Developing expert visual attentional control for optimal golf performance under pressure

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Introduction

"It's just you, the ball, and the course. Everything else is a distraction that gets in the way of playing your best."

Tiger Woods, 15-time major golf championship winner

As the quote above suggests, the ability to concentrate and focus on hitting good shots while ignoring distractions such as anxious feelings or slow playing partners is vital for success in golf (Hellstrom, 2009). Indeed, attentional control, defined as the goal-directed allocation of cognitive processing resources to internal (e.g., swing thoughts) or external (e.g., flagstick) stimuli (Pashler et al., 2001), is widely recognised as a key skill that enables world-class golfers to produce optimal performance during high-pressure competition (e.g., Cohn, 1991; Thomas & Over, 1994). For example, McCaffrey and Orlick (1989) interviewed 14 elite golfers and found that, alongside other mental factors (e.g., commitment, goal-setting), they attributed exceptional performance to effectively controlling their focus of attention and blocking out distractions. Attentional control is considered a limited capacity system comprised of two main functions: (1) inhibition – which prevents attentional resources from being directed to task-irrelevant stimuli, and (2) shifting – which controls and redirects attentional resources, so they remain focused on task-relevant stimuli (Miyake et al., 2000). While questionnaire-based assessments of these functions exist (e.g., attentional control scale; Derryberry & Reed, 2002), mobile eye-tracking technology has enabled researchers to objectively measure the visual attentional control of golfers (Moran et al., 2018). Thus, in this chapter, we will draw on relevant research and pertinent theory to illustrate the importance of visual attentional control

for the optimal performance of key golf-related skills (e.g., putting), and how attentional processes can be trained, improved, and made more robust under high-pressure.

Overview of relevant research and theory

Quiet eye

Gaze behaviour – the way individuals use their visual system to acquire information in the environment – is associated with expert performance in various domains (Brams et al., 2019). Several theories have been proposed to explain how gaze affects expert performance (see Gegenfurtner et al., 2011). In sports, one of those theories – the information-reduction hypothesis (Haider & Frensch, 1999) – appears to explain the differences in gaze behaviour between experts and non-experts (or novices; Brams et al., 2019). According to this hypothesis, experts in sports make more fixations and dwell more on areas of interest (AOI) that provide them with the most relevant information for the task to be performed and avoid fixating on areas that are irrelevant for the task (Gegenfurtner et al., 2011). In golf, for example, when attempting to decide on the optimal direction and velocity of a putt, a golfer is required to examine the area on the putting green between the ball and the hole. According to the information-reduction hypothesis, an expert golfer will spend more time looking at AOIs such as the hole and the high part of the slope. Based on the gathered information, the expert golfer can go ahead and perform the putt, with a favourable outcome more likely.

The putt, just like any other golf shot (e.g., drive, chip) is a closed, self-paced targeting task. For such targeting tasks, one specific type of gaze behaviour that has been associated with expert and more proficient performance is the Quiet Eye (QE). The QE is defined as the final fixation on a relevant location or object in the visuo-motor space that begins prior to the initiation of a critical movement (Vickers, 2016). In golf putting, the location of the QE is often on the ball and the final fixation on the ball begins before the initiation of the backswing. The QE is one perceptual-cognitive strategy that has been consistently shown to differentiate expert

from novice athletes. Indeed, in a meta-analysis, Lebeau et al. (2016) reported a large difference in QE durations (QED) between experts and novices (d = 1.04; 27 studies; longer QED in expert athletes). Such findings have also been reported specifically in golf (e.g., Vickers, 1992). For example, in a study by Klostermann et al. (2014), when putting from 3 meters, expert golfers were more accurate (mean radial error = 24 cm) and had longer QEDs (~2000 ms) compared with less-expert golfers (mean radial error = 32 cm, QED = ~1500 ms).

While the QE reliably differentiates between levels of expertise, the theoretical explanations are not as apparent. One theory suggests that longer QEDs allow for better movement pre-programming (Vickers, 1996). Mann et al. (2011) showed from electroencephalogram data (a non-invasive method used to measure electrical activity in the brain via electrodes placed on the scalp) that longer QEDs were related to greater Bereitschaftspotential negativity (r = ~0.30). This finding supports the pre-programming hypothesis because the Bereitschaftspotential (a readiness for movement potential in the motor cortex) represents the preparation of a movement (Shibasaki & Hallett, 2006). Another theoretical explanation for the benefits of the QE relates to the online control of movement. According to this explanation, the QE during the online control of movement allows for fine-tuning or correcting of small movement errors as they occur (Vine, Lee, et al., 2013). Indeed, the QE usually continues throughout the performance of the motor action and hence it is possible that longer QEDs improve the online control of movement (Causer et al., 2017). In golf putting, online control would include the period that begins with the initiation of the backswing and ends when the putter contacts the ball. During this stage, the QE can help golfers fine-tune their planned action, mid-action, if or when they notice a deviation from that plan.

There is literature to support both the pre-programming and the online control explanations. Indeed, Ziv and Lidor (2019) in a review of gaze behaviour in golf putting reported two studies that supported the pre-programming hypothesis (i.e., Mann et al., 2011;

Walters-Symons et al., 2018), and four studies that supported the online control hypothesis (i.e., Causer et al., 2017; Klostermann et al., 2014; Vine, Lee, et al., 2013; Vine et al., 2017). We suggest that both theories are plausible and that a combination of improved pre-programming and online control lead to longer QEDs improving performance. Moreover, whether pre-programming or online control are more or less important is probably moderated by variables such as task difficulty and athlete experience (Walters-Symons et al., 2018).

The fact that longer QEDs are related to expert sports performance is important to researchers and practitioners, but perhaps more important is the question of whether the QE can help maintain optimal performance under elevated stress or anxiety. In this respect, Vincze et al. (2022) showed that table tennis players' QEDs were shorter, and performance was poorer, under highly stressful conditions. In this study, psychological stress was induced by constant negative feedback from the coach while the participants returned serves. Similarly, Behan and Wilson (2008) reported reduced QEDs when university students performed a simulated archery task under high anxiety. In golf, Vine, Lee, et al. (2013) asked expert golfers to participate in a putting shootout in which they performed putts until they missed. The QE was shorter in the final missed putt than the first and penultimate (successful) putts. Specifically, QEDs were shorter during online putter movement and after putter movement (i.e., QE dwell).

These findings are in line with attentional control theory (see Eysenck et al., 2007), and suggest that a disruption in visual attentional control while the motor action is taking place (i.e., online control) interferes with performance. Indeed, attentional control theory suggests that anxiety disrupts the balance between goal-directed (top-down) and stimulus-driven (bottom-up) attentional systems, and Payne et al. (2019) noted that such attentional disruptions underlie the negative relationship between anxiety and performance, particularly in aiming tasks like golf shots (e.g., putts). The shorter QEDs during online putter movements found by Vine, Lee,

et al. (2013) could suggest a shift from top-down visual attention on task-relevant stimuli (e.g., ball) to bottom-up attention on task-irrelevant stimuli (e.g., worrisome thoughts).

Based on the abovementioned studies and theories, shorter QEDs and poorer performance are found under high anxiety conditions, but does maintaining longer QEDs counteract these effects? In the abovementioned study by Vincze et al. (2022), shorter QEDs and worse performance were found under highly stressful conditions in table tennis players. However, these authors also showed that under more stressful conditions, longer QEDs were associated with hits or more successful table tennis returns. In another study of shooting in 10 elite biathletes, Vickers and Williams (2007) showed that three athletes did not choke in a high-pressure situation (i.e., missed the fewest targets and maintained 80% accuracy after cycling at their maximum oxygen uptake), and that seven athletes choked (i.e., missed most targets and had 40% accuracy or less after cycling at their maximum oxygen uptake). The QEDs of those who did not choke were longer than those who choked. As the authors of this study suggested, maintaining optimal QEDs may therefore prevent the reduction in performance that often occurs in high-pressure, anxiety-provoking situations (Vickers & Williams, 2007).

In summary, longer QEDs are related to expert performance and may allow for improved movement pre-programming and better online control of the motor action. Heightened anxiety appears to reduce the QED, which is associated, in turn, with impaired performance. However, maintaining or increasing QEDs may counteract the detrimental effects of elevated anxiety on performance. It is worth noting though that just because experts demonstrate longer QEDs, this does not mean that the QE causes improved performance. It is possible that other cognitive processes are involved (e.g., self-efficacy), and that the QE is a by-product of those processes. It is therefore necessary to examine whether training interventions which encourage participants to develop longer QEDs improve performance.

Quiet eye training

Given the expertise- and proficiency-related differences in visual attentional control reported in the literature (see Brams et al., 2019 and Lebeau et al., 2016), researchers have examined whether training athletes to adopt more optimal gaze patterns (e.g., longer QEDs) benefits sports performance (Vine et al., 2014). Among novice athletes, studies have shown that QE training (QET) aids skill acquisition (e.g., Vickers et al., 2017; Vine & Wilson, 2011). For example, Moore et al. (2012) allocated 40 novice golfers to a QET or control group following 40 baseline trials on a laboratory-based golf putting task. While the control group received only technical training instructions (e.g., stand with your legs shoulder width apart), the QET group received instructions that encouraged longer QEDs (e.g., after looking at the hole, fixate the ball for 2 to 3 seconds; see Table 1). After 320 practice putts, during retention tests, the QET group displayed longer QEDs (~3400 vs. ~1800 ms) and superior performance (~30% vs. ~20% of putts holed from 10 ft) than the control group. Similar learning advantages have been found in non-sporting domains (e.g., military, surgery; Moore et al., 2014; Wilson et al., 2011). Despite these encouraging findings, some studies have reported null effects (e.g., Vine & Wilson, 2010), and the QET interventions evaluated to date have been relatively brief, lasting only a few days (e.g., Moore et al., 2012). Thus, future research should test the effects of longer-term QET interventions on the acquisition of golf-specific skills (e.g., chipping).

>>>>>>>>>>>>>>> Insert Table 1 Near Here <<<<<<<<<<<<<<<

Beyond novice performers, studies have investigated if QET benefits the performance of experienced athletes (Vine et al., 2014). Indeed, despite some research showing relatively limited effects (e.g., Broodryk et al., 2022), most studies have shown that QET aids expert performance (e.g., Causer et al., 2011; Harle & Vickers, 2001; Wood & Wilson, 2011). For instance, Vine et al. (2011) assigned 22 experienced golfers to a QET or control group and

asked them to record their putting statistics over 10 competitive rounds. Next, after performing 20 baseline putts in a laboratory, both groups watched videos of their gaze behaviour and an elite prototype, but unlike the control group, the QET group also received feedback on how to improve (e.g., keep your gaze steady on the green for ~250 ms after hitting the ball; see Table 1). The golfers then recorded their putting statistics for 10 more rounds before returning to the laboratory and completing 20 putts in a retention test. In the laboratory, the QET group displayed marginally longer QEDs (~2800 vs. ~2200 ms) and better performance (~60% vs. 45% of putts holed from 10 ft) than the control group. Interestingly, this improvement in performance transferred to the real-world, with the QET group taking approximately 2 fewer putts per round after the intervention. However, while the authors labelled their golfers as 'elite', they were largely high-level recreational golfers (mean handicap of 3). Indeed, to date, few QET studies have been run with truly elite athletes competing internationally in their sport (see Causer et al., 2011 for an exception). Thus, future research should also evaluate the efficacy of QET with professional elite golfers (e.g., via case studies; Halperin, 2018).

As well as assessing the benefits of QET for the acquisition and refinement of sports skills, research has explored if QET aids performance under pressure (Vine et al., 2014). Jack Nicklaus, the winner of a record 18 major golf championships, said that "concentration is a fine antidote to anxiety", and studies evaluating QET interventions have largely supported this assertion, both in sport (e.g., Broodryk et al., 2022; Moore et al., 2012; Vine & Wilson, 2011) and other domains (e.g., surgery; Causer et al., 2014). For example, among novice golfers, Vine and Wilson (2010) found that a QET group maintained more optimal QEDs (~2800 vs. ~800 ms) and outperformed (~300 vs. ~250 points out of 400) a control group during a pressurised putting task. Similar results were reported by Vine et al. (2011) for experienced golfers, with the QET group displaying longer QEDs (~2800 vs. ~1400 ms) and better performance (~60% vs. ~35% of putts holed from 10 ft) than the control group under high-

pressure. However, it should be noted that some studies have reported null effects (e.g., Wood & Wilson, 2011), and the mechanisms underlying the benefits of QET are poorly understood (Wilson et al., 2016). That is, despite some work showing that QET might limit the conscious control of movements (Vine et al., 2013), enhance perceived control (Wood & Wilson, 2012), and promote challenge appraisals (Moore et al., 2013), future research should uncover precisely how QET helps golfers perform better under pressure (e.g., 4-foot putt to win a competition).

Practical applications

"The most important shot in golf…is the next one"

Ben Hogan, 9-time major golf championship winner

This quote from Ben Hogan highlights that possessing an ability to shift focus from what has gone before (e.g., a previous shot) to what has yet to come (e.g., next shot to be played) is important in golf. Considered alongside the earlier quote from Tiger Woods (noting the skill of ignoring of distractions), here we gain real-world insight into some of the pragmatic challenges faced by golfers. Both Woods and Hogan consider it vital for a golfer to possess awareness of the specific stimuli that may hinder performance (for example, an external distraction or the outcome of a previous shot), whilst having the ability to shift focus onto specific stimuli that support performance (e.g., course, ball, or player themselves). Combing these insights with the theoretical frameworks (e.g., information-reduction hypothesis; Haider & French, 1999) and key research findings discussed earlier (e.g., Vine et al. 2013), we can therefore infer that to develop (and then exercise) optimal visual attentional control requires golfers to be self-aware and inhibit or shift their visual attention.

Researchers and practitioners widely believe attention to be a crucial driver of peak performance (Moore, 2009; Hansen & Haberl, 2020), and thus it is vital for golfers to train and

improve visual attentional processes. Practically speaking, visual attention is frequently likened to the light emitted from a torch or spotlight (Posner et al., 1980). Our attention, like the spotlight, can be broad or narrow, and directed toward or away from AOI. Our development of optimal visual attentional control therefore hinges on our recognition of where our attentional spotlight is shining (via self-awareness) to ensure that our attentional resources are directed to task-relevant, rather than irrelevant, stimuli. It is important therefore that, through our practical recommendations, we help the golfer to: (1) raise awareness of what stimuli they are visually attending (e.g., asking where our spotlight is shining) when executing golf-specific skills (e.g., driving, putting, chipping); and (2) develop and implement appropriate strategies that support the shifting of visual attention (i.e., learning to move their spotlight to task-relevant stimuli). To help with this, below is a step-by-step guide for players and coaches.

Players

Step one. With the knowledge that longer QEDs are associated with better sports performance (see Lebeau et al., 2016), it is recommended that players initially check what they are attending to. Specifically, players are encouraged to actively notice which task-relevant or irrelevant stimuli (e.g., cues, thoughts) they are attending to in certain elements of their golf practice (e.g., while holing short putts). Players should also dedicate part of their practice routine to noticing what they are visually attending to (e.g., a dimple, line, or logo on the golf ball, breaking point on the green, the hole or clubhead). Whilst doing so, a log of evidence should be created, detailing awareness of the specific gaze behaviours and visually fixated AOI, as well as key details about the practice (e.g., number of strokes, outcome of practice repetitions). This is an impactful way for players to develop a strong foundation of awareness to support further development of optimal visual attentional control. Table 2 offers an example of how a golfer could evidence their gaze behaviour and visually fixated AOI in practice.

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Step two. With this log of evidence, players can raise their awareness of any patterns that arise in their gaze behaviour when executing key golf skills (e.g., driving, chipping) either successfully or unsuccessfully (e.g., I tend to miss short golf putts when I rush to see if the ball has dropped into the hole). Players should strive to leverage this knowledge (e.g., of the AOI they visually fixate on) to inform any changes, maintenance, or development work they engage in. It is important to compare actual patterns observed, with the specific AOI associated with expert performance in the golf skill they are practicing. To elaborate, players should become aware of whether they are fixating on the right stimuli for sufficiently long to provide them with relevant information they need to aid skill execution (e.g., green and hole in golf putting), or if they find themselves attending to less relevant information (e.g., playing partners, worrisome thoughts). To ensure that the specific AOI they fixate on are optimal for performance, it is vital that players share the patterns they have noticed with knowledgeable coaches. Through a reflective discussion with a coaching professional, players will be able to establish where any improvements in visual attentional control are required.

Further to seeking the advice of a coaching professional, where equipment and professional competence allow, players should consult sport psychologists who can use novel technologies (e.g., mobile eye-tracking) to further check and challenge whether visual fixations are on task-relevant stimuli at optimal times and for sufficient durations (e.g., on the back of the ball for 2 to 3 seconds prior to the backswing in golf putting; Vine et al., 2011). Table 2 includes examples of how players could include this in their log of practice evidence.

Step Three. Armed with greater awareness of the preferred AOI to fixate upon, players should incorporate longer QEDs into their pre-performance routines. For example, if looking to improve their golf putting accuracy, players should actively try and extend their QEDs to 2

or 3 seconds by fixating their gaze on the top of the ball (e.g., one specific dimple), the point at which the putter contacts the ball, or a chosen mark on the ball (e.g., ball logo, coloured line, or dot; Vickers, 2007). To help fixate the ball for a sufficient period, players could use positive internal self-talk such as "see it, roll it, hole it" (as Vine & Wilson, 2011).

Step Four. Finally, with research suggesting that elevated stress and anxiety can reduce QEDs and deter performance (e.g., Vincze et al. 2022), it is important that players engage with practical strategies that reduce anxiety and thus enable better performance under pressure (e.g., slow breathing). With mindfulness-based approaches considered a useful means of improving the ability to tolerate anxiety (e.g., Kaufman, Glass, & Pineau, 2018), our final recommendation for players is to engage in mindfulness practice, which has been shown to help athletes perform better under pressure (e.g., Henriksen & Hansen, 2019; see chapter X).

Coaches

Step One. Initially, coaches should collaborate with players to provide information, education, and guidance on establishing specific AOI and gaze patterns associated with peak performance. In doing so, coaches can support players to first develop their awareness of the AOI they visually fixate, when, and for how long, and then support them in optimising their visual attentional control (e.g., longer fixations on the desired target during the preparation of a golf drive). Specifically, coaches should dedicate time and resources to provide 1-1 education to upskill players in their knowledge of how expert performers (e.g., elite professional golfers) use their gaze behaviour to perform optimally (e.g., longer QEDs in golf putting; see Mann et al., 2011; Vickers, 1992). This education could utilise a range of methods, for example, the use of digital media (e.g., demonstration and discussion of elite professional players gaze behaviour), live coaching (e.g., providing in-session feedback on the gaze behaviour observed, such as lifting of head too early to see the outcome of a golf shot), creating peer-to-peer

feedback opportunities between players (e.g., focus group sessions or workshops), or asking players to engage in reflective practice focused on where they look, when, and for how long.

Step Two. Next, to complement efforts to educate players on where they fixate, when, and for how long, it important that coaches implement specific elements of QET into the practice routines they recommend and create for their players. Indeed, Vickers (2016) noted several key stages of QET interventions that coaches can follow with their players to develop and improve their visual attentional control. First, coaches should identify or develop an expert QE prototype (i.e., gaze patterns of an elite professional golfer), so that targeted feedback can be provided to a player on how to improve (i.e., in relation to the expert QE prototype). Next, when working with the player, a coach should encourage selection of one aspect of the expert QE prototype to work on (e.g., lengthen fixation on the ball prior to starting the backswing, maintain fixation on the green after contacting the ball). Support could then be offered to aid the player to practise using the chosen QE characteristic in blocked (e.g., hitting golf putts from a single location to the same hole 8 feet away) and random (e.g., taking golf putts from a range of locations and distances to various hole positions) practice, and finally persuade the player to use this new QE characteristic in real-world competition under elevated stress and anxiety.

Step Three. Finally, linked to our recommendations for players, coaches are encouraged, where possible, to co-create pre-performance routines with their players for key golf-specific skills (e.g., putting, chipping). In doing so, coaches can help players develop consistent behavioural actions (e.g., fixating gaze at a single dimple on the top of the golf ball) that support performance and prevent distraction from the naturally occurring external stimuli (e.g., opposing players, worrisome thoughts) that negatively influence their gaze behaviour in specific situations (e.g., putting for par, chipping over a bunker). Coaches should also seek the expertise of sport psychologists trained in technologies such as eye-tracking to gain a deeper understanding of their players visual attentional control and how it can be optimised.

Summary

"Golf is a game of inches. The most important are the six inches between your ears."

Arnold Palmer, 7-time major golf championship winner

As the above quote suggests, psychological factors play a vital role in golf performance (Hellstrom, 2009), and none more than visual attentional control, or the ability to focus gaze on task-relevant stimuli (e.g., ball) and ignore irrelevant distracting stimuli (e.g., opposing players). Indeed, top professional golfers have acknowledged the importance of task-focused attention for excellent performance (e.g., McCaffrey & Orlick, 1989), and research using eye-tracking technology has illustrated that through amassed experience, higher-level golfers tend to display more optimal visual attentional control (e.g., fewer fixations of a longer duration towards the hole) than lower-level golfers (e.g., Vickers, 1992). Moreover, regardless of expertise level, golfers often exhibit better visual attentional control (e.g., longer QEDs) during successful compared to unsuccessful shots (e.g., Wilson & Pearcy, 2009). Finally, studies have shown that training novice and expert golfers to adopt superior visual attentional control (e.g., longer QEDs via QET) can improve the performance of key skills (e.g., golf putting; Moore et al., 2012; Vine et al., 2011). Crucially, such training can insulate golfers from the detrimental effects of anxiety (e.g., worrisome thoughts), helping them perform better during high-pressure competition (e.g., Vine & Wilson, 2010). Thus, coaches and sport psychologists should use novel technologies (e.g., mobile eye-tracking, virtual reality; Gray, 2019) and creative methods (e.g., marked golf balls; Vickers, 2007) to improve golfer's visual attentional control. In doing so, practitioners should help golfers develop skills that are robust under pressure.

Further reading

1. Brams, S., Ziv, G., Levin, O., Spitz, J., Wagemans, J., Williams, A.M., & Helsen, W.F. (2019). The relationship between gaze behaviour, expertise, and performance: A systematic review. *Psychological Bulletin, 145*, 980-1027. doi:10.1037/bul0000207.
2. 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 & Exercise Psychology, 38*, 441-457. doi:10.1123/jsep.2015-0123.
3. Ziv, G., & Lidor, R. (2019). Gaze behaviour in golf putting: A review. *International Journal of Golf Science*, *7*(2).
4. 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.* doi:10.3389/fpsyg.2011.00008.
5. Moran, A., 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.

References

Baron, R. S., Moore, D., & Sanders, G. S. (1978). Distraction as a source of drive in social facilitation research. Journal of personality and social psychology, 36(8), 816. doi.org/10.1037/0022-3514.36.8.816.

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.

Brams, S., Ziv, G., Levin, O., Spitz, J., Wagemans, J., Williams, A.M., & Helsen, W.F. (2019). The relationship between gaze behaviour, expertise, and performance: A systematic review. *Psychological Bulletin, 145*, 980-1027. doi:10.1037/bul0000207.

Broodryk, R., Moore, L.J., & Kruger, A. (2022). Quiet eye training during the rugby union goal-kick: Practice and transfer effects in low- and high-pressure conditions. *International Journal of Sports Science & Coaching*. doi:10.1177/17479541221082631.

Causer, J., Hayes, S. J., Hooper, J. M., & Bennett, S. J. (2017). Quiet eye facilitates sensorimotor preprograming and online control of precision aiming in golf putting. *Cognitive Processing, 18*, 47-54. doi: 10.1007/s10339-016-0783-4.

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

Causer, J., Vickers, J.N., Snelgrove, R., Arsenault, G., & Harvey, A. (2014). Performing under pressure: Quiet eye training improves surgical knot-tying performance. *Surgery*, *156*, 1089-1096. doi:10.1016/j.surg.2014.05.004.

Cohn, P.J. (1991). An exploratory study on peak performance in golf. *The Sport Psychologist*, *5*, 1-14. doi:10.1123/tsp.5.1.1.

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.

Eysenck, M. W., Derakshan, 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.

Gegenfurtner, A., Lehtinen, E., & Säljö, R. (2011). Expertise differences in the comprehension of visualizations: A meta-analysis of eye-tracking research in professional domains. *Educational Psychology Review, 23*, 523-552. doi: 10.1007/s10648-011-9174-7.

Gray, R. (2019). Virtual environments and their role in developing perceptual-cognitive skills in sports. In R.C. Jackson, A.M. Williams (Eds.), *Anticipation and decision making in sport* (1st ed., pp. 342-359). Taylor & Francis. doi:10.4324/9781315146270-19.

Haider, H., & Frensch, P. A. (1999). Eye movement during skill acquisition: More evidence for the information-reduction hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25*, 172. doi: 10.1037/0278-7393.25.1.172.

Halperin, I. (2018). Case studies in exercise and sport sciences: A powerful tool to bridge the science-practice gap. *International Journal of Sports Physiology & Performance, 13*, 824-825. doi:10.1123/ijspp.2018-0185.

Harle, S.K., & Vickers, J.N. (2001). Training quiet eye improves accuracy in the basketball free throw. *The Sport Psychologist, 15*, 289-305. doi:10.1123/tsp.15.3.289.

Henriksen, K., Hansen, J., & Larsen, C. H. (2019). Mindfulness and acceptance in sport: How to help athletes perform and thrive under pressure. Routledge.

Herrebrøden, H., S., Sæbø, E., & Hystad, S. W. (2017). Are auditory distractions disturbing and detrimental to the performance of expert golfers? A field experiment. *Journal of Applied Sport Psychology*, 29(3), 323-336. doi: 10.1080/10413200.2017.1286696.

Hellstrom, J. (2009). Psychological hallmarks of skilled golfers. *Sports Medicine, 39*, 845-855. doi:10.2165/11317760-000000000-00000.

Kaufman, K. A., Glass, C. R., & Pineau, T. R. (2018). Mindful sport performance enhancement: Mental training for athletes and coaches. American Psychological Association.

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*, 392-400. doi: 10.1123/jsep.2013-0273.

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 & Exercise Psychology, 38*, 441-457. doi:10.1123/jsep.2015-0123.

Mann, D. T. Y., Coombes, S. A., Mousseau, M. B., & Janelle, C. M. (2011). Quiet eye and the Bereitschaftspotential: Visuomotor mechanisms of expert motor performance. *Cognitive Processing, 12*, 223-234. doi: 10.1007/s10339-011-0398-8.

McCaffrey, N., & Orlick, T. (1989). Mental factors related to excellence among top professional golfers. *International Journal of Sport Psychology, 20*, 256-278.

Miyake, A., Friedman, N.P., Emerson, M.J., Witski, A.H., & Howerter, A. (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, Z. E. (2009). Theoretical and empirical developments of the Mindfulness-Acceptance-Commitment (MAC) approach to performance enhancement. *Journal of Clinical Sport Psychology*, 3(4), 291-302.

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.

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 & Exercise Psychology, 11*, 169-183. doi:10.1080/1612197X.2013.773688.

Moore, L.J., Vine, S.J., & Wilson, M.R. (2014). Quiet eye training improves small arms maritime marksmanship. *Military Psychology*, *26*, 355-365. doi:10.1037/mil0000039.

Moran, A., 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.

Pashler, H., Johnston, J.C., & Ruthruff, E. (2001). Attention and performance. *Annual Review of Psychology*, *52*, 629-651. doi:10.1146/annurev.psych.52.1.629.

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

Posner, M. I., Snyder, C. R., & Davidson, B. J. (1980). Attention and the detection of signals. *Journal of experimental psychology*: General, 109(2), 160.

Shibasaki, H., & Hallett, M. (2006). What is the Bereitschaftspotential? *Clinical Neurophysiology*, *117*, 2341-2356. doi: 10.1016/j.clinph.2006.04.025.

Thomas, P.R., & Over, R. (1994). Psychological and psychomotor skills associated with performance in golf. *The Sport Psychologist*, *8*, 73-86. doi:10.1123/tsp.8.1.73.

Vickers, J.N. (1992). Gaze control in putting. *Perception*, *21*, 117-132. doi:10.1068/p210117.

Vickers, J. N. (1996). Control of visual attention during the basketball free throw. *The American Journal of Sports Medicine, 24*, S93-S97. doi: 10.1177/036354659602406S25.

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

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

Vickers, J.N., Vandervies, B., Kohut, C., & Ryley, B. (2017). Quiet eye training improves accuracy in basketball field goal shooting. *Progress in Brain Research, 234*, 1-12. doi:10.1016/bs.pbr.2017.06.011.

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.

Vincze, A., Jurchis, R., & Iliescu, D. (2022). The dynamics of Quiet Eye under stress in elite table tennis performance. *International Journal of Sport and Exercise Psychology*, doi: 10.1080/1612197X.2022.2078853.

Vine, S. J., Lee, D., Moore, L. J., & Wilson, M. R. (2013). Quiet eye and choking: Online control breaks down at the point of performance failure. *Medicine and Science in Sports and Exercise, 45*), 1988-1994. doi: 10.1249/MSS.0b013e31829406c7.

Vine, S. J., Lee, D. H., Walters-Symons, R. M., & Wilson, M. R. (2017). An occlusion paradigm to assess the importance of the timing of the quiet eye fixation. *European Journal of Sport Science, 17*, 85-92. doi: 10.1080/17461391.2015.1073363.

Vine, S.J., Moore, L.J., Cooke, A., Ring, C., & Wilson, M.R. (2013). Quiet eye training: A means to implicit motor learning. *International Journal of Sport Psychology*, *44*, 367-386. doi:10.7352/IJSP.2013.44.367.

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*. 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.

493 Vine, S.J., & Wilson, M.R. (2010). Quiet eye training: Effects on learning and performance
494 under pressure. *Journal of Applied Sport Psychology*, *22*, 361-376.
495 doi:10.1080/10413200.2010.495106.
496 Vine, S.J., & Wilson, M.R. (2011). The influence of quiet eye training and pressure on attention
497 and visuo-motor control. *Acta Psychologica*, *136*, 340-346.
498 doi:10.1016/j.actpsy.2010.12.008.
499 Walters-Symons, R., Wilson, M., Klostermann, A., & Vine, S. (2018, Feb). Examining the
500 response programming function of the Quiet Eye: Do tougher shots need a quieter
501 eye? *Cognitive Processes, 19,* 47-52. doi: 10.1007/s10339-017-0841-6.
502 Wilson, M.R., & Pearcy, R.C. (2009). Visuomotor control of straight and breaking golf puts.
503 *Perceptual & Motor Skills*, *109*, 555-562. doi:10.2466/pms.109.2.555-562.
504 Wilson, M.R., Vine, S.J., Bright, E., Masters, R.S.W., Defriend, D., & McGrath, J.S. (2011).
505 Gaze training enhances laparoscopic technical skill acquisition and multi-tasking
506 performance: A randomised, controlled study. *Surgical Endoscopy*, *25*, 3731-3739.
507 doi:10.1007/s00464-011-1802-2.
508 Wilson, M.R., Wood, G., & Vine, S.J. (2016). Say it quietly, but we still do not know how
509 quiet eye training works – comment on Vickers. *Current Issues in Sport Science, 1:117*.
510 doi:10.15203/CISS_2016.117.
511 Wood, G., & Wilson, M.R. (2011). Quiet-eye training for soccer penalty kicks. *Cognitive*
512 *Processing*, *12*, 257-266. doi:10.1007/s10339-011-0393-0.
513 Wood, G. & Wilson, M.R. (2012). Quiet-eye training, perceived control, and performing under
514 pressure. *Psychology of Sport & Exercise*, *13*, 721-728.
515 doi:10.1016/j.psychsport.2012.05.003.
516 Ziv, G., & Lidor, R. (2019). Gaze behaviour in golf putting: A review. *International Journal*
517 *of Golf Science, 7*(2)

518 **Table 1.** An overview of the QET instructions delivered to novice and experienced golfers in
519 Vine and Wilson (2010), Vine et al. (2011), and Moore et al. (2012).
520

Vine & Wilson (2010)	Vine et al. (2011)	Moore et al. (2012)
Assume your stance and ensure that your gaze is on the back of the ball.	Assume your stance and align the clubhead so your gaze is resting on the back of the ball.	Assume your stance, and ensure your gaze is located on the back of the ball.
Fixate the hole no more than three times.	After setting up over the ball, fix your gaze on the hole. Do not make any more than three fixations towards the hole.	After setting up over the ball, fix your gaze on the hole. Do not make any more than three fixations towards the hole.
Your final fixation should rest on the back of the ball and last for two to three seconds.	The final fixation should be a QE on the back of the ball. The onset of the QE should occur before your putting stroke begins and last for two to three seconds.	Your final fixation should be a QE on the back of the ball. The onset of the QE should occur before the putting stroke begins and last for two to three seconds.
You should not direct your gaze towards the clubhead or shaft during the putt.	No gaze should be directed to the clubhead during the backswing or foreswing.	Ensure you direct no gaze towards the clubhead during the putting stroke.
Your fixation should remain steady on the green for 200 to 300 ms after contacting the ball.	The QE should remain steady on the green for 200 to 300 ms after the putter contacts the ball.	The QE should remain steady on the green for 200 to 300 ms after the putter contacts the ball.

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Table 2. Example of how a golfer could evidence their gaze behaviour and visually fixated AOI in practice (e.g., when holing different putts on a practice green), as well as any feedback they received from coaches or sport psychologists regarding where to look and for how long.

Developing Optimal Visual Attention - Logging Practice Evidence				
Putt #	**Details**	**Outcome**	**Gazing at? Fixating on? For how long?**	***Ideal AOIs (from coach feedback)***
1	8ft straight	Holed	Small dimple on the back of the ball for 2 to 3 seconds	Coloured dimple on the back of the ball
2	4ft breaking	Missed	Breaking point on the green for approximately 1 second	Hole for approximately 2 seconds
3				
4				
5				