Chapter 5: Attention and Visuomotor Performance Under Pressure

Lee J. Moore[1], Samuel J. Vine[2], and Mark R. Wilson[2]

[1] Department for Health, University of Bath, United Kingdom; ORCID ID: 0000-0001-7394-7762

[2] College of Life and Environmental Sciences, University of Exeter, United Kingdom; ORCID IDs: 0000-0001-9329-1262 and 0000-0001-8145-6971

Abstract

The ability to focus attention and block out distractions during stressful competition separates world-class athletes from the rest. This chapter explains how athletes respond to stress, and how these responses impact attention and performance during visually guided sports skills. First, the chapter describes athletes' psychophysiological responses to stress using the biopsychosocial model of challenge and threat as a theoretical framework. Second, it discusses how negative responses to stress, and specifically elevations in state anxiety, disrupt attentional processes via the predictions of attentional control theory. Third, the chapter outlines the assumptions of the integrative framework of stress, attention, and visuomotor performance, and reviews supporting evidence. Fourth, it explains how practitioners can help athletes optimize their attention and performance during stressful competition. Finally, the chapter concludes by outlining potential avenues for future research.

"Concentration and mental toughness are the margins of victory"

(Bill Russell, eleven-time NBA Champion)

In line with the above quote, research has shown that concentration is a key skill that enables world-class athletes (e.g., Olympic medalists) to produce high levels of performance during stressful competition (e.g., Gould, Eklund, & Jackson, 1993; Orlick & Partington, 1988; Robazza & Bortoli, 1998). For instance, Gould, Dieffenbach, and Moffett (2002) found that, alongside other psychological characteristics (e.g., coping with anxiety, mental toughness), Olympic champions attributed their success to their ability to focus attention and block out distractions. Attention is widely accepted as the process of concentrating mental activity on environmental, sensory, or cognitive events (Moran, 2009), and can be split into two main dimensions, namely selective and divided attention. While selective attention allows athletes to 'zoom in' on task-relevant information and ignore less-relevant information (e.g., block out the crowd when hitting a golf shot), divided attention enables athletes to focus on multiple stimuli and complete two or more actions simultaneously (e.g., monitor a goalkeepers' movements while taking a soccer penalty; Moran, 1996). Stress is proposed to influence the performance of visually guided sports skills via its effects on attention, a process that will be explored in this chapter using the integrative framework of stress, attention, and visuomotor performance as a guide (Vine, Moore, & Wilson, 2016).

Integrative Framework of Stress, Attention, and Visuomotor Performance

To explain the effects of stress on visually guided motor (visuomotor) performance, and inter- and intra-individual variability in performance during potentially stressful situations, Vine et al. (2016) developed a conceptual framework (see Figure 5.1). This framework was developed from existing evidence and integrated the core predictions of the biopsychosocial model (BPSM) of challenge and threat (Blascovich & Tomaka, 1996), and attentional control theory (ACT; Eysenck, Derakshan, Santos, & Calvo, 2007). In the following sections, the BPSM and ACT are briefly summarized before the predictions of the integrative framework of stress, attention, and visuomotor performance are outlined.

Biopsychosocial Model of Challenge and Threat

The BPSM helps explain why athletes respond and perform differently during potentially stressful competition (Blascovich, 2008). The BPSM applies to motivated performance situations, or contexts in which individuals must perform instrumental responses (cognitive and/or physical) to attain important and self-relevant goals (e.g., sporting competition, tests, interviews, and public speaking; Seery, 2013). Inspired by the work of Lazarus and Folkman (1984), the BPSM contends that how an athlete reacts to a stressful competition is determined by their evaluations of situational demands and personal coping resources (Blascovich, 2008). If an athlete perceives that they have sufficient resources to cope with the demands of the competition, they evaluate it as a challenge. Conversely, if an athlete judges that they lack the necessary resources, they evaluate it as a threat (Seery, 2011; see also Chapter 2). The BPSM argues that these demand and resource evaluations occur at a more subconscious and automatic, rather than conscious and deliberate, level (Blascovich & Mendes, 2000). Additionally, these evaluations are thought to be relatively dynamic (Blascovich, 2008), meaning that while an athlete might initially evaluate a competition as a threat, after a few minutes, they might re-evaluate it as a challenge.

Drawing on the work of Dienstbier (1989), the BPSM predicts that varying psychological evaluations trigger distinct physiological responses (Blascovich, 2008). If an athlete evaluates a stressful competition as a challenge, sympathetic-adrenomedullary activation increases and catecholamines are released (e.g., adrenaline), causing blood vessels to dilate and blood flow to increase (Seery, 2011). In contrast, if an athlete evaluates a competition as a threat, pituitary-adrenocortical activation increases, attenuating sympathetic-adrenomedullary activity and releasing cortisol, resulting in little change in or constriction of the blood vessels, and little change in or decreased blood flow (Seery, 2011). Thus, compared to a threat state, a challenge state is marked by greater reductions in total peripheral resistance (TPR; net constriction vs. dilation in the arterial system) and increases in cardiac output (CO; amount of blood pumped by the heart per minute) from rest (Blascovich, 2008). Importantly, this cardiovascular response is considered more efficient because it quickly mobilizes energy for the brain and muscles, preparing the body for immediate action (Mendes & Park, 2014). The cardiovascular responses marking challenge and threat are argued to provide an indirect and objective (relatively bias-free) measure of underlying demand and resource evaluations, offering a window into an athletes' mind (Seery, 2013; see also Chapter 2).

The BPSM predicts that an athlete who responds to a stressful competition with a challenge state will outperform an athlete who reacts with a threat state (Blascovich, 2008). Research has supported this assertion, with a challenge state associated with better performance in baseball batting (Blascovich, Seery, Mugridge, Norris, & Weisbuch, 2004), netball shooting (Turner, Jones, Sheffield, & Cross, 2012), golf putting (Moore, Vine, Wilson, & Freeman, 2012), cricket batting (Turner, Jones, Sheffield, Slater, Barker, & Bell, 2013), dart throwing (Moore, Young, Freeman, & Sarkar, 2018), sprint cycling (Wood, Parker, Freeman, Black, & Moore, 2018), simulated car racing (Trotman, Williams, Quinton, & Van Zanten, 2018), and soccer penalty taking (Brimmell, Parker, Wilson, Vine, & Moore, 2019). As well as predicting performance in laboratory-based tasks, a challenge state has also been linked to superior performance in real-world sporting competition (Dixon, Jones, & Turner, 2019; Moore, Wilson, Vine, Coussens, & Freeman, 2013). To summarize work in this area, Hase, O'Brien, Moore, and Freeman (2019) conducted a systematic review of 38 studies (3257 participants), revealing that a challenge state was related to better performance in 74% of studies (see Behnke & Kaczmarek, 2018 for a meta-analysis).

Despite ample research demonstrating that challenge and threat states have divergent effects on sports performance (Hase et al., 2019; see also Chapter 2), relatively little is known about the potential mechanisms underlying these effects (e.g., emotional; see Jones, Meijen, McCarthy, & Sheffield, 2009). Although the BPSM can explain athletes' psychological and physiological responses to potentially stressful competition, and why these responses might vary between athletes and across situations, it does not specify precisely how these responses influence sports performance. Thus, to better elucidate how challenge and threat states impact the performance of visually guided sports skills, Vine et al. (2016) integrated the predictions of the BPSM with the core assumptions of ACT (Eysenck et al., 2007).

Attentional Control Theory

Like its predecessor, Processing Efficiency Theory (Eysenck & Calvo, 1992), ACT has been used to explain how anxiety affects sports performance via its impact on attentional control (Wilson, 2008) - defined as the ability to flexibly focus and shift attention (Muris, Mayer, Van Lint, & Hofman, 2008). While other mechanistic explanations argue that performance deteriorates because highly anxious athletes direct attention inward to consciously control movements (e.g., Theory of Reinvestment; Masters & Maxwell, 2008), ACT contends that performance suffers because anxious athletes become less focused and more distractible (Eysenck & Wilson, 2016). ACT was originally developed in relation to trait anxiety or one's general propensity to experience anxiety; however, in sport, it has mostly been applied to state anxiety, defined as a negative transient emotional state evoked during stressful situations (Eysenck et al., 2007; see also Chapter 4). ACT has three main assumptions, which have received empirical support (see Shi, Sharpe, & Abbott, 2019 for a review). First, ACT predicts that anxiety impairs processing efficiency (ratio between performance effectiveness and effort) more than performance effectiveness or quality (e.g., dart throwing accuracy; Eysenck & Derakshan, 2011), such that anxious athletes can offset the negative effects of anxiety by using extra processing resources or effort (Wilson, 2008).

Second, ACT predicts that anxiety disrupts the balance of two attentional systems, increasing the influence of the stimulus-driven (bottom-up) system at the expense of the goal-directed (top-down) system (Eysenck et al., 2007). The goal-directed system is located in the dorsal posterior parietal and frontal cortex, and directs attention based on knowledge, expectations, and current goals (Corbetta & Shulman, 2002). In contrast, the stimulus-driven system is located in the temporoparietal and ventral frontal cortex, and helps detect salient and threatening environmental stimuli (Corbetta, Patel, & Shulman, 2008). The most notable effect of the anxiety-induced imbalance in these attentional systems is that athletes become more distractible by task-irrelevant and threatening stimuli (e.g., crowd or negative thoughts during a basketball free throw). Third, in explaining this imbalance, ACT predicts that anxiety impairs the inhibition and shifting functions of the central executive of working memory (Eysenck et al., 2007). While the inhibition function stops interference or disruptions from task-irrelevant stimuli (negative attentional control), the shifting function allocates attention flexibly to remain focused on task-relevant cues (positive attentional control; Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000). Studies in cognitive psychology have supported these disruptions to inhibition and shifting (Shi et al., 2019).

Beyond controlled cognitive tasks, research in sport psychology has also supported the assumptions of ACT (Payne, Wilson, & Vine, 2019; Roberts, Jackson, & Grundy, 2019). In particular, anxiety has been shown to disrupt attentional control in studies using eye-tracking technology, which allows the location and duration of visual attention (via fixations – when the eyes rest steady on a location or object) to be recorded during skill execution (Kredel, Vater, Klostermann, & Hossner, 2017). Optimal attentional control in many sports skills (e.g., rifle shooting) involves fewer fixations of a longer duration, or lower search rates

(Mann, Williams, Ward, & Janelle, 2007), and longer fixations immediately before skill execution, also know as extended quiet eye durations (Lebeau et al., 2016; Vickers, 2016). However, when highly anxious, athletes tend to display less efficient attentional control characterized by higher search rates and shorter quiet eye durations (Behan & Wilson, 2008; Causer, Holmes, Smith, & Williams, 2011; Nibbeling, Oudejans, & Daanen, 2012; Nieuwenhuys, Pijpers, Oudejans, & Bekker, 2008; Vickers & Williams, 2007; Williams, Vickers, & Rodrigues, 2002; Wilson, Wood, & Vine, 2009). For example, Wilson, Vine, and Wood (2009) found that during free throws under high-anxiety, basketball players displayed more erratic visual search, including more fixations of a shorter duration to various locations (e.g., hoop, backboard, net), owing to the increased influence of the stimulus-driven system, and shorter quiet eye durations, due to the reduced impact of the goal-directed system.

Although considerable research has supported the attentional disruptions proposed by ACT in sports skills, the theory is not without its limitations (see Eysenck & Wilson, 2016). Indeed, while ACT provides a mechanistic explanation for how maladaptive stress responses (i.e., heightened anxiety) can disrupt attentional processes that are critical in supplying the visual information needed to plan and execute accurate sports skills, it fails to explain precisely how psychophysiological responses to stress arise, and why these responses might vary between athletes and across situations (Vine et al., 2016). Indeed, this limitation is also relevant to other models that explain the anxiety-performance relationship (e.g., integrated model of anxiety and perceptual-motor performance; Nieuwenhuys & Oudejans, 2012, 2017). Thus, the integrative conceptual framework by Vine et al. (2016) aimed to align the strengths and weaknesses of the BPSM and ACT to better explain how athletes respond to stress, and the impact of these stress responses on attentional control and sports performance.

Predictions of Integrative Framework and Supporting Evidence

The integrative framework of stress, attention, and visuomotor performance applies to stressful situations, in which individuals must perform visually guided skills to achieve important and meaningful goals (e.g., sporting competition; Vine et al., 2016). Consistent with the BPSM, this framework predicts that during stressful competition, an athlete will evaluate situational demands and if they have the resources to cope with these demands (see also Chapters 1-3). An athlete who believes that they have the coping resources will evaluate the competition as a challenge, and respond with lower TPR and higher CO reactivity. In contrast, an athlete who believes that they lack the coping resources will evaluate the competition as a threat, and respond with higher TPR and lower CO reactivity. Next, inspired by ACT, the integrative framework proposes that challenge and threat evaluations effect attentional control differently. Specifically, a challenge evaluation leads an athlete to optimally pick-up visual information from task-relevant stimuli, because the goal-directed and stimulus-driven attentional systems are balanced. Conversely, a threat evaluation causes an athlete to become more distractible by task-irrelevant and threatening stimuli, resulting in the suboptimal pick-up of information due to the stimulus-driven system dominating the goal-directed system. In the integrative framework, this imbalance is attributed to the greater anxiety commonly accompanying a threat evaluation, which ultimately causes disruptions in attentional control that degrade performance quality during visually guided sports skills, unless additional processing resources are mobilized (e.g., effort; Vine et al., 2016).

Research has supported the core predictions of the integrative framework in the sport psychology literature, demonstrating that the goal-directed system predominately controls attention during a challenge state, while the stimulus-driven system largely directs attention during a threat state (Vine et al., 2016). For example, Moore et al. (2012) manipulated novice golfers into either a challenge or threat state before a stressful golf putting task, and found that golfers who were manipulated into a challenge state performed better, reported less anxiety, and displayed longer quiet eye durations reflecting superior goal-directed attentional control. These findings were replicated by Moore et al. (2013), who found that experienced golfers who were manipulated into a threat state performed worse, reported more anxiety, and exhibited shorter quiet eye durations, during a stressful golf putting task. More recently, Brimmell et al. (2019) found that soccer players who responded to a stressful penalty task with a challenge state (lower TPR and higher CO) performed better and displayed gaze behavior more indicative of goal-directed attentional control, including longer quiet eye durations, lower search rates, more fixations toward the goal and ball, and more time spent fixating on the goal (see Figure 5.2). Similar results have been found outside of sport (e.g., surgery; Vine et al., 2013). For example, Vine et al. (2015) found that pilots who evaluated a stressful aviation task as a threat displayed higher search rates and spent more time fixating on less-relevant areas of the cockpit, reflecting greater stimulus-driven attentional control.

In addition to the core predictions noted above, three feedback loops were also outlined in the integrative framework, suggesting that athletes are more likely to evaluate similar stressful competitions as a threat in the future if they, (1) experience more threat-like cardiovascular reactivity (higher TPR and lower CO), (2) overly attend to task-irrelevant and potentially threatening stimuli, and (3) perform poorly, during a current stressful competition (Vine et al., 2016). To date, few studies have tested these feedback loops, with evidence only offering mixed support. For example, Brimmell et al. (2019) asked experienced soccer players to complete two trials on a stressful penalty task, and found that players who took a more accurate penalty during the first trial were more likely to evaluate the second trial as a challenge. However, neither cardiovascular reactivity nor time spent fixating threatening stimuli (goalkeeper) during the first trial predicted challenge and threat evaluations during the second trial (Brimmell et al., 2019). Studies in social psychology have also provided mixed results. For instance, while Rith-Najarian, McLaughlin, Sheridan, and Nock (2014) found that participants who performed poorly during a stressful speech task were more likely to evaluate the task as a threat in the future, Quigley, Feldman-Barrett, and Weinstein (2002) found that prior performance in a stressful mental arithmetic task did not predict future challenge and threat evaluations. Although the feedback loops proposed by the integrative framework require further testing, practitioners can use the core predictions of the framework to develop interventions that help athletes perform better during stressful competition.

Optimizing Attention and Performance Under Pressure

The assumptions of the integrative framework of stress, attention, and visuomotor performance highlight several evidence-based interventions that could help athletes improve their attentional control and performance during stressful competition (Vine et al., 2016). First, given that a challenge state is associated with superior attentional control and sports performance (Hase et al., 2019), interventions that encourage athletes to view stressful competition as a challenge rather than a threat, could be beneficial. While research into challenge-promoting interventions is still growing, some strategies have been shown to foster a challenge state, including imagery (e.g., Williams, Van Zanten, Trotman, Quinton, & Ginty, 2017), self-talk (e.g., Hase, Hood, Moore, and Freeman, 2019), and verbal instructions that promote self-efficacy, perceived control, and a focus on approach goals (e.g., Turner, Jones, Sheffield, Barker, & Coffee, 2014; see also Chapters 2 and 12). Another promising intervention is arousal reappraisal, which helps athletes' re-interpret stress-induced increases in physiological arousal (e.g., racing heart) as a tool that can aid performance (Jamieson, Mendes, & Nock, 2013; Sammy, Anstiss, Moore, Freeman, Wilson, & Vine, 2017). For example, Moore, Vine, Wilson, and Freeman (2015) found that during a stressful golf putting task, novice golfers who received an arousal reappraisal intervention displayed a challenge state and better performance compared to golfers assigned to a control group.

Second, the integrative framework suggests that if disruptions in attentional control can be prevented, then athletes may be able to produce performance that is resilient to stress. One evidence-based intervention that has been shown to accomplish this is quiet eye training (Vine, Moore, & Wilson, 2014). Indeed, as well as being indicative of skilled sports performance, and a marker of optimal goal-directed attention control, research has shown that the quiet eye is trainable (Wilson, Wood, & Vine, 2016). Training athletes to display longer quiet eye durations has been found to counteract the negative effects of anxiety on attentional control and performance (Moore, Vine, Cooke, Ring, & Wilson, 2012; Vine & Wilson, 2011; Wood & Wilson, 2011). For example, Vine and Wilson (2010) found that novice golfers who received quiet eye training maintained effective quiet eye durations and performance under high anxiety, while golfers in a control group exhibited shorter quiet eye durations and poorer performance. Crucially, the benefits of quiet eye training transfer to real-world sporting competition (e.g., Causer, Holmes, & Williams, 2011; Vine, Moore, & Wilson, 2011). While it is still unclear precisely how quiet eye training works, it might provide a pre-performance routine that promotes perceptions of control and helps athletes view stressful competition as a challenge (Moore, Vine, Freeman, & Wilson, 2013; Wood & Wilson, 2012).

Beyond quiet eye training, cognitive training that improves inhibitory attentional control has also been shown to create sports skills that are robust under stress (e.g., Ducrocq, Wilson, Vine, & Derakshan, 2016). Interestingly, this form of attentional control training has also been used with vulnerable individuals affected by anxiety and depression, helping them to become less sensitive to threatening stimuli (e.g., Owens, Koster, & Derakshan, 2013; Sari, Koster, Pourtois, & Derakshan, 2016). Another intervention that has shown promise in helping athletes optimize attentional control and performance during stressful competition is pressure training, or training with anxiety (Gropel & Mesagno, 2017; see also Chapter 12). For example, Alder, Ford, Causer, and Williams (2016) found that elite badminton players who trained under high anxiety made longer final fixations and better anticipatory judgements during a stressful serve reception task, compared to players assigned to a control group or trained under low anxiety. Similar findings have also been reported outside of sport in other domains (e.g., law enforcement; Low, Sandercock, Freeman, Winter, Butt, & Maynard, 2020). For instance, Nieuwenhuys and Oudejans (2011) found that police officers that trained under high anxiety displayed lower search rates and superior shooting accuracy relative to police officers in a control group. Undoubtedly, other interventions could help athletes optimize attentional control and performance during stressful competition (e.g., pre-performance routines; Mesagno, Hill, & Larkin, 2015); however, many of these require further investigation using objective measures of attention (e.g., eye-tracking metrics).

Future Research

There are several potential avenues for future research. First, most of the research examining stress-related disruptions in attentional control has used objective measurements, such as eye movements (e.g., fixations) recorded via eye-tracking technology (Moran, Campbell, & Ranieri, 2018). However, according to ACT (Eysenck et al., 2007), the elevated anxiety experienced during potentially stressful situations not only makes athletes more distractible by task-irrelevant environmental stimuli (e.g., crowd during a basketball free throw), but also internal thoughts (e.g., concerns about poor performance; Eysenck & Wilson, 2016). Thus, to offer a more complete test of theoretical predictions (e.g., Vine et al., 2016), future research is encouraged to employ multiple measures of attentional control, including trait-like indices before (e.g., Attentional Control Scale; Derryberry & Reed, 2002), eye-tracking metrics (e.g., quiet eye; Vickers, 2016) and think-aloud protocols (Eccles & Arsal, 2017) during, and retrospective self-report measures after (e.g., Thought Occurrence Questionnaire for Sport; Hatzigeorgiadis & Biddle, 2000), highly stressful competition. Second, despite being developed from existing evidence, some predictions of the integrative framework require further testing (e.g., elevated state anxiety triggers imbalance in goal-directed and stimulus-driven attentional systems; Vine et al., 2016). In particular, the framework proposes that athletes who evaluate a stressful competition as a threat can still perform well, particularly if they use additional processing resources (e.g., effort). Indeed, this notion fits with the results of Turner et al. (2013), who found that a small subset of cricketers responded to a stressful batting task with a threat state (higher TPR and lower CO), still performed well, possibly due to higher self-efficacy.

Third, while a recent study highlighted that challenge and threat evaluations are mostly situation-specific, it also revealed that athletes have general tendencies to evaluate all stressful situations as a challenge or threat (Moore, Freeman, Hase, Solomon-Moore, & Arnold, 2019). Given that frequently appraising stressors as a threat has been linked to poorer mental and physical health (e.g., social anxiety, cellular aging; O'Donovan et al., 2012; Tomaka, Palacios, Champion, & Monks, 2018), future research is encouraged to move beyond athletic performance and examine the long-term effects of challenge and threat states on athlete health and well-being (see Chapters 6-8). Specific to the focus of this chapter, this research could also explore if challenge and threat states impact health via their effects on attention (e.g., depression is linked with greater attentional bias towards negative stimuli; Peckham, McHugh, & Otto, 2010). Finally, although some interventions have shown promise in helping athletes optimize attentional control and performance during stressful competition (e.g., quiet eye training; Vine et al., 2014), more techniques should be evaluated (e.g., breathing; Zaccaro et al., 2018). For instance, mindfulness and acceptance interventions fit neatly with the predictions of the integrative framework, as they are thought to help athletes sustain task-focused attention by training open, non-reactive, and present-moment awareness (Noetel, Ciarrochi, Van Zanden, & Lonsdale, 2017). While qualitative studies have supported this proposition (e.g., Bernier, Thienot, Pelosse, & Fournier, 2014), few studies have supported it using objective measures of attentional control (e.g., eye tracking indices).

Conclusion

According to the integrative framework of stress, attention, and visuomotor performance, an athlete who evaluates a potentially stressful competition as a challenge (coping resources exceed situational demands) will react with a cardiovascular response marked by lower TPR and higher CO, which benefits sports performance by keeping attention goal-directed and optimally focused on important task-relevant stimuli. In contrast, an athlete who evaluates a potentially stressful competition as a threat (situational demands exceed coping resources) will react with a cardiovascular response marked by higher TPR and lower CO, which hampers sports performance by increasing distractibility and shifting attention to less-relevant and potentially threatening stimuli. Therefore, to help athletes perform better during stressful competition, practitioners are encouraged to help their athletes view competition as a challenge not a threat, and to maintain optimal attentional control.

References

Alder, D., Ford, P. R., Causer, C., & Williams, A. M. (2016). The effects of high- and low-anxiety training on the anticipation judgments of elite performers. *Journal of Sport and Exercise Psychology*, *38*, 93-104. doi: 10.1123/jsep.2015-0145.

Behnke, M., & Kaczmarek, L. D. (2018). Successful performance and cardiovascular markers of challenge and threat: A meta-analysis. *International Journal of Psychophysiology*, *130*, 73-79. doi: 10.1016/j.ijpsycho.2018.04.007.

Behan, M., & Wilson, M. (2008). State anxiety and visual attention: The role of the quiet eye period in aiming to a far target. *Journal of Sports Sciences*, *26*, 207-215. doi: 10.1080/02640410701446919.

Bernier, M., Thienot, E., Pelosse, E., & Fournier, J. F. (2014). Effects and underlying processes of a mindfulness-based intervention with young elite figure skaters: Two case studies. *The Sport Psychologist*, *28*, 302-315. doi: 10.1123/tsp.2013-0006.

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

Blascovich, J., & Mendes, W. B. (2000). Challenge and threat appraisals: The role of affective cues. In J. P. Forgas (Ed.), *Feeling and thinking: The role of affect in social cognition* (pp. 59-82). Cambridge, UK: Cambridge University Press.

Blascovich, J., Seery, M. D., Mugridge, C. A., Norris, R. K., & Weisbuch, M. (2004). Predicting athletic performance from cardiovascular indexes of challenge and threat. *Journal of Experimental Social Psychology*, *40*, 683-688. doi: 10.1016/j.jesp.2003.10.007.

Blascovich, J., & Tomaka, J. (1996). The biopsychosocial model of arousal regulation. In M. Zanna (Ed.), *Advances in experimental social psychology* (pp. 1-51). New York, NY: Academic Press.

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*, 63-79. doi: 10.1037/spy0000147.

Causer, J., Holmes, P. S., Smith, N. C., & Williams, A. M. (2011). Anxiety, movement kinematics, and visual attention in elite-level performers. *Emotion*, *11*, 595-602. doi: 10.1037/a0023225.

Causer, J., Holmes, P. S., & Williams, A. M. (2011). Quiet eye training in a visuomotor control task. *Medicine and Science in Sports and Exercise*, *43*, 1042-1049. doi: 10.1249/MSS.0b013e3182035de6.

Corbetta, M., Patel, G., & Shulman, G. L. (2008). The reorienting system of the human brain: From environment to theory of mind. *Neuron*, *58*, 306-324. doi: 10.1016/j.neuron.2008.04.017.

Corbetta, M. & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews and Neuroscience*, *3*, 201-215. doi: 10.1038/nrn755.

Derryberry, D., & Reed, M. A. (2002). Anxiety-related attentional biases and their regulation by attentional control. *Journal of Abnormal Psychology*, *111*, 225-236. doi: 10.1037/0021-843X.111.2.225.

Dienstbier, R. A. (1989). Arousal and physiological toughness: Implications for mental and physical health. *Psychological Review*, *96*, 84-100. doi: 10.1037/0033-295X.96.1.84.

Dixon, J. G., Jones, M. V., & Turner, M. J. (2019). The benefits of a challenge approach on match day: Investigating cardiovascular reactivity in professional academy soccer players. *European Journal of Sport Science*. Advance online publication. doi: 10.1080/17461391.2019.1629179.

Ducrocq, E., Wilson, M. R., Vine, S. J., & Derakshan, N. (2016). Training attentional control improves cognitive and motor task performance. *Journal of Sport and Exercise Psychology*, *38*, 521-533. doi: 10.1123/jsep.2016-0052.

Eccles, D.W., & Arsal, G. (2017). The think aloud method: What is it and how do I use it? *Qualitative Research in Sport, Exercise and Health*, *9*, 514-531. doi: 10.1080/2159676X.2017.1331501.

Eysenck, M. W., & Calvo, M. G. (1992). Anxiety and performance: The processing efficiency theory. *Cognition and Emotion*, *6*, 409-434. doi: 10.1080/02699939208409696.

Eysenck, M. W., & Derackshan, N. (2011). New perspectives in attentional control theory. *Personality and Individual Differences*, *50*, 955-960. doi: 10.1016/j.paid.2010.08.019.

Eysenck, M. W., Derackshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion*, *7*, 336-353. doi: 10.1037/1528-3542.7.2.336.

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* (pp. 329-350). London, UK: Routledge.

Gould, D., Dieffenbach, K., & Moffett, A. (2002). Psychological characteristics and their development in Olympic champions. *Journal of Applied Sport Psychology*, *14*, 172-204. doi: 10.1080/10413200290103482.

Gould, D., Eklund, R. C., & Jackson, S. A. (1993). Coping strategies used by US Olympic wrestlers. *Research Quarterly for Sport and Exercise*, *64*, 83-93. doi: 10.1080/02701367.1993.10608782.

Gropel, P., & Mesagno, C. (2017). Choking interventions in sports: A systematic review. *International Review of Sport and Exercise Psychology*, *12*, 176-201. doi: 10.1080/1750984X.2017.1408134.

Hase, A., Hood, J., Moore, L. J., & Freeman, P. (2019). The influence of self-talk on challenge and threat states and performance. *Psychology of Sport and Exercise*. Advance online publication. doi: 10.1016/j.psychsport.2019.101550.

Hase, A., O'Brien, J., Moore, L. J., & Freeman, P. (2019). The relationship between challenge and threat states and performance: A systematic review. *Sport, Exercise, and Performance Psychology*, *8*, 123-144. doi: 10.1037/spy0000132.

Hatzigeorgiadis, A., & Biddle, S. J. H. (2000). Assessing cognitive interference in sport: Development of the thought occurrence questionnaire for sport. *Anxiety, Stress, and Coping*, *13*, 65-86. doi: 10.1080/10615800008248334.

Jamieson, J. P., Mendes, W. B., & Nock, M. K. (2013). Improving acute stress responses: The power of reappraisal. *Current Directions in Psychological Science*, *22*, 51-56. doi: 10.1177/0963721412461500.

Jones, M., Meijen, C., McCarthy, P. J., & Sheffield, D. (2009). A theory of challenge and threat states in athletes. *International Review of Sport and Exercise Psychology*, *2*, 161-180. doi: 10.1080/17509840902829331.

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*. doi: 10.3389/fpsyg.2017.01845.

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

Lebeau, J. C., Liu, S., Saenz-Moncaleano, C., Sanduvete-Chaves, S., Chacon-Moscoso, S., Becker, B. J., & Tenenbaum, G. (2016). Quiet eye and performance in sport: A meta-analysis. *Journal of Sport and Exercise Psychology*, *38*, 441-457. doi: 10.1123/jsep.2015-0123.

Low, W. R., Sandercock, G. R. H., Freeman, P., Winter, M. E., Butt, J., & Maynard, I. (2020). Pressure training for performance domains: A meta-analysis. *Sport, Exercise, and Performance Psychology*. doi: 10.1037/spy0000202.

Mann, D. T. Y., Williams, M. A., Ward, P., & Janelle, C. M. (2007). Perceptual-cognitive expertise in sport: A meta-analysis. *Journal of Sport and Exercise Psychology*, *29*, 457-478. doi: 10.1123/jsep.29.4.457.

Masters, R. S. W., & Maxwell, J. P. (2008). The theory of reinvestment. *International Review of Sports and Exercise Psychology*, *1*, 160-183. doi: 10.1080/17509840802287218.

Mendes, W. B., & Park, J. (2014). Neurobiological concomitants of motivational states. *Advances in Motivational Science*, *1*, 233-270. doi: 10.1016/bs.adms.2014.09.001.

Mesagno, C., Hill, D. M., & Larkin, P. (2015). Examining the accuracy and in-game performance effects of pre- and post-performance routines: A mixed methods study. *Psychology of Sport and Exercise*, *19*, 85-94. doi: 10.1016/j.psychsport.2015.03.005.

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*, 49-100. doi: 10.1006/cogp.1999.0734.

Moore, L. J., Freeman, P., Hase, A., Solomon-Moore, E., & Arnold, R. (2019). How consistent are challenge and threat evaluations? A generalizability analysis. *Frontiers in Psychology*. Advance online publication. doi: 10.3389/fpsyg.2019.01778.

Moore, L. J., Vine, S. J., Cooke, A., Ring, C., & Wilson, M. R. (2012). Quiet eye training expedites motor learning and aids performance under heightened anxiety: The roles of response programming and external attention. *Psychophysiology*, *49*, 1005-1015. doi: 10.1111/j.1469-8986.2012.01379.x.

Moore, L. J., Vine, S. J., Freeman, P., & Wilson, M. R. (2013). Quiet eye training promotes challenge appraisals and aids performance under elevated anxiety. *International Journal of Sport and Exercise Psychology*, *11*, 169-183. doi: 10.1080/1612197X.2013.773688.

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*, 1417-1425. doi: 10.1111/j.1469-8986.2012.01449.x.

Moore, L. J., Vine, S. J., Wilson, M. R., & Freeman, P. (2015). Reappraising threat: How to optimize performance under pressure. *Journal of Sport and Exercise Psychology*, *37*, 339-343. doi: 10.1123/jsep.2014-0186.

Moore, L. J., Wilson, M. R., Vine, S. J., Coussens, A. H., & Freeman, P. (2013). Champ or chump? Challenge and threat states during pressurized competition. *Journal of Sport and Exercise Psychology*, *35*, 551-562. doi: 10.1123/jsep.35.6.551.

Moore, L. J., Young, T., Freeman, P., & Sarkar, M. (2018). Adverse life events, cardiovascular responses, and sports performance under pressure. *Scandinavian Journal of Medicine and Science in Sports*, *28*, 340-347. doi: 10.1111/sms.12928.

Moran, A. P. (1996). *The psychology of concentration in sport performers: A cognitive analysis.* London, UK: Routledge.

Moran, A. P. (2009). Attention in sport. In S. Mellalieu & S. Hanton (Eds.), *Advances in applied sport psychology: A review* (pp. 195-220). London, UK: Routledge.

Moran, A. P., Campbell, M., & Ranieri, D. (2018). Implications of eye-tracking technology for applied sport psychology. *Journal of Sport Psychology in Action*, *9*, 249-259. doi: 10.1080/21520704.2018.1511660.

Muris, P., Mayer, B., Van Lint, C., & Hofman, S. (2008). Attentional control and psychopathological symptoms in children. *Personality and Individual Differences*, *44*, 1495-1505. doi: 10.1016/j.paid.2008.01.006.

Nibbeling, N., Oudejans, R. R. D., & Daanen, H. A. M. (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*, 427-435. doi: 10.1016/j.psychsport.2012.02.002.

Nieuwenhuys, A., & Oudejans, R. R. D. (2011). Training with anxiety: Short- and long-term effects on police officers' shooting behavior under pressure. *Cognitive Processing*, *12*, 277-288. doi: 10.1007/s10339-011-0396-x.

Nieuwenhuys, A., & Oudejans, R. R. D. (2012). Anxiety and perceptual-motor performance: Toward an integrated model of concepts, mechanisms, and processes. *Psychological Research*, *76*, 747-759. doi: 10.1007/s00426-011-0384-x.

Nieuwenhuys, A., & Oudejans, R. R. D. (2017). Anxiety and performance: Perceptual-motor behavior in high-pressure contexts. *Current Opinion in Psychology*, *16*, 28-33. doi: 10.1016/j.copsyc.2017.03.019.

Nieuwenhuys, A., Pijpers, J. R., Oudejans, R. R. D., & Bakker, F. C. (2008). The influence of anxiety on visual attention in climbing. *Journal of Sport and Exercise Psychology*, *30*, 171-185. doi: 10.1123/jsep.30.2.171.

Noetel, M., Ciarrochi, J., Van Zanden, B., & Lonsdale, C. (2017). Mindfulness and acceptance approaches to sporting performance enhancement: A systematic review. *International Review of Sport and Exercise Psychology*, *12*, 139-175. doi: 10.1080/1750984X.2017.1387803.

O'Donovan, A., Tomiyama, A. J., Lin, J., Puterman, E., Adler, N. E., Kemeny, M., & Epel, E. S. (2012). Stress appraisals and cellular aging: A key role for anticipatory threat in the relationship between psychological stress and telomere length. *Brain, Behaviour, and Immunity*, *26*, 573-579. doi: 10.1016/j.bbi.2012.01.007.

Orlick, T., & Partington, J. (1988). Mental links to excellence. *The Sport Psychologist*, *2*, 105-130. doi: 10.1123/tsp.2.2.105.

Owens, M., Koster, E. H. W., & Derakshan, N. (2013). Improving attention control in dysphoria through cognitive training: Transfer effects on working memory capacity and filtering efficiency. *Psychophysiology*, *50*, 297-307. doi: 10.1111/psyp.12010.

Payne, K. L., Wilson, M. R., & Vine, S. J. (2019). A systematic review of the anxiety-performance relationship in far-aiming tasks. *International Review of Sport and Exercise Psychology*, *12*, 325-355. doi: 10.1080/1750984X.2018.1499796.

Peckham, A. D., McHugh, R. C., & Otto, M. W. (2010). A meta-analysis of the magnitude of biased attention in depression. *Depression and Anxiety*, *27*, 1135-1142. doi: 10.1002/da.20755.

Quigley, K. S., Feldman Barrett, L., & Weinstein, S. (2002). Cardiovascular patterns associated with threat and challenge appraisals: A within-subjects analysis. *Psychophysiology*, *39*, 292-302. doi: 10.1017.S0048577201393046.

Rith-Najarian, L. R., McLaughlin, K. A., Sheridan, M. A., & Nock, M. K. (2014). The biopsychosocial model of stress in adolescence: Self-awareness of performance versus stress reactivity. *Stress*, *17*, 193-203. doi: 10.3109/10253890.2014.891102.

Robazza, C., & Bortoli, L. (1998). Mental preparation strategies of Olympic archers during competition: An exploratory investigation. *High Ability Studies*, *9*, 219-235. doi: 10.1080/1359813980090207.

Roberts, L. J., Jackson, M. S., & Grundy, I. H. (2019). Choking under pressure: Illuminating the role of distraction and self-focus. *International Review of Sport and Exercise Psychology*, *12*, 49-69. doi: 10.1080/1750984X.2017.1374432.

Sammy, N., Anstiss, P. A., Moore, L .J., Freeman, P., Wilson, M. R., & Vine, S. J. (2017). The effects of arousal reappraisal on stress responses, performance, and attention. *Anxiety, Stress, and Coping: An International Journal*, *30*, 619-629. doi: 10.1080/10615806.2017.1330952.

Sari, B. A., Koster, E. H. W., Pourtois, G., & Derakshan, N. (2015). Training working memory to improve attentional control in anxiety: A proof-of-principle study using behavioural and electrophysiological measures. *Biological Psychology*, *121*, 203-212. doi: 10.1016/j.biopsycho.2015.09.008.

Seery, M. D. (2011). Challenge or threat? Cardiovascular indexes of resilience and vulnerability to potential stress in humans. *Neuroscience and Biobehavioural Reviews*, 35, 1603-1610. doi: 10.1016/j.neubiorev.2011.03.003.

Seery, M. D. (2013). The biopsychosocial model of challenge and threat: Using the heart to measure the mind. *Social and Personality Psychology Compass*, *7*, 637-653. doi: 10.1111/spc3.12052.

Shi, R., Sharpe, L., & Abbott, M. (2019). A meta-analysis of the relationship between anxiety and attentional control. *Clinical Psychology Review*, *72*, 101754. doi: 10.1016/j.cpr.2019.101754.

Tomaka, J., Palacios, R. L., Champion, C., & Monks, S. (2018). Development and validation of an instrument that assesses individual differences in threat and challenge appraisal. *Journal of Depression and Anxiety*, *7*, 1-10. doi: 10.4172/2167-1044.1000313.

Trotman, G. P., Williams, S. E., Quinton, M. L., & Van Zanten, J. J. C. S. (2018). Challenge and threat states: Examining cardiovascular, cognitive and affective responses to two distinct laboratory stress tasks. *International Journal of Psychophysiology*, *126*, 42-51. doi: 10.1016/j.ijpsycho.2018.02.004.

Turner, M. J., Jones, M. V., Sheffield, D., Barker, J. B., & Coffee, P. (2014). Manipulating cardiovascular indices of challenge and threat using resource appraisals. *International Journal of Psychophysiology*, *94*, 9-18. doi: 10.1016/j.ijpsycho.2014.07.004.

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*, 48-57. doi: 10.1016/j.ijpsycho.2012.08.004.

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*, 387-397. doi: 10.1123/jsep.35.4.387.

Vickers, J. N. (2016). Origins and current issues in quiet eye research. *Current Issues in Sports Science*, *1,*101. doi: 10.15203/CISS_2016.101.

Vickers, J. N., & Williams, A. M. (2007). Performing under pressure: The effects of physiological arousal, cognitive anxiety, and gaze control in biathlon. *Journal of Motor Behavior*, *39*, 381-394. doi: 10.3200/JMBR.39.5.381-394.

Vine, S. J., Freeman, P., Moore, L. J., Chandra-Ramanan, R., & Wilson, M. R. (2013). Evaluating stress as a challenge is associated with superior attentional control and motor skill performance: Testing the predictions of the biopsychosocial model of challenge and threat. *Journal of Experimental Psychology, 19*, 185-194. doi: 10.1037/a0034106.

Vine, S. J., Moore, L. J., & Wilson, M. R. (2011). Quiet eye training facilitates competitive putting performance in elite golfers. *Frontiers in Psychology, 2*(8), 1-9. doi: 10.3389/fpsyg.2011.00008.

Vine, S. J., Moore, L. J., & Wilson, M. R. (2014). Quiet eye training: The acquisition, refinement and resilient performance of targeting skills. *European Journal of Sport Science*, *14*, S235-S242. doi: 10.1080/17461391.2012.683815.

Vine, S. J., Moore, L. J., & Wilson, M. R. (2016). An integrative framework of stress, attention, and visuomotor performance. *Frontiers in Psychology*, *7*(1671), 1-10. doi: 10.3389/fpsyg.2016.01671.

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*, 467-477. doi: 10.1080/10615806.2014.986722.

Vine, S. J., & Wilson, M. R. (2010). Quiet eye training: Effects on learning and performance under pressure. *Journal of Applied Sport Psychology*, *22*, 361-376. doi: 10.1080/10413200.2010.495106.

Vine, S. J., & Wilson, M. R. (2011). The influence of quiet eye training and pressure on attention and visuo-motor control. *Acta Psychologica*, *136*, 340-346. doi: 10.1016/j.actpsy.2010.12.008.

Williams, S. E., Van Zanten, J. J. C. S., Trotman, G. P., Quinton, M. L., & Ginty, A. T. (2017). Challenge and threat imagery manipulates heart rate and anxiety responses to stress. *International Journal of Psychophysiology*, *117*, 111-118. doi: 10.1016/j.ijpsycho.2017.04.011.

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 & Exercise Psychology*, *24*, 438-455. doi: 10.1123/jsep.24.4.438.

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*, 184-201. doi: 10.1080/17509840802400787.

Wilson, M. R., Vine, S. J., & Wood, G. (2009). The influence of anxiety on visual attentional control in basketball free throw shooting. *Journal of Sport and Exercise Psychology*, *31*, 152-168. doi: 10.1123/jsep.31.2.152.

Wilson, M. R., Wood, G., & Vine, S. J. (2009). Anxiety, attentional control, and performance impairment in penalty kicks. *Journal of Sport and Exercise Psychology*, *31*, 761-775. doi: 10.1123/jsep.31.6.761.

Wilson, M. R., Wood, G., & Vine, S. J. (2016). Say it quietly, but we still do not know how quiet eye training works – comment on Vickers. *Current Issues in Sport Science*, *1,* 117. doi: 10.15203/CISS_2016.117.

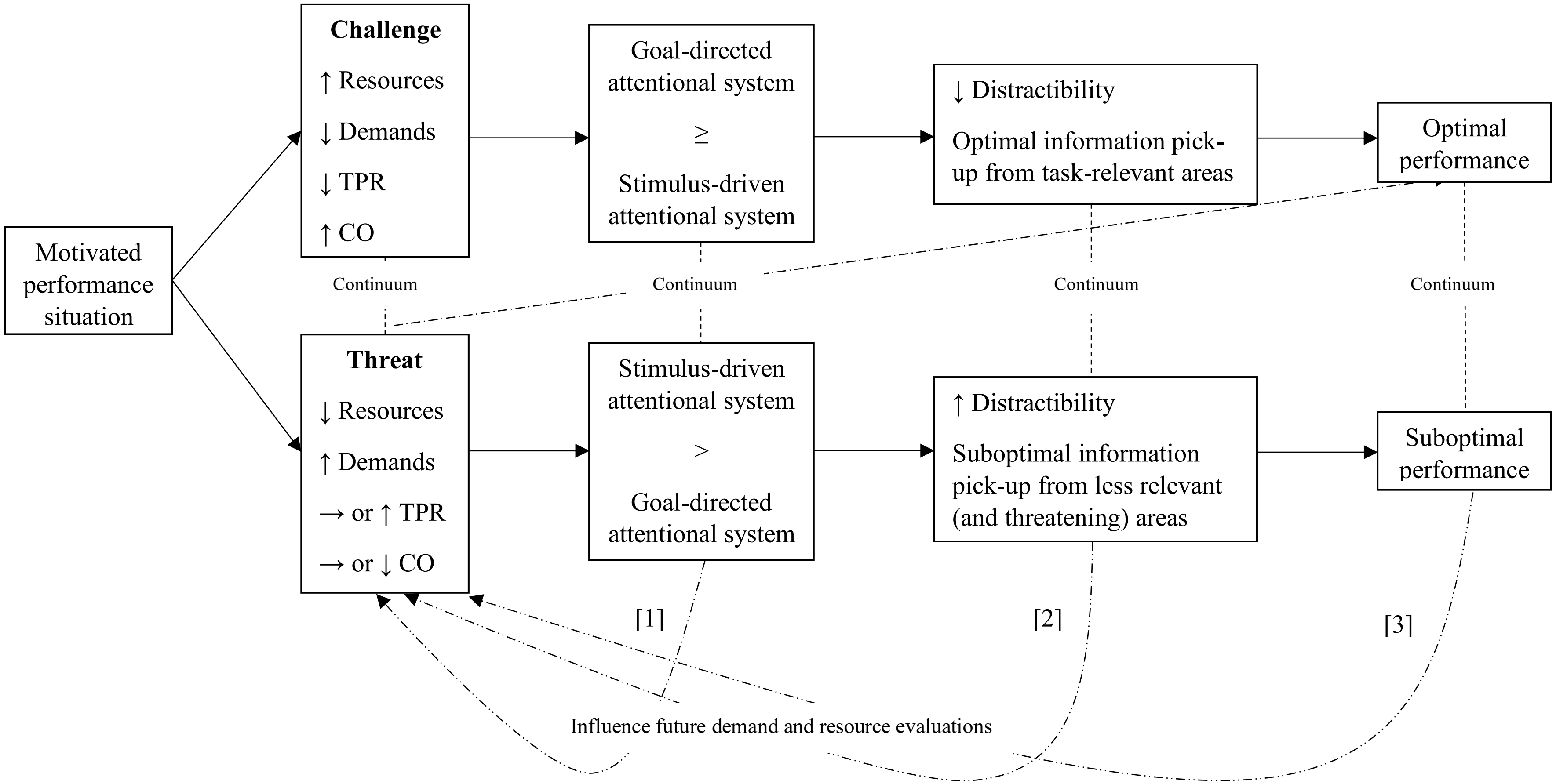
Wood, N., Parker, J., Freeman, P., Black, M., & Moore, L. J. (2018). The relationship between challenge and threat states, anaerobic power, core affect, perceived exertion, and self-focused attention during a competitive sprint cycling task. *Progress in Brain Research*, *240*, 1-17. doi: 10.1016/bs.pbr.2018.08.006.

Wood, G., & Wilson, M. R. (2011). Quiet-eye training for soccer penalty kicks. *Cognitive Processing*, *12*, 257-266. doi: 10.1007/s10339-011-0393-0.

Wood, G., & Wilson, M. R. (2012). Quiet-eye training, perceived control and performing under pressure. *Psychology of Sport and Exercise*, *13*, 721-728. doi: 10.1016/j.psychsport.2012.05.003.

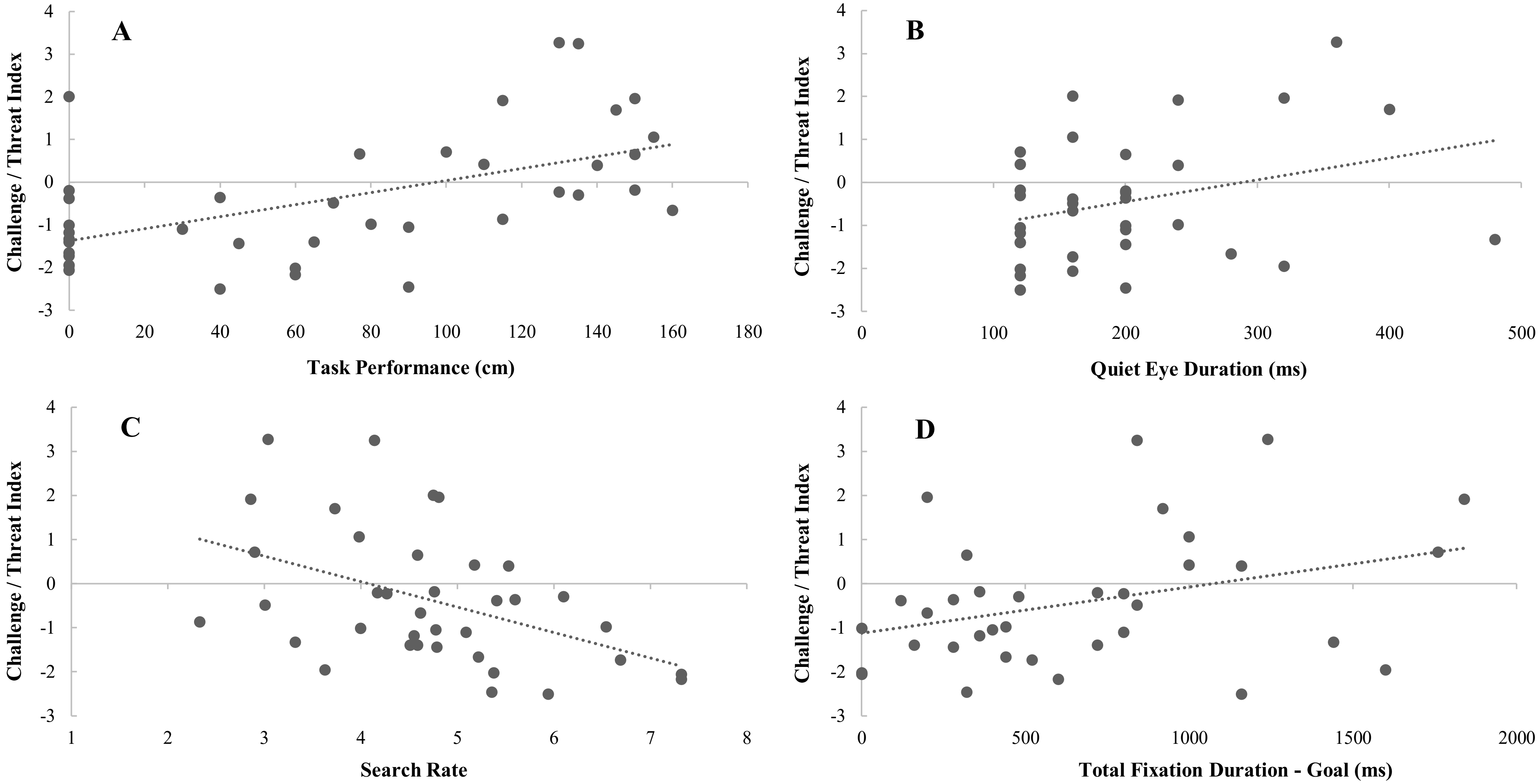
Zaccaro, A., Piarulli, A., Laurino, M., Garbella, E., Menicucci, D., Neri, B., & Gemigani, A. (2018). How breath-control can change your life: A systematic review of the psycho-physiological correlates of slow breathing. *Frontiers in Human Neuroscience*, 12: 353. doi: 10.3389/fnhum.2018.00353.

Figure 5.1 The Integrative Framework of Stress, Attention, and Visuomotor Performance (adapted from Vine et al., 2016)



Notes: TPR = total peripheral resistance, CO = cardiac output, Diagonal dash dot line = compensatory strategies (e.g., increased effort), Curved dash dot lines = feedback loops

Figure 5.2 The relationship between challenge and threat states (challenge/threat index) and task performance (soccer penalty accuracy) and attentional control (quiet eye duration, search rate, and total fixation duration on the goal) using data from Brimmell et al. (2019).



Notes: Panel A = challenge/threat index and task performance (cm), Panel B = challenge/threat index and quiet eye duration (ms), Panel C = challenge/threat index and search rate, and Panel D = challenge/threat index and total fixation duration on the goal (ms). A positive challenge/threat index reflects a challenge state (relatively lower TPR and higher CO reactivity), and a negative index reflects a threat state (relatively higher TPR and lower CO reactivity).