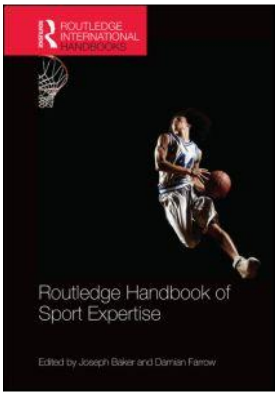

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AIMING FOR EXCELLENCE

The quiet eye as a characteristic of expertise

Mark R. Wilson, Joe Causer, and Joan N. Vickers

> Talent hits a target no one else can hit; genius hits a target no one else can see.
>
> *(Arthur Shopenhauer, 1788–1860)*

While the above quotation may simply be using the concepts of perception and action as a metaphor for genius, research has revealed that expert sport performers actually do attend to "to-be-acted-upon" targets differently than their less-skilled counterparts. Indeed, a consistent body of research has revealed significant differences between the gaze behaviors of experts and non-experts when performing sport skills. With experience and through training, experts learn to conserve limited cognitive resources and strategically direct their gaze control system to maximize information acquisition and guide accurate, goal-directed movement (Land, 2009). There has been increasing interest in understanding the perceptual-cognitive advantage of expert performers, with experts differing from non-experts on sport-specific measures of attention allocation and information pickup (Causer & Williams, 2013; Mann *et al.*, 2007).

This chapter discusses research that points to a role for effective gaze behavior in supporting expert-like planning and control of visually guided skills. Specifically, the role of a particular gaze strategy – the quiet eye (QE; Vickers, 1996) – in underpinning expert performance will be discussed in four main sections:

1. *What is the QE?* Defining the QE and reviewing the literature that has identified the QE as a discriminating characteristic of expertise.
2. *QE and competitive pressure.* A key characteristic of expertise is being able to execute skills when it matters most. We discuss the role of the QE in maintaining performance under pressure.
3. *QE training.* Discussing interventions that can help even experienced performers extend their QE and improve performance.
4. *Future directions.* Discussing how researchers should further our understanding of how the QE "works" to support skilled performance.

What is the quiet eye (QE)?

The QE is the final fixation to a target during the preparation phase of a goal-directed movement. Specifically, the QE is defined for a given motor task as the final fixation or tracking gaze directed to a single location or object in the visuomotor workspace within three degrees of visual angle (or less) for a minimum of 100 milliseconds (ms) (Vickers, 1996, 2007). The onset of the QE occurs before a critical phase of the motor task and the offset occurs when this final fixation deviates off the target by more than three degrees of visual angle for more than 100 ms. The QE represents a critical period of cognitive processing during which the parameters of the movement such as force, direction, and velocity are fine-tuned and programmed (Vickers, 1996). It is during this period when sensory information is synthesized with the mechanisms necessary to both plan (preprogram) and control (online) the appropriate motor response.

The key processes underpinning the QE period – setting parameters for movement, processing appropriate environmental cues, synchronizing motor strategies (Mann *et al.*, 2007) – are related to functions of attentional control. Over the last decade we have learned a good deal about the basic mechanisms of visual-attentional control at both functional and neural levels. For example, fMRI data indicate the role of a large-scale fronto-parietal network, which is involved in both top-down control of attention and in attentional orienting to strong stimulus cues (Corbetta & Shulman, 2002). This network is involved both in excitatory guidance of attention to behaviorally relevant targets and in the suppression of irrelevant distraction (Medendrop *et al.*, 2011; Mevorach *et al.*, 2006, 2010).

The quiet eye and attention

Corbetta *et al.*'s model of attention reflects the delicate balance between a goal-directed, top-down (dorsal) and stimulus-driven, bottom-up (ventral) system (Corbetta & Shulman, 2002; Corbetta *et al.*, 2008). First, a top-down, goal-directed, attentional system (dorsal attention network), which is centered on the dorsal posterior parietal and frontal cortex, is important for response or action selection and is involved in linking relevant stimuli to appropriate motor responses. Second, a stimulus-driven, attentional system (ventral attention network), centered on the temporoparietal and ventral frontal cortex, is recruited during the detection of salient and unattended stimuli (Corbetta *et al.*, 2008).

Both the dorsal and ventral systems interact dynamically during normal perception to determine where and what we attend to. However, when attention is focused, the ventral system is suppressed to prevent reorienting to distracting/irrelevant cues (Corbetta *et al.*, 2008). Therefore, Vickers' (1996) suggestion that longer QE periods may allow performers an extended duration of response programming, while minimizing distraction from other cues, can be explained using the model of Corbetta and colleagues; the QE helps maintain effective, goal-directed attentional control, while reducing the impact of the stimulus-driven, attentional system (see Figure 3.1).

Kinematic correlates

Longer QE durations provide a period to efficiently pass visually acquired goal position information to the motor control systems, which should therefore result in movement kinematics and patterns of muscle activation that are more effective for successful skill performance (Vickers, 2009; Figure 3.1). For example, Causer *et al.* (2010) revealed that not only did elite shotgun shooters have significantly longer QE durations than their sub-elite counterparts, but they also had more efficient gun barrel kinematics. Stronger evidence of a role of QE in supporting efficient

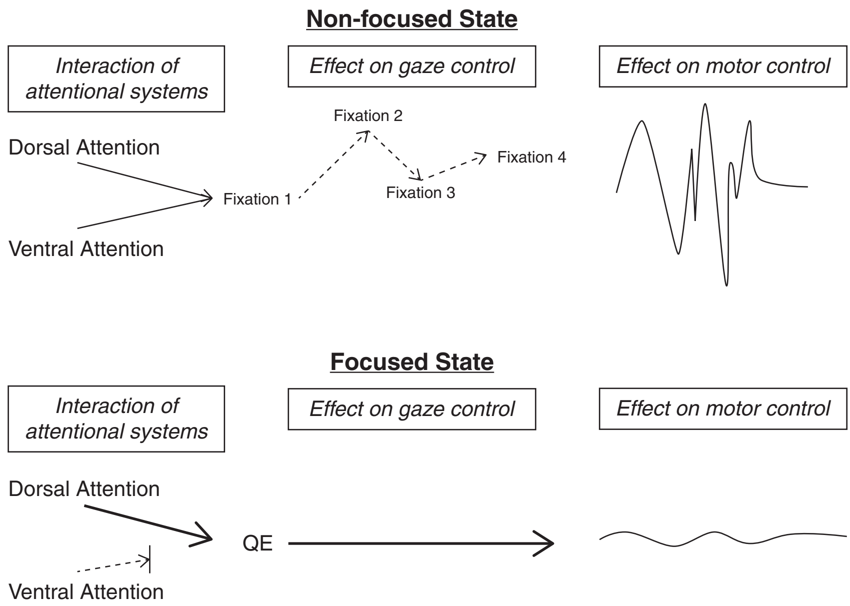

Figure 3.1 A representation of the proposed links between attentional networks, the quiet eye (QE), and movement control.

kinematics is provided by QE training studies (e.g., Causer *et al.*, 2011a; Moore *et al.*, 2012). Causer *et al.* (2011a) reported that a QE-trained group of elite shotgun shooters displayed significantly reduced gun barrel displacement and absolute peak velocity (over and above improvements revealed by a control group), despite neither of these variables being explicitly trained. Similarly, Moore *et al.* (2012), in a golf putting task, found that, following training, a QE-trained group of novices displayed more efficient club head acceleration and electromyography (EMG) activity in the extensor carpi radialis muscle of the left arm than their control group counterparts.

Neural correlates

The use of event-related potentials (ERP) has been reported in various psychophysiological investigations that have examined attentional processes involved prior to task execution. The ERP is derived from the average of multiple responses and represents the temporal relationship of cortical activation to a specific event, thereby providing a time-locked index of the psychological correlates of performance (Fabiani *et al.*, 2000). The Bereitschaftspotential (BP) is a class of ERP that is of particular interest when studying the preparatory period preceding task execution. The BP is a negative potential that precedes an actual, intended, or imagined event by one to 1.5 seconds (s) and indexes anticipatory attention and movement preparation (Simonton, 2004). Mann *et al.* (2011) explored the association of the BP and QE period in high and low handicap golfers during execution of a golf putt. The low handicap golfers were more accurate and less variable in their performance than the high handicap golfers. Systematic differences in QE duration and BP were observed, with experts exhibiting a prolonged QE period and greater cortical activation in the right-central region compared to non-experts. A significant association between cortical activation and QE duration was noted, longer QE being positively correlated with the magnitude (negativity) of the BP.

Quiet eye research evidence

Since Vickers' (1996) seminal study in basketball free-throw shooting, evidence has been growing supporting the QE as an objective measure of attentional control predicting motor performance. In Mann *et al.*'s (2007) meta-analysis of perceptual-cognitive expertise in sport, the QE was reported as one of three gaze behaviors that differentiated experts from their non-expert counterparts. A moderate to large effect size was uncovered ($r = 0.62$, $p < .001$). On average, experts maintained a QE duration that was approximately 62 per cent longer than non-experts. These findings were consistent over tasks that were as diverse as rifle shooting (Janelle *et al.*, 2000) and volleyball service return (Vickers & Adolphe, 1997). The following section outlines the two types of discrete sport skills where expertise differences in QE have most frequently been examined: targeting and interceptive tasks.

Targeting tasks

Targeting tasks are self-paced and generally require a great deal of accuracy as an object is propelled towards a distal target. In sports such as golf, archery, and shooting, the ability to accurately select the correct parameters for movement is crucial for successful performance. Access to pertinent visual stimuli and the effective processing of information are essential in these sports (Causer *et al.*, 2010). For example, successful performance in golf putting requires the golfer to attend to cues related to distance, direction, and force, which are in turn influenced by environmental conditions (e.g., slope, grain direction). Accordingly, the visual system must orient to and process the most salient perceptual cues necessary to ascertain both distance and direction information, while working memory is called upon for matching stroke tempo with the requisite stroke force (Mann *et al.*, 2011). Vickers (2012) postulates that experts are better able to maintain the longer duration QE that helps to organize and sustain the underlying organization and control of this information (via dorsal networks, while suppressing ventral attention). Table 3.1 below outlines studies that have examined proficiency differences in QE in targeting skills.

While there are differences in the actual QE values reported, depending on specific task demands, it is evident that experts' QE durations are generally longer than their non-expert counterparts. From a basic perspective of reward-based learning, it is likely that experts have found that adopting a task-optimal QE increased the expected probability of success of the subsequent action (see Gottlieb, 2012). Current research suggests that a longer QE helps to ensure both the efficient preplanning of the movement response (e.g., Klostermann *et al.*, 2013; Mann *et al.*, 2011) and its subsequent online control under visual guidance (Oudejans *et al.*, 2002; Vine *et al.*, 2013). The relative weighting of preplanning and online control functions for the QE will depend on task-specific demands. For example, in rifle shooting, where the movement time (trigger pull) is short, the QE duration likely reflects a purely preprogramming function (Janelle *et al.*, 2000). In golf putting, the QE appears to provide both a preprogramming (Mann *et al.*, 2011) and online control (Vine *et al.*, 2013) function.

The QE literature may seem counterintuitive in that experts generally "do more with less" visual information than non-experts. For example, experts can anticipate more accurately than novices even when visual information is limited or occluded (see Chapter 2 of this volume). Why should experts need more information via a longer QE in order to be accurate than less expert performers in targeting skills? We suggest that a single, long, final fixation to a relevant target is actually *more* efficient than a series of fixations around the target. The longer QE durations found for experts in the studies outlined in Table 3.1 are typically measured within a similar preparation period as non-expert performers. Therefore, experts do not necessarily extend the absolute processing period, but are more efficient at executing relatively longer QE durations within the time available.

Table 3.1 A summary of the studies that have examined expertise differences in quiet eye in targeting tasks.

Authors	*Year*	*Sport/Task*	*Participants*	*Findings*
Vickers	1992	Golf putting	5 low handicap (0–8) and 7 high handicap (10–16) golfers	QE duration was significantly longer for low handicap (2 s) than high handicap golfers (1.5 s).
Vickers	1996	Basketball free-throw shooting	8 elite shooters (M = 75% accuracy) and 8 near-elite shooters (M = 42% accuracy)	QE duration was significantly longer for elite (~900 ms) than near-elite (~350 ms) performers.
Williams, Singer, & Frehlich	2002	Billiards potting	12 highly skilled and 12 less-skilled players	Experts had significantly longer QE durations on successful shots (~600 ms) than non-experts (~300 ms).
Janelle, Hillman, Apparies, Murray, Meili, Fallon, & Hatfield	2000	Rifle shooting	12 elite and 13 non-elite marksmen	QE was significantly longer (11 s) for elite shooters than non-elite shooters (7 s).
Nagano, Kato, & Fukuda	2006	Football penalty	3 better performers and 3 poorer performers	The top scorers had significantly longer QE durations than their less successful counterparts.
Wilson, McGrath, Vine, Brewer, Defriend, & Masters	2011	Laparoscopic surgery	10 experienced surgeons (> 60 procedures) and 15 novice surgeons (< 10 procedures)	Experienced operators used a significantly longer QE period than novices (1120 ms versus 600 ms) to guide precision grasping movements and hence needed fewer grasp attempts (2.5 versus 3.3).
Mann, Coombes, Mousseau, & Janelle	2011	Golf putting	10 low handicap (< 2) and 10 mid-handicap (10–12) golfers	Experts had significantly longer QE durations (> 2 s) than non-experts (< 2 s).
Panchuk & Vickers	2011	Line walking	11 professional ballet dancers; 9 control adults	QE duration prior to stepping on the line was significantly longer for ballet dancers (2,350 ms) than the controls (1,330 ms), and significantly further ahead (55% of fixations were straight ahead, cf. 26% for controls).

Vickers & Lewinski	2012	Officer-involved shooting; live simulation	11 elite Emergency Response Team officers and 13 rookies	Elite accuracy 75% and rookie 54%. Elite officers kept their QE on assailant for ~350 ms before pulling trigger; rookies employed saccadic gestures back to sights of their own gun and often fired without fixating assailant. On catch trials, when a phone was drawn instead of a gun, the rookies shot the assailant on 62% of trials, compared to 19% for the elite.
Rienhoff, Baker, Fischer, Strauss, & Schorer	2012	Dart throwing	13 skilled (competitive) darts players; 16 novices (physical education students)	QE duration differences between skilled and less-skilled players were not statistically significant ($p = 0.08$; ES = 0.52).
Rienhoff, Hopwood, Fischer, Strauss, Baker, & Schorer	2013	Basketball free throw& darts	13 elite basketball players	Throwing accuracy and quiet eye duration for skilled and less-skilled basketball players were examined in basketball free-throw shooting and the transfer task of dart throwing. Skilled basketball players showed significantly higher throwing accuracy and longer quiet eye duration in the basketball free-throw task compared to their less-skilled counterparts.
Wilson, Miles, Vine, & Vickers	2013	Throwing and Catching	57, 8–10-year-old children were divided into high (HMC: n = 16), median (MMC: n = 25) and low (LMC: n = 16) coordination abilities.	The HMC group was more successful in the catching task than both other groups (catching percentage: HMC = 92%, MMC = 62%, LMC = 35%) and had longer targeting QE fixations before the release of the ball (HMC = 500 ms, MMC = 410 ms, LMC = 260 ms) and longer tracking QE durations before catching (HMC = 260 ms, MMC = 200 ms, LMC = 150 ms).
Harvey, Vickers, Snelgrove, Scott, & Morrison	2014b	Thyroidesctomy: identification and dissection of the recurrent laryngealnerve (RLN) in a human cadaver model	3 highly experienced (HE) surgeons and 7 low experienced (LE)	HE surgeons rated higher than LE through blind review of gaze videos; groups did not differ in operating time or hand MT. HE had a longer QE duration on the RLN prior to dissections (2.4s) compared to 844 ms for the LE.

Interceptive tasks

Interceptive timing tasks require coordination of the athlete's body, or a held implement, and an object, or target area, in the environment. Whereas targeting tasks generally have a fixed and consistent target, interceptive tasks are often moving in a predictable or unpredictable way towards or away from the athlete. For interceptive tasks, athletes have to develop strategies to fixate and track the target object, as well as process and anticipate the speed and direction of the object and consistently update that information based on environmental perturbations. Alongside this, athletes also have to program the forces, distances, and direction of their limbs in order to coincide their action with the moving target (see Table 3.2).

Table 3.2 A summary of the studies that have examined expertise differences in quiet eye in interceptive tasks.

Authors	*Year*	*Sport/Task*	*Participants*	*Findings*
Vickers & Adolphe	1997	Volleyball service return	12 Team Canada Men's Team – elite receivers versus near-elite	Elite receivers fixated on ball earlier and tracked for ~400 ms before ball reached the net, compared to 0 ms for near-elite.
Panchuk & Vickers	2006	Ice hockey goal tending	8 elite goaltenders at college and semi-pro level	On saves, QE duration was significantly longer before puck left stick (~900 ms) than goals for all goaltenders.
Rodrigues, Vickers & Williams	2002	Table tennis return	Elite table tennis players and non-elite recreational players	No significant QE difference in groups due to QE being measured only during flight of the ball.
Causer, Bennett, Holmes, Janelle, & Williams	2010	Shotgun shooting	24 elite and 24 sub-elite shotgun shooters in trap, double trap, and skeet	Elite shooters demonstrated both an earlier onset and a longer relative duration of QE than their sub-elite counterparts. Also, in all three disciplines, QE duration was longer and onset earlier during successful compared with unsuccessful trials for elite and sub-elite shooters.
Piras & Vickers	2011	Soccer goaltending	Male college and club level	Saves occurred during kick when duration QE was longer (~900 ms) on a "visual pivot" location between the ball and kicking leg.
Millslagle, Hines, & Smith	2013	Softball umpires	4 expert; 4 near expert	Experts fixated earlier and for a longer period of time on the area where the ball would be released, and were able to track the ball earlier and for a longer period of time.

Vickers (2007) identified three gaze control phases for interceptive actions: object recognition, object tracking, and object control. During the object recognition phase, fixations and pursuit tracking are used to determine the trajectory and movement parameters of the target. The object tracking phase involves smooth pursuit tracking to keep the target in the fovea (the center of the retina where there is close pairing of ganglion cells to photoreceptors, thereby permitting greatest visual acuity) to ensure any changes in trajectory are detected. Finally, in the object control phase, fixations and tracking behaviors are used to stabilize the eyes as the target is successfully intercepted.

The most effective method of determining object flight varies depending on the task. For predictable object flight, fixations or pursuit tracking early in the flight should enable an athlete to successfully intercept the object (Vickers, 2007). For more unpredictable object flights, such as baseball pitching or cricket bowling, a continuous tracking strategy will be more effective to enable the athlete to make online adjustments based on late deviations to the object flight (Causer *et al.*, 2010). Predictions of object flight can be made in certain tasks before the object has started moving, such as penalty kicks, based on early postural cues of the opponent (Causer & Williams, 2013), which can then be corroborated by early ball flight information. However, in most interceptive tasks, early detection of the target followed by a continuous tracking of the target seems to be the most effective strategy. For example, in a series of studies, Causer *et al.* (2010, 2011a, 2011b) examined the gaze strategies of expert and less-skilled shotgun shooters. Analysis of eye movement data showed that expert shooters demonstrated an earlier target pickup (QE onset) and a longer target tracking (QE duration) when compared to their less-skilled counterparts. Successful shots were characterized by the trend in both skill levels compared to unsuccessful shots, demonstrating that this gaze strategy is the most effective.

Researchers have shown similar findings in other interceptive tasks, such as in ice hockey goaltending (Panchuk & Vickers, 2006) and table tennis or volleyball returns (Rodrigues *et al.*, 2002; Vickers & Adolphe, 1997). Panchuck and Vickers (2006) found that QE duration was longer for saves, compared to goals, with the fixations on the moving puck critical to successful interception. Vickers and Adolphe found early detection of the ball and longer QE duration on the ball led to more successful serve returns. It is clear from the data presented above and in Table 3.2 that an early onset of QE and longer QE duration is critical for the successful interception of objects: the early QE onset maximizes the tracking time and enables early flight information to be processed, while a longer QE duration provides sufficient time for flight trajectory information to be accurately calculated.

QE and competitive pressure

An important characteristic of expert performers is their ability to perform at their limits just when it matters most – usually under intense competitive pressure. The ability to control attention and remain focused under elevated anxiety has frequently been discussed as a key component of success in sport, and there is considerable research evidence suggesting that anxiety-induced disruptions to attentional control lead to degradation in task performance (see Janelle, 2002; Wilson, 2012 for reviews). Several studies have revealed that the QE may be a useful index of optimal attentional control, and sensitive to the influence of increased anxiety (e.g., Behan & Wilson, 2008; Causer *et al.*, 2011b; Vickers & Williams, 2007; Wilson *et al.*, 2009; see Table 3.3).

For example, Wilson *et al.* (2009), in a basketball free-throw task, found that under conditions of elevated cognitive anxiety, QE durations were reduced, as participants took more fixations

Table 3.3 A summary of the studies that have examined the effect of increased anxiety on quiet eye and performance.

Authors	*Year*	*Sport/Task*	*Participants*	*Findings*
Vickers & Williams	2007	Biathlon/rifle shooting during 5 power output levels: Pre, 55%, 70%, 85%, 100% of individual capacity	10 Elite (international) biathletes	Athletes who choked (performed worse under high pressure compared to a practice condition) had shorter QE duration than practice condition. Those who did not choke maintained a longer QE duration after 100% power output during the high-pressure situation.
Behan & Wilson	2008	Simulated archery	20 trained students	QE durations (as a percentage of the alignment phase) reduced significantly from 62% in low-pressure to 50% in high-pressure session.
Wilson, Vine, & Wood	2009	Basketball free throw	10 university basketball players	There were significant reductions in both the QE duration (by 34%) and performance (by 26%) in the high-threat compared with control condition.
Wood & Wilson	2010	Football penalty	18 university footballers	Players fixated the goalkeeper for longer during the aiming phase and hit the ball more centrally when under pressure and with a moving goalkeeper.
Causer, Holmes, Smith & Williams	2011	Shotgun shooting	16 elite shotgun shooters	Shooters demonstrated shorter QE durations, and less efficient gun motion, along with a decreased performance outcome (fewer successful trials) under high compared with low-anxiety conditions.
Nibbeling, Oudejans, & Daanen	2012	Dart throwing	11 experts; 9 novices	Novices' QE durations reduced significantly when they were anxious, whereas experts' didn't.
Vine, Lee, Moore, & Wilson	2013	Golf putting	50 expert golfers (mean handicap of 3.6)	QE duration was significantly shorter on the missed putt in a shootout than other putts.
Causer, Harvey, Snelgrove, Arsenault & Vickers	2014	Surgical knot-tying	20 first year medical students divided into quiet eye (QE) or technical (TT) training groups	Both QE and TT groups significantly improved knot-tying performance post-intervention, with QE group improving significantly more than the TT. More efficient eye movements and movement times were reported for the QE group. The QE group transferred their performance improvements into a high anxiety condition; the TT group reverted to pre-test scores.

around the vicinity of the target compared with a low-anxiety condition. These findings are consistent with other research by Behan and Wilson (2008) in simulated archery and Nibbeling *et al.* (2012) in a dart-throwing task. Furthermore, Causer *et al.*, (2011b) found that in a shotgun-shooting task, anxiety shortened QE durations by delaying the onset of QE under conditions of elevated anxiety. In all four of these studies, these reductions in the efficiency of attentional control (QE) were also associated with poorer performance.

The theoretical support for this impairment in attentional control comes from a recent theory developed by Michael Eysenck and colleagues to explain how trait anxiety might influence cognitive performance – attentional control theory (ACT; Eysenck *et al.*, 2007). Eysenck *et al.* (2007) suggest that anxiety is likely to cause a diversion of processing resources from task-relevant stimuli toward task-irrelevant (and particularly threatening) stimuli. This impairment in attentional control is proposed to occur irrespective of whether these stimuli are external (e.g., environmental distractors) or internal (e.g., worrying thoughts). The authors explicitly relate this impairment of attentional control to a disruption in the balance of the two attentional systems outlined by Corbetta and colleagues.

According to ACT, anxiety alters the strength of output from the pre-attentive threat evaluation system, so that threat-related stimuli are more likely to capture attention. In this way, anxiety increases the sensitivity of the stimulus-driven system (ventral attention), making individuals more distractible, at the expense of goal-directed control (dorsal attention). In terms of QE, this increased sensitivity of ventral attention is likely to disrupt efficient QE processing, and subsequent visuomotor performance. A long QE duration prior to and during task performance may therefore be needed to suppress competing stimuli/emotions and allow the dorsal network to carry out the action as planned (Wilson, 2012). Indeed, Vickers and Williams (2007) found that elite biathletes who increased their QE duration during simulated competition compared with practice were less susceptible to the adverse effects of anxiety. As such, the authors suggested that the act of allocating attention externally to critical task information (via the QE) may insulate athletes from the debilitating effects of anxiety.

Quiet eye training

Several researchers have examined the potential of training perceptual-cognitive skills such as QE in sport and other domains (see Causer *et al.*, 2012; Vine *et al.*, 2014 for recent reviews). QE training is typically carried out in six steps:

1. Expertise research is carried out to determine the four QE characteristics of experts as they perform the task: the specific location, an early onset prior to a critical movement, an offset that is task specific, a longer duration.
2. Videos of expert QE are coupled with instruction and/or routines.
3. Trainees are tested on the same task while wearing a mobile eye tracker.
4. The trainees are taught how to mirror the QE focus of the experts through a process of video modeling, video feedback, and questioning, thus allowing them to witness the task performed through the eyes of an expert.
5. The trainees are shown their own QE as collected in step 3. Questions are asked in relation to the difference between the four QE characteristics of the expert compared to their own.
6. The trainee selects one of the QE characteristics to adopt and practice over a number of trials. Steps 4–6 are repeated as needed.

Vine and colleagues have recently demonstrated that novice performers can expedite the acquisition of sporting skills and be more resilient to pressure via QE training, compared to via traditional, technical instructions (see Moore *et al.*, 2012; Vine & Wilson, 2010, 2011). For example, Vine and Wilson (2011) examined the efficacy of a training intervention designed to improve QE characteristics in basketball free throws. The authors examined whether such training would protect participants against disruptions in attention when anxious. Novice participants were allocated to either a control or QE training group, with the latter receiving a 360-trial training period. The training group performed more accurately than a control group across retention tests, under "normal" conditions. Under increased anxiety, the control group performed worse than in the pre-test, whereas the QE training group maintained their levels of performance (see also Vine & Wilson, 2010).

While elite athletes might have developed longer QE durations than their novice counterparts, this does not mean that they cannot improve further and be more resilient to the effects of competitive pressure. In fact, expert performers can also benefit from similar QE training programs. For example, Causer *et al.* (2011b) developed a training program designed to improve QE characteristics in elite, international skeet shooters. The participants in the training group underwent an eight-week intervention consisting of eight training sessions and three video feedback sessions. Participants in the training group improved the efficiency of their gaze behaviors, as indexed by earlier QE onset and longer QE duration, from the pre- to post-test. However, the control group showed no changes in gaze characteristics. Furthermore, the training group increased shooting accuracy from 63 per cent in the pre-test to 77 per cent in the post-test; there were no differences in the control group. The improved accuracy scores transferred into competition, with the training group scoring higher in competitions post- compared to pre-intervention. Also, the intervention group demonstrated more efficient kinematic behaviors post- compared to pre-test, as indexed by decreased gun barrel displacement and absolute peak velocity. These results highlight the potential of training key skills to enhance performance at any skill level.

QE training can be a useful practical intervention for dealing with pressure, especially as it can fit extremely well within a performer's existing pre-performance routine. Singer's five-step strategy, a particular example of a pre-performance routine, has been shown to facilitate learning and performance in a number of laboratory and field studies (see Singer, 2000). It focuses on creating the conditions for a "just do it" performance state and emphasizes that optimally focused attention is best achieved by selecting one appropriate, external cue. The QE may be seen as part of such a pre-performance routine, helping the performer focus on what he or she can control (an external, process-related cue) rather than on non-productive (internal) thoughts and emotions (see Mann *et al.*, 2011; Wilson & Richards, 2011). The purpose of such a routine is to help the performer 'focus with a quiet eye and execute with a quiet mind.'

One of the important strengths inherent in the QE literature is that the studies have adopted meaningful tasks where eye-hand coordination can be examined in situ. The concept has also proved robust enough to apply outside of the sporting environment. Indeed, research has identified expert-novice differences in QE in tasks as varied as firearm scenarios in law enforcement (Vickers & Lewinski, 2012), surgery (Harvey *et al.*, 2014a; Wilson *et al.*, 2011), and children's motor coordination ability (Wilson *et al.*, 2013) (see Table 3.4). Recent research has also suggested that QE training might be effective in these domains (Wilson *et al.*, 2011; Miles *et al.*, 2014).

Table 3.4 A summary of the studies that have examined the utility of quiet eye training with novice and experienced performers.

Authors	*Year*	*Sport/Task*	*Participants*	*Findings*
Adolphe, Vickers & Laplante	1997	Volleyball service return	9 Men Team Canada	Longer QE duration early on the ball after QE training. Three year follow-up – high 72% reception versus 68% for top receivers in World Cup League.
Harle & Vickers	2001	Basketball free throw	Three teams playing Collegiate basketball	The QE trained team improved free-throw percentage by 23% over two seasons. One control team reduced performance by 1% and the other increased by 13%.
Oudejans, Koedijker, Bleijendaal, & Bakker	2005	Basketball jump shot	10 elite players (best shooters on their team)	The attention-trained group improved performance in games from 46% to 61%, after training, whereas a control group did not improve (remaining at 42%).
Vickers	2007	Golf putting	14 elite university team and club players divided by handicap (range 0–29, average 11.5) into QE-trained and gaze-trained groups	QE group significantly increased QE duration and QE dwell time more than gaze-trained. QE-trained were more accurate than gaze-trained, but not significantly.
Vine & Wilson	2010	Golf putting	14 novice golfers	The QE-trained group maintained more effective attentional control (QE = 2800 ms) and performed significantly better in the pressure test compared to the control group (QE = 900 ms). Furthermore, longer QE periods were associated with better performance across all test putts.
Vine & Wilson	2011	Basketball free throw	16 novice basketball players	The QE-trained group maintained more effective visual-attentional control (QE = 550 ms) and performed significantly better in the pressure test compared to the control group (QE = 300 ms).
Vine, Moore, & Wilson	2011	Golf putting	22 elite golfers (mean handicap of 3) divided into QE-trained and control groups who were given no awareness of their gaze control	The QE-trained group maintained their optimal QE under pressure conditions, whereas the control group experienced reductions in QE when anxious, with subsequent effects on performance. These advantages transferred to the golf course, where QE-trained golfers made 1.9 fewer putts per round, compared to pre-training, whereas the control group showed no change in their putting statistics.

(*Continued*)

Table 3.4 (Continued)

Authors	*Year*	*Sport/Task*	*Participants*	*Findings*
Causer, Holmes, & Williams	2011	Shotgun shooting	20 elite shotgun shooters divided into a QE-trained and control groups	The QE group significantly increased their mean QE duration, used an earlier onset of QE, and recorded higher shooting accuracy scores from pre-test to post-test. The QE group significantly reduced gun barrel displacement and absolute peak velocity in the post-test compared with the pre-test. A transfer test based on performance during competition indicated that QE group significantly improved shooting accuracy from pre- to post-intervention. No pre-test to post-test differences were observed for the control group on the measures reported.
Wood & Wilson	2011	Football penalty	10 university players following QE training and 10 in a control group	Results from a retention test indicated that the QE-trained group had more effective visual-attentional control, were significantly more accurate, and had 50% fewer shots saved by the goalkeeper than the control group.
Moore, Vine, Cooke, Ring, & Wilson	2012	Golf putting	40 novice golfers	The quiet eye group performed more accurately and displayed more effective gaze control, lower club head acceleration, greater heart rate deceleration, and reduced muscle activity than the technical-trained group during retention and pressure tests.
Wood & Wilson	2012	Football penalty	10 university players following QE training and 10 in a control group	QE participants significantly reduced their perceptions of outcome uncertainty (contingency) and increased their perceptions of shooting ability (competence) and ability to cope with the pressure (control), compared to control participants, when taking part in a penalty shootout task.
Causer, Harvey, Snelgrove, Arsenault & Vickers	2014	Surgical knot-tying	20 first-year medical students divided into quiet eye (QE) or technical (TT) training groups	Both QE and TT groups significantly improved knot-tying performance post-intervention, with QE group improving significantly more than the TT. More efficient eye movements and movement times were reported for the QE group. The QE group transferred their performance improvements into a more complex transfer test; the TT group reverted to pre-test scores.
Miles, Vine, Wood, Vickers, & Wilson	2014	Catching	16, 10-year-old children	Significant interaction effects for performance and quiet eye durations revealed that only the QET group significantly lengthened QE durations, which contributed to significant improvements in catching from pre- to post-test (23% cf. 4%).

Future directions and conclusions

While recent research has started to improve our understanding of the processes underpinning the QE performance relationship (e.g., Klostermann *et al.*, 2013), future research needs to further this understanding of *how* the QE works. Important questions include:

- To what extent are task differences important in understanding how the QE underpins performance?
- How exactly does maintaining a longer QE help performance under pressure?
- To what extent is the timing of the QE more important than duration?
- Is the QE crucial in sport skills that require decision-making?
- What are the underlying neurological events that occur during the QE period?

To conclude, the body of literature reviewed in this chapter suggests that a longer QE helps to ensure both the efficient preplanning of a movement and its subsequent online control, irrespective of whether the task is a self-paced targeting task or an interceptive timing task. While elite performers will have learned to adopt effective QE durations via experience, these can still break down under pressure and therefore it may be important to implement QE training programs to ensure systematic gaze behaviors to maintain focus on critical cues.

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