appear to suggest that improved cognitive attention (i.e., EF) leads to more optimal VA and finally, improved performance soccer penalty performance.

The relationships between inhibition and updating and soccer penalty performance were significantly mediated by the quiet eye duration, quiet eye location, search rate, and the number of fixations to the goal. This particular pattern of results was interesting for a number of reasons. First, the association between greater inhibition ability and longer quiet eye durations may support the inhibition hypothesis. The inhibition hypothesis states that during the quiet eye period inappropriate motor responses are subdued and a suitable motor outcome is selected (Klostermann, 2020). Though research has manipulated within-task inhibition demands (Klostermann & Hossner, 2018), until the present thesis there was no study that used an objective inhibition task. Here, this thesis shows that an enhanced ability to withhold a dominant response (i.e., inhibition) in an independent task was related to significantly longer quiet eye duration and performance during a soccer penalty task. This thesis expands upon the importance of inhibition by showcasing the additional relevance of updating. Specifically, greater nback performance (i.e., updating) was associated with greater soccer penalty performance through the mediating effect of quiet eye duration. It may be that updating is used to constantly update the individual that certain motor plans are suboptimal while a more suitable option is located.

These results supported the somewhat expected idea that more goal-directed VA leads to improved soccer penalty performance found in previous research (e.g., Wood & Wilson, 2010b). That is, more fixations toward the striking target (i.e., the goal) the more distally located penalty kicks were. However, the present results expanded upon this by highlighting the cognitive mechanism that may allow for such performance. Both inhibition and updating ability predicted soccer penalty performance through the number of goal fixations as a mediator. This may suggest that it is an individual's enhanced ability to withhold dominant responses (i.e., inhibition) and manipulate content within working memory (i.e., updating) that is linked to an ability to withhold goal-directed VA.

Another interesting result was the lack of any association of shifting. Shifting was originally outlined in Chapter 2 as the only lower-order EF to not feature in relation to VA (measured with an eye-tracker) in sport. This may be because research has focused elsewhere but could also be because, like Chapter 5, findings were non-significant and not published as a result. This is a little sceptical though and perhaps relationships do exist as correlations were found between all lower-order EFs in Chapter 4. More work is needed to better understand the role of shifting for VA and sport performance.

7.3.6 The Longitudinal Executive Function, Visual Attention, and Soccer Penalty Performance Relationship – More Questions to Address

To better understand the stability and causality of the relationship between EF, VA, and sport performance (i.e., soccer penalty performance) the present thesis measured these variables across a 24-week period, while considering known covariates. The study modelled the trajectory of soccer penalty performance over three timepoints and compared this baseline model to numerous subsequent experimental and interaction models. The results largely indicated that EF and the hypothesised covariates (i.e., anxiety, stress, physical activity, expertise, commitment) did not contribute to soccer penalty performance fluctuations over the 24-week period. However, VA variables (i.e., quiet eye duration, quiet eye location, search rate, and time fixating the goalkeeper) showed significantly improved model fit and greater variance explained than the baseline model which suggested a key role for these variables for soccer penalty performance over time. While the results were largely surprising, the interaction effect between search rate and inhibition showed significantly better model fit and more variance explained than the baseline model. This result suggests that future work would do well to target these facets of attentional control to improve performance in aiming tasks.

Given the surprising results, more work is needed to understand the relationship between EF, VA, and soccer penalty performance over time. Given the theme from Chapter 2, 4, and 5 (i.e., that EF and VA are significantly related) it is possible that the longitudinal study was limited and therefore, unable to detect relationships. This is likely due to the low sample size and low number of data points per person. Though EF is a malleable construct (i.e., fluctuates with age; Diamond, 2013), it is unlikely that age changes for the participants in Chapter 6 (over a 24-week period) caused any significant EF fluctuations. Indeed, boxplots in Figure 6.2 showed that performance on all EF measures was fairly stable across three timepoints (bar inhibition effectiveness, which was very low at timepoint 1). Therefore, it may be that the task selected was not the most optimal. The soccer penalty is a highly variable situation that often sees between-subject variation in technique used (e.g., fixating the goalkeeper one time and then the goal the next; Wood & Wilson, 2010b) and therefore, may in itself be flawed when looking for a consistent measure of sporting performance. To exasperate this, at each timepoint the participants performed just a single penalty kick (to maintain ecological validity; Wood & Wilson 2011).

7.4 Implications of the Present Thesis

Together the findings of the present thesis provide the first empirical investigation into the relationship between EF, VA, and sport performance (i.e., soccer penalty performance). Over four studies the present thesis systematically reviewed, tested latent constructs, cross-sectionally evaluated, and longitudinally examined the theoretical components of ACT and ACT-S (i.e., EF) and more typically utilised measures of attention (i.e., VA) in sport performance and as a result, have advanced theory and practice. These findings are important for ACT-S as they showcase that the proposed EF components of attention are relevant for sport performance. Also, that such EFs interact with the typically used VA measures (e.g., quiet eye; Vickers, 2007). Previous research has trained components of attentional control (i.e., EF and VA) but have only targeted either EF or VA and examined some element of subsequent sport performance (see Ducrocq et al., 2016; 2017, for exceptions). The present thesis implies that sports performance is in-part reliant on both of these facets of attentional control and that they may work together. As such, applied researchers are encouraged to incorporate methods of training that focus on EF and VA when working with athletes.

7.4.1 Theoretical Implications

Attention forms a key part of ACT and ACT-S (Eysenck et al., 2007; Eysenck & Wilson, 2016). Within ACT and ACT-S, attention comprises a set of functions housed within the central executive (i.e., EFs; Eysenck et al., 2007) and only infrequently was examined through eye movements (Alting & Markham, 1993; Janelle et al., 1999; Nottelman & Hill, 1977). This is very a different approach to that which has been used by sport and exercise psychology researchers. Sport and exercise psychology often utilised eye-trackers to ascertain "objective" attention by understanding which visual cues individuals attend to during skilled performance (e.g., Wilson, Vine, & Wood, 2009; Wilson, Wood, & Vine, 2009; Vine et al., 2013). Despite this disparity between theory and research, when describing ACT or ACT-S in a schematic diagram or model, research tends to use a similar approach. That is, to depict attention as a singular object (see Harris et al., 2019, for an example). This is where the present thesis extends theory and suggests that it is imprecise to label attention broadly when it is in fact more nuanced and can be considered an umbrella term for cognitive (i.e., EF) and visual (i.e., gaze) processes.

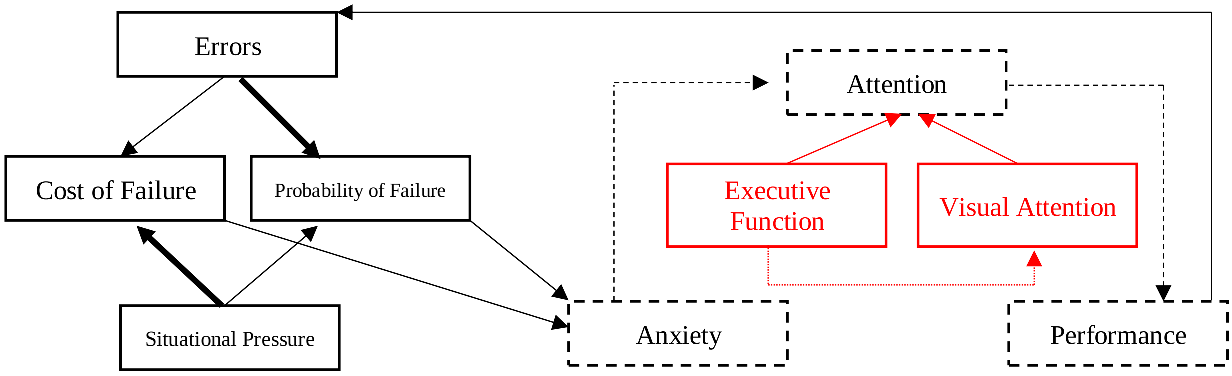
The originally proposed theoretical extension is outlined in Figure 1.3. This model was proposed to build upon previous iterations of ACT (Eysenck et al., 2007) and ACT-S (Eysenck & Wilson, 2016) outlined visually in recent work (e.g., Harris et al., 2019). The key tenet of the proposed extension was to parse the attention component into separate EF and VA elements with the two joined via a bidirectional arrow. The bidirectional arrow was an important part of the model signifying that EF and VA may influence one another. The idea for of a bidirectional relationship stemmed from a lack of clarity on a unidirectional relationship between EF and VA. For example, Bishop et al. (2014) suggested that VA might influence EF as early fixations to the soccer ball lead to more correct decisions when assessing opponent movement direction. Alternatively, Klostermann's (2020) "inhibition hypothesis" outlined that inhibition is a key cognitive component that may facilitate quiet eye duration. However, the results of the present thesis are perhaps not completely supportive of this bidirectional relationship and instead may suggest EF influences VA.

The first indication that EF may influence VA was in Chapter 4. Specifically, the effectiveness and efficiency models that comprised both EF and VA (i.e., Figure 4.1B) aimed to test a hierarchical relationship where EF may underpin VA. The indices of model fit did indeed support this idea and outlined that the lower-order model of EF (i.e., inhibition, shifting, and updating) may support the more complex VA variables (i.e., those that require multiple lower-order EFs to function). The idea that EF might impact VA was then bolstered in Chapter 5. Several mediation models showed that EF predicted soccer penalty performance through VA as a mediator and suggest EF may first impact VA, before subsequent performance. As a result, the current thesis may be better placed to proposed the revised model shown in Figure 7.1. Figure 7.1 is highly similar to Figure 1.3 but the arrow between

EF and VA (in red) is now unidirectional (i.e., EF to VA) as opposed to bidirectional to better reflect the findings of the present thesis.

Figure 7.1.

The final proposed adapted model of Attentional Control Theory-Sport. The addition the present thesis is making is in red. The adaptation from Figure 1.3. here is that the now a unidirectional relationship between EF and VA is proposed given mediation findings.



It is important to note that the present thesis does not rule completely in favour of Figure 7.1 over Figure 1.3 and it may indeed be that Figure 1.3 is more appropriate. For example, the neuroscientific and cognitive psychology work outlined in Chapter 1 do allude to the potential of a bidirectional relationship outside of sport. For example, in the model proposed by Itti and Koch (2001) attention appears to be more cyclical in nature with the two systems constantly feeding back to one another (i.e., VA informs EF, before EF directs subsequent VA and so on). First, visual stimuli is attended to and this information reaches the visual cortex before being processed by the dorsal and ventral systems in tandem. This information then reaches the pre-frontal cortex where EF processes the attended to information before directing subsequent eye movement (i.e., VA; Itti & Koch, 2001). Such a model may indeed support a bidirectional relationship and support Figure 1.3.Therefore, future research is encouraged to better understand the directionality of the EF and VA relationship.

Additionally, the results of the present thesis may offer partial support for the proposed theoretical extension (i.e., Figure 7.1). That is, whilst most findings support our initial ideas the longitudinal work (i.e., Chapter 6) questions the extension. To start with supporting results, the correlations between EFs and VA from Chapter 4 showcased that variables were related but not the same (i.e., significant Pearson correlations but not overly close to 1.00). As a result, it is not appropriate to consider attention as a singular simple process, but rather to understand the complexity and the role of cognitive (EF) and visual (gaze) processes within attentional control. More support for this premise came in Chapter 5 as numerous relationships were found between EF, VA, and soccer penalty performance. In Chapter 5 distinctly different measures of attention were used to understand the interplay between theorised EFs (e.g., inhibition) and applied gaze metrics (e.g., quiet eye; Vickers, 2007). The results showed that on EF tasks that are cognitively based, and less-demanding on visual processes, predicted soccer penalty performance through the mediator of gaze behaviour. This supported the idea that EF and VA can be considered as two separate components of attentional control.

The present thesis suggests that the attention component of ACT and ACT-S can be represented by covert attentional processes (i.e., EF) that may in some capacity support, or be supported by, overt attentional processes (i.e., VA). Specifically, VA allows individuals to attend to salient information within a scene before they are cognitively processed and a motor response is selected (also supporting the inhibition hypothesis; Klostermann, 2020). More support for the need to separate EF and VA in theory may stem from previous experimental work. For example, Wood and Wilson (2010b) noted that individuals often use deceptive strategies within soccer penalties (i.e., direct VA to a completely different location to intended kicking direction) and are still successful. This may suggest that the actual point of gaze is not important, but rather the stability of gaze allows cognitive attentional control (i.e., EF) to function properly. In the present work, this thesis did not examine whether the predominantly fixated goal side (left or right) aligned with the actual striking direction but instead show that a combination of EF and VA work to improve soccer penalty performance.

The longitudinal findings (Chapter 6) nonetheless provide less support to the above. Besides the combined effect of search rate and inhibition, no EF and VA combination was a better model fit or explained more variance than time alone when examining soccer penalty performance across 24-weeks. This finding may indeed suggest that the strongest and potentially most relevant EF and VA variables for soccer penalty performance are search rate and inhibition. It is likely that, if repeated, other significant associations between EF and VA may emerge. In sum, the present thesis outlines that theory and individuals applying ACT and/or ACT-S as theoretical underpinnings for their work should respect the distinction between the attentional processes of EF and VA in sport performance.

The present thesis is also important for the theoretical proposition of performance effectiveness and efficiency. At the conception of ACT, and retained in ACT-S, the distinction between effectiveness and efficiency was a paramount assumption (Eysenck et al., 2007). The distinction being that anxiety is more likely to influence efficiency (i.e., accuracy by time) than effectiveness (i.e., accuracy). This is in part due to the compensatory factors (e.g., time or effort; Wilson, 2008) required to ensure that effectiveness is maintained when an individual is anxious. Despite this clear distinction, research utilising tasks to assess the lower-order model of EF (i.e., inhibition, shifting, and updating) is void of examples where effectiveness and efficiency have been clearly distinguished conceptually or statistically (e.g., Ducrocq et al., 2016; 2017; Scharfen & Memmert, 2021). Though such studies do not explicitly state any theoretical grounding in ACT or ACT-S, they are concerned with sports performers, and therefore may better understand the relationship between EF and sports performance through the inclusion of more specific outcomes (i.e., effectiveness and efficiency). Chapter 4 showcased that effectiveness and efficiency could not be modelled the same in the acquired sample and that the proposed model of EF (i.e., inhibition, shifting, and updating) was better reflected in effectiveness.

7.4.2 Applied Implications

From an applied standpoint the present thesis also has some interesting applications and implications for future research. The applied implications tend to centre around trainability and how these elements of perceptual-cognition (i.e., EF and VA) may be targeted and improved within athletes. The present thesis is not the first to suggest that EF may be a good target for training in athletes and various studies have attempted to do such (e.g., Harris et al., 2020; Scharfen & Memmert, 2021). One common theme amongst such research is the effects of training rarely transfer from lab to field (i.e., far transfer; Scharfen & Memmert, 2021). As a result, it is difficult to suggest that athletes and coaches use such methods given the uncertainty around their real-world application. However, these studies often maintain the domain-general nature of EF tasks (i.e., stimuli are general and non-specific) and fail to include stimuli or actions that are fully representative of the real-world. For applied researchers the present thesis outlines that EF can be important for the completion of aiming tasks (though longitudinally more work is needed) but perhaps our current training approach is wrong. Therefore, researchers are encouraged to develop and validate new measures of existing EFs but with sport-specific context. These tasks can then be compared to domain-general tasks and the transferability truly tested. One potential avenue for future research to use as an EF training tool could be virtual reality (Wood et al., 2021).

The proposed implications for VA appear to be a little more straightforward. Specifically, in both experimental chapters (i.e., Chapter 5 and 6) that included gaze behaviour recorded via an eye-tracker there was an effect of VA on soccer penalty performance. These results suggest that VA is indeed important for aiming tasks as expected. However, the specific line of approach for training is not clear from the present thesis due to the somewhat mixed findings. The cross-sectional and longitudinal results presented some similar and some alternate findings. First, the results of the cross-sectional study showed that superior inhibition and updating was associated better soccer penalty performance through the mediators of increased fixation time to goal area, longer quiet eye duration, more distal quiet eye locations, and lower search rates.

However, the longitudinal study showed that goal area fixations could not predict soccer penalty performance variance over time but more time fixating the goalkeeper could. Search rate was significantly associated with soccer penalty performance both cross-sectionally and longitudinally, but the direction altered. That is, reduced search rate was associated with EF and improved soccer penalty performance cross-sectionally but increased search rate appeared beneficial for soccer penalty performance longitudinally. As Chapter 2 outlined, it's not unusual for sports tasks to require different search rates. For example, Moore et al. (2019) noted that referees in elite rugby demonstrated that a reduced search rate benefitted performance while Vaeyens et al. (2007a) suggested that task success was associated with increased search rate in soccer players. What was not anticipated here though is that the same variable (i.e., search rate) in the same task (i.e., soccer penalty) would appear to shift (i.e., move from shorter being better to longer being better). This makes training applications tricky for aiming tasks like the soccer penalty as it's unsure whether a decreased or increased search rate is better for performance. The change in direction may be due to previously mentioned variability and deception in soccer penalties. That is, individuals may have altered their approach across time to avoid repetition and the goalkeeper learning their preferred striking direction and this may have induced more fixations of shorter duration in order to select new striking directions (see Wood et al., 2017 for how deceptive or altered attention is used in soccer penalties).

The most stable VA variable appears to be the quiet eye (duration and location; Vickers, 2007). Therefore, the present thesis suggests that the final fixation before movement within which task related information is processed may be the most fruitful avenue for future training-focused research. Both quiet eye duration and location were positively (i.e., increased duration and more distal locations) associated with soccer penalty performance cross-sectionally and longitudinally. Researchers therefore may wish to target these functions as previous work has alluded (e.g., Wood & Wilson, 2012) or work to understand the causal mechanisms behind the quiet eye (e.g., Harris et al., 2019). Another potential applied implication concerns dual-training. The present thesis has shown at various points that EF and VA are divergent but related constructs. One way to potentially circumvent issues around transferability is to build a training programme that targets both the cognitive (i.e., EF) and visual (i.e., gaze) processes that are required in sport.

7.5 Limitations and Future Directions

The present thesis sought to bridge a gap between the theoretically proposed EFs of attentional control (inhibition, shifting, and updating; Eysenck et al., 2007) and the more typically examined VA variables (e.g., quiet eye; Vickers, 2007) during sport performance (i.e., soccer penalty kicks). In doing so, the present thesis has extended theoretical and applied understanding of attentional control. However, there are some limitations and future directions that should be mentioned. One key extension of ACT-S were the antecedents of anxiety. Specifically, ACT-S proposed that situational pressure influences attention in anxious individuals and that previous errors can influence attention. The present thesis focused on situational pressure and replicated sporting scenarios where individuals may feel anxious. As a result, the present thesis is limited in its ability to comment on the specific role of previous errors upon subsequent performance. Future work should look to examine how an error effects future sporting performance. One reason the present thesis was unable to comment on errors is partially due to task design (i.e., the soccer penalty task). In order to maintain ecological validity (Wood & Wilson, 2011) this thesis adopted a single-penalty design however, this meant observing how a missed penalty impacted subsequent penalties was not possible. The longitudinal design did allow for multiple penalties to be observed from the same individual but whether a missed penalty at timepoint 1 was followed by another miss at timepoint 2 was not part of the hypothesis, therefore future work is encouraged to utilised another task.

The present thesis is limited in its capacity to comment on the trainability and transfer of EFs and VA for sports performance. The topic of trainability, and the subsequent transfer, is a hot topic in the area of EF and VA (Scharfen & Memmert, 2021). With no real training protocol in the present thesis, it is difficult to comment definitively on this important subject matter. However, the present thesis does outline that domain-general EF tasks were related to objective soccer penalty performance through certain VA mediators (Chapter 5). Chapter 6, however, then suggested that, in general, EF was not a strong influencer of soccer penalty performance over time and therefore, training experiments may be best considering training protocols that include both EF and VA (potentially starting with search rate and inhibition). There is currently a lack of tasks with sport-specific designs intended to measure lower-order EFs. Therefore, future work is encouraged to build this gap by designing and validating such tasks before examining whether trainability and transfer is more consistent as a result (i.e., utility of domain-specific vs domain-general measurement).

7.6 Conclusion

Across four studies the present thesis helped showcase that attention can be broken into EF and VA and that the two are positively related and important for soccer penalty performance. Initially, this thesis outlined that research was particularly lacking in regard to how the lower-order model of EF (i.e., inhibition, shifting, and updating) and VA related before explicitly modelling this relationship with CFA. It was also noted that effectiveness and efficiency are not the same and that research should at least consider this distinction when they are examining sport performance under pressure. Next, a cross-sectional experimental study showed that the EF-soccer penalty performance relationship was mediated by VA. Finally, longitudinal results were mixed as VA appears to influence soccer penalty performance over time, but not EF. However, the combination of search rate and inhibition may be a fruitful avenue for future research. In sum, there appears to be a joint effect of EF and VA on sport performance and future research should look into dual-training paradigms that improve overall perceptual-cognition in athletes.

References

References preceded with an asterisk were included in the systematic review.

Abt, G., Boreham, C., Davison, G., Jackson, R., Nevill, A., Wallace, E., & Williams, M. (2020). Power, precision, and sample size estimation in sport and exercise science research. *Journal of Sport Sciences*, *38*(17), 1933-1935.

Adjerid, I., & Kelley, K. (2018). Big data in psychology: A framework for research advancement. *American Psychologist*, *73*(7), 899.

*Afonso, J., & Mesquita, I. (2013). Skill-based differences in visual search behaviours and verbal reports in a representative film-based task in volleyball. *International Journal of Performance Analysis in Sport*, *13*(3), 669-677.

*Afonso, J., Garganta, J., Mcrobert, A., Williams, A. M., & Mesquita, I. (2012). The perceptual cognitive processes underpinning skilled performance in volleyball: Evidence from eye-movements and verbal reports of thinking involving an in situ representative task. *Journal of Sports Science and Medicine*, *11*(2), 339.

*Alder, D., Ford, P. R., Causer, J., & Williams, A. M. (2014). The coupling between gaze behavior and opponent kinematics during anticipation of badminton shots. *Human Movement Science*, *37*, 167-179.

Allport, A. (1987). Selection for action: Some behvaioral and neurophysiological considerations of attention in action. In H. Heuer, & A. F. Sanders (Eds.), *Perspectives on perception and action* (pp. 395-419). New Jersey: Erlbaum.

Alting, T., & Markham, R. (1993). Text anxiety and distractibility. *Journal of Research in Personality*.

Anderson, P. (2002). Assessment and development of executive function (EF) during childhood. *Child Neuropsychology*, *8*(2), 71-82.

Anwyl-Irvine, A. L., Massonnié, J., Flitton, A., Kirkham, N., & Evershed, J. K. (2020). Gorilla in our midst: An online behavioral experiment builder. *Behavior Research Methods*, *52*(1), 388-407.

Anzender, C. P., & Bosel, R. (1998). Modulation of the spatial extent of the attentional focus in high-level volleyball players. *European Journal of Cognitive Psychology*, *10*, 247-267.

Arbuckle, J. L., & Wothke, W. (2004). *Structural equational modelling using AMOS: An introduction*. Chicago: SmallWaters.

Arent, S. M., & Landers, D. M. (2003). Arousal, anxiety, and performance: A reexamination of the inverted-U hypothesis. *Research Quarterly for Exercise and Sport*, *74*(4), 436-444.

Ariyo, O., Lesaffre, E., Verbeke, G., & Quintero, A. (2022). Model selection for Bayesian linear mixed models with longitudinal data: sensitivity to the choice of priors. *Communications in Statistics-Simulation and Computation*, *51*(4), 1591-1615.

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

Baddeley, A. (2010). Working memory. *Current Biology*, *20*(4), 136-140.

Baddeley, A. D., & Hitch, G. (2001). *Working memory in perspective*. Psychology Press.

Balk, Y. A., Adriaanse, M. A., De Ridder, D. T., & Evers, C. (2013). Coping under pressure: Employing emotion regulation strategies to enhance performance under pressure. *Journal of Sport and Exercise Psychology*, *35*(4), 408-418.

Ball, K. K., Beard, B. L., Roenker, D. L., Miller, R. L., & Griggs, D. S. (1988). Age and visual search – expanding the useful field of view. *Journal of the Optical Society of America A*, *5*, 2210-2219.

Balsamo, M., Cataldi, F., Carlucci, L., & Fairfield, B. (2018). Assessment of anxiety in older adults: a review of self-report measures. *Clinical Interventions in Aging*, *13*, 573.

Banerjee, A., Chitnis, U. B., Jadhav, S. L., Bhawalkar, J. S., & Chaudhury, S. (2009). Hypothesis testing, type I and type II errors. *Industrial Psychiatry Journal*, *18*(2), 127.

Bar-Haim, Y., Lamy, D., Pergamin, L., Bakermans-Kranenburg, M. J., & Van Ijzendoorn, M. H. (2007). Threat-related attentional bias in anxious and nonanxious individuals: a meta-analytic study. *Psychological Bulletin*, *133*(1), 1.

Barnard, J., McCulloch, R., & Meng, X. L. (2000). Modeling covariance matrices in terms of standard deviations and correlations, with application to shrinkage. *Statistica Sinica*, 1281-1311.

*Barton, H. (2013). *Identifying the visual information and processes underlying expert judgements of deceptive intent* [Doctoral dissertation, Brunel University School of Sport and Education].

Bater, L. R., & Jordan, S. S. (2019). Selective attention. *Encyclopedia of Personality and Individual Differences*, 1.

Baumeister, R. F. (1984). Choking under pressure: self-consciousness and paradoxical effects of incentives on skillful performance. *Journal of personality and social psychology*, *46*(3), 610.

Baumeister, R. F., & Showers, C. J. (1986). A review of paradoxical performance effects: Choking under pressure in sports and mental tests. *European Journal of Social Psychology*, *16*(4), 361-383.

Beavan, A., Spielmann, J., Mayer, J., Skorski, S., Meyer, T., & Fransen, J. (2020). The rise and fall of executive functions in high-level football players. *Psychology of Sport and Exercise*, *49*, 101677.

Beck, A. T., Epstein, N., Brown, G., & Steer, R. A. (1988). An inventory for measuring clinical anxiety: Psychometric properties. *Journal of Consulting and Clinical Psychology*, *56*, 893-897.

Beilock, S. L., & Carr, T. H. (2001). On the fragility of skilled performance: What governs choking under pressure?. *Journal of Experimental Psychology: General*, *130*(4), 701.

Berenbaum, H. (2010). An initiation–termination two-phase model of worrying. *Clinical Psychology Review*, *30*(8), 962-975.

Binsch, O., Oudejans, R. R., Bakker, F. C., & Savelsbergh, G. J. (2010). Ironic effects and final target fixation in a penalty shooting task. *Human Movement Science*, *29*(2), 277-288.

*Bishop, D. (2016). Effects of spoken cues on decision-making in netball: An eye movement study. *International Journal of Sport Psychology*, *47*(1), 1-12.

*Bishop, D., Kuhn, G., & Maton, C. (2014). Telling people where to look in a soccer-based decision task: A nomothetic approach. *Journal of Eye Movement Research*, *7*(2).

Blascovich, J. (2008). Challenge and threat. In A. J. Elliot (Ed.) *Handbook of approach and avoidance motivation* (pp. 431-445). New York: Psychology Press.

Booth, M. (2000). Assessment of physical activity: an international perspective. *Research Quarterly for Exercise and Sport*, *71*(sup2), 114-120.

Borenstein, M., Hedges, L. V., Higgins, J. P., & Rothstein, H. R. (2011). *Introduction to meta-analysis*. Chichester, U.K: John Wiley & Sons.

Boyd, L., Berardi, V., Hughes, D., Cibrian, F., Johnson, J., Sean, V., DelPizzo-Cheng, E., Mackin, B., Tusneem, A., Mody, R., Jones, S., & Lotich, K. (2022). Manipulating image luminance to improve eye gaze and verbal behavior in autistic children. *Humanities and Social Sciences Communications*, *9*(1), 1-9.

Brams, S., Ziv, G., Levin, O., Spitz, J., Wagemans, J., Williams, A. M., & Helsen, W. F. (2019). The relationship between gaze behavior, expertise, and performance: A systematic review. *Psychological Bulletin*, *145*(10), 980.

Brimmell, J., Parker, J., Wilson, M. R., Vine, S. J., & Moore, L. J. (2019). Challenge and threat states, performance, and attentional control during a pressurized soccer penalty task. *Sport, Exercise, and Performance Psychology*, *8*(1), 63.

Broadbent, D. (1958). *Perception and communication.* London: Pergamon Press.

Brugnera, A., Zarbo, C., Adorni, R., Tasca, G. A., Rabboni, M., Bondi, E., Compare, A., & Sakatani, K. (2017). Cortical and cardiovascular responses to acute stressors and their relations with psychological distress. *International Journal of Psychophysiology*, *114*, 38-46.

Bulger, E., Shinn-Cunningham, B. G., & Noyce, A. L. (2021). Distractor probabilities modulate flanker task performance. *Attention, Perception, & Psychophysics*, *83*(2), 866-881.

Burnham, K. P., & Anderson, D. R. (2002). *Model selection and inference: A practical information-theoretic approach* (2nd Ed.). New York: Springer.

Burris, K., Liu, S., & Appelbaum, L. (2020). Visual-motor expertise in athletes: Insights from semiparametric modelling of 2317 athletes tested on the Nike SPARQ Sensory Station. *Journal of Sports Sciences*, *38*(3), 320-329.

*Buszard, T., Farrow, D., & Kemp, J. (2013). Examining the influence of acute instructional approaches on the decision-making performance of experienced team field sport players. *Journal of Sports Sciences*, *31*(3), 238-247.

Carlucci, L., Watkins, M. W., Sergi, M. R., Cataldi, F., Saggino, A., & Balsamo, M. (2018). Dimensions of anxiety, age, and gender: Assessing dimensionality and measurement invariance of the State-Trait for Cognitive and Somatic Anxiety (STICSA) in an Italian sample. *Frontiers in Psychology*, *9*, 2345.

Casler, K., Bickel, L., & Hackett, E. (2013). Separate but equal? A comparison of participants and data gathered via Amazon's MTurk, social media, and face-to-face behavioral testing. *Computers in Human Behavior, 29*(6), 2156-2160.

*Castro, H. D. O., Praça, G. M., Costa, G. D. C. T., Pedrosa, G. F., & Greco, P. J. (2016). Visual behavior and the quality of decision-making on volleyball. *Revista Brasileira de Cineantropometria & Desempenho Humano, 18*, 638-647.

*Catteeuw, P., Helsen, W., Gilis, B., Van Roie, E., & Wagemans, J. (2009). Visual scan patterns and decision-making skills of expert assistant referees in offside situations. *Journal of Sport and Exercise Psychology, 31*(6), 786-797.

Chen, J., Li, Y., Zhang, G., Jin, X., Lu, Y., & Zhou, C. (2019). Enhanced inhibitory control during re-engagement processing in badminton athletes: An event-related potential study. *Journal of Sport and Health Science, 8*(6), 585-594.

Chung, Y., Rabe-Hesketh, S., Dorie, V., Gelman, A., & Liu, J. (2013). A nondegenerate penalized likelihood estimator for variance parameters in multilevel models. *Psychometrika*, *78*(4), 685-709.

Cisek, P. (2012). Making decisions through a distributed consensus. *Current Opinion in Neurobiology*, *22*(6), 927-936.

Comrey, A. L., & Lee, H. B. (1992). *A first course in factor analysis*. New Jersey: Lawrence Eribaum Associates.

Cook, R. D. (1977). Detection of influential observation in linear regression. *Technometrics*, *19*(1), 15-18.

Corbetta, M. (1998). Frontoparietal cortical networks for directing attention and the eye to visual locations: identical, independent, or overlapping neural systems?. *Proceedings of the National Academy of Sciences*, *95*(3), 831-838.

Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience*, *3*(3), 201-215.

Craft, L. L., Magyar, T. M., Becker, B. J., & Feltz, D. L. (2003). The relationship between the Competitive State Anxiety Inventory-2 and sport performance: A meta-analysis. *Journal of Sport and Exercise Psychology*, *25*(1), 44-65.

*Crespi, S., Robino, C., Silva, O., & De'Sperati, C. (2012). Spotting expertise in the eyes: Billiards knowledge as revealed by gaze shifts in a dynamic visual prediction task. *Journal of Vision*, *12*(11), 30-30.

Crump, M. J., McDonnell, J. V., & Gureckis, T. M. (2013). Evaluating Amazon's Mechanical Turk as a tool for experimental behavioral research. *PloS One*, *8*(3), e57410.

*del Campo, V., & Gracia, I. (2018). Exploring Visual Patterns and Judgments Predicated on Role Specificity: Case Studies of Expertise in Gymnastics. *Current Psychology*, *37*(4).

*del Campo, V., Farinas, A. C., Marquez, F. J. D., & Martin, J. M. (2018). The influence of refereeing experiences judging offside actions in football. *Psychology of Sport and Exercise*, *37*, 139-145.

Dennis, R. E., Boddington, S. J. A., & Funnell, N. J. (2007). Self-report measures of anxiety: are they suitable for older adults?. *Aging and Mental Health*, *11*(6), 668-677.

Derakshan, N. & Eysenck, M. W. (1998). Working memory capacity in high trait-anxious and repressor groups. *Cognition and Emotion*, *12*(5), 697-713.

Derakshan, N., & Eysenck, M. W. (2009). Anxiety, processing efficiency, and cognitive performance: New developments from attentional control theory. *European Psychologist*, *14*(2), 168-176.

Derryberry, D., & Tucker, D. M. (1994). Motivating the focus of attention. In P. M. Niedenthal, & S. Kitayama (Eds.), *The heart's eye: Emotional influences in perception and attention* (pp. 167-196). San Diego: Academic Press.

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*, 135-168.

Diamond, A., & Ling, D. S. (2016). Conclusions about interventions, programs, and approaches for improving executive functions that appear justified and those that, despite much hype, do not. *Developmental Cognitive Neuroscience*, *18*, 34-48.

*Dicks, M., Button, C., & Davids, K. (2010). Examination of gaze behaviors under in situ and video simulation task constraints reveals differences in information pickup for perception and action. *Attention, Perception, and Psychophysics*, *72*(3), 706-720.

Downs, S. H., & Black, N. (1998). The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *Journal of Epidemiology & Community Health*, *52*(6), 377-384.

Ducrocq, E. (2019). *Understanding the neurocognitive mechanisms of sport performance under pressure through cognitive training, [Doctoral dissertation, Birkbeck University].* Online Repository of Birkbeck Institutional Theses.

*Ducrocq, E., Wilson, M., Smith, T. J., & Derakshan, N. (2017). Adaptive working memory training reduces the negative impact of anxiety on competitive motor performance. *Journal of Sport and Exercise Psychology*, *39*(6), 412-422.

*Ducrocq, E., Wilson, M., Vine, S., & Derakshan, N. (2016). Training attentional control improves cognitive and motor task performance. *Journal of sport and exercise psychology*, *38*(5), 521-533.

DuRant, R. H. (1994). Checklist for the evaluation of research articles. *Journal of Adolescent Health*, *15*(1), 4-8.

Edwards, M. S., Burt, J. S., & Lipp, O. V. (2006). Selective processing of masked and unmasked verbal threat material in anxiety: Influence of an immediate acute stressor. *Cognition and Emotion*, *20*(6), 812-835.

Edwards, E. J., Edwards, M. S., & Lyvers, M. (2015). Cognitive trait anxiety, situational stress, and mental effort predict shifting efficiency: Implications for attentional control theory. *Emotion*, *15*(3), 350.

Edwards, M. S., Edwards, E. J., & Lyvers, M. (2016). Cognitive trait anxiety, stress and effort interact to predict inhibitory control. *Cognition and Emotion, 31*(4), 671-686.

Edwards, T., Kingston, K., Hardy, L., & Gould, D. (2002). A qualitative analysis of catastrophic performances and the associated thoughts, feelings and emotions. *The Sport Psychologist*, *16*, 1-19.

Emmonds, S., Heyward, O., & Jones, B. (2019). The challenge of applying and undertaking research in female sport. *Sports Medicine-Open*, *5*(1), 1-4.

Erickson, K. I., Hillman, C. H., & Kramer, A. F. (2015). Physical activity, brain, and cognition. *Current Opinion in Behavioral Sciences*, *4,* 27-32.

Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review*, *100*(3), 363.

Eysenck, M. W. (1992). *Anxiety: The cognitive perspective.* Hove, England; Erlbaum.

Eysenck, M. W., & Calvo, M. G. (1992). Anxiety and performance: The processing efficiency theory. *Cognition and Emotion*, *6*(6), 409-434.

Eysenck, M. W., & Wilson, M. R. (2016). Sporting performance, pressure, and cognition: Introducing attentional control theory: Sport. In D. Groome, & M. Eysenck (Eds.), *An introduction to applied cognitive psychology* (2nd ed., pp. 329-350). London: Routledge.

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: attentional control theory. *Emotion*, *7*(2), 336.

Faubert, J., & Sidebottom, L. (2012). Perceptual-cognitive training of athletes. *Journal of Clinical Sport Psychology*, *6*(1), 85-102.

Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2009). Statistical power analyses using G* Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, *41*(4), 1149-1160.

Field, A. (2013). *Discovering statistics using IBM SPSS statistics* (4th Ed). Sage.

Filaire, E., Sagnol, M., Ferrand, C., Maso, F., & Lac, G. (2001). Psychophysiological stress in judo athletes during competitions. *Journal of Sports Medicine and Physical Fitness*, *41*(2), 263-268.

*Fortin-Guichard, D., Laflamme, V., Julien, A. S., Trottier, C., & Grondin, S. (2020). Decision-making and dynamics of eye movements in volleyball experts. *Scientific Reports*, *10*(1), 1-14.

*Frank, C., Land, W. M., & Schack, T. (2016). Perceptual-cognitive changes during motor learning: The influence of mental and physical practice on mental representation, gaze behavior, and performance of a complex action. *Frontiers in Psychology*, *6*, 1981.

Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: a latent-variable analysis. *Journal of Experimental Psychology: General*, *133*(1), 101.

Friedman, N. P., Miyake, A., Altamirano, L. J., Corley, R. P., Young, S. E., Rhea, S. A., & Hewitt, J. K. (2016). Stability and change in executive function abilities from late adolescence to early adulthood: A longitudinal twin study. *Developmental Psychology*, *52*(2), 326.

Friedman, N. P., Miyake, A., Young, S. E., DeFries, J. C., Corley, R. P., & Hewitt, J. K. (2008). Individual differences in executive functions are almost entirely genetic in origin. *Journal of experimental psychology: General*, *137*(2), 201.

Furley, P. A., & Memmert, D. (2012). Working memory capacity as controlled attention in tactical decision making. *Journal of Sport and Exercise Psychology*, *34*(3), 322-344.

Furley, P., & Memmert, D. (2013). "Whom should I pass to?" The more options the more attentional guidance from working memory. *PloS One*, *8*(5), e62278.

Furley, P., & Wood, G. (2016). Working memory, attentional control, and expertise in sports: A review of current literature and directions for future research. *Journal of Applied Research in Memory and Cognition*, *5*(4), 415-425.

Furley, P., Noël, B., & Memmert, D. (2017). Attention towards the goalkeeper and distraction during penalty shootouts in association football: a retrospective analysis of penalty shootouts from 1984 to 2012. *Journal of Sports Sciences*, *35*(9), 873-879.

Gaillard, C., & Ben Hamed, S. (2022). The neural bases of spatial attention and perceptual rhythms. *European Journal of Neuroscience, 55*(11-12), 3209-3223.

Genaidy, A. M., Lemasters, G. K., Lockey, J., Succop, P., Deddens, J., Sobeih, T., & Dunning, K. (2007). An epidemiological appraisal instrument–a tool for evaluation of epidemiological studies. *Ergonomics, 50*(6), 920-960.

Gerber, M., Brand, S., Lindwall, M., Elliot, C., Kalak, N., Herrmann, C., Puhse, U., & Jonsdottir, I. H. (2012). Concerns regarding hair cortisol as a biomarker of chronic stress in exercise and sport science. *Journal of Sports Science and Medicine*, *11*(4), 571.

Goldstein, D. S. (2010). Adrenal responses to stress. *Cellular and Molecular Neurobiology, 30*(8), 1433-1440.

Gopalakrishnan, S., & Ganeshkumar, P. (2013). Systematic reviews and meta-analysis: understanding the best evidence in primary healthcare. *Journal of Family Medicine and Primary Care, 2*(1), 9.

Gordon, B., & Caramazza, A. (1982). Lexical decision for open-and closed-class words: Failure to replicate differential frequency sensitivity. *Brain and Language*, *15*(1), 143-160.

*Gorman, A. D., Abernethy, B., & Farrow, D. (2015). Evidence of different underlying processes in pattern recall and decision-making. *Quarterly Journal of Experimental Psychology*, *68*(9), 1813-1831.

*Gredin, N. V., Bishop, D. T., Broadbent, D. P., Tucker, A., & Williams, A. M. (2018). Experts integrate explicit contextual priors and environmental information to improve anticipation efficiency. *Journal of Experimental Psychology: Applied*, *24*(4), 509.

Green, P., & MacLeod, C. J. (2015). SIMR: An R package for power analysis of generalized linear mixed models by simulation. *Methods in Ecology and Evolution, 7*, 493-498.

Grol, M., & Raedt, R. D. (2014). Effects of positive mood on attentional breadth for emotional stimuli. *Frontiers in Psychology, 5*, 1277.

Gropel, P., & Mesagno, C. (2019). Choking interventions in sports: A systematic review. *International Review of Sport and Exercise Psychology*, *12*(1), 176-201.

Gros, D. F., Antony, M. M., Simms, L. J., & McCabe, R. E. (2007). Psychometric properties of the state-trait inventory for cognitive and somatic anxiety (STICSA): comparison to the state-trait anxiety inventory (STAI). *Psychological Sssessment*, *19*(4), 369.

*Hagemann, N., Schorer, J., Cañal-Bruland, R., Lotz, S., & Strauss, B. (2010). Visual perception in fencing: Do the eye movements of fencers represent their information pickup?. *Attention, Perception, & Psychophysics*, *72*(8), 2204-2214.

Hagyard, J., Brimmell, J., Edwards, E. J., & Vaughan, R. S. (2021). Inhibitory control across athletic expertise and its relationship with sport performance. *Journal of Sport and Exercise Psychology*, *43*(1), 14-27.

Hammer, C., & Podlog, L. (2016). Motivation and marathon running. In C. Zinner & B. Erlich (Eds.), *Marathon running: Physiology, psychology, nutrition and training aspects* (pp. 107-124). Springer, Champaign.

*Hancock, D. J., & Ste-Marie, D. M. (2013). Gaze behaviors and decision making accuracy of higher-and lower-level ice hockey referees. *Psychology of Sport and Exercise*, *14*(1), 66-71.

Hanin, Y. (2010). From anxiety to performance-related emotions in top-level sport. *Kalokagathia*, *2*(3), 59-76.

Hanton, S., Neil, R., Mellalieu, S. D., & Fletcher, D. (2008). Competitive experience and performance status: An investigation into multidimensional anxiety and coping. *European Journal of Sport Science*, *8*(3), 143-152.

Hardy, L., & Parfitt, G. (1991). A catastrophe model of anxiety and performance. *British journal of psychology*, *82*(2), 163-178.

Harris, D. J., Allen, K. L., Vine, S. J., & Wilson, M. R. (2021b). A systematic review and meta-analysis of the relationship between flow states and performance. *International Review of Sport and Exercise Psychology*, 1-29.

Harris, D. J., Vine, S. J., Eysenck, M. W., & Wilson, M. R. (2021a). Psychological pressure and compounded errors during elite-level tennis. *Psychology of Sport and Exercise*, *56*, 101987.

Harris, D. J., Vine, S. J., Eysenck, M. W., & Wilson, M. R. (2019). To err again is human: Exploring a bidirectional relationship between pressure and performance failure feedback. *Anxiety, Stress, and Coping*, *32*(6), 670-678.

*Harris, D. J., Wilson, M. R., Crowe, E. M., & Vine, S. J. (2020). Examining the roles of working memory and visual attention in multiple object tracking expertise. *Cognitive Processing*, *21*(2), 209-222.

Harvey, R. J., Billings, R. S., & Nilan, K. J. (1985). Confirmatory factor analysis of the Job Diagnostic Survey: Good news and bad news. *Journal of Applied Psychology*, *70*(3), 461.

Hauke, J. & Kossowski, T. (2011). Comparison of values of Pearson's and Spearman's correlation coefficients on the same sets of data. *Quaestiones Geographicae, 30*(2), 87-93.

Hayes, A. F. (2018). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach*. London: Guilford.

Hedge, C., Powell, G., & Sumner, P. (2018). The reliability paradox: Why robust cognitive tasks do not produce reliable individual differences. *Behavior Research Methods*, *50*(3), 1166-1186.

Hilbig, B. E. (2016). Reaction time effects in lab-versus Web-based research: Experimental evidence. *Behavior Research Methods*, *48*(4), 1718-1724.

Hollenbeck, J. R., Klein, H. J., O'Leary, A. M., & Wright, P. M. (1989). Investigation of the construct validity of a self-report measure of goal commitment. *Journal of Applied Psychology*, *74*(6), 951.

Horikawa, M., & Yagi, A. (2012). The relationships among trait anxiety, state anxiety and the goal performance of penalty shoot-out by university soccer players. *PloS One*, *7*(4), e35727.

Howell, D., Osternig, L., Van Donkelaar, P., Mayr, U., & Chou, L. S. (2013). Effects of concussion on attention and executive function in adolescents. *Medicine & Science in Sports & Exercise*, *45*(6), 1030-1037.

Hu, L. T., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal*, *6*(1), 1-55.

Hughes, M. M., Linck, J. A., Bowles, A. R., Koeth, J. T., & Bunting, M. F. (2014). Alternatives to switch-cost scoring in the task-switching paradigm: Their reliability and increased validity. *Behavior Research Methods*, *46*(3), 702-721.

Huijgen, B. C., Leemhuis, S., Kok, N. M., Verburgh, L., Oosterlaan, J., Elferink-Gemser, M. T., & Visscher, C. (2015). Cognitive functions in elite and sub-elite youth soccer players aged 13 to 17 years. *PLoS One*, *10*(12), e0144580.

Huttermann, S., & Memmert, D. (2017). The attention window: A narrative review of limitations and opportunities influencing the focus of attention. *Research Quarterly for Exercise and Sport*, *88*(2), 169-183.

Ionescu, T. (2012). Exploring the nature of cognitive flexibility. *New Ideas in Psychology*, *30*(2), 190-200.

Ishihara, T., & Mizuno, M. (2018). Effects of tennis play on executive function in 6–11-year-old children: A 12-month longitudinal study. *European Journal of Sport Science*, *18*(5), 741-752.

Itti, L., & Koch, C. (2001). Computational modelling of visual attention. *Nature Reviews Neuroscience*, *2*(3), 194-203.

Jacobson, J., & Matthaeus, L. (2014). Athletics and executive functioning: How athletic participation and sport type correlate with cognitive performance. *Psychology of Sport and Exercise*, *15*(5), 521-527.

Jaeggi, S. M., Seewer, R., Nirkko, A. C., Eckstein, D., Schroth, G., Groner, R., & Gutbrod, K. (2003). Does excessive memory load attenuate activation in the prefrontal cortex?

Load-dependent processing in single and dual tasks: functional magnetic resonance imaging study. *NeuroImage*, *19*(2), 210-225.

Jaeggi, S. M., Buschkuehl, M., Perrig, W. J., & Meier, B. (2010). The concurrent validity of the N-back task as a working memory measure. *Memory*, *18*(4), 394-412.

Janelle, C. M., Singer, R. N., & Williams, A. M. (1991). External distraction and attentional narrowing: Visual search evidence. *Journal of Sport and Exercise Psychology*, *21*(1), 70-91.

Jones, G. (1991). Recent developments and current issues in competitive state anxiety research. *The Psychologist*, *4*, 152-155.

Kassner, M., Patera, W., & Bulling, A. (2014, September). Pupil: An open source platform for pervasive eye tracking and mobile gaze-based interaction. In *Proceedings of the 2014 ACM international joint conference on pervasive and ubiquitous computing: Adjunct publication* (pp. 1151-1160).

Kenny, D. A. (2015). *Measuring model fit*. Retrieved September 29th 2021, from http://davidakenny.net/cm/fit.htm

Kenny, D. A. (2017, February). MedPower: An interactive tool for the estimation of power in tests of mediation [Computer software]. Available from https://davidakenny.shinyapps.io/MedPower/

Klein, H. J., Wesson, M. J., Hollenbeck, J. R., Wright, P. M., & DeShon, R. P. (2001). The assessment of goal commitment: A measurement model meta-analysis. *Organizational Behavior and Human Decision Processes*, *85*(1), 32-55.

Kline, R. B. (1998). *Principles and practice of structural equation modeling*. New York: Guilford Publications.

Kline, R. B. (2005). *Principles and practice of structural equation modelling* (2nd Ed.). New York: Guilford Publications.

*Klostermann, A. (2019). Picking an apple from a tree: Response-selection demands, inhibition requirements, and the functionality of the Quiet Eye in a far-aiming task. *Quarterly Journal of Experimental Psychology*, *72*(5), 1233-1241.

*Klostermann, A. (2020). Perception and action in a far-aiming task: Inhibition demands and the functionality of the Quiet Eye in motor performance. *Psychology of Sport and Exercise*, 101736.

Klostermann, A., & Hossner, E. J. (2018). The Quiet Eye and motor expertise: Explaining the "efficiency paradox". *Frontiers in Psychology*, *9*, 104.

Klostermann, A., & Moeinirad, S. (2020). Fewer fixations of longer duration? Expert gaze behavior revisited. *German Journal of Exercise and Sport Research*, *50*(1), 146-161.

Klostermann, A., Kredel, R., & Hossner, E. J. (2014). On the interaction of attentional focus and gaze: the quiet eye inhibits focus-related performance decrements. *Journal of Sport and Exercise Psychology*, *36*(4), 392-400.

*Klostermann, A., Vater, C., Kredel, R., & Hossner, E. J. (2015). Perceptual training in beach volleyball defence: different effects of gaze-path cueing on gaze and decision-making. *Frontiers in Psychology*, *6*, 1834.

Koch, P., & Krenn, B. (2021). Executive functions in elite athletes–Comparing open-skill and closed-skill sports and considering the role of athletes' past involvement in both sport categories. *Psychology of Sport and Exercise*, *55*, 101925.

Kotsopoulos, D., & Lee, J. (2012). A naturalistic study of executive function and mathematical problem-solving. *The Journal of Mathematical Behavior*, *31*(2), 196-208.

Krane, V. (1992). Conceptual and methodological considerations in sport anxiety research: From the inverted-U hypothesis to catastrophe theory. *Quest*, *44*(1), 72-87.

Krane, V. (1994). The mental readiness form as a measure of competitive state anxiety. *The Sport Psychologist*, *8*(2), 189-202.

Kredel, R., Vater, C., Klostermann, A., & Hossner, E. J. (2017). Eye-tracking technology and the dynamics of natural gaze behavior in sports: A systematic review of 40 years of research. *Frontiers in Psychology*, *8*, 1845.

Krenn, B., Finkenzeller, T., Würth, S., & Amesberger, G. (2018). Sport type determines differences in executive functions in elite athletes. *Psychology of Sport and Exercise*, *38*, 72-79.

Kuhn, W. (1988). Penalty-kick strategies for shooters and goalkeepers. *Science and Football*, 489-492.

Langenecker, S. A., Zubieta, J. K., Young, E. A., Akil, H., & Nielson, K. A. (2007). A task to manipulate attentional load, set-shifting, and inhibitory control: Convergent validity and test–retest reliability of the Parametric Go/No-Go Test. *Journal of Clinical and Experimental Neuropsychology*, *29*(8), 842-853.

Lazarus, R. S. (1966). *Psychological stress and the coping process.* London: McGraw-Hill.

Lazarus, R. S. (1999). *Stress and emotion: A new synthesis.* New York: Springer.

Lazarus, R. S., & Folkman, S. (1984). *Stress, appraisal, and coping.* New York: Springer.

Lebeau, J. C., Liu, S., Sáenz-Moncaleano, C., Sanduvete-Chaves, S., Chacón-Moscoso, S., Becker, B. J., & Tenenbaum, G. (2016). Quiet eye and performance in sport: A meta-analysis. *Journal of Sport and Exercise Psychology*, *38*(5), 441-457.

Lee, S. Y., Poon, W. Y., & Bentler, P. M. (1990). Full maximum likelihood analysis of structural equation models with polytomous variables. *Statistics & Probability Letters*, *9*(1), 91-97.

Lewis, B. P., & Linder, D. E. (1997). Thinking about choking? Attentional processes and paradoxical performance. *Personality and Social Psychology Bulletin*, *23*(9), 937-944.

*Lex, H., Essig, K., Knoblauch, A., & Schack, T. (2015). Cognitive representations and cognitive processing of team-specific tactics in soccer. *PloS One*, *10*(2), e0118219.

Liu, J., Shen, K., & Li, H. (2019). How state anxiety and attentional bias interact with each other: The moderating effect of cognitive appraisal. *Attention, Perception, & Psychophysics*, *81*, 694-706.

Locke, E. A., & Latham, G. P. (2019). The development of goal setting theory: A half century retrospective. *Motivation Science*, *5*(2), 93.

Logan, G. D., & Cowan, W. B. (1984). On the ability to inhibit thought and action: A theory of an act of control. *Psychological Review, 91*(3), 295.

Lohse, K. R., Shen, J., & Kozlowski, A. J. (2020). Modelling longitudinal outcomes: A contrast of two methods. *Journal for Motor Learning and Development, 8*(1), 145-165.

*Lorains, M., Panchuk, D., Ball, K., & MacMahon, C. (2014). The effect of an above real time decision-making intervention on visual search behaviour. *International Journal of Sports Science and Coaching*, *9*(6), 1383-1392.

*Luo, X., Zhang, L., & Wang, J. (2017). The benefits of working memory capacity on attentional control under pressure. *Frontiers in Psychology*, *8,* 1105.

MacCallum, R. C., Browne, M. W., & Sugawara, H. M. (1996). Power analysis and determination of sample size for covariance structure modeling. *Psychological Methods*, *1*(2), 130.

MacCallum, R. C., Widaman, K. F., Preacher, K. J., & Hong, S. (2001). Sample size in factor analysis: The role of model error. *Multivariate Behavioral Research*, *36*(4), 611-637.

Magnusson, A. (1996). Validation of the seasonal pattern assessment questionnaire (SPAQ). *Journal of Affective Disorders*, *40*(3), 121-129.

Mann, D. T., Williams, A. M., Ward, P., & Janelle, C. M. (2007). Perceptual-cognitive expertise in sport: A meta-analysis. *Journal of Sport and Exercise Psychology*, *29*(4), 457-478.

Marsh, H. W., Hau, K. T., & Wen, Z. (2004). In search of golden rules: Comment on hypothesis-testing approaches to setting cutoff values for fit indexes and dangers in overgeneralizing Hu and Bentler's (1999) findings. *Structural Equation Modelling, 11*, 320-341.

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

Martenuik, R. G. (1976). *Information processing in motor skills*. New York: Holt, Rinehart & Winston.

Maydeu-Olivares, A., Shi, D., & Rosseel, Y. (2018). Assessing fit in structural equation models: A Monte-Carlo evaluation of RMSEA versus SRMR confidence intervals and tests of close fit. *Structural Equation Modeling: A Multidisciplinary Journal*, *25*(3), 389-402.

*McRobert, A. P., Ward, P., Eccles, D. W., & Williams, A. M. (2011). The effect of manipulating context-specific information on perceptual–cognitive processes during a simulated anticipation task. *British Journal of Psychology*, *102*(3), 519-534.

Meades, R., & Ayers, S. (2011). Anxiety measures validated in perinatal populations: a systematic review. *Journal of Affective Disorders*, *133*(1-2), 1-15.

Mellalieu, S. D., Hanton, S., & Thomas, O. (2009). The effects of a motivational general-arousal imagery intervention upon preperformance symptoms in male rugby union players. *Psychology of Sport and Exercise*, *10*(1), 175-185.

Memmert, D., Simons, D. J., & Grimme, T. (2009). The relationship between visual attention and expertise in sports. *Psychology of Sport and Exercise*, *10*(1), 146-151.

Mesagno, C., & Hill, D. M. (2013). Definition of choking in sport: Re-conceptualization and debate. *International Journal of Sport Psychology, 44*, 267-277.

Mesagno, C., Marchant, D., & Morris, T. (2009). Alleviating choking: The sounds of distraction. *Journal of Applied Sport Psychology*, *21*(2), 131-147.

*Milazzo, N., Farrow, D., & Fournier, J. F. (2016). Effect of implicit perceptual-motor training on decision-making skills and underpinning gaze behavior in combat athletes. *Perceptual and Motor Skills*, *123*(1), 300-323.

Miller, J. (1991). Reaction time analysis with outlier exclusion: Bias varies with sample size. *The Quarterly Journal of Experimental Psychology*, *43*(4), 907-912.

Miyake, A., & Friedman, N. P. (2012). The nature and organization of individual differences in executive functions: Four general conclusions. *Current Directions in Psychological Science*, *21*(1), 8-14.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, *41*(1), 49-100.

Moffitt, T. E., Arseneault, L., Belsky, D., Dickson, N., Hancox, R. J., Harrington, H., Houts, R., Poulton, R., Roberts, B. W., Ross, S., Sears, M. R., Thomson, W. M., & Caspi, A. (2011). A gradient of childhood self-control predicts health, wealth, and public safety. *Proceedings of the National Academy of Sciences*, *108*(7), 2693-2698.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & Prisma Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS med*, *6*(7), e1000097.

*Moore, L. J., Harris, D. J., Sharpe, B. T., Vine, S. J., & Wilson, M. R. (2019). Perceptual-cognitive expertise when refereeing the scrum in rugby union. *Journal of Sports Sciences*, *37*(15), 1778-1786.

Moore, L. J., Vine, S. J., Wilson, M. R., & Freeman, P. (2012). The effect of challenge and threat states on performance: An examination of potential mechanisms. *Psychophysiology*, *49*(10), 1417-1425.

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*(6), 551-562.

Moran, A., Campbell, M., & Toner, J. (2019). Exploring the cognitive mechanisms of expertise in sport: Progress and prospects. *Psychology of Sport and Exercise*, *42*, 8-15.

*Mori, S., & Shimada, T. (2013). Expert anticipation from deceptive action. *Attention, Perception, and Psychophysics*, *75*(4), 751-770.

Morrison, G. E., Simone, C. M., Ng, N. F., & Hardy, J. L. (2015). Reliability and validity of the NeuroCognitive Performance Test, a web-based neuropsychological assessment. *Frontiers in Psychology*, *6*, 1652.

Moss, T. P., Lawson, V., & White, P. (2015). Identification of the underlying factor structure of the Derriford Appearance Scale 24. *PeerJ*, *3*, e1070.

Motter, B. C., & Simoni, D. A. (2008). Changes in the functional visual field during search with and without eye movements. *Vision Research*, *48*(22), 2382-2393.

Muthen, L. K., & Muthen, B. O. (2002). How to use a Monte Carlo study to decide on sample size and determine power. *Structural Equation Modeling: A Multidisciplinary Journal*, *9*(4), 599-620.

Nakagawa, S., & Schielzeth, H. (2013). A general and simple method for obtaining R2 from generalized linear mixed-effects models. *Methods in Ecology and Evolution, 4*(2), 133-142.

*Natsuhara, T., Kato, T., Nakayama, M., Yoshida, T., Sasaki, R., Matsutake, T., & Asai, T. (2020). Decision-Making While Passing and Visual Search Strategy During Ball Receiving in Team Sport Play. *Perceptual and Motor Skills*, *127*(2), 468-489.

Neath, A. A., & Cavanaugh, J. E. (2012). The Bayesian information criterion: background, derivation, and applications. *Wiley Interdisciplinary Reviews: Computational Statistics*, *4*(2), 199-203.

Neil, R. (2007). *(Re)conceptualizing competition stress in sport performers, [Doctoral dissertation, Swansea University].* ProQuest.

Nibbeling, N., Oudejans, R. R., & Daanen, H. A. (2012). Effects of anxiety, a cognitive secondary task, and expertise on gaze behavior and performance in a far aiming task. *Psychology of Sport and Exercise*, *13*(4), 427-435.

Nicholls, A. R., & Polman, R. C. (2007). Coping in sport: A systematic review. *Journal of Sports Sciences*, *25*(1), 11-31.

Nigg, C. R., Fuchs, R., Gerber, M., Jekauc, D., Koch, T., Krell-Roesch, J., Lippke, S., Mnich, C., Novak, B., Ju, Q., Sattler, M. C., Schmidt, S. C. E., van Poppel, M., Reimers, A. K., Wagner, P., Woods, C., & Woll, A. (2020). Assessing physical activity through questionnaires–A consensus of best practices and future directions. *Psychology of Sport and Exercise*, *50*, 101715.

North, J. S., Ward, P., Ericsson, A., & Williams, A. M. (2011). Mechanisms underlying skilled anticipation and recognition in a dynamic and temporally constrained domain. *Memory*, *19*(2), 155-168.

*North, J. S., Williams, A. M., Hodges, N., Ward, P., & Ericsson, K. A. (2009). Perceiving patterns in dynamic action sequences: Investigating the processes underpinning stimulus recognition and anticipation skill. *Applied Cognitive Psychology: The Official Journal of the Society for Applied Research in Memory and Cognition*, *23*(6), 878-894.

Nottelmann, E. D., & Hill, K. T. (1977). Test anxiety and off-task behavior in evaluative situations. *Child Development*, 225-231.

Otten, M. (2009). Choking vs. clutch performance: A study of sport performance under pressure. *Journal of Sport and Exercise Psychology*, *31*(5), 583-601.

Oudejans, R. R., & Nieuwenhuys, A. (2009). Perceiving and moving in sports and other high-pressure contexts. *Progress in Brain Research*, *174*, 35-48.

Oudejans, R. R., Kuijpers, W., Kooijman, C. C., & Bakker, F. C. (2011). Thoughts and attention of athletes under pressure: skill-focus or performance worries?. *Anxiety, Stress, & Coping*, *24*(1), 59-73.

*Page, J. L. (2009). *The development and effectiveness of perceptual training programme for coaches and judges in gymnastics* [Doctoral dissertation, University of Chester].

Panchuk, D., Davids, K., Sakadjian, A., MacMahon, C., & Parrington, L. (2013). Did you see that? Dissociating advanced visual information and ball flight constrains perception and action processes during one-handed catching. *Acta Psychologica*, *142*(3), 394-401.

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*(1), 325-355.

Pijpers, J. R., Oudejans, R. R., Holsheimer, F., & Bakker, F. C. (2003). Anxiety–performance relationships in climbing: a process-oriented approach. *Psychology of Sport and Exercise*, *4*(3), 283-304.

*Piras, A., Lobietti, R., & Squatrito, S. (2014). Response time, visual search strategy, and anticipatory skills in volleyball players. *Journal of Ophthalmology*, *2014*.

*Pizzera, A., Möller, C., & Plessner, H. (2018). Gaze behavior of gymnastics judges: Where do experienced judges and gymnasts look while judging?. *Research Quarterly for Exercise and Sport*, *89*(1), 112-119.

Polman, R. (2012). Elite athletes experiences of coping with stress. In J. Thatcher, M. Jones, & D. Lavellee (Eds.), *Coping and emotion in sport* (2nd ed., pp. 284-301). Abingdon: Routledge.

Posner, M. I. (2016). Orienting of attention: Then and now. *The Quarterly Journal of Experimental Psychology*, *69*(10), 1864-1875.

Posner, M. I., & Raichle, M. E. (1994). *Images of mind*. New York: Scientific American Library.

Preacher, K. J., & Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behavior Research Methods*, *40*(3), 879-891.

R Core Team. (2022). *R: A language and environment for statistical computing.* Vienna, Austria: R Foundation for Statistical Computing. Retrieved from https://www.R-project.org/

Radvansky, G. A., & Ashcraft, M. H. (2016). *Cognition, 6 Edition*. New Jersey, NJ: Pearson Education, Inc.

Ragland, J. D., Turetsky, B. I., Gur, R. C., Gunning-Dixon, F., Turner, T., Schroeder, L., Chan, R., & Gur, R. E. (2002). Working memory for complex figures: an fMRI comparison of letter and fractal n-back tasks. *Neuropsychology*, *16*(3), 370.

Ree, M. J., French, D., MacLeod, C., & Locke, V. (2008). Distinguishing cognitive and somatic dimensions of state and trait anxiety: Development and validation of the State-Trait Inventory for Cognitive and Somatic Anxiety (STICSA). *Behavioural and Cognitive Psychotherapy*, *36*(3), 313-332.

Reynolds, C. R. (1997). Forward and backward memory span should not be combined for clinical analysis. *Archives of Clinical Neuropsychology*, *12*(1), 29-40.

Ridderinkhof, K. R., van der Molen, M. W., Band, G. P., & Bashore, T. R. (1997). Sources of interference from irrelevant information: A developmental study. *Journal of Experimental Child Psychology*, *65*(3), 315-341.

*Roca, A., Ford, P. R., & Memmert, D. (2018). Creative decision making and visual search behavior in skilled soccer players. *PloS One*, *13*(7), e0199381.

*Roca, A., Ford, P. R., & Memmert, D. (2020). Perceptual-cognitive processes underlying creative expert performance in soccer. *Psychological Research*, 1-10.

*Roca, A., Ford, P. R., McRobert, A. P., & Williams, A. M. (2011). Identifying the processes underpinning anticipation and decision-making in a dynamic time-constrained task. *Cognitive Processing*, *12*(3), 301-310.

*Roca, A., Ford, P. R., McRobert, A. P., & Williams, A. M. (2013). Perceptual-cognitive skills and their interaction as a function of task constraints in soccer. *Journal of Sport and Exercise Psychology*, *35*(2), 144-155.

Roebuck, G. S., Urquhart, D. M., Che, X., Knox, L., Fitzgerald, P. B., Cicuttini, F. M., Lee, S., Segrave, R., & Fitzgibbon, B. M. (2020). Psychological characteristics associated with ultra-marathon running: An exploratory self-report and psychophysiological study. *Australian Journal of Psychology*, *72*(3), 235-247.

Rowe, G., Hirsh, J. B., & Anderson, A. K. (2007). Positive affect increases the breadth of attentional selection. *Proceedings of the National Academy of Sciences*, *104*(1), 383-388.

*Ryu, D., Abernethy, B., Mann, D. L., Poolton, J. M., & Gorman, A. D. (2013). The role of central and peripheral vision in expert decision making. *Perception*, *42*(6), 591-607.

*Ryu, D., Mann, D. L., Abernethy, B., & Poolton, J. M. (2016). Gaze-contingent training enhances perceptual skill acquisition. *Journal of Vision*, *16*(2), 2-2.

*Saez-Gallego, N. M., Vila-Maldonado, S., Abellan, J., & Contreras, O. R. (2018). Perceptive training of female youth volleyball blockers. *Revista Internacional de Medicina y Ciencias de la Actividad Física y del Deporte*, *18*(69).

Sakamoto, S., Takeuchi, H., Ihara, N., Ligao, B., & Suzukawa, K. (2018). Possible requirement of executive functions for high performance in soccer. *PloS One*, *13*(8), e0201871.

*Savelsbergh, G. J., Van der Kamp, J., Williams, A. M., & Ward, P. (2005). Anticipation and visual search behaviour in expert soccer goalkeepers. *Ergonomics*, *48*(11-14), 1686-1697.

*Savelsbergh, G. J., Williams, A. M., van der Kamp, J., & Ward, P. (2002). Visual search, anticipation and expertise in soccer goalkeepers. *Journal of Sports Sciences*, *20*(3), 279-287.

Scharfen, H. E., & Memmert, D. (2019). Measurement of cognitive functions in experts and elite athletes: A meta-analytic review. *Applied Cognitive Psychology*, *33*(5), 843-860.

Scharfen, H. E., & Memmert, D. (2021). Cognitive training in elite soccer players: evidence of narrow, but not broad transfer to visual and executive function. *German Journal of Exercise and Sport Research*, *51*(2), 135-145.

Shelton, J. T., Elliott, E. M., Hill, B. D., Calamia, M. R., & Gouvier, W. D. (2009). A comparison of laboratory and clinical working memory tests and their prediction of fluid intelligence. *Intelligence*, *37*(3), 283-293.

Singer, R. N. (2000). Performance and human factors: Considerations about cognition and attention for self-paced and externally-paced events. *Ergonomics*, *43*(10), 1661-1680.

Spielberger, C. C., Gorsuch, R. L., Lushene, R., Vagg, P. R., & Jacobs, G. A. (1983). *Manual for the State-Trait Anxiety Inventory*. Palo Alto, CA: Consulting Psychologists Press.

Spielberger, C. D. (1989). Stress and anxiety in sports. In D. Hackfort, & C. D. Spielbeger (Eds.), *Anxiety in sports: An international perspective* (pp. 3-17). New York: Hemisphere.

*Spitz, J., Put, K., Wagemans, J., Williams, A. M., & Helsen, W. F. (2016). Visual search behaviors of association football referees during assessment of foul play situations. *Cognitive Research: Principles and Implications*, *1*(1), 1-11.

Sullivan, G. M., & Feinn, R. (2012). Using effect size—or why the P value is not enough. *Journal of Graduate Medical Education*, *4*(3), 279.

Swann, C., Moran, A., & Piggott, D. (2015). Defining elite athletes: Issues in the study of expert performance in sport psychology. *Psychology of Sport and Exercise*, *16*, 3-14.

Swann, C., Rosenbaum, S., Lawrence, A., Vella, S. A., McEwan, D., & Ekkekakis, P. (2021). Updating goal-setting theory in physical activity promotion: A critical conceptual review. *Health Psychology Review*, *15*(1), 34-50.

Tabachnick, B. G., & Fidell, L. S. (2007). *Using multivariate statistics*. Boston: Allyn and Bacon.

*Takeuchi, T., & Inomata, K. (2009). Visual search strategies and decision making in baseball batting. *Perceptual and Motor Skills*, *108*(3), 971-980.

Timmis, M. A., Piras, A., & van Paridon, K. N. (2018). Keep your eye on the ball: The impact of an anticipatory fixation during successful and unsuccessful soccer penalty kicks. *Frontiers in Psychology*, *9*, 2058.

Tomporowski, P. D., Davis, C. L., Miller, P. H., & Naglieri, J. A. (2008). Exercise and children's intelligence, cognition, and academic achievement. *Educational Psychology Review*, *20*(2), 111-131.

Turner, M. J., Jones, M. V., Sheffield, D., & Cross, S. L. (2012). Cardiovascular indices of challenge and threat states predict competitive performance. *International Journal of Psychophysiology*, *86*(1), 48-57.

Turner, M. J., Jones, M. V., Sheffield, D., Slater, M. J., Barker, J. B., & Bell, J. J. (2013). Who thrives under pressure? Predicting the performance of elite academy cricketers using the cardiovascular indicators of challenge and threat states. *Journal of Sport and Exercise Psychology*, *35*(4), 387-397.

*Uchida, Y., Mizuguchi, N., Honda, M., & Kanosue, K. (2014). Prediction of shot success for basketball free throws: Visual search strategy. *European Journal of Sport Science*, *14*(5), 426-432.

*Vaeyens, R., Lenoir, M., Williams, A. M., & Philippaerts, R. M. (2007a). Mechanisms underpinning successful decision making in skilled youth soccer players: An analysis of visual search behaviors. *Journal of Motor Behavior*, *39*(5), 395-408.

*Vaeyens, R., Lenoir, M., Williams, A. M., Mazyn, L., & Philippaerts, R. M. (2007b). The effects of task constraints on visual search behavior and decision-making skill in youth soccer players. *Journal of Sport and Exercise Psychology*, *29*(2), 147-169.

van der Kamp, J. (2006). A field simulation study of the effectiveness of penalty kick strategies in soccer: late alterations of kick direction increase errors and reduce accuracy. *Journal of Sports Sciences*, *24*(05), 467-477.

van der Kamp, J., & Masters, R. S. (2008). The human Müller-Lyer illusion in goalkeeping. *Perception*, *37*(6), 951-954.

van der Kamp, J., Rivas, F., Van Doorn, H., & Savelsbergh, G. (2008). Ventral and dorsal system contributions to visual anticipation in fast ball sports. *International Journal of Sport Psychology*, *39*(2), 100.

van Doorn, J., Aust, F., Haaf, J. M., Stefan, A. M., & Wagenmakers, E. J. (2021). Bayes factors for mixed models. *Computational Brain & Behavior*, 1-13.

*van Maarseveen, M. J., Oudejans, R. R., Mann, D. L., & Savelsbergh, G. J. (2018a). Perceptual-cognitive skill and the in situ performance of soccer players. *Quarterly Journal of Experimental Psychology*, *71*(2), 455-470.

*van Maarseveen, M. J., Savelsbergh, G. J., & Oudejans, R. R. (2018b). In situ examination of decision-making skills and gaze behaviour of basketball players. *Human Movement Science*, *57*, 205-216.

VandenBos, G. R. (2006). Affect. *APA Dictionary of Psychology. Washington, DC: American Psychological Association, 26.*

Vansteenkiste, P., Vaeyens, R., Zeuwts, L., Philippaerts, R., & Lenoir, M. (2014). Cue usage in volleyball: A time course comparison of elite, intermediate and novice female players. *Biology of Sport*, *31*(4), 295

*Vater, C., Roca, A., & Williams, A. M. (2016). Effects of anxiety on anticipation and visual search in dynamic, time-constrained situations. *Sport, Exercise, and Performance Psychology*, *5*(3), 179.

Vater, C., Williams, A. M., & Hossner, E. J. (2020). What do we see out of the corner of our eye? The role of visual pivots and gaze anchors in sport. *International Review of Sport and Exercise Psychology*, *13*(1), 81-103

Vaughan, R. S., & Edwards, E. J. (2020). Executive function and personality: The moderating role of athletic expertise. *Personality and Individual Differences*, *161*, 109973.

Vaughan, R. S., & Laborde, S. (2021). Attention, working-memory control, working-memory capacity, and sport performance: The moderating role of athletic expertise. *European Journal of Sport Science*, *21*(2), 240-249.

Vaughan, R. S., Hagyard, J. D., Brimmell, J., & Edwards, E. J. (2021). The effect of trait emotional intelligence on working memory across athletic expertise. *Journal of Sports Sciences*, *39*(6), 629-637.

Vaughan, R., Laborde, S., & McConville, C. (2019). The effect of athletic expertise and trait emotional intelligence on decision-making. *European Journal of Sport Sciences, 19*(2), 225-233.

Verbruggen, F., & Logan, G. D. (2008). Automatic and controlled response inhibition: associative learning in the go/no-go and stop-signal paradigms. *Journal of Experimental Psychology: General*, *137*(4), 649.

Verbruggen, F., Aron, A. R., Band, G. P., Beste, C., Bissett, P. G., Brockett, A. T., Brown, J. W., Chamberlain, S. R., Chambers, C. D., Colonius, H., Colzato, L. S., Corneil, B. D., Coxon, J. P., Dupuis, A., Eagle, D. M., Garavan, H., Greenhouse, I., Heathcote, A., Huster, R. J., … & Boehler, C. N. (2019). A consensus guide to capturing the ability to inhibit actions and impulsive behaviors in the stop-signal task. *Elife*, *8*, e46323.

Verburgh, L., Scherder, E. J. A., van Lange, P. A., Oosterlaan, J. (2014). Executive functioning in highly talented soccer players. *PLoS One, 9*(3), e91254.

Vestberg, T., Gustafson, R., Maurex, L., Ingvar, M., & Petrovic, P. (2012). Executive functions predict the success of top-soccer players. *PloS One*, *7*(4), e34731.

Vestberg, T., Reinebo, G., Maurex, L., Ingvar, M., & Petrovic, P. (2017). Core executive functions are associated with success in young elite soccer players. *PloS One*, *12*(2), e0170845.

Vickers, J. N. (2007). *Perception, cognition, and decision training: The quiet eye in action*. Champaign, IL: Human Kinetics.

*Vila-Maldonado, S., Saez-Gallego, N. M., García-Lopez, L. M., & Contreras, O. R. (2019). Influence of visual behaviour on decision making in volleyball blocking. *Revista Internacional de Medicina y Ciencias de la Actividad Física y del Deporte*, *19*(75).

Vine, S. J., & Wilson, M. R. (2010). Quiet eye training: Effects on learning and performance under pressure. *Journal of Applied Sport Psychology*, *22*(4), 361-376.

Vine, S. J., & Wilson, M. R. (2011). The influence of quiet eye training and pressure on attention and visuo-motor control. *Acta Psychologica*, *136*(3), 340-346.

Vine, S. J., Moore, L. J., Cooke, A., Ring, A., & Wilson, M. R. (2013). Quiet eye and choking: Online control breaks down at the point of performance failure. *Medicine & Science in Sports & Exercise*, *45*(10), 1988-1994.

Vine, S. J., Moore, L., & Wilson, M. R. (2011). Quiet eye training facilitates competitive putting performance in elite golfers. *Frontiers in Psychology*, *2*, 8.

Vine, S. J., Uiga, L., Lavric, A., Moore, L. J., Tsaneva-Atanasova, K., & Wilson, M. R. (2015). Individual reactions to stress predict performance during a critical aviation incident. *Anxiety, Stress, & Coping*, *28*(4), 467-477.

Voss, M. W., Prakash, R. S., Erickson, K. I., Basak, C., Chaddock, L., Kim, J. S., Alves, H., Heo, S., Szabo, A. N., White, S. M., Wojcicki, T. R., Mailey, E. L., Gothe, N., Olson, E. A., McAuley, E., & Kramer, A. F. (2010). Plasticity of brain networks in a randomized intervention trial of exercise training in older adults. *Frontiers in Aging Neuroscience*, *2*, 32.

Votruba, K. L., & Langenecker, S. A. (2013). Factor structure, construct validity, and age- and education-based normative data for the Parametric Go/No-Go Test. *Journal of Clinical and Experimental Neuropsychology*, *35*(2), 132-146.

Weinstein, A. M., Voss, M. W., Prakash, R. S., Chaddock, L., Szabo, A., White, S. M., Wojcicki, T. R., Mailey, E., McAuley, E., Kramer, A. F., & Erickson, K. I. (2012). The association between aerobic fitness and executive function is mediated by prefrontal cortex volume. *Brain, Behavior, and Immunity*, *26*(5), 811-819.

Wentzell, P. D., Cleary, C. S., & Kompany-Zareh, M. (2017). Improved modelling of multivariate measurement errors based on the Wishart distribution. *Analytica Chimica Acta, 959*, 1-14.

*Williams, A. M., & Davids, K. (1998). Visual search strategy, selective attention, and expertise in soccer. *Research Quarterly for Exercise and Sport*, *69*(2), 111-128.

Williams, A. M., Davids, K., & Williams, J. G. (1999). *Visual perception and action in sport.* London: E & FN Spon.

*Williams, A. M., Vickers, J., & Rodrigues, S. (2002). The effects of anxiety on visual search, movement kinematics, and performance in table tennis: A test of Eysenck and Calvo’s processing efficiency theory. *Journal of Sport and Exercise Psychology*, *24*(4), 438-455.

Wilson, M. (2008). From processing efficiency to attentional control: a mechanistic account of the anxiety–performance relationship. *International Review of Sport and Exercise Psychology*, *1*(2), 184-201.

Wilson, M. (2012). Anxiety: Attention, the brain, the body, and performance. In S. M. Murphy (Ed.), *The Oxford handbook of sport and performance psychology* (pp. 173-190. Oxford University Press.

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*(2), 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*(6), 761-775.

Wilson, M., & Smith, N. C. (2007). A test of the predictions of processing efficiency theory during elite team competition using the Thought Occurrence Questionnaire for Sport. *International Journal of Sport Psychology*.

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*(3), 411-428.

Wood, G., & Wilson, M. R. (2010a). A moving goalkeeper distracts penalty takers and impairs shooting accuracy. *Journal of Sports Sciences, 28*(9), 937-946.

Wood, G., & Wilson, M. R. (2010b). Gaze behaviour and shooting strategies in football penalty kicks: Implications of a" keeper-dependent" approach. *International Journal of Sport Psychology*, *41*(3), 293.

Wood, G., & Wilson, M. R. (2011). Quiet-eye training for soccer penalty kicks. *Cognitive Processing*, *12*(3), 257-266.

Wood, G., & Wilson, M. R. (2012). Quiet-eye training, perceived control and performing under pressure. *Psychology of Sport and Exercise, 13*(6), 721-728.

Wood, G., Wright, D. J., Harris, D., Pal, A., Franklin, Z. C., & Vine, S. J. (2021). Testing the construct validity of a soccer-specific virtual reality simulator using novice, academy, and professional soccer players. *Virtual Reality*, *25*, 43-51.

*Wood, G., Vine, S. J., & Wilson, M. R. (2016). Working memory capacity, controlled attention and aiming performance under pressure. *Psychological Research*, *80*(4), 510-517.

Wood, G., Vine, S. J., Parr, J., & Wilson, M. R. (2017). Aiming to deceive: Examining the role of the quiet eye during deceptive aiming actions. *Journal of Sport and Exercise Psychology*, *39*(5), 327-338.

Woods, D. L., Kishiyama, M. M., Yund, E. W., Herron, T. J., Edwards, B., Poliva, O., Hink, R. F., & Reed, B. (2011). Improving digit span assessment of short-term verbal memory. *Journal of Clinical and Experimental Neuropsychology*, *33*(1), 101-111.

Yaşlioglu, M., & Yaşlioglu, D. T. (2020). How and When to Use Which Fit Indices? A Practical and Critical Review of the Methodology. *Istanbul Management Journal*, (88), 1-20.

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Punishment: Issues and Experiments*, 27-41.

Zelazo, P. D., & Carlson, S. M. (2012). Hot and cool executive function in childhood and adolescence: Development and plasticity. *Child Development Perspectives*, *6*(4), 354-360.

Ziv, G., & Lidor, R. (2021). Attentional focus instructions do not affect choice reaction time. *Frontiers in Psychology*, *12*, 1649.

Appendices

Appendix 1. Ethics Approval Letters for A) Chapter 3 and 4, B) Chapter 5, and C) Chapter 6

A)

School of Education, Language and Psychology

9 December 2020

Dear Jack Brimmell,

I am pleased to inform you that your project "A direct assessment of executive function, visual attention, and anxiety in sport " has now been approved by the School Research Ethics Committee for the School of Education, Language and Psychology. The approval is made on the basis that you make the following specific change to your project:

- Please use OneDrive rather than personal hard drives or computers to save research data as it is more secure.

The approval code is RECPSY00035

You may now proceed with the project and we wish you good luck.

Yours sincerely,

Dr Scott Cole, Chair
Ethics committee
School of Education, Language and Psychology.

Est. 1841

A Church of England Foundation 1841. A Company Registered in England with Exempt Charitable Status. Company No: 4498683

B)

York St John University

York St John University,
Lord Mayors Walk,
York,
YO31 7EX

23rd October, 2018

York St John University Cross School Research Ethics Committee
(Health Sciences, Sport, Psychological and Social Sciences and Business)

Dear Jack,

Title of study:	Executive function, attentional control, and performance during a pressurized soccer penalty task.
Ethics reference:	Brimmell_23102018
Date of submission:	21/09/2018

I am pleased to inform you that the above application for ethical review has been reviewed by the Cross School Research Ethics Committee and I can confirm a favourable ethical opinion on the basis of the information provided in the following documents:

Document	Date
Application for ethical approval form	22/10/2018
Responses to feedback sheet	22/10/2018

Please notify the committee if you intend to make any amendments to the original research as submitted at date of this approval, including changes to recruitment methodology or accompanying documentation. All changes must receive ethical approval prior to commencing your study.

Yours sincerely,

Nathalie Noret

C)

York St John University,
Lord Mayors Walk,
York,
YO31 7EX

17th June, 2019

York St John University Cross School Research Ethics Committee
(Health Sciences, Sport, Psychological and Social Sciences and Business)

Dear Jack,

Title of study: Executive function, attentional control, and performance under pressure: A longitudinal examination.
Ethics reference: Brimmell_17062019
Date of submission: 06/05/2019

I am pleased to inform you that the above application for ethical review has been reviewed by the Cross School Research Ethics Committee and I can confirm a favourable ethical opinion on the basis of the information provided in the following documents:

Document	Date
Application for ethical approval form	16/06/2019
Responses to feedback sheet	16/06/2019

Please notify the committee if you intend to make any amendments to the original research as submitted at date of this approval, including changes to recruitment methodology or accompanying documentation. All changes must receive ethical approval prior to commencing your study.

Yours sincerely,

Nathalie Noret

Appendix 2. Basic Demographic and Expertise Questions

Please enter the current month and year

November | 2020

Please enter your current age

Gender

- ☐ Male
- ☐ Female
- ☐ Other (please specify)

Ethnicity

- ☐ Black
- ☐ African
- ☐ Caribbean
- ☐ Asian
- ☐ Indian
- ☐ Mixed race
- ☐ White
- ☐ Other (please specify)

Do you participate in sport?

- ☐ Yes
- ☐ No

If yes, enter that sport here

How much experience, in years, do you have in this sport?

What is your current performance level in this sport

- ☐ International
- ☐ Senior national
- ☐ Junior national
- ☐ Collegiate/University
- ☐ County
- ☐ Club
- ☐ Recreational
- ☐ Other (please specify)

What is the highest level you have achieved in this sport?

- ☐ International
- ☐ Senior national
- ☐ Junior national
- ☐ Collegiate/University
- ☐ County
- ☐ Professional club
- ☐ Local club
- ☐ Recreational
- ☐ Other (please specify)

What success have you had at your HIGHEST level only (please report your HIGHEST achievement only)?

- ☐ Single/Team world championships
- ☐ Olympic success
- ☐ Olympic invitations
- ☐ Represented your country
- ☐ Single/Team national championships
- ☐ Professional status
- ☐ Semi-professional status
- ☐ Single/Team county championships
- ☐ Single/Team local championships
- ☐ Regular participation at any level
- ☐ Other (please specify)

Appendix 3. International Physical Activity Questions-Short Form

We are interested in finding out about the everyday physical activity levels of people. The questions you will answer here are concerned with THE PAST SEVEN DAYS. Please answer each question honestly, even if you do not consider yourself an active person. Think about activities at work, getting from place to place, recreation time, and sport and exercise participation. Finally, we will ask about VIGOROUS, MODERATE, and WALKING activities.

During the last seven days, on how many days did you complete at least 10 minutes of VIGOROUS physical activity (e.g., breathing much harder than normal, heavy lifting, aerobics, football)? - please answer between 0-7

How much time (in hours!) did you spend on average completing VIGOROUS activity over those days?

During the last seven days, on how many days did you complete at least 10 minutes of MODERATE physical activity (e.g., breathing somewhat harder than normal, carrying light loads, light bicycling)? - please answer between 0-7

How much time (in hours!) did you spend on average completing MODERATE activity over those days?

During the last seven days, on how many days did you complete at least 10 minutes of WALKING (e.g., walking to walk, walking at home, walking from place to place, recreational walking)? - please answer between 0-7

How much time (in hours!) did you spend on average completing WALKING activity over those days?

Appendix 4. Stress Rating Questionnaire

Below are five dimensions that range from one feeling to another (e.g., Calm to Nervous). For each of the dimensions, select the option that best describes **HOW YOU FEEL RIGHT NOW.**

Calm to Nervous

Very Calm	Quite Calm	Slightly Calm	Neither Calm nor Nervous	Slightly Nervous	Quite Nervous	Very Nervous

Fearless to Fearful

Very Fearless	Quite Fearless	Slightly Fearless	Neither Fearless nor Fearful	Slightly Fearful	Quite Fearful	Very Fearful

Relaxed to Anxious

Very Relaxed	Quite Relaxed	Slightly Relaxed	Neither Relaxed nor Anxious	Slightly Anxious	Quite Anxious	Very Anxious

Unconcerned to Worried

Very Unconcerned	Quite Unconcerned	Slightly Unconcerned	Neither Unconcerned nor Worried	Slightly Worried	Quite Worried	Very Worried

Comfortable to Tense

Very Comfortable	Quite Comfortable	Slightly Comfortable	Neither Comfortable nor Tense	Slightly Tense	Quite Tense	Very Tense

Appendix 5. State-Trait Inventory for Cognitive and Somatic Anxiety

Below are a list of items that can describe how people feel. Beside each statement are four levels which indicate the level to which each statement is self-descriptive of your mood at this moment. Please read each statement carefully and select the response that best indicates **HOW YOU FELL RIGHT NOW**, even if this is not how you usually feel.

My heart beat is fast

Not at all	A little	Moderately so	Very much so

My muscles are tense

Not at all	A little	Moderately so	Very much so

I feel agonised over my problems

Not at all	A little	Moderately so	Very much so

I think that others won't approve of me

Not at all	A little	Moderately so	Very much so

I feel like I'm missing out on things because I can't make my mind up soon enough

Not at all	A little	Moderately so	Very much so

I feel dizzy

Not at all	A little	Moderately so	Very much so

My muscles are weak

Not at all	A little	Moderately so	Very much so

I feel trembly and shaky

Not at all	A little	Moderately so	Very much so

I picture some misfortune

Not at all	A little	Moderately so	Very much so

I cant get some thoguth out of my mind

Not at all	A little	Moderately so	Very much so

I have trouble remembering things

Not at all	A little	Moderately so	Very much so

My face feels hot

Not at all	A little	Moderately so	Very much so

I think that the worst will happen

Not at all	A little	Moderately so	Very much so

My legs and arms feel stiff

Not at all	A little	Moderately so	Very much so

My throat feels dry

Not at all	A little	Moderately so	Very much so

I keep busy to avoid uncomfortable thoughts

Not at all	A little	Moderately so	Very much so

I cannot concentrate without irrelevant thoughts intruding

Not at all	A little	Moderately so	Very much so

My breathing is fast and shallow

Not at all	A little	Moderately so	Very much so

I worry that I cannot control my thoughts as well as I'd like to

Not at all	A little	Moderately so	Very much so

I have butterflies in my stomach

Not at all	A little	Moderately so	Very much so

My palms feel clammy

Not at all	A little	Moderately so	Very much so

Appendix 6. State-Trait Anxiety Inventory

Below are a number of statements that people may use to describe themselves. Beside each statement are four levels which indicate the level to which each statement is self-descriptive of your mood at this moment. Please carefully read each statement and select the response that best indicates **HOW YOU FEEL RIGHT NOW**, even if it is not how you usually feel.

I feel calm

Not at all	Somewhat	Moderately so	Very much so

I feel secure

Not at all	Somewhat	Moderately so	Very much so

I am tense

Not at all	Somewhat	Moderately so	Very much so

I feel strained

Not at all	Somewhat	Moderately so	Very much so

I feel at ease

Not at all	Somewhat	Moderately so	Very much so

I feel upset

Not at all	Somewhat	Moderately so	Very much so

I am presently worrying over possible misfortunes

Not at all	Somewhat	Moderately so	Very much so

I feel satisfied

Not at all	Somewhat	Moderately so	Very much so

I feel frightened

Not at all	Somewhat	Moderately so	Very much so

I feel comfortable

Not at all	Somewhat	Moderately so	Very much so

I feel self-confident

Not at all	Somewhat	Moderately so	Very much so

I feel nervous

Not at all	Somewhat	Moderately so	Very much so

I feel jittery

Not at all	Somewhat	Moderately so	Very much so

I feel indecisive

Not at all	Somewhat	Moderately so	Very much so

I am relaxed

Not at all	Somewhat	Moderately so	Very much so

I feel content

Not at all	Somewhat	Moderately so	Very much so

I am worried

Not at all	Somewhat	Moderately so	Very much so

I feel confused

Not at all	Somewhat	Moderately so	Very much so

I feel steady

Not at all	Somewhat	Moderately so	Very much so

I feel pleasant

Not at all	Somewhat	Moderately so	Very much so

Appendix 7. Mood and Seasonal Changes

The purpose of this form is to find out how your mood and behaviour changes over time. To what degree do the following change with the seasons (e.g., from Winter to Spring).

	No change	Slight change	Moderate change	Marked change	Extremely marked change
Sleep length	1	2	3	4	5
Social activity	1	2	3	4	5
Mood (overall feeling of well-being)	1	2	3	4	5
Weight	1	2	3	4	5
Appetite	1	2	3	4	5
Energy level	1	2	3	4	5

If your experience changes with the seasons, do you feel that these changes are a problem?

Yes
No

If you answered the above "Yes", is this problem...

Mild
Moderate
Marked
Severe
Disabling

Appendix 8. Goal Commitment Scale

Now that the task has been explained to you, please read each statement and mark the number that indicates how much the statement applies to you. There are no right or wrong answers.

	1. Strongly disagree	2	3	4	5. Strongly agree
It's hard to take this goal seriously	1	2	3	4	5
Quite frankly, I don't care if I achieve this goal or not	1	2	3	4	5
I am strongly committed to pursuing this goal	1	2	3	4	5
It wouldn't take much to make me abandon this goal	1	2	3	4	5
I think this is a good goal to shoot for	1	2	3	4	5

Appendix 9. Links to the Executive Function Tasks Used in this Thesis

Chapter 4:

2-Back Task: https://app.gorilla.sc/admin/task/124939/editor

Background Digit Span Task: https://app.gorilla.sc/admin/task/135159/editor

Stop Signal Task: https://app.gorilla.sc/admin/task/126773/editor

Go/No-Go Task: https://app.gorilla.sc/admin/task/142364/editor

Colour-Shape Task: https://app.gorilla.sc/admin/task/126791/editor

Modified Flanker Task: https://app.gorilla.sc/admin/task/136977/editor

Attentional Breadth Task: https://bit.ly/3tHVI56

Visual Search Task: https://app.gorilla.sc/admin/task/143061/editor

Chapter 5:

nback (Shape): https://bit.ly/3OhHfoV

Flanker: https://www.millisecond.com/download/library/flankertask/

Parametric Go/No-Go: https://www.millisecond.com/download/library/pgng/

Chapter 6:

nback (letter): https://bit.ly/3N0PvrF

Colour-Shape Task: https://bit.ly/3O8bi2g

Stop Signal Task: https://bit.ly/3QtkrDN