# Anxiety, Attention and Performance Variability
# In Visuo-motor Skills

## Samuel J Vine

Submitted by Samuel J Vine to the University of Exeter as a thesis
for the degree of Doctor of Philosophy in Sport and Health
Sciences, October 2010

I certify that all material in this thesis which is not my own work
has been identified and that no material has previously been
submitted and approved for the award of a degree by this or any
other University.

…………………………(Signature)

# ABSTRACT

The aims of the current program of research were to examine the impact of anxiety on performance and attentional control during the execution of two far aiming tasks, and to examine the efficacy of gaze training interventions in mediating these effects. Attentional control theory (ACT), which suggests that anxious individuals have impaired goal-directed attentional control, was adopted as a theoretical framework, and the Quiet Eye, characterised by long final fixations on relevant locations, was adopted as an objective measure of overt attentional control. In Studies 1 and 2 increased pressure impaired goal directed attentional control (QE) at the expense of stimulus-driven control (more fixations of shorter duration to various targets). The aim of studies 3 and 4 was therefore to examine the efficacy of an intervention designed to train effective visual attentional control (QE training) for novices, and determine whether such training protected against attentional disruptions associated with performing under pressure. In both studies the QE trained group maintained more effective visual attentional control and performed significantly better in a subsequent pressure test compared to the Control group, providing support for the efficacy of attentional training for visuo-motor skills. The aim of study 5 was to examine the effectiveness of a brief QE training intervention for elite golfers and to examine if potential benefits shown for novices in studies 3 and 4 transferred to competitive play. The QE-trained group maintained their optimal QE and performance under pressure conditions, whereas the control group experienced reductions in QE and performance. Importantly, these advantages transferred to the golf course, where QE-trained golfers reduced their putts per round by 1.9 putts, compared to pre-training, whereas the control group showed no change in their putting statistics. This series of studies has therefore implicated the role of attention in the breakdown of performance under pressure, but has also suggested that visual attentional training regimes may be a useful technique for alleviating this problem.

# ACKNOWLEDGMENTS

There are a few people who I would like to thank for helping me along the way!

First and foremost I would like to say thanks to my supervisor Mark Wilson. Mark has been extremely committed to guiding me through my PhD and has always made time to help me out! His advice on all aspects of my work has been priceless and I have been lucky to work with someone who has such talent and passion for research. It has been a pleasure, cheers Mark!

A helping hand has also come from other colleague's within the department. In particular I would like to thank Paul Freeman, Greg Wood and Lee Moore for all they have done. Thank you to my examiners Gaynor Parfitt, Aidan Moran and Tim Holder. I enjoyed the viva, as much as was possible, and I am grateful for your comments and recommendations regarding this thesis.

A huge thank you must go to my parents. I appreciate their unwavering love and support, even when I decided that three years of being a student wasn't enough.
I only hope I can do half as good a job as a parent!

Last, but certainly not least, a huge thanks must go to my 'wife to be' Leandra. She has been an absolute rock throughout. Thanks for keeping me motivated, making me laugh and putting up with my mood swings. I could not have done this without you!
I love you! Cheers pal!

# CONTENTS

**Page**

# LIST OF TABLES

**Page**

**Chapter 5: Study 2**

**Chapter 6: Study 3**

**Chapter 7: Study 4**

**Chapter 8: Study 5**

# LIST OF FIGURES

Page

**Chapter 2: Literature Review**

**Chapter 3: Generic Methods**

**Chapter 4: Study 1**

**Chapter 5: Study 2**

**Chapter 6: Study 3**

**Chapter 7: Study 4**

**Chapter 8: Study 5**

# Chapter 1. Introduction

Many people seek to attain an expert level in the performance of complex motor skills, such as those required during sport. The majority of sport is performed in a dynamic, ever-changing environment, under conditions of extreme stress where the limits of human behavior and achievement are continually challenged and extended (Ericsson, 2003). Despite these constraints, expert performers display precise, reproducible, smooth and effortless movements. Although historically cognitive psychologists have largely ignored sport in their quest to understand the human mind (Moran, 2009), it provides a useful domain in which to explore the attentional skills important for expert performance (Yarrow, Brown & Krakauer, 2009).

Most sports involve some form of aiming, whether it be throwing, kicking or striking an object to a player, target or goal. The performance of complex skills require complex coupling of sensory inputs and motor outputs. How this sensory information is absorbed, processed and created into movement responses has interested researchers for years and understanding how this can be optimised is a motivation for this series of studies. Research examining far aiming tasks has identified the role of higher-order cognitive processing, whereby the visuo-motor strategy is attuned to obtaining visual information to enable the pre-programming of the ensuing motor response (Schmidt & Lee, 1999; Williams, Singer & Frehlich, 2002a). Equally interesting is the influence that emotional states, in particular anxiety, exert upon the complex coordination of vision and action. As Janelle (2002) claims, "although vast amounts of research has examined the influence of anxiety upon performance there has been little systematic examination of the mechanisms underlying this relationship" (p. 237.). The aim of this thesis was to examine the anxiety performance relationship by assessing the disruption of visual attentional mechanisms. Furthermore this thesis aimed to examine the importance of visual attentional skills training, geared towards overcoming visual attentional disruptions as a result of anxiety.

## 1.1. Structure of Thesis

Chapter 2 provides a critical review of the literature relevant to this thesis; particularly from the sport, motor control, cognitive psychology and cognitive neuroscience fields. The review covers topics such as perceptual expertise, visual attention, visual search, visuo-motor control, cognitive anxiety and theoretical accounts of the anxiety performance relationship. Chapter 3 provides a critical discussion of some of the methodological issues relating to all the studies within this thesis and includes eye tracking, data analysis, and measurement issues. Chapters 4-8 then provide an introduction, methods, results, discussion, conclusions and proposed directions for future research for the five studies that were completed. Chapter 9 provides a discussion and general summary of all findings. Theoretical and applied implications of the research are considered, potential limitations discussed and proposals for future research suggested.

## 1.2. List of Articles and Abstracts

### Articles

Study 1 was published as: 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.

Study 2 was published as: Wilson, M.R. & Vine, S.J. (2009). Performing under pressure: Attentional control and the suppression of vision in basketball free-throw shooting. In, Calvin H. Chang (Ed), *Handbook of sports psychology* (pp. 277-296). Hauppauge, NY: Nova Science.

Study 3 was originally submitted as: Vine, S.J. & Wilson, M.R. Attentional Processes underpinning skilled visuo-motor performance: The influence of training and pressure. *Cognitive, Affective & Behavioural Neuroscience.*

It was then resubmitted as: Vine, S.J. & Wilson, M.R. (under review). The influence of quiet eye training and pressure on attentional control in a visuo-motor task**.** *Acta Psychologica.*

Study 4 was published as: Vine, S.J. & Wilson, M.R. (2010). Quiet Eye training expedites learning and helps to protect against stress. *Journal of Applied Sport Psychology*, *22 (4),* 361-376.

Study 5 has been submitted as: Vine, S.J., Moore, L.J. & Wilson, M.R. (under review). Quiet eye training facilitates competitive putting performance in elite golfers, *Frontiers in Movement Science and Sports Psychology.*

Data from study 4 and 5 were used for a magazine article: Vine, S.J. & Wilson, M.R. (2010). Putting with a Quiet Eye: A new approach to improving your game. *Hele Park Golf Centre Monthly News Letter*. Kingfisher, Devon.

**Conference Abstracts**

Wilson, M. & Vine, S. (2009). Visuo-motor control in far aiming tasks: Re-examining the location suppression hypothesis. *Cognitive Processing, 10* (Suppl 2), S146-147.

Vine, S.J. & Wilson, M.R. (2009). Quiet eye training improves performance and protects against stress in a golf putting task. *Journal of Sports Sciences, 27*(4), S112.

Wilson, M. & Vine, S. (2008). Anxiety, attentional control and the quiet eye period in basketball free-throw shooting. *Journal of Sports Sciences, 26(S2),* S67-S68.

Vine, S. & Wilson, M. (2008). *The effects of anxiety on visual control when performing a far aiming task.* Invited speaker; presented at the 23rd annual meeting of Psy-PAG (BPS).

# Chapter 2. Review of the Literature

## 2.1. Perceptual Expertise

Sporting expertise has been defined as the ability to consistently demonstrate superior athletic performance than their opponent (Janelle & Hillman, 2003; Starkes & Allard, 1993). Although superior performance is often apparent when observing sport, the perceptual and cognitive mechanisms that contribute to this highly skilled display are less apparent (Mann, Williams, Ward & Janelle, 2007). During the acquisition of skill large improvements in decision making and anticipation skills are evident. These adaptations are in fact essential for top level sports performance, as often the speed of play exceeds the basic speed of information processing due to the limitations of the human visual and cognitive systems (Williams & Ford, 2008; Williams, Davids & Williams, 1999). The perceptual skills developed by experts include advanced cue utilisation, pattern recognition, anticipation and decision making which require performers to focus attention on the most appropriate cues at the correct time (Williams & Ford, 2008). As it is difficult, if not impossible, to determine what these cues are through introspection, it is not surprising that the visual control of performers has received increasing research interest (Mann et al., 2007).

### 2.1.1. Visual Search

The role of vision in sport has been widely researched and early research in the field focused upon topics such as visual acuity, colour detection, contrast detection, depth perception, distance judgement and information processing (Planer, 1994). However, equivocal results examining proficiency-related differences in visual ‘hardware’ led researchers to examine differences in ‘software’. Knowing *where* and *when* to look is crucial for successful sport performance, yet the visual display can be large and often full of information both relevant and irrelevant to the task. Sport performers must be able to identify the most information-rich areas of the display, direct their attention appropriately, and extract meaning from these areas efficiently and effectively (Mann et al, 2007; Williams et al., 1999). Performers confronted with this task of picking up relevant information engage in a process of visual search.

During the visual search process an object of interest within the visual field is initially detected by peripheral vision which provides information regarding *where* it is. Movements of the eyes and head then bring the object onto the fovea, a sensitive and acute region of the retina, which allows for more detailed processing of *what* it is. Performers must therefore continually adjust the location of gaze to ensure that visual clarity is maintained (Williams et al., 1999). It has been proposed that expert performers use more efficient forms of visual search by reducing the frequency of saccadic eye movements (Williams, Davids & Burwitz, 1994a). As a performer produces eye movements to bring objects into the foveal field, a rapid movement of the eye (a saccade) causes a decline in visual sensitivity and therefore information processing. Theoretically, due to the suppression of information process during saccades, a visual search strategy which uses fewer fixations of a longer duration is assumed to be more effective and efficient (Williams et al., 1994a). Proficiency differences in visual search have been found in a large number of studies covering a wide variety of sporting tasks including soccer (Helsen & Starkes, 1999), tennis (Singer, Cauragh, Chen & Steinberg, 1996), boxing (Ripoll, Kerlirzin, Stein & Reine, 1995), basketball (Vickers, 1996), golf (Vickers, 1992), Gymnastics (Vickers, 1988), karate (Williams & Elliot, 1999) and squash (Abernethy, 1990).

The proposition that experts display efficient visual search strategies has not always been fully supported within the literature (Moran, Byrne & McGlade, 2002). For example, in a football task, Helsen and Pauwels (1993) found that experts displayed shorter mean fixation durations than their lowered skills counterparts. Similarly, Williams, Davids, Burwitz and Williams (1994b), also in a football task, revealed that experts displayed fewer fixations of a shorter duration than their novice counterparts. Although these results suggest that an extensive, rather than economical strategy is indicative of expert performance, one explanation is that search rates may be context specific (type of task) as well as proficiency specific (level of expertise) resulting in varying visual search strategies across sports (Moran et al., 2002).

## 2.2. Visual Control and Attention

The control of gaze is important to select only the necessary information within the environment, and ignore the irrelevant. The process by which this occurs is called attention. Attention had been defined as the cognitive system that facilitates the selection of some information for further processing while inhibiting other information from receiving further processing (Smith & Kosslyn, 2007). Attention is critical for performance within the complex tasks involved in sporting environments (Boutcher, 1992; Nouigier, Azemer & Stein, 1992). Skilled performers have learnt to utilise their gaze efficiently so that the correct information is attended to at the correct time (Vickers, 2007).

From a cognitive psychology perspective the term attention has been postulated to explain three different constructs. First it is postulated to explain our ability to distribute attention across several concurrent tasks (divided attention); as a form of mental time sharing ability, for example a skilful basketball player can dribble the ball whilst still looking for an opponent (Moran, 2004). The second construct is concentration, and refers to an individual's ability to exert mental effort on what is important in any given situation. For example children are asked to 'pay attention' in class, and performers must 'pay attention' to the coach before the game. Finally, and arguably the most relevant to the sports domain, is selective attention. This has been described as the perceptual ability to focus on task-relevant information while ignoring potential distractions and refers to the ability to discriminate relevant stimuli (targets) from irrelevant stimuli (distractors) that compete for our attention (Moran, 1996, 2004). Simply speaking selective attention is the process by which important information is adhered to and other information is ignored (Williams et al., 1999a).

The advancement of eye tracking and gaze registration systems has allowed research to examine the ability of sports performers to control selective attention by assessing visual attention during the execution of sporting skills. The degree to which visual overt attention is representative of covert attention has been discussed within the literature and has gone through two major schools of thought (Vickers, 2007). Previous research has suggested that it is easy to dissociate the locus of gaze with the locus of attention, and therefore eye movement data were not considered an appropriate measure of attention (Posner, 1980; Posner & Raichle, 1994). However, recent neuroscience research suggests that a shift in gaze invariably predicts a shift in attention (Corbetta, 1998). There is substantial overlap between the areas of the cortex and some of the same neuronal machinery is involved in shifting gaze and shifting covert attention (e.g., Corbetta, 1998; Shipp, 2004), and it is therefore difficult to shift the point of gaze without shifting attention (Henderson, 2003). The close linkage between gaze and visual attention is especially apparent in visually guided manual tasks. Individuals learn to program spatially congruent eye and hand motor commands, so that fixations on objects precede manual reaching and pass visually acquired goal position information to the arm and hand control systems (Land, 2009).

### 2.2.1. Attentional Functions

Research by Corbetta and Shulman (2002) has implicated the role of two independent networks of visual attention functioning. They propose that visual attention is controlled by both cognitive (top-down) factors such as knowledge, expectation and current goals, and sensory (bottom-up) factors such as visual and auditory inputs (see also, Corbetta, Patel & Schulman, 2008).

The top down system of attention (also known as goal-directed or dorsal attention) is located on the dorsal posterior parietal and frontal cortex and involves “the flow of information from higher to lower centres of the brain, conveying knowledge from previous experiences rather than sensory stimulation” (Corbetta & Schulman, 2002, p. 201). Top down control is used for the detection of objects within the visual display, as well as specific features of this object such as location, colour and shape. Knowledge and expectations create attentional sets; advanced information which flows in a top down fashion to guide the brain as to which stimuli to focus on and program the eye movements to look at them.

The bottom up system of attention (also known as stimulus-driven or ventral attention) is located on the temporoparietal and ventral frontal cortex and proceeds in a “single direction from sensory input, through perceptual analysis, towards motor output, without involving the feedback of information from higher centres to lower centres” (Corbetta & Schulman, 2002, p. 201). In this sense the bottom up system of attention describes how attention may be grabbed by salient or conspicuous stimuli, such as a poppy within a field of green grass (Corbetta & Shulman, 2002).

Despite the dorsal and ventral systems being defined as independent networks of attention, there is a vast amount of overlap and interaction between them. Although the salience of objects is detected by the bottom up system of attention, in reality the salience of objects is strongly influenced by their behavioural and task relevance (contingent orienting). Corbetta and Shulman use the example of searching for a friend wearing a red hat within a large crowd; we become more likely to notice people wearing red clothing, and less likely to notice people wearing other coloured clothing. In this sense the sensory (bottom-up) saliency of red objects interacts with the goal directed (top-down) task of finding a red object. This therefore suggests that some stimuli are more salient and attract more attention due to "some form of contingency that is hard wired in the brain by learning, development or genetics" (Corbetta & Shulman, 2002, p. 208).

Further to this notion, Corbetta and Schulman suggest that the bottom up system of attention works as a "circuit breaker" (2002, p. 201) for the top down system. When a behaviourally relevant stimulus is detected, the current attentional set is broken and a new one is adopted on the basis of the incoming stimulus. This circuit breaking effect can be an adaptive process, directing attention to potentially important or salient events. This may be particularly relevant during pressurised or stressful sporting performance when, due to the athlete's high levels of state anxiety, salient events may be threat-related and not task specific. Therefore the likelihood that threat-related stimuli will capture attention is increased, with potential implications for performance (see section 2.2).

### 2.2.2. Visuo-motor Control

The visual control required to successfully execute sport skills, as well as make decisions, has also been examined within the literature. As performers learn to execute skills successfully they not only learn to control their body and produce efficient movements but also learn to control vision and attention (Vickers, 2007). Visuo-motor control refers to the control of vision to direct and control movements. As Land (2009) suggests, the principal function of vision, from an evolutionary perspective, is the provision of information to guide actions. He describes four interlinking systems that are proposed to be responsible for the planning and control of visually guided action.

The gaze system, consisting of the frontal eye fields and located in the lateral intraparietal area of the parietal lobe, is responsible for the location of a target and the placement of this target within the fovea of the eye. The motor system, located in the primary motor cortex and premotor cortex areas, is responsible for the movements of body and limbs. The visual system, located in the occipital lobe and much of the temporal lobe, acts to provide information to the motor system to ensure accurate and finely tuned movements. These three sub systems are supervised by a schema system that programs the gaze, motor and visual systems to ensure coherent action (Figure 2.1; see Land, 2009 for an overview).

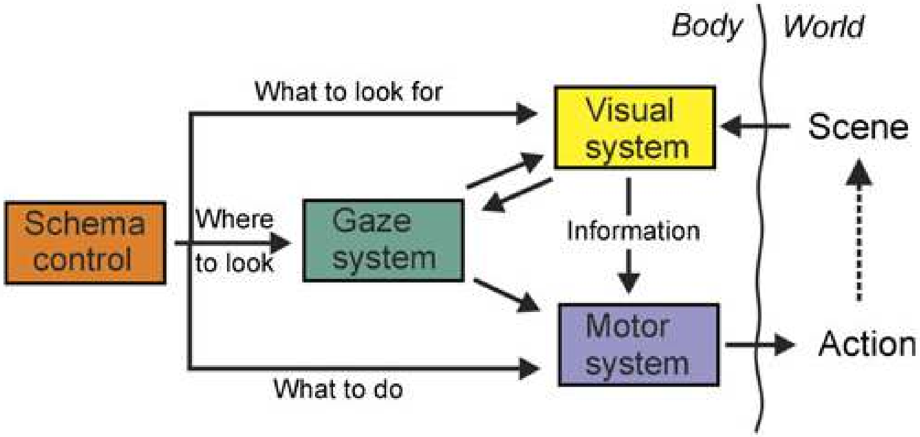


***Figure 2.1***: *The relationship between the gaze, visual and motor systems during the execution of visually guided movements (Land, 2009).*

### 2.2.3. Near Aiming Tasks

Early research into the coordination between vision and action was undertaken primarily on tasks requiring the aiming of a hand or an object to a near target in laboratory settings. This research has shown that the eyes tend to arrive at the target before the hand starts to move (Bekkering, Adam, Kingma, Huson & Whiting, 1994) and that when vision is not directed towards a target accuracy of the proceeding movement is reduced (Abrams, Meyer & Kornblum, 1990). Both findings point to the important role of visual information in the guidance of goal-directed movements. Research examining pointing tasks has highlighted a particular gaze strategy termed *anchoring* (Neggers & Bekkering, 2000). Saccades to new targets within the visual display are not initiated until the hand reaches the target that is currently being fixated. Therefore a foveal fixation must remain anchored on the target until the motor action is complete. This finding was corroborated in a subsequent study by Neggers and Bekkering (2001); the anchoring of gaze to the target was maintained throughout the entire movement, even when the moving limb was not visible. This research highlights the importance of the coordinated link between vision and aiming actions.

Research has also examined the coordination between vision and action in real life everyday tasks (see Land, 2009 for a review). Land, Mennie and Rusted (1999) adopted a tea-making task to examine the role of vision in the control of movements. They found that every step of the tea making process (locating, directing, guiding and checking) was monitored by vision. More importantly fixations on relevant targets, such as the kettle, started prior to the motor action and lasted for the duration of the manipulation of that object (i.e. from locating the kettle, to grasping it, through moving it, until putting it down). These findings were corroborated by Johansson, Westling, Backstrom and Flanagan (2001). During a custom designed ‘reach and grasp’ task, participants fixated only locations that were relevant to the task at hand. Furthermore participants fixated specific landmarks within each of the relevant objects. The most fixated landmarks were those at which grasping occurred, implicating the role of gaze in the guidance of finger contacting, as opposed to general shape detection (Johansson et al., 2001).

In order to understand how the link between vision and action develops during learning Sailer, Flanagan and Johansson (2005) examined the eye-hand coordination of subjects learning a novel visuo-motor task. The task involved guiding a cursor towards a target by manipulating a tool held between their two hands. During the early stages of learning subjects tended to fixate the moving cursor rather than the target, therefore, failing to anchor their gaze in the way that previous research has shown is important (Neggers & Bekkering, 2000, 2001; Land et al., 1999). During the later stages of learning subjects began to guide gaze towards future cursor goals, and eventually gaze was guided towards an end target. The authors suggest that the early stage of learning, when gaze was directed to the cursor, is required to allow for an understanding of the constraints of the task. A foveal fixation on the target allowed for precise monitoring of the movements of the cursor in relation to the hands.

### 2.2.4. Far Aiming (targeting) Tasks

Within the sports domain the optimal coordination of vision and action when aiming towards a distant target is often of more interest to researchers. Instead of being able to maintain control over the object throughout the action, all control is lost once the object leaves the aiming hand. A distinction is therefore made between aiming skills to near targets and those to far targets where control is lost at the point of release (Vickers, 1996).

Optimal visuo-motor control has been defined for three categories of motor task: targeting, interceptive and tactical (Vickers, 2007). In targeting tasks the function of gaze is to locate the target and control the aiming of an object towards that target. Vickers identifies three subcategories of targeting tasks: fixed targets, abstract targets and moving targets. During fixed target motor tasks the target is fixed in space and is therefore predictable. Accuracy requires visual control which involves fixating a specific location before the action is carried out. During abstract target motor tasks the targets are multiple and often abstract in nature (such as putting on a sloped green). Accuracy requires interpretation of the complex workspace, and an optimal sequence of fixations to relevant locations before the action occurs. During moving target motor tasks the target is singular but in motion. Anticipation of the movement of the target is important for accuracy.

Vickers (2007) has highlighted four factors which influence the form of visual control required for different sporting tasks: the number of visuo-motor work spaces, the number of locations within the visuo-motor workspace, the location of spotlights of attention and the optimal coupling of gaze and action. Although some targeting tasks have only one visuo-motor work space (such as darts) other sports may have two (such as the golf putt: the hole and the ball) requiring the performer to guide their gaze between the two. However, each visuo-motor work space may contain a different number of objects or locations within that space (for example the goal, the ball and the goalkeeper in football penalties) requiring goal directed shifting of visual control. With regards to the spotlight of attention, as previously discussed both bottom up and top down processing of visual information will help define any spotlights of attention. During bottom up processing salient or conspicuous stimuli grab the performers gaze and attention. In top down processing the athlete utilise previous experiences and expectation to dictate how the environment is perceived (Vickers, 2007). While experts will utilise both bottom up and top down processing, novices tend to be controlled more by bottom up processing (Williams et al., 1999; Starkes & Ericsson, 2003). The fourth factor that influences the form of visual control required is the gaze-action coupling. The control of vision within each visuo-motor work space, towards the relevant locations, objects and spotlights of attention must also be timed with respect to the timings of the motor behaviours.

Research has examined the visual control required for a wide variety of targeting tasks and revealed distinct differences between experts and novices (Vickers, 2009). Seminal work in this area assessed the basketball free throw and the golf putt. Accuracy has been shown to be underpinned by gaze being directed to a single location on a relevant target, during a period when information needs to be extracted. Elite and accurate shooting is also underpinned by a lower frequency of fixations over a smaller area. Elite performers direct gaze to a narrow location on the target, as proposed by Treisman’s (1993) notion of a smaller spotlight of attention for accurate performance. Contrastingly, novices tend to produce more fixations over a wider area. As the location of gaze is likely to reflect the location of attention (Corbetta, 1998), it seems that experts not only display superior visual control during the execution of skills, but also manage to maintain control of their attention. As Vickers (1996) highlighted, although fixations towards relevant targets are necessary for accurate aiming, the specific location, timing and duration of these fixations are equally as important. The ability to control a steady fixation on the target during the execution of the shot has since been named the Quiet Eye (QE; Vickers, 1996).

## 2.3. The Quiet Eye

The QE can be defined as the final fixation or tracking gaze directed to a single location or object in the visuo-motor workspace within 3° of visual angle (or less) for a minimum of 100ms (Vickers, 2007). The onset of QE occurs before the critical movement of the motor task and offset of the QE occurs when the final fixation deviates off the target by more than 3° of visual angle for more than a 100ms. Research into QE tends to involve performers of varying levels executing skills whilst having their gaze recorded. The athletes perform until an equal number of hits and misses have been achieved, often under various experimental conditions in which task complexity, pressure/anxiety and physiological arousal are manipulated. The goal of this research is to determine the attributes of a QE fixation under successful and unsuccessful performance (Vickers, 2009).

The QE has been found to be robust in a variety of interceptive timing, targeting and tactical tasks, with lengthy QE durations linked to both the proficiency state (expert or novice) and the outcome (successful or unsuccessful) of performance (see Vickers, 2009 for a review). Janelle et al., (2000) examined the QE of elite and sub-elite rifle shooters and found that experts had significantly longer QE periods than their non expert counterparts when taking shots from 5m distances. Lengthier QE periods were accompanied by superior performance, suggesting a more optimal preparatory period for the expert shooters. Behan and Wilson (2008) examined the QE periods of novice participants whilst performing a simulated archery task. The QE was 50% shorter in unsuccessful attempts when compared to successful attempts, highlighting the robustness of the QE across novice as well as expert populations. Causer, Bennett, Holmes, Janelle and Williams (2010) found additional support for importance of the QE in shotgun shooting. Whilst rifle shooting and archery can be classified as fixed target aiming tasks, shot-gun shooting involves tracking a moving target which has to be intercepted in space. Nevertheless results showed that QE durations were significantly longer for elite compared with sub elite performers and successful compared with unsuccessful shots. These results are among the first to highlight the importance of the QE in a moving target aiming task.

Two of the most frequently researched targeting tasks assessed within the visual control and QE literature are the basketball free throw and the golf putt. Classified as self paced, static, far aiming tasks, requiring minimal movement and easily performed in controlled environments, these skills lend themselves to research assessing visuo-motor control.

### 2.3.1 The QE in Basketball

Vickers (1996) carried out the first examination of the QE period in basketball free throw shooting, and revealed that experts displayed significantly longer and earlier QE durations than their near expert counterparts. Experts had a QE that began ~998ms into the preparation phase of the shooting action and continued for durations of ~ 972ms on hits and ~806ms on misses. Conversely near experts had a QE that began ~1068ms into the preparation phase and only continued for ~357ms on hits and ~393ms for misses. Results therefore highlighted the role of the QE in both the overall proficiency and precise accuracy of basketball free throw shooting (see also section 2.2.4).

As Vickers highlighted, the importance of the critical timing of the QE period in basketball relates closely to the type of control utilised in a far aiming task. Skilled performers fixated on the target early in the aiming phase but did not look towards the target when their hands and the ball entered their field of view; despite the fact that this is the key propulsion phase of the shooting action (Vickers, 1996). These findings indicate that although the free throw was of long enough duration for feedback to impact the movement outcome, skilled performers had learned to suppress their vision, by blinking or moving their gaze freely during the shooting action. Vickers (1996) referred to this finding as the location suppression hypothesis (LSH) and suggested that such suppression of visual processing prevented interference from the moving hands and ball in the visual field, preserving the aiming commands derived from the QE.

### 2.3.2. The Location Suppression Hypothesis

The specific predictions of the LSH have received limited attention within the literature in comparison to QE research in general. Partial support was found for the LSH by Vickers, Rodriguez and Edworthy (2000) in a study examining darts performance. The authors found that the gaze of a darts player deviated from the relevant target prior to the critical movement of the dart throw (as the flights occluded the target), providing support for an open loop model of control. However, Williams, et al. (2002a) found that while billiards players performed better when adopting early and longer QE periods, vision was suppressed prior to the execution of the final movement. From these limited findings it could be proposed that visual suppression is not necessary when the target is visible throughout the duration of the execution of the skill, only when the target is occluded during the movement phase of the skill.

However, research examining basketball shooting has also called into question the benefit of an open loop, location suppression strategy of visual control. Oudejans, van de Langenberg and Hutter (2002) investigated the use of visual information at different times during the execution of the basketball jump shot by manipulating when the participants could see the basket using computer controlled occlusion goggles. They concluded that shooting performance was as good in late vision as full vision but that early vision severely impaired performance. They therefore concluded that shooting movements were dictated by information obtained throughout the whole of the shooting action right up until release.

De Oliviera, Oudejans and Beek (2006) extended the research of Oudejans et al. (2002) and suggested that the timing of optical information pick up is perhaps dependent on the particular style of jump shooting adopted. Some performers shoot the ball with their hands above their head (high style shooters), whereas others shoot the ball from in front of their face (low style shooters). By again constraining the time at which a performer could view the target, they found that low style shooters utilised an early window of visual information extraction, whereas high style shooters utilised a late window. The authors concluded therefore that performers tended to wait ‘as late as possible’ to pick up information about the target; immediately prior to the ball and arms blocking the target for low style shooters; and immediately prior to release for high style shooters. The authors question the importance of an early onset and lengthy duration of the QE, as their findings suggest that accuracy is just as high when the basket is only visible during the final 350-450ms of the shot. The QE may only be important during tasks which require pre-programming, and not for tasks during which ‘online’ information allows for adjustment of the movement. It may be that the lengthy QE durations displayed by experts are not essential, and if required to, performers could be as accurate with shorter viewing times.

While Williams et al. (2002a) found no support for the LSH in a billiards task, the authors suggested that the strategy may be specific to skills in which the target becomes temporarily occluded; however, findings from both the Oudejans et al. (2002) and De Oliviera et al. (2006) studies are not supportive of the LSH in the basketball free throw. A strategy defined by an early QE and subsequent visual suppression may therefore not be optimal, even for aiming tasks where the target is occluded during the movement phase of performance. However as neither of the above studies examined gaze behavior it was difficult to fully test the predictions of the LSH.

### 2.3.3. The QE in Golf

Golf putting is a skill which requires the control of vision over two visual workspaces and is therefore an inherently different visuo-motor task to the basketball free throw. When taking a stance over a putt the performer must control their vision between the visuo-motor works space at their feet, which includes the feet, the club head and the ball, and the second visuo-motor work space which includes the hole and the area surrounding the hole. Furthermore while performers of the basketball free throw are in direct contact with the object ball golf putting requires the accurate movement of a putter, increasing the level of motor control required. The seminal study investigating the role of gaze control across two visuo-motor work spaces in golf was carried out by Vickers (1992). Vickers identified that experts fixate the hole longer (about 2 seconds) and use slow saccades (about 500 milliseconds) to switch between the hole and the ball. Interestingly experts directed two or three fixations on the hole and then on the ball, with saccades linking these fixations. In contrast novice performers had a higher frequency of fixations, faster saccadic eye movement between hole and ball, and often ‘spot-sighted’ the line of the ball (Vickers, 2007).

As well as proficiency differences in scan paths during the alignment phase of the putt, there were also differences in the timing and orientation of gaze during the putting action itself. Expert performers maintained a final fixation (later termed the QE fixation) on the centre or back of the ball that was initiated prior to the execution of the initial movement of the putter head away from the ball and lasted for approximately two seconds. Conversely less skilled golfers had a final fixation that lasted for only one to one and a half seconds. Expert golfers also maintained a steady fixation after contact with the ball, keeping their gaze steady on the green for about 250-300 milliseconds (QE dwell). In contrast novices tended to track the ball towards the hole immediately after contact; an eye movement that must have been pre-planned during the swing, as covert attention shifts precede overt shifts of gaze. This transfer of attention during the ball strike may cause a less than optimal or inconsistent contact between putter and ball.

As most putts in golf occur on a green that is to some extent sloped, research has started to examine the control of gaze during breaking putts. Pelz's early work, based on his coaching (1994, 2000), identified that although most golfers believe that visually tracking the line which the ball is going to take is the best strategy for accuracy, this was not the case. Instead Pelz identified that performers tended to focus on an abstract point, at which they believed the ball would break (the visible break). A limitation of Pelz's work is that he did not measure eye movements. Therefore the exact location of gaze before and during the stroke could not be calculated.

Lier, Kamp and Salvesbherg (2008), in a recent study examining the effects of slope on visual control found that increased slope caused a spatial change in visual control. As the slope increased (from right to left) participants fixated more to the right of the hole. Furthermore on sloped putts participants spent more time fixating the areas around the hole than they did the ball, potentially causing a reduction in the QE duration which may have lead to poorer performance. Wilson and Pearcey (2009) examined the QE durations of golfers during straight and breaking putts and found that performers had significantly longer QE durations on successful (1693ms) than unsuccessful (1231ms) putts. Findings corroborate those of Vickers (1992) and highlight the importance of the QE in accurate putting. Wilson and Pearcey also examined changes in the QE as a result of the change in the slope of the putt, although results revealed no change in QE due to increased slope. This result is in contrast with research by Williams et al (2002a) who suggested that QE should increase as a result of increased difficulty, due to more time being required for cognitive programming.

### 2.3.4. Perspectives on the Quiet Eye

Although the QE has been identified as an optimal visual attentional strategy for a wide range of sporting skills, it is not understood why or indeed how adopting the QE strategy can lead to improved performance. The notion that experts utilise longer fixations than their novice counterparts to extract the critical information from a target seems at odds with the visual search literature which suggests that experts are more efficient and therefore quicker at extracting critical information (see Williams et al. 1999). Although the mechanisms through which the QE works are yet to be fully understood, several different theoretical perspectives have been proposed (Vickers, 2007, 2009).

#### 2.3.4.1. The Cognitive Neuroscience Perspective

It has been suggested that during the QE fixation the neural networks required for accurate aiming are being organised. Therefore longer QE periods have been proposed to reflect a critical period of cognitive processing during which the parameters of the movement such as force, direction and velocity are fine-tuned and programmed (Williams et al., 2002a). Longer quiet eye periods therefore allow performers an extended duration of response programming, while minimizing distraction from other environmental cues (Vickers, 1996).

Vickers (1996) used Posner and Raichle’s (1994) conceptualisation of three neural networks (posterior orienting, anterior executive & vigilance networks) to provide support for her postulations of *how* the QE may provide this ‘quiet focus’. The posterior orienting network, responsible for the location of gaze in space, may be used by performers to hold a stable and steady gaze on the target as well as preventing disengagement of this location to other locations. The anterior executive then acts to understand what is being seen and may account for adjustments in the timing of fixations in relation to the movement (longer QE periods), improving accuracy. The vigilance network is responsible for coordinating both of these networks and ensures there is no interference during sustained focus, something that is particularly relevant during periods of high pressure.

More recent developments of these networks by Posner and colleagues (e.g., Posner & Rothbart, 1998) have tended to focus on the importance of (anterior) executive control in self-regulation and volition, rather than attentional control per se. Corbetta and colleagues (Corbetta & Schulman, 2002; Corbetta et al., 2008) recent work may therefore provide a more appropriate model to support the proposed motor-planning function of the QE. As previously discussed (section 2.2.1) the top-down, goal directed attentional system (or 'dorsal attention') is important for response or action selection and is involved in linking relevant stimuli to motor planning (Corbetta et al., 2008). The stimulus driven attentional system ('ventral attention'; Corbetta et al., 2008) acts as a circuit breaker and is responsive to bottom up attentional processes. The suggestion that longer QE periods may allow performers an extended duration of action programming, while minimizing distraction from other environmental cues, can therefore be explained in the same language as Corbetta and colleagues; the QE may help maintain effective goal-driven attentional control, while reducing the impact of the stimulus-driven attentional system.

In an attempt to understand the cognitive mechanisms underlying the QE, Janelle et al. (2000) examined the gaze behaviour (QE) and cortical activation (via electroencephalography) of expert and near expert shooters. Their results showed that experts displayed more efficient gaze (as indexed by a lengthy QE) and more efficient cortical processing (as indexed by levels of alpha and beta power in the left and right hemispheres). These findings point to the link between gaze and cortical quiescence during refined and accurate aiming. A higher magnitude of hemispheric asymmetry among the expert, as opposed to near expert shooters, implicates the role of specific relevant neural pathways during the pre-programming of visual guided movements (Janelle et al., 2000) and therefore provides preliminary support for the cognitive neuroscience perspective of the QE.

#### 2.3.4.2. The Ecological Psychology Perspective

Researchers from an ecological or dynamic systems perspective suggest that performers perceive environments directly, and are unaided by inference, memories or other neural representations as proposed by cognitive psychologists (Gibson, 1979; Vickers, 2009). They also argue that spatial information is a central aspect of the ‘education of attention’ (Vickers, 2007; p. 51) and have suggested that the QE may provide information central to the intrinsic dynamics of skilled actions (Oudejans, Koedijker, Bleijendaal & Bakker, 2005). The QE is proposed to act by facilitating the orientation of the body and arm movements in space, allowing for the execution of movements that are attuned to any present constraints (Vickers, 2007). Perceiving the target in relation to a changing point of observation over a period of time (i.e., the distance and direction of the target, and how this is changing) may provide the necessary platform for accurate movements (Oudejans et al., 2005). In this sense longer QE durations reflect a longer period of information collection, allowing for more controlled actions.

Another related view within the ecological psychology perspective is that the QE may act as a form of visual pivot (Williams & Elliott, 1999) that improves the coordination of the performer’s body and arms in relation to the target. Visual pivots consist of a gaze strategy characterised by foveal fixations on a central location, allowing for the use of peripheral attention to detect peripheral stimuli. Visual pivots have three proposed advantages. Firstly, a single fixation (or visual pivot) rather than several saccadic eye movements is more efficient as saccadic suppression is minimised. Secondly, while the fovea is excellent at determining detail, the peripheral regions of the retina are more efficient at detecting movement. Therefore, if moving stimuli need to be detected, a centrally focused fixation (visual pivot) allows peripheral vision to pick up motion. Thirdly, research has shown that attention can be shifted more quickly when done so covertly rather than overtly (via eye movements) (Posner & Raichle, 1994). The effectiveness of visual pivots has been examined in Karate (Williams & Elliot, 1999) and results show that experts tend to use visual pivots on the head and shoulders, rather than trying to pick up the cues from the hand and feet. Evidence also exists in basketball (see Vickers, 2007); where by occluding the basketball hoop, so that only the top of the back board was visible during the jump shot, players seemed to utilise a unique QE, fixating the top of the backboard, to enable them to maintain accuracy.

### 2.3.4.3. The Sport Psychology Perspective

Some sports psychologists suggest that the QE may be a simple way for performers to maintain focus and concentration whilst performing sports skills under pressure (Vickers & Williams, 2007). Using a QE fixation may facilitate performers being ‘in the zone’, with a lengthy fixation in one location preventing changing visual information and creating a feeling of emptiness (Vickers, 2007; Wilson & Richards, 2010). Kremer and Moran (2008), suggested that performers should block out internal and external distractions and refrain from focusing on the mechanics of a skill by keeping the mind on ‘what the performer is doing’ and ‘focusing outwards’ when nervous. As concentration is very limited, we can focus on only one target at a time. Whether this target is the correct one for the task at hand will determine success. This relates closely to the work of Singer (1988, 2000, & 2002). In his 5-step strategy for accurate self paced athletic performance, Singer describes that an individual should focus their attention on one isolated cue to help block out internal and external distractions. In this sense a QE fixation may be viewed as a pre performance routine which helps to block out distractions, concentrate on the correct target and achieve a ‘just do it’ state (Singer, 2000; Kremer & Moran, 2008).

The work of Wulf and colleagues (see Wulf, 2007 for a review) also highlights the importance of an external focus of attention during the learning and execution of a skill. Wulf, Mcnevin and Shea (2001) proposed the constrained action hypothesis, which suggests that an internal focus of attention may act to disrupt the automaticity of a movement; while conversely an external focus of attention promotes the use of automatic processes and is more conducive of effective learning and performance. Recent research in this area by Bell and Hardy (2009) examined the effectiveness of three different foci of attention (internal, proximal external and distal external) on performance in a golf chipping task among a skilled population. Their results showed that a distal external focus of attention was associated with the greatest improvements in performance. The QE may therefore provide this external focus of attention.

### 2.3.4.4. The Cognitive-Physiological Facilitation Perspective

The final perspective on the QE considers the work of Setchenov (1935), who showed that the diversion of attention away from internal processes can lead to improvements in physiological work. More recent work has shown that directing attention externally to task relevant information improves performance in a wide variety of tasks, and appears to be related to the reticular formations regulating physiological arousal and the perception of pain (Hoffman, 2004; Wulf et al., 2001; Vickers, 2007). Vickers and Williams (2007) in a study examining the gaze behaviour of elite, Olympic level biathletes found that those who managed to maintain lengthy QE durations during high levels of physiological fatigue and cognitive anxiety were able to maintain subsequent shooting accuracy. The authors suggested that the QE may have acted as an external focus of attention, redirecting attention away from the demands of the task, resulting in an ability to perform at higher levels. The focus of attention, through the QE, may have prevented reticular information from inhibiting their physiological response to exercise. In contrast those who did not maintain external attention, i.e. reduced QE periods, may have been suffering from a suppressed physiological system due to reticular formation. These results suggest that the QE may insulate performers from the normally delimitating effects of exercise, anxiety and pain, allowing for maintenance of performance levels (Vickers, 2007).

The theoretical perspectives of the QE have important inferences for the way in which scientific enquiry examining the QE is performed. Depending on what view of the QE is taken, the coding of gaze data in perception action studies may vary (Vickers, 2009). Cognitive/neuroscience research tends to base methods on precedents arising from eye movement literature which has identified three main eye movements: fixations, pursuit tracking, and saccades (Bridgeman, Hendry & Start, 1975). These eye movements are defined according to rules that have been established over decades of eye tracking research (Vickers, 2009). As the research in this thesis primarily follows a cognitive psychology framework, this perspective of the QE is adopted. However, it is recognised that the QE may play a number of roles and the importance of a generic arousal and attentional control function (the sport psychology perspective) is also considered (Note, the coding of gaze derived from eye movement data is discussed in more detail in chapter 3).

### 2.3.5. Quiet Eye Training

As well as being indicative of expert and highly skilled performance the QE has also been shown to be trainable. QE training is a subsection of Vickers (2007) decision training model. Decision training refers to a new method of teaching and coaching that incorporates, into the regular practise environment, high levels of decision making. “Decision training brings the science of how we think, or cognition, to the fore of sports preparation. It is designed to improve the athlete’s attention, anticipation, concentration, memory and problem solving skills through practise where cognitive training is incorporated with physical and technical training” (p. 162).

In conjunction with these ideas, QE training specifically guides decisions about where and when to fixate areas of interest within the visuo-motor work space whilst performing a skill. Using a combination of video modelling and verbal feedback performers are guided to develop the same QE focus and motor control as expert performers, leading to improvements in accuracy and performance.

Vickers and Adolphe (1997) were the first to examine the benefits of QE training for volleyball service returning. The QE training regime utilised video footage of an elite prototype, identifying the important gaze behaviours, which were highlighted to the participants by the researchers. Participants were then shown videos of their own gaze behaviours and asked to make comparisons with the expert prototype. This was then followed by QE training sessions, aimed at improving detection and tracking of the ball. A month after the training regime participants’ gaze control was again measured so that pre-post comparisons could be made. Results showed that QE training led to earlier and longer tracking fixations and an improved ability to maintain a stable head whilst making a pass to the setter. Interestingly, results also revealed improvements in skills that were not purposefully trained, such as step correction to achieve the correct position. This highlights the potential positive impact of QE training on the motor action as well as the gaze control. Follow up performance data from the subsequent two seasons of play revealed that those participants who had received QE training showed a steady improvement in their pass accuracy. The performance of those that had not received QE training remained relatively constant.

Harle and Vickers (2001) utilised a similar QE training protocol in an attempt to improve the free throw accuracy of a Canadian Women's basketball team. Team A took part in a QE training regime and teams B & C acted as control groups. The QE of each member of team A was recorded and viewed relative to an elite prototype in a feedback session using vision-in-action data (Vickers, 1996). Participants were then taught a three step QE training regime aimed at improving their visuo-motor control. In the laboratory team A showed a significant increase in QE from pre (783ms) to post (981ms) and this was accompanied by a significant improvement in free throw accuracy (11.98%). Results also showed that training transferred to match performance: After two seasons of competitive play, team A had improved their free throw percentage by 22.62%, whereas the free-throw performance of teams B and C remained relatively constant.

While the improvement of visuo-motor skill performance via gaze training is clearly of interest to psychologists and coaches alike, most sport skills are performed in ego-threatening conditions. However, the effect of anxiety on visuo-motor control has not received a great deal of research attention in the sport literature (Janelle, 2002). Training regimes therefore need to help performers to maintain their effective visuo-motor control under conditions when they may be experiencing high levels of anxiety.

## 2.4. Anxiety in Sport

Given that top level sport is characterised by a demand to perform to optimum levels in intense pressure situations, it is not surprising that both research and consultant sports psychologists have been focused on understanding how performers are affected by, and learn to cope with, heightened levels of anxiety (Jones, 1995; Hill, Hanton, Matthews & Flemming, 2010).

Early research into the performance-anxiety relationship tended to view anxiety as a unitary and global phenomenon (Lundqvist & Hassmen, 2005), an approach that often led to inconsistent and weak findings. As a result the multidimensional view of anxiety was proposed (Martens, Vealey & Burton, 1990) which suggested that anxiety consists of two sub components: somatic and cognitive anxiety. Somatic anxiety concerns an individual's perceptions of physical manifestations of arousal, such as racing heart, sweaty palms and butterflies in the stomach; whereas cognitive anxiety consists of negative concerns of worry to perform, an inability to concentrate and disrupted attention (Krane, 1994; Martens et al, 1990). It is important to differentiate between these subcomponents because they are theorised to have differing antecedents and hence influence performance differently.

Generally, cognitive anxiety is postulated to occur as a result of threat and is related to the subjective evaluation of a situation with regard to one's self esteem (Eysenck, 1992). It is considered a negative emotional state characterized by nervousness, worry and apprehension and associated with increased physiological arousal. In sport settings, cognitive anxiety is usually related to the ego-threatening nature of the competitive environment and "refers to an unpleasant psychological state in reaction to perceived threat concerning the performance of a task under pressure" (Cheng, Hardy, & Markland, 2009, p. 271). Baumeister (1984) defined pressure as "any factor or combination of factors that increases the importance of performing well" (p. 610).

Early research in the sports domain was dominated by descriptive models of the relationship between anxiety and performance such as drive theory (Hull, 1943), the inverted U hypothesis (Yerkes & Dodson, 1908), the multidimensional anxiety theory (Martens et al, 1990), catastrophe models (Hardy, 1990) and zones of optimal functioning models (Hanin, 1980). While these models provided a description of the relationship between anxiety and / or arousal and performance, they did not explain the mechanisms underlying this relationship. Recently researchers have utilised evidence from the cognitive psychology literature to understand the relationship from an attentional processing perspective (Janelle, 2002; Weierich, Treat & Hollingworth, 2008).

### **2.4.1. The Influence of Anxiety upon Attention**

There is a great deal of interest in mainstream cognitive psychology in gaining an understanding of the mechanisms underlying anxiety. Research that has attempted to discover differences in the mechanisms of attention between anxious and non anxious individuals is of use to sports psychologists assessing state differences in anxiety as a result of competitive or pressurised performance. Research refers to the selection, orienting, control and capacity of attention and the influence that anxiety has upon these features (see Yiend, 2009 for a recent review). Most theoretical models of anxiety from the disorder literature implicate attention being biased towards threat related information (Weierich et al., 2008). For example, an enhanced tendency to select threatening stimuli for processing is likely to lead to an artificially increased perception of the extent of threat in the environment, thereby influencing subsequent cognitive and emotional processes related to anxiety (Yiend, 2009). The use of eye tracking methodology has facilitated the examination of visual attentional control among anxious individuals (Weierich et al., 2008). The results of such studies have revealed that anxiety causes an attentional bias towards threat related stimuli, a reduced ability to 'disengage' from these stimuli, and a general distractibility in the presence of threatening stimuli (see Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van Ijzendoorn, 2007 for a recent review). For example, several studies investigating attention and phobia have found that phobic participants were more vigilant towards phobia-relevant targets than a control group (Ohman, Flykte & Esteeves, 2001).

Within sport the role of attention within the anxiety performance relationship appears to be particularly relevant in skills classified as closed and self paced. Williams et al. (1999) suggested that while performing open skills in invasion games such as hockey, performers are capable of overcoming the apparent paradox of *needing to see*, yet performing in an environment in which it is difficult to *see well*. Conversely the most highly skilled and talented performers can struggle in closed environments where there is time to *think*, thus pointing to the role of emotion and attention in the successful performance of skills or 'choking under pressure'.

Recent research has identified that the pre-emption of attentional resources may lead to poorer performance, and in extreme cases can lead to choking (Wilson, 2008). Two competing attention-related theoretical accounts have been proposed; broadly categorised as either self focus or distraction theories (see Beilock & Gray, 2007; Wilson 2008 for discussion). Distraction theorists suggest that anxiety causes a shift in attention away from task relevant cues to task irrelevant distracting cues. Self focus theorists generally suggest that anxiety causes an inward shift of attention that causes a step-by-step conscious control of movement, disrupting automaticity.

Despite making opposing predictions regarding how anxiety exerts its impact on performance, both classes of theory have been proposed to play a role in understanding the anxiety performance relationship (e.g. Gucciardi, Longbottom, Jackson, & Dimmock, 2010; Hill et al., 2010). The cognitive psychology literature offers a number of theories which have been examined in sporting environments, both distraction and self focused, for understanding the influence of cognitive anxiety upon performance.

#### **2.4.1.1. The Theory of Reinvestment (Masters, 1992)**

The theory of reinvestment argues that perceived pressure may cause the performer to focus disproportionally on the *process* of performance. The proposed mechanism of disruption is therefore the effortful allocation of attention to previously automated processes: Under pressure, “the individual begins thinking about how he or she is executing the skill, and endeavours to operate it with his or her explicit knowledge of its mechanics” (Masters, 1992, p. 345). By ‘reinvesting’ in the knowledge base that supports performance, the fluency associated with expert performance is disrupted, causing performance to break down. The theory of reinvestment is a form of self awareness theory (see Baumeister, 1984), developed specifically for sport and has received considerable support in the sport anxiety literature (see Masters & Maxwell, 2008 for a review of reinvestment in sport).

#### **2.4.1.2. The Theory of Ironic Mental Processes (Wegner, 1994)**

Wegner’s (1994) theory of ironic processing concerns the proposition that the instruction to avoid a thought or action may ironically increase the tendency to engage in this thought or action (Janelle, 1999). Wegner (1994) proposes that consciousness comprises of an intentional operating process and an ironic monitoring process. The ironic monitoring process is automatic and scans the contents of consciousness for any unwanted thoughts. The role of the controlled intentional process is to replace any unwanted thought with a more appropriate task-related one. When attentional resources are taxed, the controlled intentional process can be compromised resulting in the manifestation of unwanted thoughts. As a particular drain on attentional resources, the effects of anxiety on ironic processing effects have recently received support in aiming skills including football penalties (Bakker, Oudejans, Binsch, & Van der Kamp, 2006) and golf putting (Binsch, Oudejans, Bakker & Savelsbergh, 2009; Woodman & Davis, 2008).

#### 2.4.1.3. Attentional Narrowing (Cue utilization hypothesis; Easterbrook, 1959)

One of the earliest and most influential models of attentional narrowing was developed by Easterbrook (1959). He postulated that arousal narrows attention, restricting the range of incidental cues that are used (i.e., the attentional field narrows). As a result, performance on central tasks will be facilitated at the expense of performance on peripheral tasks. Janelle, Singer and Williams (1999) found support for attentional narrowing effects due to heightened anxiety in an auto racing simulation, as participants were less successful at detecting peripherally presented targets when anxious, although central task performance was maintained.

Notwithstanding the arguments made for an attentional explanation of choking, it is important to note that, in general, the support for the predicted negative influence of cognitive anxiety on performance is less than would be expected (Wilson, 2008). In a review of cognitive anxiety, assessing its potential facilitative role, Hanton, Neil, and Mellalieu (2008) suggested that sports performance may not always be negatively influenced. Calls have been made for a theoretical framework which can be used to examine the effects of anxiety upon performance and can account for these equivocal findings (Wilson, 2008; Janelle, 2002). The distraction-based Processing Efficiency Theory (PET; Eysenck & Calvo, 1992), and its successor, the Attentional Control Theory (ACT; Eysenck, Derakshan, Santos, & Calvo, 2007), are arguably the most dominant, acknowledged and empirically supported theories that specify a crucial theoretical distinction between performance effectiveness and processing efficiency (Murray & Janelle, 2007).

#### 2.4.1.4. Processing Efficiency Theory (PET; Eysenck & Calvo, 1992)

PET predicts that cognitive anxiety, in the form of worry, has two main effects. Firstly a reduction in the processing and storage ability of the central executive of the working memory causes a reduction in the attentional resources available for the task at hand. Second, worry acts to motivate the performer, stimulating increases in on-task effort and auxiliary processing resources and strategies. This compensatory effort is aimed at maintaining performance at a desired level and serves to reduce, or eliminate, apprehension associated with worrisome thoughts related to the aversive consequences of poor performance (Eysenck & Calvo, 1992). One of the central predictions of PET is that the potential aversive effects of anxiety upon performance are often less than those on processing efficiency, where processing efficiency refers to the relationship between the effectiveness of performance and the level of effort invested (Eysenck & Calvo, 1992). This is because the reduction in available attentional resources caused by worry may be partially or completely compensated for by increased effort (Calvo, 1985).

The predictions of the PET have been examined in a number of sporting environments including golf putting (Wilson, Smith, & Holmes, 2007b), table-tennis (Williams, Vickers & Rodriguez, 2002), simulated archery (Behan & Wilson, 2008), karate defense techniques (Williams & Elliott, 1999), field hockey (Wilson & Smith, 2007), volleyball (Smith, Bellamy, Collins, & Newell, 2001), climbing (Nieuwenhuys, Pijpers, Oudejans, & Bakker, 2008); and simulated racing driving (Murray & Janelle, 2003, 2007; Wilson, Smith, Chattington, Ford & Marple-Horvat, 2006; Wilson, Stephenson, Chattington & Marple-Horvat, 2007a). While a range of self-report, dual-task, performance and psycho-physiological measures of efficiency have been adopted; gaze indices have the potential to offer a more direct measure of the efficiency and effectiveness of information processing (Wilson, 2008).

### 2.4.2. Anxiety and Gaze Research

An impressive body of research evidence examining PET using gaze indices has been accumulated from sporting tasks (see Wilson, 2008 for a review). There have been differences in the extent to which the findings support all the predictions of PET, particularly with respect to the influence of anxiety on performance. While most studies demonstrated that anxiety negatively affected the efficiency of information processing, in some studies there was also a subsequent degradation of performance.

Murray and Janelle (2003) examined the predictions of PET using a simulated driving task. In these studies, anxiety was manipulated as the drivers navigated a virtual racecourse while performing a secondary task involving the identification of information in the periphery of the visual fields. Murray and Janelle showed that whilst driving performance was maintained in a highly anxious condition, peripheral task performance significantly declined. The visual search data revealed that in the high anxiety condition there was a decline in detection of peripheral signals (secondary task) which was also associated with a dramatic increase in saccadic and fixation activity to such locations. Driving performance was therefore maintained despite the relative inefficiency with which the secondary task was performed, as indexed by less efficient visual gaze.

Williams et al (2002b) examined the predictions of the PET in a table tennis task and found that anxiety impaired both the efficiency of information processing *and* performance effectiveness. Subjects performed fore-hand returns in conditions of high and low working memory and high and low cognitive anxiety. Results showed that performers had poorer performance (lower accuracy of return) and less efficient visual search (more alterations of location of gaze) when anxious. The alteration in visual search efficiency is similar to that reported by Murray and Janelle (2003), and other research testing PET (e.g., Williams & Elliott, 1999; Wilson et al., 2007a). However, the degradation in performance is only partially supportive of PET's predictions. Eysenck and Calvo (1992) suggest that anxiety can impair performance effectiveness if the demands on working memory are high, but other attentional mechanisms (e.g., self-focus) may also explain such a disruption (see Wilson, Smith et al., 2007).

While alterations in visual search characteristics due to heightened anxiety have been studied in the sport literature, there has been less interest in examining the influence of anxiety on the visuo-motor control of targeting sport skills. As an objective measure of visuo-motor control, the QE provides an interesting dependent variable to examine the influence of anxiety on the efficiency of attentional control. The first study to adopt these methods was Behan and Wilson (2008). The authors examined the influence of anxiety upon the QE period from the perspective of PET. Results showed that under highly anxious conditions the QE, adopted as an objective measure of efficient visual attentional processing, was altered. Similar to findings from the visual search literature, disruptions were characterised by a shorter QE, leading to more fixations around the vicinity of the target. The QE may therefore be a useful index of the efficiency of visual attention in aiming or targeting tasks (Behan & Wilson, 2008; Wilson, 2008).

Following the submission of the Behan and Wilson (2008) paper, a development of PET was published which more explicitly considers the influence of anxiety on attention, rather than the more imprecise concept of processing efficiency. The following section outlines the main tenets of the development and how they might apply to research adopting the QE as an objective measure of attentional control in targeting tasks.

## 2.5. Attentional Control Theory (ACT; Eysenck, Derakshan, Santos & Calvo, 2007)

ACT is an extension and development of PET which is more explicit about the influence of anxiety on attentional control than its predecessor. ACT assumes that the effects of anxiety upon attentional processes are of fundamental importance to understanding how anxiety affects performance. As anxiety is experienced when a current, valued goal is threatened (Power & Dalgleish, 1997) this causes attention to be allocated to detecting the source of threat and deciding how to respond. As a result, processing resources are more likely to be diverted away from task relevant stimuli towards task irrelevant ones. This is assumed to be the case irrespective of whether these stimuli are external (e.g. environmental distracters) or internal (e.g. worrying thoughts) (Eysenck et al, 2007; Wilson, 2008).

Eysenck et al. (2007) related the impairment of attentional control to a disruption in the balance of two attentional systems first outlined by Corbetta and Schulman (2002): a goal-directed (top-down) attentional system and a stimulus-driven (bottom-up) attentional system (see section 2.3.4.1). ACT overcomes some of the limitations of PET by making more specific predictions regarding lower level functions of the central executive of the working memory system (Baddeley, 1986) that are related to the goal directed attentional system. While PET suggested that anxiety impairs processing efficiency generally, ACT is more precise about the specific functions of the central executive which are impaired; namely the ‘inhibition’ and ‘shifting’ functions (Miyake et al., 2000).

The inhibition function of the central executive involves using attentional control to resist disruption or interference from task-irrelevant stimuli (negative attentional control), whereas the shifting function involves using attentional control to shift the allocation of attention to maintain focus on task relevant stimuli (positive attentional control; Eysenck et al., 2007). It is the impairment of these functions that is proposed to disrupt the balance between the goal-directed and stimulus-driven attentional systems (Eysenck et al., 2007). As Eysenck and colleagues suggested that future research should attempt to investigate the strategies used by anxious individuals when processing becomes inefficient, alterations in gaze control (e.g., reduced QE) may provide an opportunity to meet these demands (Wilson, 2008).

The predictions of ACT, with respect to the impairment of the inhibition and shifting functions, have recently received empirical tests in the cognitive psychology literature. Derakshan, Ansari, Hansard, Shoker and Eysenck (2009) examined eye movements during an anti saccade task to examine the impact of trait anxiety on the inhibition function. In this task, participants are presented with an abrupt peripheral stimulus to one side of a central fixation point and are instructed not to look at the stimulus but to direct their gaze as quickly as possible to the mirror side of screen. Correct performance in this task requires top down attentional processes to suppress a reflexive saccade towards a peripheral cue (an oval circle) and simultaneously generate a saccade to its mirror position as fast as possible (i.e., inhibit). Immediately after its arrival an arrow replaced the cue and subjects were asked to identify the direction in which it was pointing and indicate this using the arrow keys on a keyboard. Subjects were divided into low and high trait anxious groups. The latency of the first corrective saccade, towards the cue, was used to assess the efficiency of negative attentional control. The percentage of incorrect saccades and the ability to successful identity the direction of the arrow were used as a measure of performance effectiveness. Results showed that the high anxious group took significantly longer and were therefore less efficient, in making a correct saccade in the anti saccade task when compared to the low anxiety group. Furthermore there were no differences in the percentage of incorrect saccades or identification of arrow direction (effectiveness) between groups. In a second experiment Derakshan et al. (2009) used various facial expressions depicting different emotions (angry, happy and neutral) as the cue (as opposed to the plain oval circle) and again asked high and low anxious individuals to perform the anti saccade task. ACT predicts that high anxious individuals process threatening stimuli more than low anxious individuals, and also take longer to disengage from them. Performance efficiency (time to make correct saccade) was reduced among the high anxious group, and this effect was greatest during the threatening stimuli. Again performance effectiveness (percentage of incorrect saccades) was similar across groups and conditions.

These sorts of ‘process pure’ tasks that isolate inhibition or switching functions are difficult to replicate in sport settings. However, by tracking eye movements on tasks in which it is possible to specify *where* visual attention should be and *how* it might switch over time, optimal top down attentional control (whether it is negative or positive) can be assessed. The first study in this thesis will therefore examine more general predictions of ACT; that anxiety causes a greater influence of stimulus driven attentional control at the expense of goal directed attentional control. Corbetta and Shulman’s (2002) attentional systems have been implicated in both expert visual attentional processing (the QE) and the influence of anxiety upon attentional processes (ACT). There therefore seems to be convergent evidence from both the visuo-motor literature and the cognitive psychology literature supporting the premise that the QE is an objective measure of attentional control in targeting tasks; longer QE periods are associated with better performance and the QE is also sensitive to the impact of anxiety.

## 2.6. Overview of Research Questions

This series of studies employed a recently established measure of optimal visuo-motor control, namely the Quiet Eye (QE; Vickers, 1996). Despite being extensively shown to be indicative of accurate and expert performance, research has failed to examine the influence of anxiety upon this optimal strategy.

Study 1 will examine some of the apparent links between the theoretical concepts described in this chapter. The QE has been described as a critical period of cognitive processing during which the parameters of the movement such as force, direction and velocity are fine-tuned (Vickers, 1996). This explanation of the QE resonates with Corbetta and Shulman's (2002) top-down, goal directed attentional system (or 'dorsal attention'; Corbetta et al., 2008). In the language of Corbetta and colleagues, the QE may help maintain effective goal-driven attentional control, while reducing the impact of the stimulus-driven attentional system. If the predictions of ACT are to be upheld for visuo-motor skills, anxiety should disrupt the QE, as the relative emphasis between goal-directed and stimulus-driven attentional control is shifted.

Study 2 (chapter 5) will assess a particular form of visuo-motor control relevant to tasks where vision may be obscured during performance. The location suppression hypothesis (LSH; Vickers, 1996) suggests that in order to protect the aiming commands set down by the QE fixation performers suppress their vision by blinking or allowing their eyes to move freely if the target subsequently becomes occluded. An examination of the influence of anxiety upon these specific forms of visual control, i.e. the suppression of vision, is therefore warranted.

QE training has been shown to aid the performance of visuo-motor skills by promoting optimal visuo-motor control (Adolphe, Vickers, & LaPlante, 1997; Harle & Vickers, 2001). Despite calls from several researchers (Janelle, 2002; Wilson, 2008) the notion that QE training may help protect an individual from the adverse effects of cognitive anxiety has never been examined. Study 3 (chapter 6) will therefore introduce novices to a QE training intervention and examine their performance and QE in retention and pressure tests. This will offer an insight into the mechanisms underlying the QE, and establish whether QE training can create robust performance under pressure.

It is also important to establish whether the benefits of QE training are seen in a number of different visuo-motor skills. Therefore Study 4 (chapter 7) will adopt a golf putting task. The golf putt requires the control of visual-attention across two visuo-motor workspaces. Again novices will be introduced to a QE training regime, and performance and QE assessed though retention and pressure tests.

Although QE training among experts has been shown to lead to laboratory and competitive performance improvements (Adolphe, Vickers, & LaPlante, 1997; Harle & Vickers, 2001), studies have failed to examine the role of QE training in protecting experienced performers from the adverse effects of anxiety associated with performance pressure. Studies 1 and 2 will examine the role of anxiety in the breakdown of visual attention processes and studies 3 and 4 will examine the role of QE training in reducing or alleviating such attentional and performance disruptions for novice performers. The aim of study 5 (chapter 8) is therefore to examine the utility of a brief (and therefore practically applicable) QE training intervention among an elite, highly skilled population and the transfer to *real* competitive settings.

In summary this series of studies will aim to examine:

1- The influence of anxiety upon visual attentional control (as indexed by changes to the QE and LSH strategy).
2- The potential utility of ACT as a theoretical framework for understanding the influence of cognitive anxiety upon visual attention control in far aiming skills.
3- The benefits of QE training in protecting performers from the adverse effects of anxiety.
4- The potential transfer effects of the QE into the ‘competitive’ world of sport.

# Chapter 3. Methodological Issues

Tracking the movements of the human eye is a relatively non-invasive technique that has been used by researchers to understand human behaviour and movement for decades. Advances in eye tracking technology mean that an otherwise painstaking method of data collection has now become relatively simple and more automated. Advances in eye tracking have allowed for detailed, mobile and therefore more ecologically valid assessment of eye movements in a range of environments, including the sport domain.

## 3.1. Structure and Function of the Eye

The eyes are the peripheral organs of vision and the primary sensory outpost of the brain (Williams et al., 1999). The eyes work in a complementary fashion to produce binocular vision by picking up reflections from objects in the visual field. Light entering the human eye is received by the retina, a light sensitive area at the back of the eye which is lined with two types of visual receptors called rods and cones. The amount of light entering the eye is dependent upon the cillary muscles that control the size of the pupil opening, and varies based on the availability of external light. Light entering the eye is focused by the curvature of the cornea and lens, and focused upon the fovea of the retina, an area of concentrated cone cells that is responsible for the detection of colour and light. Due to the relatively small size of the fovea the area across which we are able to see clear and detailed images is about 2-3° of visual angle, roughly the size of your thumb nail at arm’s length (Vickers, 2007). This means that for humans to perceive their environment accurately they must produce purposeful movements of the eye and head to place images upon the fovea; a process known as gaze control. The main objective of the complete human occulomotor system is to adjust line of gaze so that fixation point and fovea correspond (Williams et al., 1999). The retina converts light into neural messages that travel down the optic nerve where they are processed in several parts of the brain. A detailed description of these processes is outside the scope of this thesis (see Just & Carpenter, 1976).

## 3.2. Data Collection and Analysis

While early research measuring eye movements adopted simple observation techniques (Hackman & Guilford, 1936) recently more technologically advanced automatic measures of eye movements have been developed; for example simple corneal reflection systems such as the NAC Eye Mark recorder (California; USA). The NAC system compromises a primary visual camera (viewing the scene) and a corneal reflection system. Two light emitting diodes (LED's) send light into the performer's eye providing an image of the cornea. This reflection is then picked up by adjustable mirrors in two small cameras fitted to each side of a pair of head mounted goggles. As a subject moves the eye, the virtual image made by the LED also moves. This indicates the location of gaze as a set of X and Y coordinates. The NAC system was extensively used by research throughout the 1990s in the sport and performance domain (Williams et al., 1999).

A major advancement in the use of eye trackers was the addition of dark pupil tracking. The ASL series 4000 (Bedford; USA) system utilised a similar corneal reflection as the NAC system known as corneal reflex (reflection of a light source from the surface of the cornea). However, the ASL system also tracks the location of the pupil, via dark pupil tracking, and therefore uses two pieces of information to indicate the location of gaze. As well as being more robust and requiring less calibration, another advantage of this form of system is that the location of gaze can be super imposed into a video of the scene. This allows for post hoc analysis of the live event, rather than analysis of X and Y coordinates. ASL has since developed a range of head and desk mounted units using the corneal reflex and dark pupil tracking technique (see www.asleyetracking.com). While other systems (e.g., Eyelink) tend to be more popular in cognitive psychology research, and new dark pupil eye trackers have been developed (e.g., Tobii glasses), ASL systems have been by far the most frequently adopted gaze registration systems in the sporting literature.

### 3.2.1 The ASL Mobile Eye

The most recent of these is the ASL Mobile Eye (ME; ASL; Bedford, MA). The system incorporates a pair of lightweight glasses fitted with eye and scene cameras and a set of three light emitting diodes (LED) which project harmless near infra-red (IR) light onto the eye via a reflective 'monocle' (Figure 3.1). Some of this light is reflected by the cornea (corneal reflection) and appears to the eye camera as a triangle of three dots at a fixed distance from each other. The pupil appears black as light does not exit the inside of the eye, enabling the system to register its position and determine its centre. When the eye turns, the centre of the pupil moves relative to the head; however, the corneal reflection remains in the same position. Therefore, by comparing the vector (angle and distance) between the pupil and the cornea, the eye tracking system can compute the angle at which the eye is pointed. The system also incorporates a modified Digital Video Cassette Recorder (DVCR), which combines the two video streams from the eye and scene cameras at 25Hz and records them. The recorder is attached to a computer system installed with 'Eyevision' (ASL) software which performs several roles including registering the dark pupil, calibrating the position of the gaze cursor and recording the video data for offline analysis.

***Figure 3.1:*** *The Applied Sciences Laboratory Mobile Eye tracker (ME; ASL; Bedford).*

Calibration of the eye tracker takes place by asking the participant to fixate several specific locations within the visual field. By teaching the system how the angles calculated by the eye camera relate to the image from the second camera that is viewing the environment (the scene camera), the eye tracker can compute what the eye is pointed at. A cursor, representing 1° of visual angle with a 4.5mm lens, indicating the location of gaze in a video image of the scene (spatial accuracy ~0.5° visual angle; precision ~ 0.1°) is viewed in real time and can be recorded for off line analysis. The biggest selling point of this eye tracker is its lightweight and unobtrusive design. This allows for subjects to perform sporting tasks without wearing large head mounted units. The ME is also the first eye tracker to function without the need for a connecting cable. Previous models, such as the ASL5000, were attached to a control system via a 25 metre cable, although it must be noted that most researchers have reported minimal interferences from this cable (Vickers, 1992, 1988).

Instead the ME records data to a modified DVCR (see figure 3.1) which can be worn around the performer's waist whilst they perform. Developments in the corneal reflex and dark pupil tracking hardware and software mean that the ME is extremely robust to changing light conditions and requires limited calibration. All of these factors allow for ecologically valid data to be collected in sporting environments as close to the real event as is possible. Despite this, problems with data collection were encountered throughout the studies in this thesis. On occasion an individual's eye could not be captured by the eye tracker. This was likely due to the physiology of the individual (colour of eye and position of the eye within the face). Although the ME provides some adjustment for changes in the position of the eye within the head, at times these were not enough to allow for an accurate calibration. In studies 1 and 2 a total of 22 individuals attended the laboratory but only 10 could be calibrated effectively. A lack of experience and knowledge of using the eye tracker was partly to blame for this, as during studies 3, 4 and 5 the drop out (due to the eye tracker) was only 4, 3 and 4 respectively. These studies involved extensive use of the eye tracker over multiple trials and days, and once an individual had been successfully calibrated on day one there were no further complications. However, it appeared that for some individuals the eye tracker just would not work.

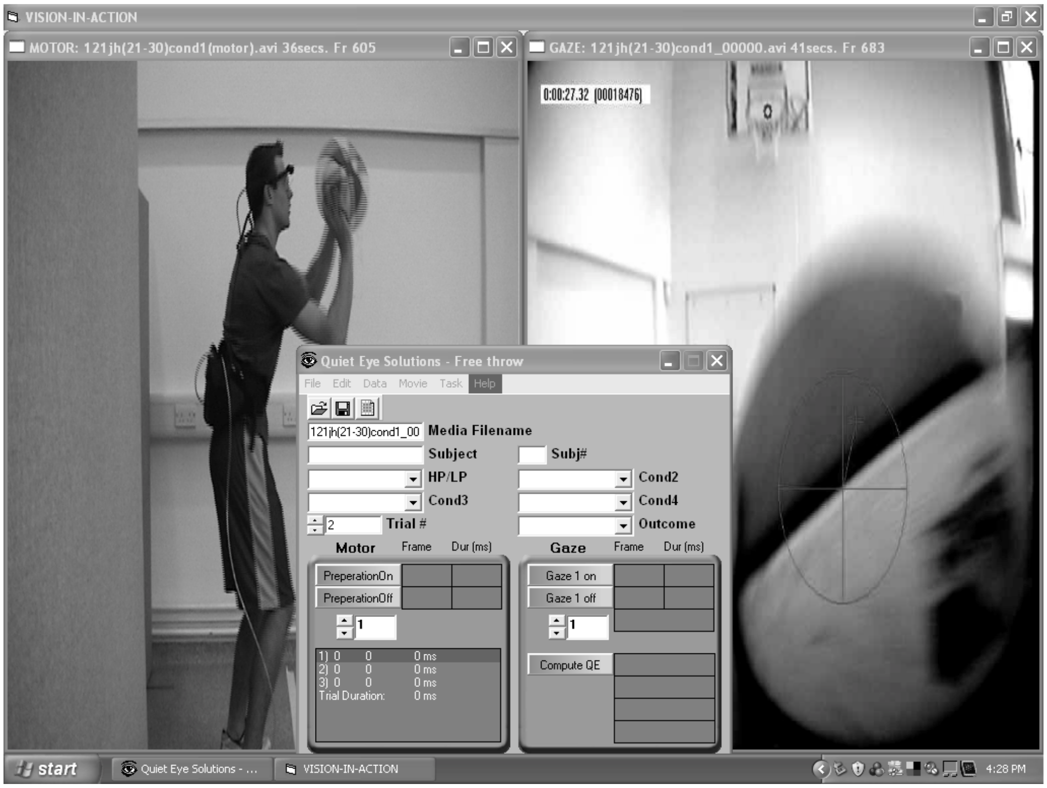
A further limitation of the ME is the capture rate. A capture rate of (25 Hz) allows for data to be captured every 40ms (25 frames per second) and is significantly lower than some of its predecessors (NAC: 600Hz; Eyelink: 500Hz; ASL 501: 50Hz). However the benefits of capturing data whilst subjects perform in *real* conditions outweigh the sampling limitations, especially as the research questions in sport psychology tend to be related to registering fixations (>100ms) as opposed to saccade analyses. Eye movements and the relevance of a 25 Hz capture rate are discussed later in this chapter.

### 3.2.2. Measuring Motor Phases

In order to calculate the QE variables for a given task, a temporal analysis of the phases of movement was required. A digital video camera (Canon MDl01) was utilised to capture the actions of performers in the basketball studies (the scene camera of the Mobile Eye picked up the movement of the putter in the golf putting studies). This video allowed viewing of the whole motor action and was used, in conjunction with the gaze video, for offline analysis. On occasion a different digital video camera (Sony HDV 1080i) and eye tracker (ME) were used due to the availability of equipment (experiment 5). Both the Sony camera and the new ME had capture rates of 29 Hz. This meant that each video frame equated to 33.3ms of real time video, rather than the 40ms provided by the original ME and Canon camera. This was overcome by converting the video from 29 Hz into 25 Hz using Blade Media Pro software (www.blazemp.com).

Analysis of data was performed using the Quiet Eye Solutions software (Quiet Eye Inc). Figure 3.2 shows the split screen view of the Vision-in-Action (Vickers, 1996) video data, with the left side showing the external video of the participant performing the skill. The right side shows the view from the scene camera of the eye-tracker, with the point of gaze indicated by the circular cursor. The software time-locks the two video files and allows for manual coding of the movement phases (position of limbs over time) from the external video, in relation to the coding of the gaze behavior (gaze location and duration) from the eye-tracker. First, the temporal sequences are coded by viewing the video and indicating the start and end of each phase of movement. This consists of pausing the video at the relevant points (i.e. first backwards movement of the putter head and first forward movement of putter head) and clicking the onset and offset buttons to define the start and end of this phase of movement (see Figure 3.2). This is repeated for each of the phases of movement for the skill. The motor phases of each task can be derived from the biomechanical and motor control literature (see Vickers, 2007). For basketball three phases of movement were coded. The preparation phase was coded as a consistent 1000 ms prior to the first upward movement of the ball for all participants. The lift phase was coded from the first upward movement of the ball until extension of the elbow occurred. The extension phase was coded from the first extension at the elbow until the ball left the fingertips. In golf three phases of movement were also coded. The *preparation* began when the club-head was first set square behind the ball; the *backswing* began with the first observable backward movement of the club-head away from the ball; and the *fore-swing* began with the first observable forward movement of the club-head and lasted until contact with the ball. Although movement phases were coded for the purposes of calculating the QE, this series of studies made no specific predictions regarding the effects of anxiety or QE training upon movement and therefore movement data was not statistically analysed.

The next step is to code the eye movements of the performer. This is achieved by returning back to the start of the video and coding the location, duration and type of gaze behavior. This is achieved by scanning backwards and forwards through the video to determine the duration of each gaze (by clicking the onset and offset buttons; see Figure 3.2). The experimenter then identifies the location and type of gaze (e.g. fixation, tracking fixation or saccade). Finally, the software then calculates the QE variables; including on set, off set, location and duration. The process of coding requires the consistent use of constant rules to ensure that each phase of movement and gaze were coded equally. Checks to ensure the objectivity of the coder were performed and are discussed later in this chapter. The QE solutions software is a relatively simple piece of software to use, however, the coding process is extremely time consuming. Throughout the analysis of studies included in this thesis it was estimated that for every minute of video data collected, four minutes of analysis was required. The software also requires objectivity on the part of the coder, as both phases of movement (positioning of body over time) and gaze (position of gaze cursor over time) are manually coded. For studies within this thesis a subset of shots were selected for analysis. For studies 1 and 2 a subset of 10 hits and 10 misses were selected and analysed, this is conjunction with previous research examining the QE (Vickers, 1996) and research adopting a within subject design (Williams et al., 2002a). For studies 3, 4 and 5 every fourth trial during pre-test, retention and stress tests were analysed. Every fourth shot was selected as this would give a representation of the QE period across the whole of the block and account for any learning effects.



Media Filename: 121jh(21-30)cond1_00
Trial #: 2

```
1) 0      0        0 ms
2) 0      0        0 ms
3) 0      0        0 ms
Trial Duration:    0 ms
```

***Figure 3.2****: A screen grab of the Quiet Eye Solutions software analysis environment; showing the external video of the participant (left), the view from the scene camera of the eye-tracker (right) and the coding entry fields (centre).*

In order to assess the objectivity and reliability of the coding process coder reliability checks were performed. Inter reliability checks involved a second coder blindly coding a subsection of the data for comparison with the original coders. The use of inter rater reliability checks is consistent with previous research coding eye movements (Adolphe & Vickers, 1997; Vickers, 1996; Vickers & Williams, 2007; Causer et al., 2010; Panchuk & Vickers, 2006, 2009). Intra-class correlations were determined as outlined in Thomas and Nelson (2001). R values ranged from 0.83 to 0.98 validating the consistency and objectivity of the coding process.

## 3.3. Analysing Eye Movements

As discussed in chapter 2 the literature has defined a set of specific rules for the coding of eye movements. Three main categories have been identified: fixations, pursuit tracking, and saccades. Saccades occur when the eyes move quickly from one fixed or tracked location to another. Saccades are rapid movements that bring the most important and relevant stimuli in the visual field onto the fovea. We average around three saccades a second, usually ranging from 60-100ms (Vickers, 2009) and due to the rapid nature of saccades information processing is suppressed (Bridgeman et al., 1975). Fixations occur when the gaze is steady on one location (within 3°of visual angle) for 100ms or longer (Just & Carpenter, 1976; Carl & Gellman, 1987). 100ms is considered to be a long enough duration for processing of information which allows us to recognise a stimulus and has been used in a number of studies specifically examining the QE (Vickers, 1996; Janelle et al., 2000; Panchuk & Vickers, 2009, Martell & Vickers, 2004). Pursuit tracking occurs when the gaze follows or tracks a slowly moving object.

For the purpose of this thesis a fixation was defined as a gaze that remained steady on the same location (within 1° of visual angle) for ≥120ms. A minimum fixation of 120ms was chosen for two reasons. Firstly, a capture rate of 25 Hz means that each individual video frame equates to 40ms in real time, therefore 120ms would represent exactly three frames of video, allowing for simple and accurate analysis. Secondly, 120ms is above the minimum threshold required for information processing (Just & Carpenter, 1976; Carl & Gellman, 1987) and also above the minimum used in previous similar research (Williams et al., 1999; Vickers, 2007). The use of 25 Hz sampling eye trackers, 120ms minimum fixation durations, and the vision-in-action form of analysis (via the Quiet Eye Solutions software environment) is in conjunction with recent research (Wilson & Pearcey, 2009; Causer et al., 2010).

## 3.4. Defining the QE

The QE period is generally defined as the final fixation directed to a single location or object in the visuo-motor workspace within 3° of visual angle (or less) for a minimum of 100 ms. The QE has an onset that occurs before the final movement in the motor task and an offset that occurs when the fixation or tracking deviates off the target by more than 3° of visual angle for more than 100 ms (see Vickers, 2007).

Although previous research has been inconsistent in its operational definition of the QE (i.e. what is the final or critical movement), for the basketball free throw the consensus is that the final movement can be categorized as the final extension of the arms; the first video frame where the angle between upper and lower arm starts to increase (see Vickers, 2007).

For studies 1, 2 and 3 the QE was therefore operationally defined as the final fixation to a single location or object in the visuo-motor workspace within 1° of visual angle for a minimum of 120 ms (3 frames). QE onset occurred prior to the initiation of the extension phase of the free throw, and is reported relative to how long it occurred after the initiation of the preparation phase (in ms). QE offset occurred when the gaze deviated off the fixated location (by 1° or more) for more than 3 frames. If the cursor disappeared for one or two frames (e.g., a blink) and then returned to the same location, the QE duration resumed (www.quieteyesolutions.com).

For studies 4 and 5 the QE was operationally defined as the final fixation towards the ball prior to the initiation of the back swing. This has been consistently adopted as the final or critical movement within the literature (see Vickers, 1992, 2007; Wilson & Pearcey, 2009). As with basketball the QE offset occurred when the gaze deviated off the fixated location (by 1° or more) for more than 3 frames. If the cursor disappeared for one or two frames (e.g., a blink) and then returned to the same location, the QE duration resumed (www.quieteyesolutions.com).

## 3.5. Measuring Anxiety

Self reported measures of anxiety were adopted throughout the studies within this thesis. However, there are some concerns about the validity of self-report measures due to the possibility of response distortion (Lazarus, 1996). Lazarus discussed two main concerns regarding the reporting of subjective states. First, the verbal labels used to describe a particular state may differ between individuals. Second, participants may distort their responses either unconsciously, or due to an unwillingness to reveal their genuine subjective experiences. A critique of self report questionnaires is the imprecision with which they asses cognitive and physiological symptoms and deem these to be representative of an anxious state (Jones, 1995). As symptoms can be interpreted by individuals differently, questionnaires should include the measurement of other affective variables such as self confidence. A further problem stems from the non-synchronous nature of questionnaires. It is unlikely that there will be a correlation between anxiety and performance if measurements are taken more than half an hour prior to or proceeding performance (Jones, 1995).

Calls to measure both cognitive and somatic anxiety independently have lead to the development of multi-dimensional assessments of anxiety. The assessment of multidimensional state anxiety in sport has relied almost exclusively on the Competitive State Anxiety Inventory–2 (CSAI-2; Martens et al., 1990). The CSAI-2 is a 27 item questionnaire with subscales reflecting cognitive anxiety, somatic anxiety and self-confidence and has been accepted as both a reliable (reliability coefficients of 0.76-0.91; Burton, 1998) and valid (Martens et al., 1990) assessment of state anxiety (although see Lane et al., 1999). The main criticism of the CSAI-2 is that it takes too long to complete in advance of performance. Anxiety measures that take a significant period of time to complete before or after performance, rather than in vivo, will weaken both the ecological validity of data and the generalization of findings to competitive sport (Parfitt & Pates, 1999). As a result a number of shorter and more expedient versions of the CSAI-2 have been developed (Cox, Russell & Rob, 1998; Hardy & Upton, 1992; Krane, 1994; Thomas, Hanton & Jones, 2002) and subsequently adopted by other researchers (e.g. Parfitt & Pates., 1999; Smith et al., 2001).

The Mental Readiness Form 3 (MRF-3; Krane, 1994; appendix 2) is a developed version of the original MRF (Murphy, Greenspan, Jowdy & Tammen, 1989). The MRF-3 has three bipolar 11-point Likert scales that are anchored between *worried–not worried* for the cognitive anxiety scale, *tense–not tense* for the somatic anxiety scale, and *confident–not confident* for the self-confidence scale. Krane's validation work on the MRF-3 revealed Pearsons correlations between the MRF-3 and the CSAI-2 subscales of .76 for cognitive anxiety, .69 for somatic anxiety and .68 for self-confidence. Participants are asked to record how they feel 'right now' when completing the scales (see appendix 2). As with previous research investigating the effect of worry on sporting performance (e.g., Wilson et al., 2007a), the cognitive anxiety scale provided the main focus for the research. The constraints of eye tracking and anxiety related research require expedient measures to allow for ecologically valid data to be collected. In all studies state anxiety levels were measured prior to each block of 10 trials during the test phase of the research (high anxiety, low anxiety, retention test or pressure test). This was to ensure that the manipulation of pressure had caused an increase in anxiety throughout the whole of the testing period.

## 3.6. Experimental Manipulation of Anxiety

Research examining the influence of anxiety upon performance will utilise anxiety manipulations to artificially increase anxiety in a laboratory setting. Notwithstanding the ethical concerns regarding misguiding or stressing a subject, the biggest challenge for researchers in this area is the recreation of the levels of anxiety experienced in real competitive sport.

Varying instructions and techniques were used during the studies in this thesis to ensure that two distinct conditions were created. In control conditions, non-evaluative instructions were provided to participants, asking them to do their best but stressing that their success rate would not to be used for comparison with other participants. In the high threat condition several manipulations were used to attempt to ensure that high levels of pressure were created (see also Behan & Wilson, 2008; Murray & Janelle, 2003). Participants were informed that their success rate and performance levels were to be compared among their peers and that their average success rate was going to be compared to other performers within the same competitive league.

Financial rewards were offered to the best participants within each study. For studies 1 and 2 participants were from the same team so a leader board was drawn up and prizes of £30 for first place, £20 for second and £10 for third were awarded. However, for studies 3, 4 and 5 participants were not team mates and so a £50 prize was offered as a larger incentive. Non-contingent feedback was also used (see Williams & Elliott, 1999) whereby participants were informed that their previous 20 attempts put them in the bottom 30% when compared to other participants that had already taken part. The previous 20 attempts came from their warm up or the control condition depending upon whether they were completing the high threat condition first or second. The participants were informed that being in the bottom 30% meant that the data was of no use for the study and that they should try and be more accurate.

# Chapter 4 (Study 1): The Influence of Anxiety on Visual Attentional Control in Basketball Free-throw Shooting.

-Study 1 was published as: 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.

## 4.1. Introduction

Anxiety's influence on performance is one of the main research interests for sport psychologists (Woodman & Hardy, 2001). Anxiety is postulated to occur as a result of threat and is related to the subjective evaluation of a situation with regard to one's self esteem (Eysenck, 1992). Several theorists have suggested that the negative performance effects of anxiety (for definition see section 2.4.) are due to the manner in which worry and other forms of cognitive interference occupy attention (e.g., Kahneman, 1973; Sarason, 1988). One theory that provides an explanatory account of the mechanisms involved in the anxiety-performance relationship, and which has been the focus of recent research in sport settings, is processing efficiency theory (PET: Eysenck & Calvo, 1992).

PET predicts that cognitive anxiety in the form of worry has two main effects. First, it reduces the processing and storage capacity of the central executive of working memory (Baddeley, 1986), thereby reducing the attentional resources available for the task at hand. Second, worry can have a motivational role, stimulating increases in on-task effort and auxiliary processing resources and strategies. This compensatory effort is aimed at maintaining performance at a desired level and serves to reduce, or eliminate, apprehension associated with worrisome thoughts related to the aversive consequences of poor performance (Eysenck & Calvo, 1992). The efficiency by which performers process information when anxious is therefore decreased, potentially resulting in poorer performance (Janelle, 2002).

The predictions of PET have recently been tested using a variety of measures of processing efficiency in a number of sport settings; including golf putting (Wilson, Smith & Holmes, 2007); table-tennis (Williams et al., 2002b); simulated archery (Behan & Wilson, 2008); karate defence techniques (Williams & Elliott, 1999); field hockey (Wilson & Smith, 2007); volleyball (Smith et al., 2001); climbing (Nieuwenhuys et al., 2008); and simulated driving (Murray & Janelle, 2003, 2007; Wilson et al., 2006; Wilson et al., 2007a). Of particular interest to the current investigation are the findings from studies that have used indices of gaze behavior to test the predictions of PET. Such findings provide more specific insight into how visual attentional control is affected in threatening settings rather than changes in the more generic concept of 'processing efficiency' (Wilson, 2008).

In line with the predictions of PET, anxiety has been shown to reduce the efficiency of gaze behavior, both in motor tasks requiring visual search and detection, and tasks requiring aiming. Although limited in number, the findings from such studies have been relatively consistent, with increased anxiety being reflected in less efficient visual search strategies and gaze orientation behavior (see Janelle, 2002; Wilson, 2008, for reviews). First, in tasks requiring the detection of peripherally presented targets, performers show higher search rates, characterized by more foveal fixations of shorter duration to the target areas when anxious as opposed to control conditions (e.g., Murray & Janelle, 2003; Williams et al., 2002a). This finding has been taken to reflect a decrease in efficiency, as a greater number of fixations appear needed to gather the same information acquired by fewer fixations in the low anxiety condition. Also, as eye movements between successive fixations, known as saccades*,* are believed to suppress information processing (Bridgeman et al., 1975), a visual search strategy involving fewer fixations of longer duration allows more time for information extraction and can be thought of as more efficient (Mann et al., 2007).

In aiming tasks, a particular fixation termed the 'quiet eye' (QE; Vickers, 1996), defined as the final fixation to a target before the initiation of the motor response, has also been shown to become less efficient under pressure. Vickers proposed that the QE is a period of time when task relevant environmental cues are processed and motor plans are coordinated for the successful completion of the upcoming task. Theoretically, longer QE periods therefore allow performers an extended duration of programming, while minimizing distraction from other environmental cues (Vickers, 1996).

A number of studies have demonstrated that longer QE periods are indicative of superior performance in aiming tasks (see Vickers, 2007 for a review), however, to date, only two studies have examined the influence of anxiety on the QE period (Behan & Wilson, 2008; Vickers & Williams, 2007). Vickers and Williams (2007) found that elite biathletes who increased their QE duration during high pressure competition, compared to low pressure practice, were less susceptible to sudden performance disruption or 'choking' as physiological arousal increased to maximum. Behan and Wilson (2008), in a simulated archery task found that under conditions of elevated cognitive anxiety, QE durations were reduced, as participants took more fixations around the vicinity of the target than they did in the low pressure condition. These results show that the QE period is sensitive to increases in anxiety and may be a useful index of the efficiency of visual attentional control in aiming tasks.

The preceding discussion reflects the utility of adopting gaze behavior measures to assess the efficiency of visual attention in anxiety-inducing situations. However, while the specific forms of inefficiency (e.g., increased search rate to peripheral targets; reduced QE period) can be explained by current cognitive approaches, (e.g., hypervigilance; Eysenck, 1992; attentional narrowing; Easterbrook, 1959) there is no over-riding theoretical framework to explain the effect of anxiety on the efficiency of attentional control in aiming and visual search tasks. However, a recent theoretical development and extension of PET by Eysenck and colleagues; attentional control theory (ACT: Eysenck et al., 2007) may provide a framework by which the preceding gaze behavior results can be interpreted, and the development of future gaze control research structured.

ACT (Eysenck et al., 2007) assumes that the effects of anxiety on attentional processes are of fundamental importance in understanding how anxiety influences performance. As anxiety is experienced when a current, valued goal is threatened, this causes attention to be allocated to detecting the source of the threat and deciding how to respond (e.g., Power & Dalgleish, 1997). As a result, processing resources are more likely to be diverted away from task relevant stimuli and toward task irrelevant stimuli. This is assumed to be the case irrespective of whether these stimuli are external (e.g., environmental distractors) or internal (e.g., worrying thoughts) (Eysenck et al., 2007). The authors relate this impairment of attentional control to a disruption in the balance of two attentional systems first outlined by Corbetta and Schulman (2002); a goal-directed (top-down) attentional system and a stimulus-driven (bottom-up) attentional system. Generally, anxiety is associated with an increased influence of the stimulus-driven attentional system and a decreased influence of the goal-directed attentional system (Eysenck et al., 2007).

ACT makes more specific predictions regarding lower level functions of the central executive of working memory that are related to the goal-directed attentional system (Baddeley, 1986). In this way, ACT overcomes some of the limitations of PET (Eysenck & Calvo, 1992) in terms of its lack of precision or explanatory power. While PET suggested that anxiety impairs the processing efficiency of the central executive of working memory, ACT is more precise about the *specific* functions of the central executive which are most adversely affected by anxiety; namely, the ‘inhibition’ and ‘shifting’ functions (based on Miyake et al., 2000). It is the impaired functioning of these elements of attentional control (i.e., inhibition and shifting) which is proposed to disrupt the balance between the goal-directed and stimulus-driven attentional systems.

The central prediction of PET, that anxiety impairs processing efficiency more than performance effectiveness, is still retained within ACT. The processing inefficiency caused by the disruption of the inhibition and shifting functions of the central executive does not necessarily lead to decrements in performance effectiveness provided that anxious individuals respond by using compensatory or alternative processing strategies (Eysenck et al., 2007). In outlining future directions for research into ACT, Eysenck et al. discussed the need for investigation into the strategies used by anxious individuals when their processing becomes inefficient. Potential alterations in gaze control strategies, particularly QE, during visuo-motor task performance provide an ideal opportunity to accomplish this (see also Nieuwenhuys et al., 2008).

An important consideration when examining gaze behavior indices is the degree to which the location of overt gaze is reflective of the target of covert attention. Although the extent to which gaze behavior accurately represents attention has been questioned (e.g., Kuhn, Tatler, Findlay, & Cole, 2008; Posner & Raichle, 1991; Viviani, 1990), recent research suggests that it is difficult to shift the point of gaze without shifting attention (Henderson, 2003; Shinoda, Hayhoe, & Shrivastava, 2001). Furthermore, the attention shifts that precede goal directed, saccadic eye movements are directly associated with their preparation and involve some of the same neuronal 'machinery' (e.g., Corbetta, 1998). Finally, Eysenck et al. (2007) suggest that direct measures of attentional control, such as gaze indices should be adopted in order that the influence of anxiety on attention be better understood.

The current study therefore aims to examine the influence of anxiety on the QE period and accuracy of basketball players performing free-throws. The basketball free-throw was felt to be an appropriate task, as it has been adopted in previous research examining the QE period (e.g., Harle & Vickers, 2001; Vickers, 1996), and a number of standardized definitions and analysis procedures have already been clarified (see Vickers, 2007). In terms of the predictions of ACT, it is evident that the free-throw relies heavily on the goal-directed attentional system, therefore impairment of inhibitory control will likely result in reductions in the QE periods of anxious basketball players. The impairment of inhibitory control should also be reflected in more gazes of shorter duration around the target area (i.e., the basketball hoop) when anxious, due to increased influence of the stimulus-driven attentional system.

While ACT predicts that performance effectiveness may not necessarily be negatively affected by such reduced efficiency of attentional control, both Vickers and Williams (2007) and Behan and Wilson (2008) found that increased anxiety caused reductions in QE periods and subsequent performance. It is therefore predicted that performance, as measured by free-throw percentage accuracy will be worse when participants are anxious if the QE period is significantly reduced.

## 4.2. Method

### Participants

Ten male basketball players from university teams (Mean age, 20.3 years, *SD* = 0.9) with 7.1 years of experience (*SD* = 1.9) volunteered to take part in the study. All players took free-throws for their teams during the current season (mean percentage accuracy, 64.6%, *SD* = 9.91). Participants attended individually and had the general nature of the study explained to them. Written information was provided and written consent was gained from all participants (see appendices 1 & 3). Ethics approval was obtained from the School of Sport and Health Sciences ethics committee at the University of Exeter prior to the start of testing.

### Apparatus

The free throws were taken from standard distance (i.e., 4.60 m) and to a hoop set at standard height (3.04m) from the ground. Gaze was measured using an Applied Science Laboratories (ASL; Bedford, MA) Mobile Eye tracker. This lightweight system measures eye-line of gaze at 25Hz, with respect to eye and scene cameras, mounted on a pair of glasses. The system works by detecting two features, the pupil and corneal reflection (determined by the reflection of an infrared light source from the surface of the cornea), in a video image of the eye. The relative position of these features is used to compute visual gaze with respect to the optics.

The system incorporates a recording device (a modified DVCR) worn in a pouch around the waist and a laptop (Dell inspiron6400) installed with ‘Eyevision’ (ASL) recording software. A circular cursor, representing 1° of visual angle with a 4.5-mm lens, indicating the location of gaze in a video image of the scene (spatial accuracy of ± 0.5° visual angle; 0.1° precision) is viewed in real time on the laptop and recorded for offline analysis. The DVCR was linked to the laptop via a 10-meter firewire cable, permitting near normal mobility for the participant. The experimenter and the laptop were located behind and to the right of the participant, to minimize distraction.

An externally positioned digital video camera (Canon, MDl01) was located three metres to the right of the participants, perpendicular to the direction in which they were shooting (i.e. sagittal plane). The view allowed the entire free-throw action of each participant to be captured for subsequent offline analyses.

### Measures

***State anxiety.*** (see section 3.5).

***Fixations***. Fixations were defined as a gaze which remained on a location (within 1° visual angle), for a minimum of 120 ms, or three frames. The number and mean duration of all fixations made during the free-throw preparation and execution period were analyzed for a subset of shots (see procedure).

***QE period.*** (see section 3.4).

***Movement phases***. (see section 3.2.2).

***Performance***. Free-throw percentage success in each condition was adopted as the measure of performance effectiveness in the current study (number of successful throws x 100 / total number of throws).

### Procedure

After reading the written information introducing the study (appendix 3) and providing informed consent (appendix 1), participants were allowed to take 20 practice free throws at will to become familiar with the testing surroundings. After one minute break they were asked to take 10 free throws without the eye tracker being fitted and to score as many baskets as possible. Participants were then fitted with the eye-tracking device and calibration took place using a grid presented at the same distance as the hoop, displaying 9 individually numbered crosses arranged in a 3x3 format. Participants were then asked to take 10 more free throws and score as many shots as possible. Performance was recorded in both conditions to ensure that there were no changes in performance due to the wearing of the eye tracker.

Participants were then provided with instructions related to the condition in which they were going to perform under and were asked to give a reading from the three scales on the MRF-3. Before every block of ten shots participants were asked to face the external camera and clap their hands in front of their face, in order that a clear event could be used to time-lock the footage from the external camera and the eye-tracker scene camera for subsequent offline analyses. Each block of ten free-throws was split into five sets of two consecutive throws, with an experimenter returning the ball to the participant after each throw. This was to ostensibly follow the typical game situation whereby free-throws occur in pairs. During the early stages of testing, when the eye tracker was a new and unfamiliar piece of equipment a quick calibration check was performed after every two shots to ensure that data was still accurate. If necessary, the line of gaze was re-calibrated quickly before proceeding with the testing protocol.

After every 10 free throws the video data was saved and the participants were then asked to report their current anxiety levels using the MRF-3. This procedure was repeated until the participants had performed 10 successful free throws and 10 unsuccessful free throws (as Vickers, 1996), although they were unaware of this requirement. The participants were then allowed a five minute rest before the second condition was explained and the same testing procedure followed. At the end of the testing period, participants were debriefed about the true purpose of the study.

### Experimental Conditions

Participants were asked to take free throws in two counter balanced conditions, designed to manipulate the level of anxiety experienced. Several manipulations were utilized to ensure that anxiety levels were significantly higher in an anxious condition compared to a control condition (see section 3.6).

### Data Analysis

As with previous studies examining the QE period (e.g., Behan & Wilson, 2008; Harle & Vickers, 2001; Vickers, 1996; Williams et al., 2002a) a subset of shots were selected for frame-by-frame analyses (see section 3.2.2). If ten successful shots were made before ten misses, then all misses were included and a randomly selected group of ten successful shots. This procedure was reversed if ten misses occurred first. A random number generator (www.random.org) was used to select the ten random shots to be analysed by inputting the total number of successful shots or misses into the generator and selecting the first ten numbers generated. Values for gaze behavior and movement phase dependent variables were calculated for the ten successful shots and ten misses for each condition and used in subsequent statistical analyses.

## 4.3. Results

Performance accuracy percentages in the familiarization condition (with and without the eye-tracker) were subjected to paired samples t-test analysis. Anxiety and performance accuracy data were also subjected to paired samples t-test analyses (control vs. high threat conditions). QE and fixation data were all subjected to a fully repeated measures 2x2x10 ANOVA: threat (control, high) x accuracy (hit, miss) x trial (1-10). Effect sizes ($\omega^2$) were calculated as outlined in Howell (2002).

### Familiarization Performance

Percentage accuracy was 56.0% (*SD* = 20.11) while wearing the eye-tracker and 51.0% (*SD* = 11.97) while not wearing the eye-tracker. This difference was not significant, $t(9) = .86$, $p = .41$, $\omega^2 = .38$, suggesting that wearing the eye-tracker had no effect on shooting performance.

### State Anxiety: MRF-3

Participants reported significantly higher cognitive anxiety scores in the high threat (mean rating of 5.05, *SD* = .90) than the control (mean rating of 3.29, *SD* = 1.24) condition, $t(9) = 5.17$, $p < .005$, $\omega^2 = 1.30$. Somatic anxiety scores were also significantly higher in the high threat (mean rating of 5.63, *SD* = 1.01) than the control (mean rating of 3.60, *SD* = .84) condition, $t(9) = 5.97$, $p < .001$, $\omega^2 = 2.10$. Self-confidence scores were significantly lower in the high threat (mean rating of 6.54, *SD* = 1.66) than the control (mean rating of 7.73, *SD* = 1.26) condition, $t(9) = 2.57$, $p < .05$, $\omega^2 = .86$.

### Performance

Performance, as measured by free-throw percentage accuracy, was lower in the high threat (50.50%, *SD* = 5.07) than the control (68.60%, *SD* = 11.02) condition, $t(9) = 5.52$, $p < .001$, $\omega^2 = 1.50$.

### QE Duration

Significant main effects were found for threat, $F(1,9) = 12.11$, $p < .01$, $\omega^2 = .55$, and accuracy, $F(1,9) = 30.13$, $p < .001$, $\omega^2 = .80$. There was no main effect for trial, $F(39.8) = .83$, $p = .52$, and no significant interaction effects. Participants had longer QE periods in the control condition compared to the high threat condition, and for successful shots (hits) compared to misses. The QE duration data are presented in Figure 4.1 (left).

### QE Onset

A significant main effect was found for accuracy, $F(1,9) = 9.98$, $p < .05$, $\omega^2 = .30$, with earlier QE onsets occurring for successful shots (hits) as opposed to misses. There were no significant main effects for threat, $F(1,9) = 2.43$, $p = .15$, $\omega^2 = .18$, or trial, $F(9,81) = 1.18$, $p = .12$, and no significant interaction effects. The QE onset data are presented in Figure 4.1 (right).

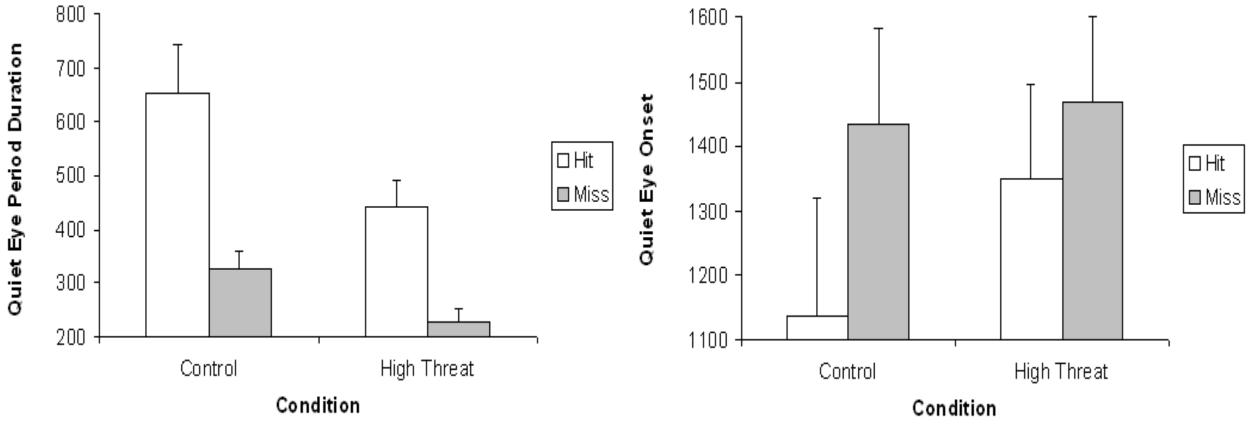


***Figure 4.1:*** *QE period data: Mean quiet eye duration (ms; left) and onset (ms after initiation of preparation phase; right) for successful (hits) and unsuccessful (misses) shots, during control and high threat conditions (with standard error bars).*

### Number of Fixations

Significant main effects were found for threat, $F(1,9) = 32.44$, $p < .001$, $\omega^2 = .82$, and accuracy, $F(1,9) = 6.10$, $p < .05$, $\omega^2 = .25$. There was no significant main effect for trial, $F(9,81) = .87$, $p = .56$, and no significant interaction effects. Participants used more fixations in the high threat as opposed to control condition and for misses as opposed to successful shots (hits). The fixation count data are presented in Figure 4.2 (left).

### Mean Fixation Duration

Significant main effects were found for threat, *F*(1,9) = 63.98, $p < .001$, $\omega^2 = 2.18$, and accuracy, *F*(1,9) = 7.40, $p < .05$, $\omega^2 = .40$. There was no significant main effect for trial, *F*(9,81) = . 57, $p = .66$, and no significant interaction effects. Participants used shorter duration fixations in the high threat as opposed to control condition and for misses as opposed to successful shots (hits). The mean fixation duration data are presented in Figure 4.2 (right).

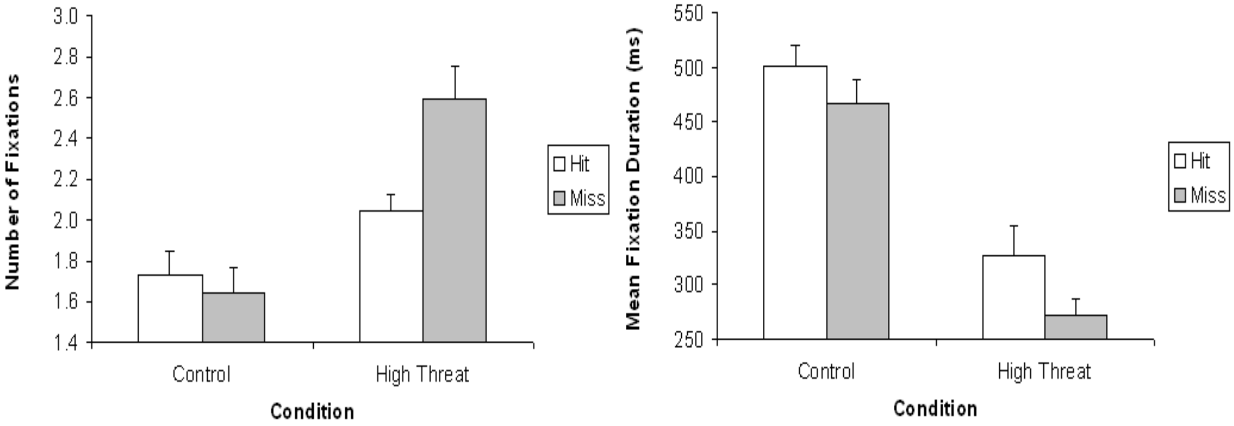


***Figure 4.2:*** *Fixation data: Mean number of fixations (top) and duration (ms; bottom) for successful (hits) and unsuccessful (misses) shots, during control and high threat conditions (with standard error bars).*

## 4.4. Discussion

This study aimed to test the predictions of the recently developed attentional control theory (ACT; Eysenck et al., 2007), using gaze behavior measures frequently adopted in the sport psychology and motor control literature. While ACT, was developed to examine the effects of anxiety on cognitive tasks, it is clear that attentional control is also a key component in the successful performance of visuo-motor tasks. As Janelle (2002) highlights; “Given the heavy reliance on visual input for decision making and response planning in sport tasks, logical questions concern whether and how visual attention is modified under increased anxiety" (p. 237). ACT may therefore provide a framework by which anxiety's effect on visual attention and subsequent performance be better understood.

## State Anxiety

Notwithstanding concerns regarding the efficacy of artificially manipulating cognitive state anxiety in laboratory-based studies (e.g., Williams et al., 2002b), the cognitive state anxiety data support the effectiveness of the experimental manipulation in elevating worry. Participants reported higher levels of cognitive anxiety in the high threat as opposed to control condition. A similar pattern was found for somatic anxiety, while participants reported feeling significantly less confident in the high threat as opposed to control condition. A limitation of the study is that participants were not asked to report their potentially changing anxiety levels at more frequent durations (e.g., prior to each pair of free-throw completions). However, by recording anxiety levels *during*, as opposed to just prior to each testing condition, the mean value determined at least reflects any changes in anxiety levels over time (see also Wilson et al., 2007a).

## Gaze Behavior

The primary measure of gaze behavior adopted in this study was the QE period (Vickers, 1996). This final fixation on the target has previously been shown to be indicative of superior performance in basketball free-throws (Harle & Vickers, 2001; Vickers, 1996) and jump shots (Oudejans et al., 2005). The results from the current study support these previous research findings in that participants displayed both a longer duration and earlier onset of QE periods during successful shots (hits) as opposed to unsuccessful shots (misses), across both conditions (see Figure 4.1). The QE durations found in the current study (of around half a second) are also of a similar magnitude to those discussed by Harle and Vickers (2001) and Vickers (2007). This provides support for the procedures used to determine the QE period in the current study, and suggests that the QE has a relatively stable optimal duration for each aiming task.

In a similar manner as reported by Behan and Wilson (2008), the duration of the QE period in the current study reduced significantly (by 34%) in the high threat compared to control condition. As there were no significant differences in when participants initiated the onset of the QE period in each condition (Figure 4.1, bottom), this reduction is clearly due to this key fixation being disrupted earlier in the high threat than control condition. This reduction in QE duration may reflect an impairment of attentional control in terms of the mechanisms highlighted by Eysenck et al. (2007); longer QE periods allow performers an extended duration of programming (goal directed control), while minimizing distraction from other environmental cues (stimulus-driven control). The shorter QE periods in the high threat condition therefore reflect the disruption caused by anxiety to these functions, as there appears to be an increased influence of the stimulus-driven attentional system at the cost of goal directed control.

Support for an increased influence of stimulus-driven attentional control is reinforced by the fixation data, which shows that there was an increase in the total number of fixations made, and a decrease in their mean duration (Figure 4.2). The data suggest that rather than maintaining a fixation on a single target (QE), participants directed their gaze to a number of targets in the vicinity of the hoop for shorter periods. Vickers' (1996) seminal study of gaze behavior in basketball free-throw shooting demonstrated that better players controlled their gaze to a smaller area (they focused on one specific target point) and had a lower frequency of fixations during each shot (they maintained this 'QE period') than less skilled counterparts. The players in the current study are therefore using a less efficient and effective attentional control strategy when anxious; they initiate an optimal QE fixation but fail to maintain it.

As ACT is a relatively recent theoretical development there are no published studies in the mainstream cognitive psychology literature which might support the findings reported in the current study. However, Derakshan et al., (2009) have examined the effects of anxiety on the inhibitory function of the central executive using an anti-saccade task. In this task, participants are presented with an abrupt peripheral stimulus to one side of a central fixation point and are instructed not to look at the stimulus but to direct their gaze as quickly as possible to the other side of the fixation point. Correct performance in this task requires top down attentional processes to suppress a reflexive saccade towards the abrupt peripheral stimulus (i.e., inhibit) and simultaneously generate a saccade to its mirror position as fast as possible. The results showed that high-anxious participants had a slower first correct saccade (i.e., to the mirror position) than low-anxious participants, demonstrating less efficient attention control. While Derakshan and colleagues' study supports the predictions of ACT with regards external irrelevant stimuli, the current study demonstrates that distracting internal stimuli (increased worrisome thoughts) may also impair the inhibition function and subsequent attentional control.

### Performance

ACT, like its predecessor processing efficiency theory (PET), predicts that anxiety will have a greater impact on processing efficiency than performance effectiveness. Theoretically therefore, reduced processing efficiency caused by the disruption to the inhibition function of the central executive will not necessarily lead to decrements in performance. However, based on the findings of the two previous studies to examine the influence of anxiety on QE (Behan & Wilson, 2008; Vickers & Williams, 2007) it is clear that performance is likely to be affected if the disruption to the QE period is significant. QE durations in the current study were reduced by 34% between control and high threat conditions, whereas performance accuracy reduced by 26%. In the current study, anxiety negatively impaired both the measures of attentional control and performance effectiveness.

The participating players were not elite free-throw shooters based on Harle and Vickers' (2001) definition of free-throw shooting percentages above 75%. However, their percentage shooting accuracy figures are similar to those of Harle and Vickers' 'near elite' group. The findings of the current study therefore suggest that the influence of anxiety on performance, through impairments in attentional control (QE), is not just an issue for elite performers (cf. Vickers & Williams' (2007) findings for elite biathletes), but for lower level performers too.

A possible concern with our interpretation of the control and high threat condition results is that the familiarization condition performance (53.5%) is similar to that in the high threat condition (50.5%), but much lower than control condition performance (68.6%). Generally, it would be expected that familiarization and control condition performance should be similar and reflective of a baseline performance level. However, poor familiarization condition performance in the current study is likely due to a degree of familiarization and habituation with the particular laboratory environment and wearing of the eye-tracker. As these performers were not elite, a degree of fine-tuning could be expected during such a habituation period. Furthermore, as the mean performance values are derived from a smaller sample in the familiarization condition (ten shots in each phase) than the control condition (mean of 26.8 shots, *SD* = 6.21), any habituation effects will have been exaggerated. Since the order of the test conditions (control and high threat) was counterbalanced, the higher performance levels found in the control condition cannot be explained by learning effects. It is therefore suggest that the control, not familiarization, condition is reflective of baseline performance, and the poorer high threat condition performance caused by disruptions to attentional control, as predicted by ACT.

### Implications

Janelle (2002) has previously suggested that attentional control is one of the most critical psychological skills to perform effectively in sports. Studies like the current one help further our understanding of how attentional control and skilled performance might break down under pressure. Previous research by Vickers and colleagues has already demonstrated that performers can be taught to develop a longer and earlier QE period, with subsequent improvements to performance. For example, Harle and Vickers (2001) found that QE training improved the free-throw performance of female university basketball players in both a laboratory environment and during match-play.

The current findings would suggest that such training programmes may also be a useful intervention to enhance attentional control in stressful environments, perhaps as part of a suitably developed pre-shot routine (e.g., see Wilson & Richards, 2010). By actively maintaining an effective QE period, the negative effects of anxiety on visual attentional control and subsequent performance may be alleviated. More research is therefore required to examine the influence of anxiety on the QE and other measures of attentional control (Wilson, 2008).

From a theoretical perspective, it is clear that ACT provides a useful framework by which visual attentional control in stressful environments can be examined. To date there have been few studies even in the cognitive psychology literature which have tested its main predictions (Derakshan et al., 2009). It is possible therefore, that cognitive sport psychologists, with their experience of analyzing gaze behavior, may take the lead in the testing of the predictions of ACT in more applied settings (e.g., Nieuwenhuys et al., 2008).

## **4.5. Conclusions**

The purpose of the study was to test the predictions of ACT, using the QE period as an objective and popular index of attentional control. As predicted, anxiety caused reduced QE periods, possibly due to an impairment of the inhibition function of the central executive and an increased influence of stimulus-driven attentional control. Support for increased impairment of inhibition was provided by the fixation behavior data, which demonstrated that rather than maintaining a long fixation on a single target area (QE) participants directed their gaze to more target locations in the vicinity of the hoop for shorter durations. The findings therefore provide support for the predictions of ACT and suggest that the negative influence of anxiety on performance is likely due to disruptions in attentional control.

## **4.6. Directions for Future Research**

Vickers (1996) has highlighted a specific form of visual control for the basketball free throw. Named the location suppression hypothesis (LSH), Vickers argues that expert performers engage in a process of visual suppression during the period in which the ball and arms are occluding the target. This is to prevent distraction and allows for the aiming commands, set down by the QE, to be preserved (see chapter 2; Vickers, 1996; Williams et al, 2002a). As ACT predicts that anxious individuals are less able to inhibit attentional capture from distracting stimuli, anxiety may cause a disruption in the optimal LSH strategy. Specifically anxious participants may spend more time fixating on the ball and arms and use less suppression of vision (via blinking and looking elsewhere). This may cause a disruption to the commands set down by the QE fixation and a disruption in subsequent performance. The next study will therefore examine the influence of anxiety upon the control of gaze during the period when the ball and arms occlude the target (occlusion period) to examine whether the LSH is an important gaze strategy. A re-analysis of data from study 1 (chapter 4) was therefore performed.

# Chapter 5 (Study 2): Performing Under Pressure: Attentional Control and the Suppression of Vision in Basketball Free-throw Shooting.

-Published as: Wilson, M.R. & Vine, S.J. (2009). Performing under pressure: Attentional control and the suppression of vision in basketball free-throw shooting. In, Calvin H. Chang (Ed), *Handbook of sports psychology* (pp. 277-296). Hauppauge, NY: Nova Science.

## 5.1. Introduction

The ability to control attention and remain focused has frequently been discussed as a key component of successful sporting performance (e.g., Janelle, 2002; Moran, 1996; Orlick, 1990). Attention can be thought of as the cognitive system that facilitates the selection of some information for further processing while inhibiting other information from receiving further processing (Smith & Kosslyn, 2007). One aspect of this system is concentration, or the ability to focus effectively on the task at hand while ignoring distractions. However, what exactly should performers focus on in order to produce their best performances? Why might performers become distracted and 'lose' concentration in high-pressured environments? These questions have received considerable research interest over recent years, and this study aims to integrate research findings and theoretical developments from both fields. First, a review of research adopting 'point of gaze' recording as an objective measure of 'what' performers focus on in far aiming tasks will be performed, before reviewing contemporary theories pertaining to the influence of anxiety on attention.

### Aiming, Attention and Performance: The Quiet Eye

Our understanding of what individuals attend to while performing sport skills has been greatly advanced by the development of light-weight and mobile gaze-tracking technology. Not only are we able to determine the specific cues which performers use to help them make decisions and prepare motor responses, but we can also assess the timing of when these cues are used in relation to the motor action being performed (Vickers, 2007). Many sports involve some form of aiming, whether it be throwing, kicking or striking an object to a player, target or goal. Unlike when aiming to a near target, the performer only has control over the object until the point of release when aiming to a far target (Vickers, 1996). Research examining far aiming tasks has identified the role of higher-order cognitive processing, whereby the visuo-motor strategy is attuned to obtaining visual information to enable the pre-programming of the ensuing motor response (Williams et al., 2002a). The findings from such research have shown that in order to be successful at aiming to a far target the final fixation made by the performer must not only be on the target, but also for long enough duration to ensure accuracy (Vickers & Williams, 2007). This particular fixation has been termed the 'quiet eye' (QE; Vickers, 1996).

Vickers' (1996) original work in developing the concept of the QE period examined basketball free-throw shooting as a particularly interesting far-aiming task; one where the target is occluded for a period during the completion of the skill. Vickers found that skilled performers fixated on the target early in the aiming phase (early onset of QE) but did not look towards the target when their hands and the ball entered their field of view; despite the fact that this is the key propulsion phase of the shooting action (Vickers, 1996). These findings indicate that although the free throw was of long enough duration for visual feedback to affect the movement outcome, skilled performers had learned to suppress their vision, by blinking or moving their gaze freely during the shooting action. Vickers (1996) referred to this finding as the location suppression hypothesis (LSH) and suggested that such suppression of visual processing prevented interference from the moving hands and ball in the visual field, preserving the aiming commands derived from the QE. Figure 5.1 presents exemplar eye-tracker data demonstrating the LSH in basketball free-throw shooting. The point of gaze is indicated in each frame by the small, red circular cursor, representing 1° visual angle. The other larger, magenta cursor visible in the scene is the 'background' presentation of the pupil and corneal reflection relative positions, used to calculate point of gaze.

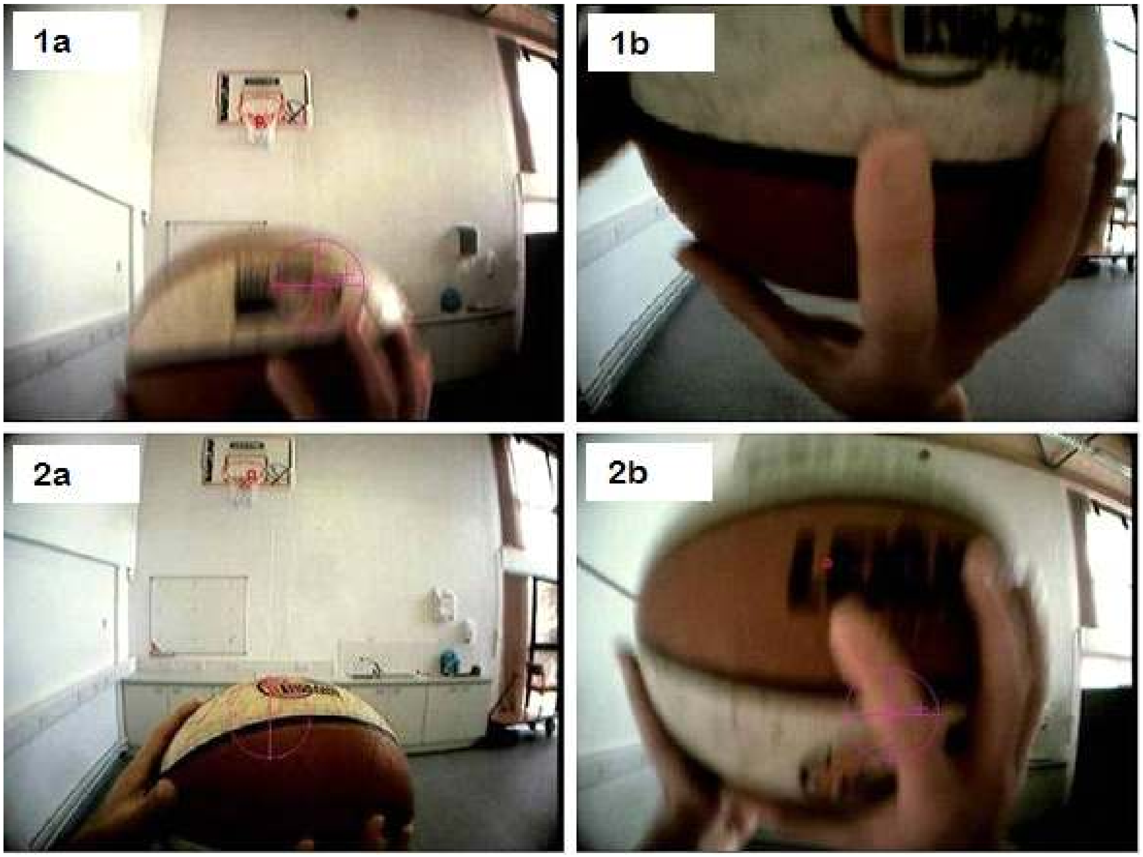


***Figure 5.1**: Four frames from the eye-tracker video file showing the point of gaze of a participant during the lift phase of two free-throws; one in the control and one in the high threat condition. In the control condition (top), a fixation on the net can be seen early in the lift phase as the ball starts to enter the visuo-motor workspace (1a), followed by a blink (loss of 'magenta' pupil) during the occlusion period (1b). In the high threat condition (bottom), a similar early fixation on the hoop is evident (2a), followed by a gaze towards the target (at the ball) during the occlusion period (2b).*

Vickers' research has furthered our understanding of the attentional and visuo-motor control structures underlying successful performance in the basketball free-throw. It is now possible to determine where and when attention should be directed in order to be most effective. Furthermore, Vickers has demonstrated that effective visual attention can be learned using a specially designed pre-shot routine. Indeed, Harle and Vickers (2001) developed such a QE training programme, focusing on an early QE onset and subsequent location suppression, which was taught to a group of female university basketball players. The authors found that QE training significantly improved the free-throw performance of the players in both a laboratory environment and during game-play over the subsequent two seasons.

The work of Vickers and colleagues has provided a useful objective measure of visual attentional control in far aiming tasks. However, as many sports performances occur under conditions of high levels of ego threat, sport psychologists need to understand how anxiety may influence attentional control and subsequent performance. As Janelle (2002) highlights; "Given the heavy reliance on visual input for decision making and response planning in sport tasks, logical questions concern whether and how visual attention is modified under increased anxiety" (p. 237). Although several theories have received support in the sport psychology literature and share a number of mechanisms (see chapter 2), the current study aims to utilise ACT's explicit predictions regarding the way in which anxiety may have an impact upon *distractibility*. Vickers' conceptualization of QE and location suppression provides objective measures of effective attentional control with which to test ACT's predictions. Goal-directed control in the free-throw requires an early QE onset followed by suppressed vision as the ball and hands enter the performer's visual field and occlude the hoop. When anxious, this specific attentional control strategy may be impaired due to a greater influence of stimulus-driven attentional control processes.

### Integrating Research Areas: Is The Quiet Eye Affected By Anxiety?

To date very few studies have examined the influence of anxiety on the QE (see study 1, chapter 4; Behan & Wilson, 2008; Vickers & Williams, 2007). Vickers and Williams (2007) found that elite biathletes who maintained or increased their QE duration during high pressure competition, compared to low pressure practice, were less susceptible to sudden performance disruption or 'choking'. Of the ten participants tested, only three maintained their QE durations when anxious and these were the only participants to perform better in competition than practice. Behan and Wilson (2008), in a simulated archery task found that under conditions of elevated cognitive anxiety, QE durations were reduced, and performance impaired compared to a low pressure condition. Study 1 (chapter 4) found that under high levels of cognitive anxiety, QE periods and subsequent performance were also significantly reduced in a basketball free throw task.

Study 1 (chapter 4) provides the back-drop to the current investigation, as results were discussed in relation to Eysenck et al.'s (2007) ACT. When anxious, participants were unable to maintain their long QE durations despite the onset of the QE period being similar to when they were less anxious. It was postulated that participants were less able to inhibit distracting thoughts, thus causing subsequent impairment of attentional control (as measured by QE duration). Instead of maintaining one aiming fixation to one location (QE), as they did under control conditions, anxious participants used significantly more fixations to a number of targets around the hoop. Worrisome thoughts and threat-related stimuli are predicted to be preferentially processed at the expense of goal-directed processing, normally derived from the extended QE. However the process by which this affects the QE is not fully understood.

The objective of the current investigation is to re-examine the attentional control strategy of these performers, but with an emphasis on the occlusion period; when the ball and hands occlude the hoop. To date no research has examined if performers' ability to suppress their vision is impaired when anxious. The optimal (goal-directed) strategy of first directing an early fixation to one point on the front of the hoop, allowing for a long QE and, second, suppressing vision for the period when the ball and arms occlude the hoop (the location suppression hypothesis [LSH]; Vickers, 1996) may therefore be impaired. ACT (Eysenck et al, 2007) predicts that when anxious, individuals are less able to inhibit attentional capture from distracting stimuli, therefore, it is proposed that the greatest disruption to attentional control should occur during the occlusion period as opposed to disrupting the early onset of QE. Specifically, anxious participants are predicted to spend more time looking at the ball and arms and use less suppression techniques (blinking and looking elsewhere) than they did in the control condition.

## 5.2. Methods

A re-analysis of the data from study 1 (chapter 4) was performed.

### Participants

As study 1 (chapter 4).

### Apparatus

As study 1 (chapter 4).

### Measures

***State Anxiety***. (see section 3.5).

***Movement Phases***. (see section 3.2.2).

***Occlusion Period.*** The occlusion period was defined as the period of time during shot execution when the hoop was not visible, due to the upward movement of the ball and arms The onset of the occlusion period was defined in relation to the onset of the preparation phase (in milliseconds) and its duration was also measured in milliseconds.

***QE Period***. (see section 3.4).

***Suppressed Vision.*** Vickers (1996) identified two visual strategies indicative of suppressed vision; brief eye closures (i.e. blinking) and moving gaze freely (i.e. not looking towards occluded target). The total duration of the time when the eyes were momentarily closed (i.e. no point of gaze registered) was calculated in milliseconds. Gazes to locations other than the ball, hands or arms during the occlusion period (i.e. not towards the target) were classed as ‘other’ and the total gaze duration to these locations was calculated in milliseconds. Gazes towards the target (on the ball, hands, or arms) were classed as ‘ball’ and again the total gaze duration to these locations was calculated in milliseconds. A single measure of suppressed visual control was calculated to represent the total amount of time (in milliseconds) during the occlusion period in which vision was suppressed, as opposed to being target focused. This measure was defined mathematically as: (total blink duration + total ‘other’ gaze duration – ‘ball’ gaze duration).

***Performance.*** Free-throw percentage success in each condition was adopted as the measure of performance effectiveness (number of successful throws x 100 / total number of throws), as study 1 (chapter 4).

### Procedure and Experimental Conditions.

As study 1 (chapter 4).

### Data Analysis

As study 1 (chapter 4).

## 5.3. Results

Anxiety and performance accuracy data were subjected to paired samples t-test analyses (control vs. high threat conditions). QE onset, occlusion onset, occlusion duration, and the measure of suppressed vision were all subjected to a fully repeated measures 2x2 ANOVA: condition (control, threat) x accuracy (hit, miss). Effect sizes ($\omega^2$) were calculated as outlined in Howell (2002).

### Cognitive State Anxiety: MRF-3

Participants reported significantly higher cognitive anxiety scores in the high threat (mean rating of 5.05, *SD* = .90) than the control (mean rating of 3.29, *SD* = 1.24) condition, $t(9) = 5.17, p < .005, \omega^2 = 1.30$.

### Performance

Performance, as measured by free-throw percentage accuracy, was lower in the high threat (50.50%, *SD* = 5.07) than the control (68.60%, *SD* = 11.02) condition, $t(9) = 5.52, p < .001, \omega^2 = 1.50$.

### QE Onset

A significant main effect was found for accuracy, $F(1,9) = 9.98$, $p < .05$, $\omega^2 = .30$, with earlier QE onsets occurring for successful shots (hits) as opposed to misses. There was no significant main effect for threat, $F(1,9) = 2.43$, $p = .15$, $\omega^2 = .18$, and no significant interaction effect. The QE onset data is presented in Figure 5.2.

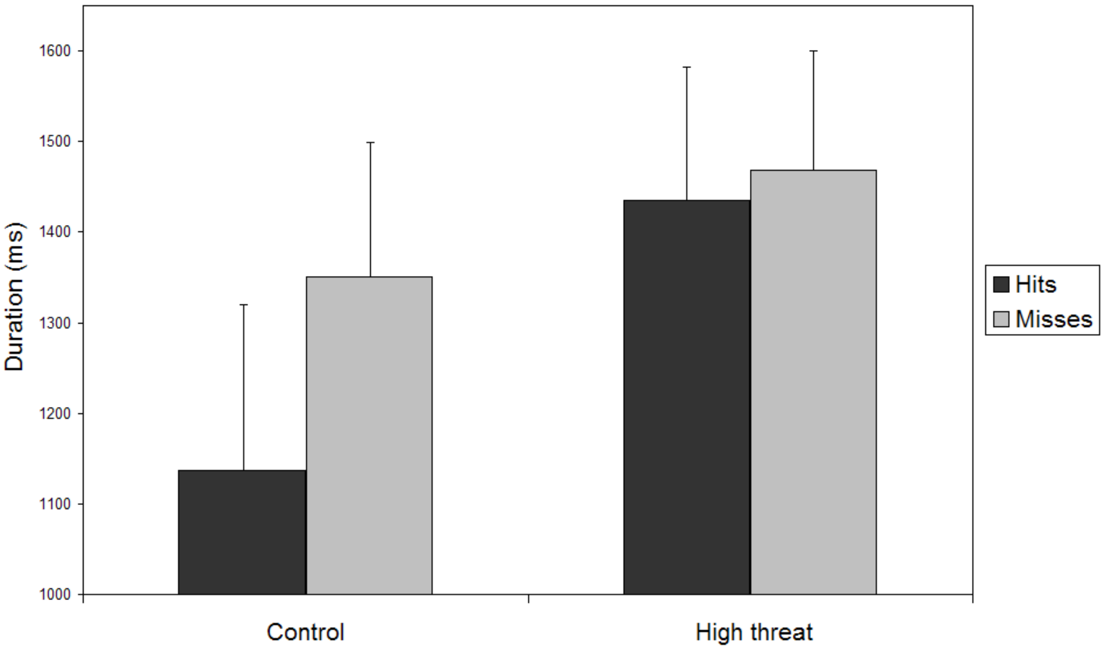


***Figure 5.2****: Mean quiet eye onset (ms after initiation of preparation phase) for successful (hits) and unsuccessful (misses) shots, during control and high threat conditions (with standard error bars).*

**Suppressed Vision**

A significant main effect was found for threat, *F*(1,9) =7.30, $p < .05$, $\omega^2 = .70$, with longer suppressed vision occurring in the control as opposed to high threat condition. There was no significant main effect for accuracy, *F*(1,9) = 0.55, $p = .48$, $\omega^2 = .08$, and no significant interaction effect, *F*(1,9) = 0.05, $p = .83$. The suppressed vision data is presented in Figure 5.3, and the separate durations for each gaze strategy making up the suppressed vision measure (i.e., blink, gazes on ball / hands, gazess to other targets) are presented in Table 5.1.

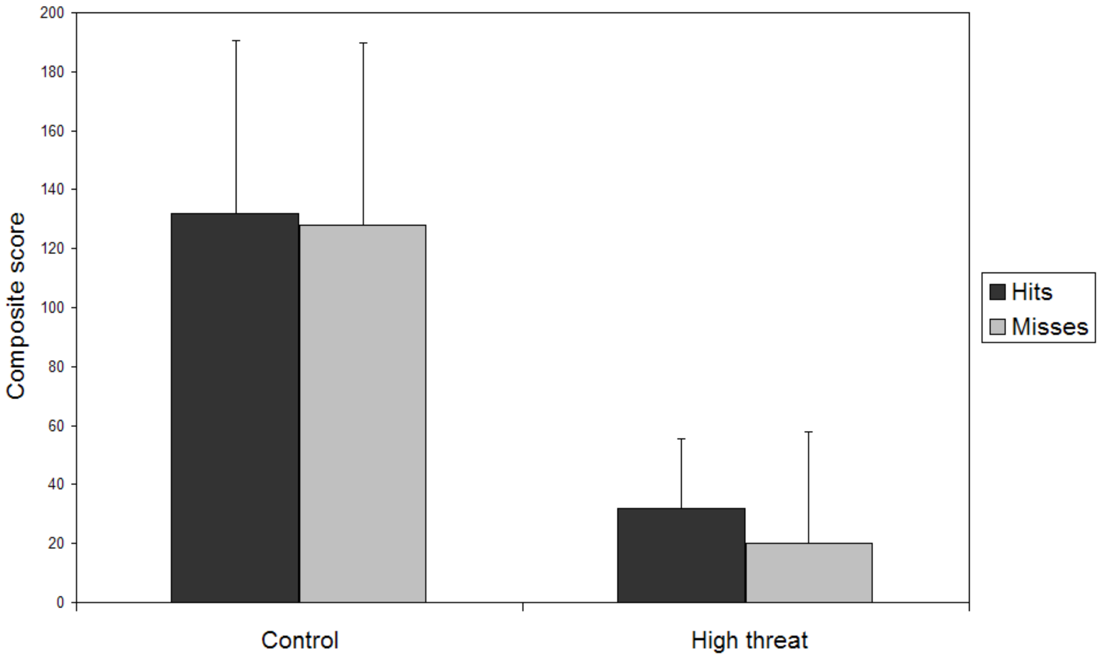


***Figure 5.3****: Mean composite measure of suppressed vision (blink duration + gaze duration to other locations – gaze duration to ball in ms) for successful (hits) and unsuccessful (misses) shots, during control and high threat conditions (with standard error bars).*

***Table 5.1:*** *Mean (standard deviation) gaze behaviour durations (ms) during the occlusion period for successful (hits) and unsuccessful (misses) shots, during control and high threat conditions.*

| | **Control** | | **High Threat** | |
|---|---|---|---|---|
| ***Variable (ms)*** | **Hit** | **Miss** | **Hit** | **Miss** |
| **Blink** | 180 (130.97) | 168 (143.35) | 100 (78.31) | 96 (84.74) |
| **Ball** | 80 (49.88) | 72 (41.31) | 108 (26.99) | 108 (26.99) |
| **Other** | 32 (31.55) | 32 (41.31) | 40 (26.66) | 32 (31.55) |

### Occlusion Duration

Although there was no significant main effect for threat, $F(1,9)$ =4.73, $p$ = .058, $\omega^2$ =0.51, the effect size was moderate, with shorter occlusion durations occurring in the high threat compared to control condition. There was no significant main effect for accuracy $F(1,9)$ =.935, $p$ = .359, $\omega^2 = 0.13$ and no significant interaction effect, $F(1,9)$ =.091., $p$ =.770. The occlusion duration data is presented in Figure 5.4.

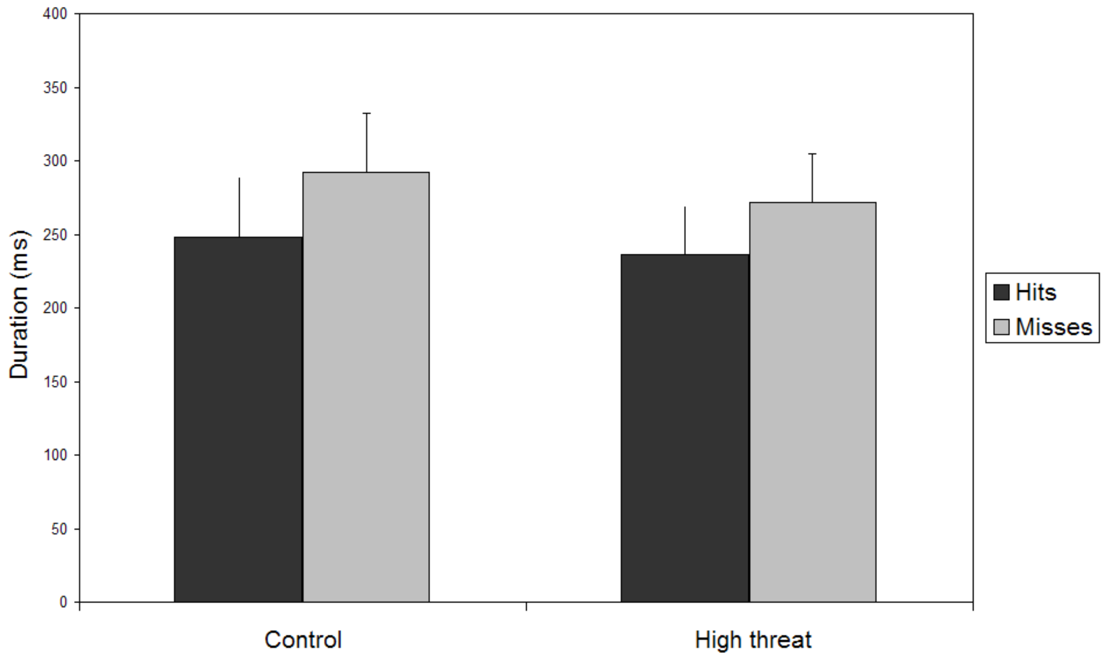


***Figure 5.4:*** *Mean occlusion period duration (ms) for successful (hits) and unsuccessful (misses) shots, during control and high threat conditions (with standard error bars).*

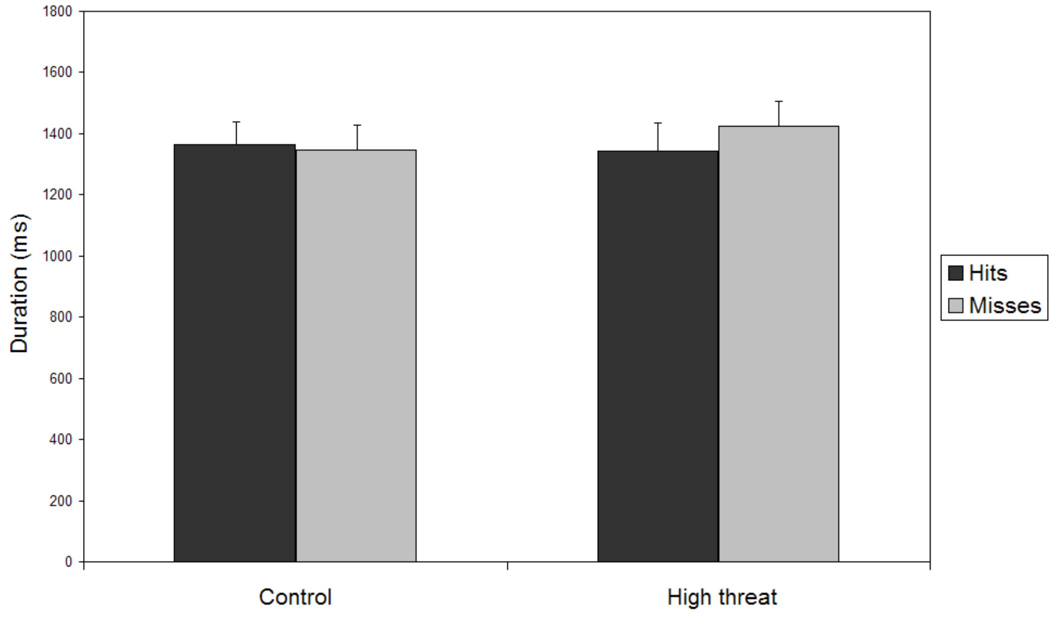


***Figure 5.5:*** *Mean occlusion period onset (ms after initiation of preparation phase) for successful (hits) and unsuccessful (misses) shots, during control and high threat conditions (with standard error bars).*

### Occlusion Onset

No significant main effects were found for threat, $F(1,9) = 3.26$, $p = .104$, $\omega^2 = 0.12$, or accuracy, $F(1,9) = 1.64$, $p = 2.32$, $\omega^2 = 0.10$, and there was no significant interaction effect, $F(1,9) = 4.02$, $p = .076$. The occlusion onset data is presented in Figure 5.5.

## 5.4. Discussion

This study aimed to test the predictions of attentional control theory (ACT; Eysenck et al., 2007) in a sports environment using a basketball free throw task. The free-throw is an interesting aiming task in terms of visuo-motor control, as the target is occluded by the object being thrown just prior to the propulsion phase of the action. Given these constraints on the timing and location of attention in this task, it is interesting to examine how optimal attentional control (early QE onset and suppression of vision during occlusion period) might be impaired when performers are anxious. Study 1 (chapter 4) has shown that anxiety significantly reduced the *duration* of the QE period of free throw shooters and this was discussed in relation to an impairment of attentional. However, this re-analysis explicitly tested ACT's fourth hypothesis, which predicts that anxious individuals are less able to inhibit the allocation of their attention to (external) distracting stimuli (Eysenck et al, 2007, pp. 344-346). It was therefore proposed that during the execution of the free throw, anxious performers may be more distracted by the ball and arms, thus disrupting 'normal' (goal-directed) attentional control, as outlined in Vickers' (1996) location suppression hypothesis (LSH).

### Anxiety and Performance

Participants reported significantly higher levels of cognitive anxiety in the high threat as opposed to control condition, supporting the effectiveness of the experimental manipulation in elevating worry. While anxiety levels may not have been as high as in '*real'* high-pressure competition, the reported values were similar to those outlined in previous studies using the MRF (e.g., Wilson et al., 2007a; Wilson et al., 2007b).

Performance was significantly worse in the high threat compared to control condition (a 26% reduction in free-throw success rate), suggesting that participants choked under pressure. It was proposed that increased anxiety may have impaired attentional control, thus explaining the significant drop in performance in the high threat condition (as Behan & Wilson, 2008; Vickers & Williams, 2007; Study 1, chapter 4).

### Attentional Control

As ACT predicts that anxiety affects the distractibility of individuals, attentional control should be most impaired during the occlusion period, when the rising ball enters the visual field and occludes the target. However, this impairment in the inhibition function (negative attentional control) should not prevent the performer from initiating an efficient early QE onset; the initial component of Vickers' (1996) LSH attentional strategy. As predicted, the manipulation of threat had no impact on the timing of the QE onset (Figure 5.2); with participants initiating their QE onset approximately 1300ms after the preparation phase in both conditions. Attentional control does not appear to have been impaired *early* in the shot preparation as would have been evidenced by later, and hence less efficient, QE onsets. However, the significant difference in QE onset between shots which were successful (hits) compared to unsuccessful (misses), demonstrates the importance of this attentional strategy in gaining critical aiming information early enough to successfully perform the motor action.

The primary measure of attentional control during the occlusion period (suppressed vision) *was* however significantly impaired in the high threat condition (Figure 5.3). Table 5.1 reveals that participants looked towards the ball much more and used less blinks when anxious, compared to in the control condition. This increase in duration of gazes to the ball during the occlusion period is particularly marked because the duration of the occlusion period was 14% shorter in the high threat as opposed to control condition; an almost significant reduction (p = .058; see Figure 5.3). Instead of adopting the optimal LSH attentional strategy used during the control condition, anxious participants' attention appears to have been 'captured' by the ball as it occluded the target. ACT proposes that an anxiety-induced impairment of negative attentional control makes an individual more distractible, and hence may have caused the attention-grabbing movement of the ball into the visual field to become more salient.

However, there is an alternative explanation for a ball-focused strategy which has less to do with the distracting nature of the ball itself, but rather is more reflective of a desire to ‘re-check’ the location of the target just prior to the final extension phase of the movement. Because of the perceived negative consequences of poor performance in the high threat condition, performers may have tried to maintain a target-focused gaze strategy, rather than trust the aiming information gained from their early QE. As the ball was in line with the hoop location during the occlusion period (see Figure 5.1) this might also explain why gaze was directed at the ball during this period. Previous research examining aiming performance in sport tasks has also shown that anxious participants do attempt to re-check target locations in a less efficient way. For example, Wilson et al. (2007a) in a golf putting task found that participants directed significantly more ‘re-checking’ glances to the target hole location in a high as opposed to low threat condition. These authors suggested that this less efficient attentional strategy was due to decay of distance cues in working memory caused by the pre-emption of attentional resources by worry. A similar effect may be occurring in the current study, with performers trying to re-fixate on the approximate location of the occluded target in order to attempt to ensure accurate aiming. Ironically, this strategy is likely to have detrimental effects on performance, as the original aiming commands derived from the QE period will be disrupted by the later, less accurate commands.

While tests of ACT’s predictions related to impairment of inhibition and negative attentional control are still limited (see Derakshan et al., 2009), the current results suggest that Vickers’ conceptualization of location suppression is a valid measure of negative attentional control in free-throw shooting. Future research therefore needs to continue to examine the LSH in basketball and other far aiming sport tasks, in order to further our understanding of how and why attentional control is disrupted and performance degraded. However, as the LSH may be a very specific attentional strategy, relevant only to skills like the free-throw where the target is fully occluded during the completion of the motor act (see Williams et al., 2002a), it is important that researchers also attempt to determine objective measures of effective attentional control for other skills.

For example, our general finding that anxious sports performers' gaze may be drawn towards inappropriate visual targets, disrupting subsequent performance, has also recently been demonstrated in a soccer penalty task (Wilson, Wood & Vine, 2009). Rather than the target being fully occluded during the shot, in soccer a goalkeeper stands on the goal line and aims to prevent the shot from going past him/her into the goal. Penalty takers directed significantly more fixations of longer duration to the centrally located goalkeeper in a high threat compared to control condition. This disruption in negative attentional control had an effect on subsequent performance, with participants hitting their shots to more central locations (closer to the goal keeper) in the high threat condition. Instead of fixating on the corners of the goal (the optimal target area), as they did in the control condition, anxious participants' gaze was directed towards the goal keeper, disrupting aiming commands and shot direction. These gaze results from soccer support those presented in this study and suggest that it may be important to actively inhibit visual distractions in order to be successful in performing target-related sport skills under pressure.

### Implications

As already mentioned, although the current results are supportive of the predictions of ACT, more research is required to further our understanding of how and why anxiety disrupts the inhibition of distracting stimuli in far aiming tasks. The results gathered so far do tentatively suggest that attentional control training regimes may be a useful strategy to protect performers from the negative influence of anxiety. One way in which attention could be directed to a series of cues to maintain appropriate attention is through a suitably designed pre-performance routine (e.g., Boutcher, 2002; Moran, 1996). For example, Singer's (2002) five step approach includes an explicit attentional component directing performers' focus to one external relevant feature of the task (e.g., the hoop in basketball). Such an external focus of attention should not only prevent reinvestment (Masters & Maxwell, 2008) but also help to block disruptive thoughts and emotions.

## 5.5. Conclusions

This study has sought to test the predictions of ACT (Eysenck et al., 2007) using a specific measure of attentional control, conceptualized for the free-throw task (i.e., location suppression hypothesis, Vickers, 1996). As predicted, negative attentional control and performance were significantly impaired in the high threat condition, suggesting that attentional mechanisms may underlie ‘choking’ under pressure. A particular interest was placed on the effect of visual distractions on performers’ attentional control and demonstrated that such distractions may become more salient when performers are anxious. These findings add strong support for the predictions of ACT in motor task performance under pressure and may offer a mechanistic explanation as to why free-throws are missed in pressure environments.

## 5.6. Directions For Future Research

Results from both study 1 (chapter 4) and the current study implicate attentional disruption (shorter QE and more distractibility) in the breakdown of performance under pressure. These findings support previous research and highlight the importance of visual attentional control in the execution of targeting tasks (Behan & Wilson, 2008; Vickers & Williams, 2007). Janelle (2002) suggests that, given the apparent importance of visual attentional processes in the execution of motor skills, visual attentional training programmes need to be utilised to maximize performance. However, as the results of the current study have demonstrated, it may not be sufficient to simply direct individuals’ gaze to a target, as they might attempt to maintain this gaze inappropriately (e.g., try to maintain a fixation on the hoop when it is occluded). More explicit gaze control instructions may be required to ensure that aiming information gained is timely, and negative attentional control applied, if required. Harle and Vickers (2001) have previously demonstrated that it is possible to train an explicit gaze control strategy in basketball free-throw shooting. While Harle and Vickers did not include an anxiety manipulation in their study, other researchers (e.g., Wilson & Richards, 2010) have highlighted how an effective pre-shot routine might allow a performer to ‘focus with a QE and execute with a quiet mind’ to protect against performance disruption due to increased pressure. QE training may also act to help novice performers jump the learning curve. By mimicking the optimal visual attentional control of experts, novices may overcome the initial technical constraints of performing motor skills. QE training may aid the expediency and robustness by which skills are acquired.

# Chapter 6 (Study 3): The Influence of Quiet Eye Training and Pressure on Attentional Control in a Visuo-motor Task.

-Initially submitted as: Vine, S.J. & Wilson, M.R. Attentional Processes underpinning skilled visuo-motor performance: The influence of training and pressure. *Cognitive, Affective & Behavioural Neuroscience*.

-Resubmitted as: Vine, S.J. & Wilson, M.R. (under review). The influence of quiet eye training and pressure on attentional control in a visuo-motor task. *Acta Psychologica*.

## 6.1. Introduction

*"Keep your eye at the place aimed at, and your hand will fetch [the target]; think of your hand, and you will likely miss your aim" (James, 1890, p. 520).*

In order to behave adaptively in a complex environment, an animal must select, from the wealth of information available to it, the information that is most relevant at any point in time. It is the mechanisms of attention which are responsible for selecting the information that gains access to working memory where plans for action can be elaborated (Knudsen, 2007). The link between attention and action is particularly interesting in sports which constitute closed, self-paced skills. A distinguishing feature of these skills is the ample amount of time for contemplation prior to the execution of the skill, during which time the neural networks involved must be organized (Milton, Solodkin, Hlustik & Small, 2007). Furthermore elevated anxiety has also been associated with attentional impairment during the execution of self paced skills (Beilock & Gray, 2007; Wilson, 2008). The aim of the current study is therefore to apply a training regime aimed at optimizing the visual attentional control and performance under pressure of a far aiming motor skill task (basketball free throw shooting).

## Visuo-motor Planning and Control: The Quiet Eye

Sport has long been considered an interesting arena to examine the limits of human physical and cognitive performance (Yarrow, Brown, & Krakauer, 2009). The development of lightweight head-mounted eye trackers has meant that studies investigating the planning and control of visually guided actions can be undertaken in more natural environments (see Land, 2009; Vickers, 2007). Such research has shown that fixations extract very specific information needed by an ongoing task (Ballard & Hayhoe, 2009; Vickers, 2009). Experts therefore tend to use more efficient gaze strategies than non-experts, focusing on only the information which is most useful to complete the task at hand (see Mann et al., 2007 for a review).

In the sport-based literature, a particular measure of efficient visual attentional control, the quiet eye (QE; Vickers, 1996) has been examined to objectively assess this spatial and temporal coordination of gaze and motor control (visuo-motor control).

The specific neural mechanisms by which the QE works are yet to be fully understood, however the QE has been proposed to reflect a critical period of cognitive processing during which the parameters of the movement such as force, direction and velocity are fine-tuned and programmed (Janelle et al., 2000; Vickers, 1996).
Vickers (1996) used Posner and Raichle’s (1994) conceptualization of three neural networks (posterior orienting, anterior executive & vigilance networks) to provide support for her postulations of *how* the QE may provide this ‘quiet focus’. However, Corbetta and Shulman’s (2002) top-down, goal directed attentional system (or ‘dorsal attention’; Corbetta et al., 2008) might provide a more appropriate explanatory framework (see chapter 2).

## The Influence of Anxiety on Attentional Control

A particular form of distraction which is prevalent in sporting tasks is that caused by the pre-emption of attentional resources by cognitive anxiety (Janelle, 2002; Wilson, 2008). Studies 1 and 2 (chapters 4 & 5) corroborated previous research showing that the QE, as an objective measure of optimal visual attentional control, is sensitive to the influence of anxiety (Behan & Wilson, 2008; Vickers & Williams, 2007; Wood & Wilson, 2010). Mean QE durations were reduced, as participants took more fixations around the vicinity of the target than they did in a low pressure condition. These impairments have been described with respect to a recent theoretical development from cognitive psychology, attentional control theory (ACT; Eysenck et al., 2007).

Eysenck et al. (2007) suggest that anxiety causes 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 distracters) 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; the goal-directed (dorsal) and the stimulus-driven (ventral) systems (Corbetta & Schulman, 2002; Corbetta et al., 2008). According to ACT, anxiety disrupts the balance between these two attentional systems by increasing the influence of the stimulus driven attentional system at the expense of the more efficient goal directed system (Eysenck et al., 2007; Wilson, 2008).

Corbetta and Schulman suggest that the stimulus driven (ventral) system works as a "circuit breaker" (2002, p. 201) for the dorsal system. This circuit breaking effect can be an adaptive process, directing attention to potentially important or salient events. However, as anxiety alters the strength of output from the pre-attentive threat evaluation system, the likelihood that threat-related stimuli will capture attention is increased (Eysenck et al., 2007). If top-down attentional control is required to effectively complete a task, such stimulus-driven (ventral) processing will likely impair effective attentional control and potentially task performance. This attentional impairment has been demonstrated in study 2 (chapter 5) as anxious participants became more distractible, disrupting the planning of movement and negatively impacting upon subsequent performance (Behan & Wilson, 2008).

Interestingly, Vickers and Williams (2007) found that elite biathletes who increased their QE duration during high pressure competition, compared to low pressure practice, were less susceptible to sudden performance disruption or 'choking'. Vickers and Williams suggested that the act of allocating attention externally to critical task information (via the QE) appeared to insulate athletes from the normally debilitating effects of anxiety. Behan and Wilson (2008) have therefore suggested that QE training programmes may be a useful intervention to enhance attentional control in stressful environments.

The responsiveness of QE to training has already been demonstrated. Harle and Vickers (2001) utilized a QE training protocol to improve the free throw accuracy of near-elite basketball players. Results showed that not only did the team significantly increase their QE durations and free-throw percentages in a laboratory setting, but after two seasons in competitive play they had improved their free throw percentage by 23% (Harle & Vickers, 2001).

### Aims

The current study therefore sought to consolidate on the research knowledge highlighting the guiding role of the QE in supporting far-aiming performance, to implement a QE-training programme for novice basketball players learning the free-throw. It was predicted that participants in a QE-trained group would perform better in both a retention task (designed to assess learning) and a transfer task (under ego-threatening instructions), compared to those in a Control group (technical instruction only). Specifically it was hypothesised that:

Learning: The QE-trained group would display longer QE durations, and hence better performance in retention tests compared to their Control group counterparts (Mann et al, 2007).

Performance under pressure: The QE-trained group would maintain QE durations when anxious and would not be affected by a manipulation designed to increase ego-threat; they would maintain QE and performance values at low threat levels (Vickers & Williams, 2007). In contrast, Control group participants would display significantly poorer performance and attentional control (reduced QE duration) when anxious.

## 6.2. Methods

### Participants

Sixteen male undergraduate students (mean age, 22.00 years, *SD* = 2.63) volunteered to take part in the study. All participants declared having little or no experience of basketball free throwing and all were right handed. Written information was provided and written consent was gained from all participants' (see appendices 1 & 4). Local ethics committee approval was obtained prior to the start of testing.

### Apparatus

As study 1 and 2 (chapters 4 & 5).

### Measures

***Performance.*** Free-throw percentage was determined as the performance measure for the task (see studies 1 & 2; Harle & Vickers, 2001; Vickers, 1996). This was calculated as the number of successful shots within a block of forty shots, converted into a percentage.

***State Anxiety.*** (see section 3.5).

***QE Period.*** (see section 3.4).

### Procedure

Participants attended individually and after reading the information sheet (appendix 4) and signing the informed consent (appendix 1), were given a chance to perform some free throws and familiarize themselves with the surroundings. When participants felt they were ready to begin, they were then fitted with the eye tracker and calibration took place. Participants adopted a stance at the free-throw line and were then asked to fixate in turn on eight locations on the backboard. Calibration checks were performed every 10 throws to provide a break for the participants and to ensure that the eye tracker had not slipped. As a better understanding of the eye tracker had been attained and calibration was successful at the first attempt, checks were only made every 10 shots, as opposed to every 2 shots as in studies 1 and 2.

The training and testing period took place over a total of eight days and was scheduled as follows. On the morning of day one, a measure of performance and QE were recorded for a block of 40 free throws. This data acted as a baseline measure and ensured that the eye tracker was working correctly and could be calibrated for each individual. During the afternoon of day one, participants began their assigned training regime (QE or control) and performed 120 free throws (3 blocks of 40). Training points were reiterated during a break between each block of 40 throws. The training regime was then repeated on days two and three to complete a total of 360 training throws. The duration of the training period and the number of trials is congruent with previous motor skill training studies (e.g., Lam, Maxwell, & Masters, 2009).

On day five participants returned and performed a retention test, consisting of a single block of 40 free throws without the guidance associated with their training regime. The use of retention tests, designed to assess the stability of learning, is consistent with previous research (e.g., Lam et al., 2009; Salmoni, Schmidt, & Walker, 1984). On day eight, participants performed a transfer test (high ego-threat), which consisted of 40 competition free throws, aimed at manipulating their levels of cognitive anxiety. Participants then performed a second retention test, which was identical to retention test one, forming the 'A-B-A' design typically adopted in the motor learning literature (Salmoni et al., 1984). Finally participants were thanked and debriefed about the aims of the study.

### Training Groups

Participants were randomly assigned to either a QE training or control group. The control group received training based on six coaching points relating to the mechanics of the free throw action (derived from http://uk.youtube.com/watch?v=JdTQi4L6khw; August, 2010). The same six coaching points were then adapted to include QE related instructions for the QE training group (derived from Vickers, 2007). Training points were matched in this way to ensure that both groups received instructions related to the same temporal components of the throw (see Table 6.1). Also, as research has shown that accruing explicit knowledge of the mechanics of a skill can be detrimental to performance when under psychological pressure (Masters & Maxwell, 2008), it was important to try and standardize the technical instructions provided to each group. The intervention consisted of the training points (Table 6.1) being discussed the participant and each step emphasised by the experimenter. The relevant training points (either coaching points or QE training) were reiterated at the start of each block of 40 throws, this consisted of the performer again viewing the training instructions (Table 6.1) and the experimenter emphasising each point step by step.

***Table 6.1***: *Instructions provided to each group during the training protocol.*

| QE training | Control |
|---|---|
| 1. Set yourself with your legs shoulder width apart. | 1. Set yourself with your legs shoulder width apart. |
| 2. Adopt the following pre-shot routine: bounce the ball 3 times and repeat the phrase ‘nothing but the net’. | 2. Adopt the following pre-shot routine: bounce the ball 3 times and repeat the phrase ‘nothing but the net’. |
| 3. Hold the ball on your finger tips not your palm (Demonstrate). | 3. Hold the ball on your finger tips not your palm (Demonstrate). |
| 4. Hold the ball in your shooting stance and maintain a focus on a single location on the front of the hoop for approximately one second. Keep this gaze stable whilst saying the words “sight…focus”. | 4. Take your shooting stance and focus. |
| 5. The shooting motion should utilise the whole body, bending the knees and extending up through the body. The ball should pass across the centre of your visual field occluding the target. During this time there is no need to maintain your gaze on the hoop as you shoot. | 5. The shooting motion should utilise the whole body, bending the knees and extending up through the body. |
| 6. After releasing the ball you must follow through and reach towards and into the rim (Demonstrate). | 6. After releasing the ball you must follow through and reach towards and into the rim (Demonstrate). |

**Anxiety Manipulation**

Several techniques consistent with previous research were used to manipulate levels of cognitive state anxiety (as study 1 & 2; see section 3.6.).

**Statistical Analysis**

Cognitive anxiety data for the test phase were subjected to a 2 (group) x 3 (test) mixed design analysis of variance (ANOVA). Performance and QE data were subjected to a 2 (Group) x 4 (Test) mixed design analysis of variance (ANOVA). As well as comparing the three conditions from the test phase, baseline (block 1) data were included in order to assess learning effects. Significant main effects were followed up with Bonferroni corrected post hoc *t*-tests; interaction effects were followed up with planned comparison *t*-tests; and effect sizes were calculated using Partial Eta squared ($\eta_p^2$) for omnibus comparisons. No data violated the sphericity assumptions of ANOVA.

### Data Analysis

A subset of shots (every fourth) was selected for analysis (see section 3.2.2).

## 6.3. Results

### Cognitive Anxiety

ANOVA revealed a significant main effect for test, $F(2,28) = 77.48$, $p < .001$, $\eta_p^2 = .85$, with anxiety being significantly higher during the pressure test than retention tests 1 ($p < .001$) and 2 ($p < .001$). There was no significant main effect for group, $F(1,14) = 0.26$, $p = .62$, $\eta_p^2 = .02$, and no interaction effect, $F(2,28) = .04$, $p = .96$, $\eta_p^2 = .03$, revealing that both groups reported similar levels of anxiety. The self-report data from the cognitive anxiety scale of the MRF-3 are presented in Figure 6.1.

### Performance (Free Throw Percentage)

ANOVA revealed significant main effects for group, $F(1,14) = 17.22$, $p < .005$, $\eta_p^2 = .55$ and test, $F(3,42) = 69.30$, $p < .001$, $\eta_p^2 = .83$. These findings were qualified by a significant interaction effect, $F(3,42) = 8.23$, $p < .005$, $\eta_p^2 = .37$. Follow up t-tests showed that there were no significant performance differences between groups at pre-test ($p = .39$) indicating that both groups were of a similar level before training commenced. However, the QE trained group demonstrated significantly higher levels of performance than their control group counterparts at retention test 1 ($p < .001$) and retention test 2 ($p < .05$). Significant differences between groups at the pressure test ($p < .001$) also suggest that the QE trained group performed significantly better under heightened levels of cognitive anxiety.

Within group analyses revealed that the QE trained group displayed significant improvements in performance between pre-test and retention test 1 ($p < .001$) but no significant differences between any of the three test conditions (all *p*'s > .54). The Control group displayed significant improvements in performance between pre-test and retention test 1 (*p* < 0.005) but reductions in performance between retention test 1 and the pressure test (*p* < .01) and retention test 2 and the pressure test (*p* < .001). As with the QE trained group, the control group displayed no significant differences between retention test 1 and retention test 2 (*p* = .83). Pre-test and test phase performance data are presented in Figure 6.2.

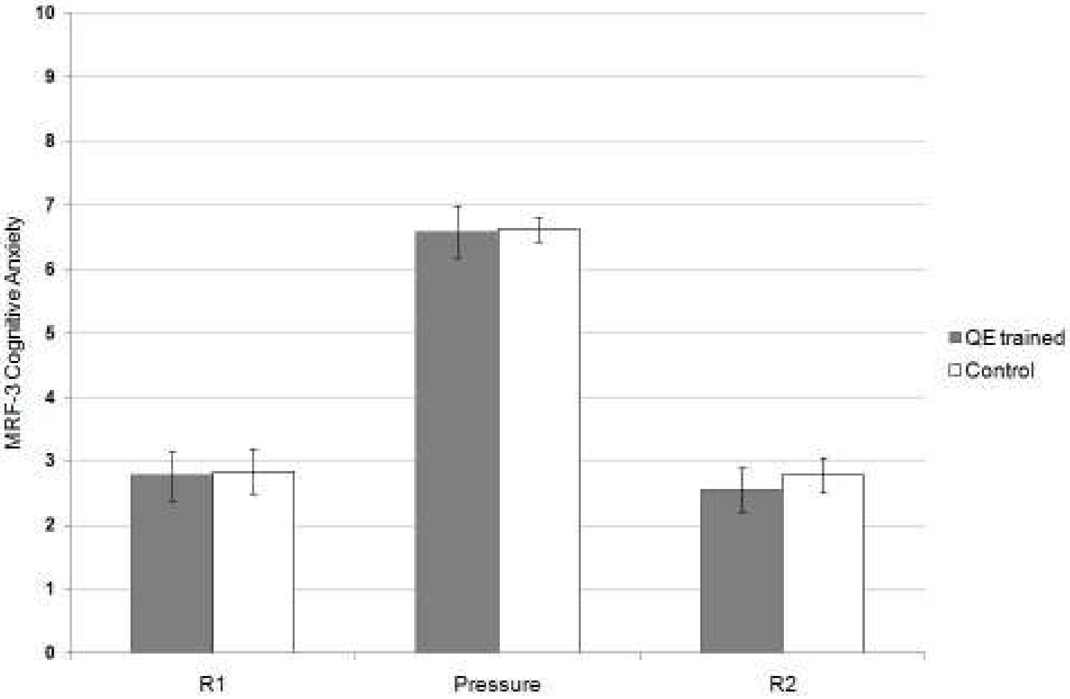


***Figure 6.1****: Mean (± s.e.m) self-reported anxiety data for participants across the three test conditions.*

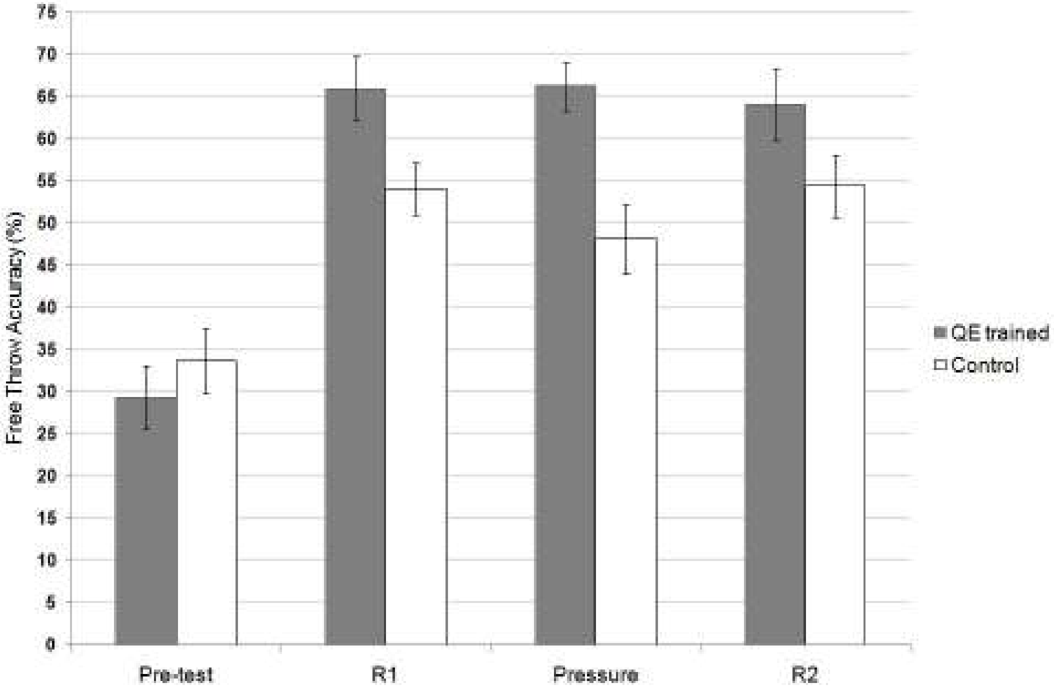


***Figure 6.2**: Mean (± s.e.m) performance data (free-throw percentage) for participants across baseline (pre-test) and test conditions.*

**QE Duration**

ANOVA revealed significant main effects for task, *F*(3,42) = 5.43, $p < .01$, $\eta_p^2 = .28$, and group, *F*(1,14) = 32.84, $p < .001$, $\eta_p^2 = .70$. These findings were qualified by a significant interaction effect, *F*(3,42) = 4.18, $p < .05$, $\eta_p^2 = .23$. Follow up t-tests showed that there were no significant QE duration differences between groups at pre-test ($p = .30$) indicating that both groups had similar QE durations before training commenced. There were significant differences between groups at retention test 1 ($p < .001$) and retention test 2 ($p < .01$) suggesting that the QE trained group had acquired significantly longer QE durations. There was also a significant difference between groups in the pressure test ($p < .001$) suggesting that the QE trained group had significantly longer QE periods under heightened levels of cognitive anxiety.

Within group analyses revealed that the QE trained group displayed a significant increase in QE between pre-test and retention test 1 ($p < .05$) but no significant differences between any of the three test conditions (all *p*'s > .84). The Control group displayed no significant increase in QE between pre-test and either of the retention tests (*p*'s > .15), or between the retention tests ($p = .88$). While QE durations were shorter in the pressure test than retention test 1 (*p* = .13) and retention test 2 (*p* = .08), these differences failed to reach significant levels. Pre-test and test phase QE data are presented in Figure 6.3.

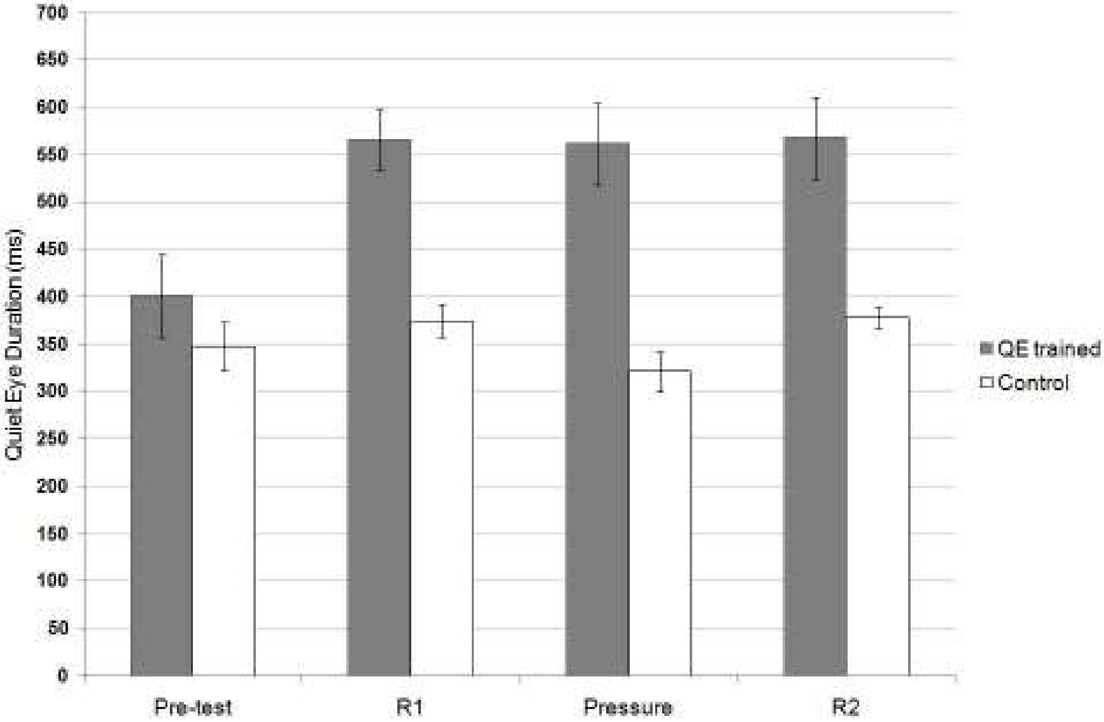


***Figure 6.3****: Mean (± s.e.m) quiet eye (QE) duration data (milliseconds) for participants across baseline (pre-test) and test conditions.*

## 6.4. Discussion

The aim of the current study was to examine the efficacy of an intervention designed to train effective attentional control (QE training) in the manner outlined by James' famous quote, for free throw shooting. Previous research in free-throw shooting has demonstrated the performance benefits of an effective QE (Vickers, 1996); the impact of training on QE and performance for skilled players (Harle & Vickers, 2001); and the impact of anxiety on QE and performance (see studies 1 & 2). However, research has not yet attempted to examine whether QE-training may help expedite the learning of motor skills for novice performers or whether this performance may be more robust under pressure. Such research is important if our understanding of the attentional mechanisms underpinning skilled performance is to be applied to the development of training programmes for novice performers (Yarrow et al., 2009).

### Learning Effects

There were no differences in the performance levels of both groups in the baseline condition (pre-test), indicating that both groups started from similar novice levels of performance (Figure 6.2). Results revealed significant improvements in performance for both groups from pre-test to retention test 1, indicating that learning had occurred. The absence of any significant differences in performance between retention tests 1 and 2 for each group suggests some level of stability of learning had been attained. As hypothesized, QE-trained participants performed better than their control group counterparts across retention test conditions (65%, 54% free throw accuracy), supporting the efficacy of the intervention for expediting learning.

The QE data (Figure 6.3) also revealed that both groups had similar QE durations at baseline (pre-test), suggesting that any subsequent changes in duration are the result of the training instructions provided. As predicted in hypothesis 1, the QE-trained participants had significantly better visual attentional control (longer QE periods) than the control group participants across both retention tests. The QE periods for the trained group (approximately 550ms) are of similar durations to those reported for experienced (though not elite) performers in previous research examining the QE in free throw shooting (Harle & Vickers, 2001; studies 1 & 2). These results therefore add further support for the critical role played by the QE in underpinning skilled far aiming performance. The QE training promotes an effective form of goal-directed attentional control (Corbetta et al., 2008), and likely helps to enable an efficient neural network for specialized motor planning that integrates visual information with motor commands (Janelle et al., 2000; Land, 2009).

### Pressure Effects

The MRF-3 data support the effectiveness of the anxiety manipulation, in that both groups were significantly more anxious during the pressure test than the retention tests (Figure 6.1). The reported anxiety levels are similar to those found in other laboratory (see studies 1 & 2; Wilson et al., 2007a; Wilson et al., 2009) and competitive (e.g., Krane, 1994; Smith et al., 2001) environments. While there were no group differences in the level of anxiety reported by the participants, the effect of this anxiety on each group was different, as hypothesized (hypothesis 2). Specifically, while the control group performed significantly worse in the pressure test than the retention tests, the QE-trained group managed to maintain pressure test performance at retention test levels (Figure 6.2). Indeed, five of the eight QE trained participants actually performed better in the pressure test compared to retention test 1, whereas none of the control group equalled their retention test 1 performance levels (cf. Vickers & Williams, 2007).

While the performance data supports our hypothesis that QE training may act in some way to insulate the performer from the negative effects of anxiety, the actual QE data results are more ambiguous (Figure 6.3). As predicted, the QE trained group adhered to their training instructions, thereby maintaining their QE durations and effective visual attentional control in the pressure test condition. However, despite performing significantly worse under pressure, the QE results for the control group were not significantly different in pressure and retention test conditions. Although the effects were in the expected direction, our hypothesis of 'matching' interaction effects for performance and QE were not supported.

There are a number of potential explanations for why the predictions of ACT (Eysenck et al., 2007) were not upheld for the control group. First, although the control group displayed a non significant drop in QE under pressure, it may be that a form of 'floor effect' was evident. QE durations during the retention test conditions for the control group were already low (approximately 375 ms), and of similar durations to those reported in studies 1 and 2 (see chapters 4 & 5) for performers who 'choked' under pressure.  Second, the small numbers recruited for this training study may have meant that there was insufficient power to demonstrate significant differences, despite the effects being reasonably strong and in the expected direction ($p$ = .08, $d$ = .85, between pressure test and retention test 2). An alternative explanation is that other mediating factors may help explain the degradation in performance beyond the influence of reduced attentional control as indexed by QE, and while extended QE may help to protect from these factors, if QE is low then performance will suffer. A regression analysis performed on the QE and performance data in the pressure test condition revealed that 71% of the variance in performance could be explained by changes in QE ($R^2 = 0.71$, $\beta = 0.84$, $p < .001$), leaving 29% unexplained. It is possible that anxiety may also have altered the muscle recruitment (Coombes, Higgins, Gamble, Cauraugh, & Janelle, 2009), or the movement mechanics (Lam et al., 2009) adopted by the participants, impacting upon subsequent throwing accuracy.

## 6.5. Conclusions

To conclude, while a number of limitations of the current study have been highlighted, there are clear implications for the training of sport. By teaching novices optimal visuo-motor control, via QE training, they were able to improve their performance to a level above that of a group receiving only technical instructions. As sport is often performed in evaluative settings it was also noteworthy that the QE-trained participants maintained (or exceeded) their performance levels when anxious. From an applied perspective, QE-training may therefore provide a useful technique for coaches to guide visuo-motor skill learning, and for sport psychologists to guide sport-specific coping strategies for performing under pressure. Further applied research is warranted in both these areas using a range of visuo-motor tasks.

## 6.6. Directions for Future Research

Results from the current study offer some support for the role of QE training in protecting sports performers from the adverse effects of anxiety. Further research should examine QE training in different visuo-motor tasks to assess whether the benefits are universal and transferable to other sports. Within both the QE and anxiety literature the golf putt has been regularly adopted as a sporting task. From a visual attentional control perspective the golf putt is interesting and distinctly different from the basketball free-throw, as it requires the control of attention across two distinct visual workspaces (the hole and the ball). Research examining the breakdown of optimal visual attentional control and the utility of visual attentional training in the golf putt is therefore warranted.

# Chapter 7 (Study 4): Quiet Eye Training Helps to Maintain Effective Attentional Control and Performance Under Pressure.

-Published as: Vine, S.J. & Wilson, M.R. (2010). Quiet Eye training expedites learning and helps to protect against stress. *Journal of Applied Sport Psychology*, *22 (4),* 361-376.

## 7.1. Introduction

Understanding how the acquisition and mastering of aiming skills may be optimized is a popular focus of research in sport psychology. Several different theoretical perspectives have been proposed which point to the role of attention in expediting learning and maintaining robust performance under conditions reflective of performance settings (e.g., ego-threatening conditions). Three of the most frequently cited approaches; Masters' (1992) conscious processing hypothesis, Singer's (2000) five step strategy, and Wulf et al's., (2001) constrained action hypothesis all implicate the negative impact of focusing inwards on the mechanics of the skill during motor learning. Indeed, both Singer and Wulf et al. explicitly recommend an external focus of attention during execution to help improve learning and maintain performance (see Singer, 2000, 2002; Wulf, 2007, for reviews). The objective of the current study was to examine the utility of an intervention designed to optimize external attentional control for a group of novices learning a golf-putting task, through QE training (Vickers, 1996).

### The Quiet Eye

Current research adopting gaze tracking technology shows that when a high level of motor skill performance is attained, gaze is directed to the most important targets and objects in the visual-performance workspace (e.g., Vickers, 2007; Williams & Ford, 2008). Mainstream neuroscience research also suggests that the neural mechanisms regulating goal-directed movements profit from the accurate and timely spatial information of the foveated target (Land, 2009; Neggers & Bekkering, 2000). A particular gaze termed the QE (Vickers, 1996) has been shown to underlie higher levels of skill and performance in a wide range of aiming and interceptive skills (see Vickers, 2007 for a review).

In golf putting specifically, the seminal study investigating the role of gaze control in mediating performance was carried out by Vickers (1992). The findings revealed proficiency differences in scan paths during the alignment phase of the putt, as well as differences in the timing and orientation of gazes during the putting action itself. Expert performers maintained a final fixation (QE) on the centre or back of the ball that was initiated prior to the execution of the initial movement of the putter head away from the ball and lasted for approximately two seconds. Conversely less skilled golfers had a final fixation that lasted for only one to one and a half seconds; a finding that has since been corroborated by Vickers (2007) and Wilson and Pearcey (2009).

The QE has not only been shown to be indicative of superior performance, but has also been demonstrated to be trainable. Harle and Vickers (2001) utilized a QE training protocol in an attempt to improve the free throw accuracy of near-elite basketball players. The QE of each member of the team was recorded and viewed relative to an elite prototype in a feedback session using vision-in-action data (Vickers, 1996). Participants were then taught a three step QE training regime aimed at improving their visuo-motor control. Results showed that not only did the team significantly increase their QE durations and free-throw percentages in a laboratory setting, but after two seasons in competitive play they had improved their free throw percentage by 22.6%. This finding is particularly noteworthy as a recent examination of free throw statistics suggests that the average free-throw percentages at the highest levels of the game have not significantly improved since the conception of the free-throw in the 1960s (75% in National Basketball Association, 69% in College basketball; Branch, 2009).

Study 3 (Chapter 6) is the first evidence of the benefits of QE training among novices. The lack of research examining QE training with novice performers is perhaps surprising given that such an approach provides a functional way to optimize external attention; postulated as a critical aspect of optimal motor skill learning (e.g., Singer, 2000; Wulf, 2007). For example, Singer (1988, 2000), incorporated focusing attention on a key external component of the task (e.g., dimples on a golf ball) as the third step of his 5-step pre-shot routine for optimal motor learning. He postulated that such an external focus helped to create an optimal state for performance, and prevented learners from focusing on internal thoughts or body mechanics (Singer, 2000).

Wulf and colleagues (see Wulf, 2007) have consistently demonstrated that an external focus of attention (on the effect of the movement) is superior for motor learning than an internal focus of attention (on the mechanics of the skill). While much of this research has focused on postural tasks, Wulf's research in aiming tasks (e.g., golf chip shots) has also implicated an external focus of attention as critical for motor learning and performance (Wulf, Lauterbach, & Toole, 1999; Wulf & Su, 2007; Bell & Hardy, 2009). Research by Zachary, Wulf, Mercer, and Bezodis (2005) examined the EMG activity of performers taking basketball free throws and found that when instructed to focus externally on the hoop (as opposed to the snapping motion of the wrist), performance improved. The performance improvements evident when participants were instructed to focus externally were also accompanied by reduced EMG activity in the shooting arm. The authors suggested that this may reflect a reduction in 'noise' in the motor system, leading to greater accuracy. Interestingly, the explanation given by Zachary et al. (2005) for the benefits of target focused attention is similar to the mechanisms by which Vickers suggests the QE may work. However, a potential strength of QE training is that not only is the *target* of the focus of attention considered, but also its optimal *duration* and *timing* relative to the key movement components of the task.

### Anxiety and Motor Skill Performance

While optimizing the learning of motor skills is important, most sports are performed in situations of high levels of ego-threat. Anxiety has been shown to influence attentional control, and as a result, much research aimed at understanding the anxiety-performance relationship has focused on the underlying attentional mechanisms (see Janelle, 2002; Wilson, 2008 for reviews). Recent research has demonstrated that optimal attention, as indexed by QE, may be impaired (shorter QE durations) under heightened levels of anxiety (see studies 1 & 2; Behan & Wilson, 2008; Vickers & Williams, 2007; Wood & Wilson, 2010). Vickers & Williams (2007) reported that, while reduced QE durations were associated with degraded performance, performers who maintained their optimal QE durations also maintained performance. Vickers and

Williams (2007) suggest that the act of allocating attention externally to critical task information (via the QE) appears to insulate athletes from the normally debilitating effects of anxiety. Behan and Wilson (2008) and Wilson and Richards (2010) have therefore suggested that QE training programmes may be a useful intervention to enhance attentional control in pressurized environments.

### Aims

The aims of this research were to again examine the efficacy of a QE training regime, aimed at experimentally manipulating the visual attentional control of novice performers (as study 3, chapter 6), but in a golf-putting task. It was predicted that participants in a QE trained group would perform better in both a retention test (designed to assess learning) and a pressure test (under ego-threatening instructions), compared to those in a Control group (technical instruction only), due to more optimal (external) attentional control. Specifically, it was hypothesized that:

1. The QE trained group would demonstrate better performance and attentional control (longer QE durations) in retention tests compared to their control group counterparts.
2. The QE trained group would maintain attentional control (QE duration) and performance at retention test levels in a high threat condition (pressure test). In comparison, Control group participants would display significantly poorer performance and attentional control in high pressure, compared to retention test conditions.

## 7.2. Methods

### Participants

Fourteen male undergraduate students (mean age, 20.30 years, *SD*= 1.15) volunteered to take part in the study. All participants declared having little or no experience in golf or putting (as Wulf et al., 1999; Wulf & Su, 2007) and all were right handed. Seven additional participants had agreed to take part in the study and attended the laboratory for calibration with the eye tracker. However it was difficult to calibrate the eye tracker for three of these participants and a subsequent four dropped out due to the time commitment required. Written information was provided and written consent was gained from all participants (see appendices 1 & 5). Local ethics committee approval was obtained prior to the start of testing.

**Apparatus**

Putts were taken from ten feet (3.33m) to a circular target (5cm radius), on an artificial putting surface, using a standard golf putter (Ben Sayers M7) and standard size (4.17cm diameter) white golf balls. Nine concentric circles surrounded the central target (increasing by 5cm in radius) to allow for a measure of performance error to be recorded. This 'archery target' set up is consistent with previous research into golf putting (e.g., Wulf et al., 1999). Gaze was recorded throughout the testing period using an Applied Science Laboratories (ASL; Bedford, MA) Mobile Eye Tracker (see studies 1, 2 & 3).

**Measures**

***Performance.*** Performance was measured in terms of performance error (distance from the target circle) utilizing the aforementioned concentric circles. If the ball landed in the target circle then a score of ten was given, if it landed in the next concentric circle then a score of nine was given, out to a final circle representing one point. If the ball did not land in a circle then a score of 0 was given. As training and testing was performed in blocks of 40 putts, a summative score was recorded, giving a maximum attainable score of 400 for each block.

***State Anxiety***. (see section 3.5).

***QE Period.*** (see section 3.4).

***Phases of Movement.*** (see section 3.2.2).

**Procedure**

Participants attended individually and after reading the written information (appendix 5) and signing the informed consent (appendix 1) were given a chance to familiarize themselves with the surroundings. When they verbally stated that they were ready to commence, participants were then fitted with the eye tracker and calibration took place. Participants adopted their putting stance and were then asked to fixate in turn on one of six golf balls placed on the mat in front of them; four balls were placed in a square approximately half a meter in front of their feet and two balls were placed half a meter away from the target hole perpendicular to the direction of putting. As in study 3 a calibration check was performed every 10 shots to ensure that the eye tracker had not slipped, if this occurred then a recalibration was performed and the testing continued (this happened on only four occasions throughout the whole testing period).

The training and testing period took place over a total of eight days and was scheduled as follows. On the morning of day one, a measure of performance and QE were recorded for a block of 40 putts. This data acted as a baseline (pre-test) measure, and ensured that the eye tracker was working correctly. During the afternoon of day 1, participants began their assigned training regime (QE or control) and performed 80 putts (2 blocks of 40). The group-specific training points were repeated to each participant before the start of each block of 40 putts (see ‘Training Protocol’ section). The training regime was then repeated on days two and three to complete a total of 360 training shots. The duration of the training period and the number of trials is congruent with previous training studies for self-paced motor skills (e.g., Lam et al., 2009; Poolton, Masters, & Maxwell, 2005; Poolton, Masters, Maxwell, & Raab, 2006).

On day five participants returned and performed a retention test, consisting of a single block of 40 putts without the guidance associated with their training regime. On day eight, participants performed a transfer (pressure) test, which consisted of 40 competition putts, aimed at manipulating levels of cognitive anxiety. Finally participants performed a second retention test (identical to retention test 1) to form the typically adopted A-B-A (retention-transfer-retention) design (as Lam et al., 2009). Three participants deviated slightly from this routine due to time commitments. One participant started late, so performed training on days three, four and five and then retention and pressure tests on days eight and nine. Two participants performed the pressure test and retention test 2 on day nine instead of day eight. Finally participants were thanked and debriefed about the aims of the study and offered the opportunity to withdraw their data. No participants withdrew due to concerns about the deceptive element of the research.

### Training Protocol

Participants were randomly assigned to either a QE training or control group. The control group received coaching guidance related to the mechanics of their putting action and stroke (derived from www.abc-of-golf.com; www.bbc.co.uk/sport). The QE trained group received the same basic coaching instructions as the control group, but also received a specific QE training element (derived from Vickers, 2007). The training instructions consisted of 5 key points in each case (see Table 7.1). Each of the technical and gaze instructions were coupled to reflect the same phase of the putt (i.e., preparation, aiming, putter-ball alignment, swing and follow through) in order to minimize differences in the focus and timing of the instructions. The intervention was given by an experimenter who provided the participant with a sheet of training instructions (Table 7.1) and each point was emphasized. The participant then practiced the routine (a maximum of ten times) to ensure that they undertood the instructions. The relevant training points (either coaching points or both coaching and QE) were repeated to each participant at the start of each block of 40 shots. The participant was again shown the training points (Table 7.1) and each point was emphasised by an experimenter.

### Anxiety Manipulation

Several techniques consistent with previous research were used to manipulate levels of cognitive anxiety for the pressure test (see section 3.5).

### Data Analysis

A subset of putts (every fourth) was selected for analysis (see section 3.2.2).

### Statistical Analysis

Acquisition phase performance data were subjected to a 2 (Group) x 9 (Block) mixed design analysis of variance (ANOVA). Anxiety data for the test phase (retention 1, pressure, retention 2) were subjected to a 2 (Group) x 3 (Test) mixed design analysis of variance (ANOVA). Performance and QE data were subjected to a 2 (Group) x 4 (Test) mixed design analysis of variance (ANOVA). As well as comparing the three conditions from the test phase, pre-test (block 1) data was included in order to assess learning. Significant main effects were followed up with Bonferroni corrected post hoc *t*-tests; interaction effects were followed up with simple t-tests; and effect sizes were calculated using Partial Eta squared ($\eta_p^2$) for omnibus comparisons. Linear regression analysis was also performed on the QE and performance variables for the test phase, to assess the degree to which QE durations predicted variance in performance.

***Table 7.1:*** *Instructions provided to each group during the training protocol*

.

| **QE training instructions** | **Technical instructions** |
|---|---|
| • Assume stance and ensure that gaze is on the back of the ball. | • Stand with legs hip width apart and keep your head still. |
| • Fixate the hole (Fixation should be made no more than three times). | • Maintain relaxation of shoulders and arms. |
| • Your final fixation should be on the back of the ball and for no longer than 2-3 seconds. | • Keep the putter head square to the ball. |
| • No gaze should be directed to the club head or shaft during the putting action. | • Perform a pendulum like swing and accelerate through the ball. |
| • Your fixation should remain steady for 200-300ms after contact with the ball. | • Maintain a still head after contact. |

## 7.3. Results

### Acquisition Phase Performance

ANOVA revealed a significant main effect for block, $F(8,96) = 9.54$, $p < .001$, $\eta_p^2 = .44$, indicating that all performers significantly improved throughout the acquisition phase. Significant improvements in performance from baseline (pre-test) occurred from block 4 onwards ($p < .05$). There was no main effect for group, $F(1,12) = 3.02$, $p = .11$, $\eta_p^2 = .20$, and no interaction effect, $F(8,96) = 1.04$, $p = .40$, $\eta_p^2 = .08$, suggesting that the rate of acquisition was similar for both groups. The acquisition phase performance data is presented in Figure 7.1.

**Cognitive Anxiety**

ANOVA revealed a significant main effect for test, $F(2,24) = 58.76$, $p < .001$, $\eta_p^2 = .83$, with anxiety being significantly higher during the pressure test than retention tests 1 ($p < .01$) and 2 ($p < .001$). There was no significant main effect for group, $F(1,12) = 0.22$, $p = .64$, $\eta_p^2 = .02$, and no interaction effect, $F(2,24) = 1.33$, $p = .28$, $\eta_p^2 = .10$, revealing that both groups reported similar levels of anxiety. While cognitive anxiety was the main focus of the analysis, the self-report data from all 3 scales of the MRF-3 are presented in Table 7.2.

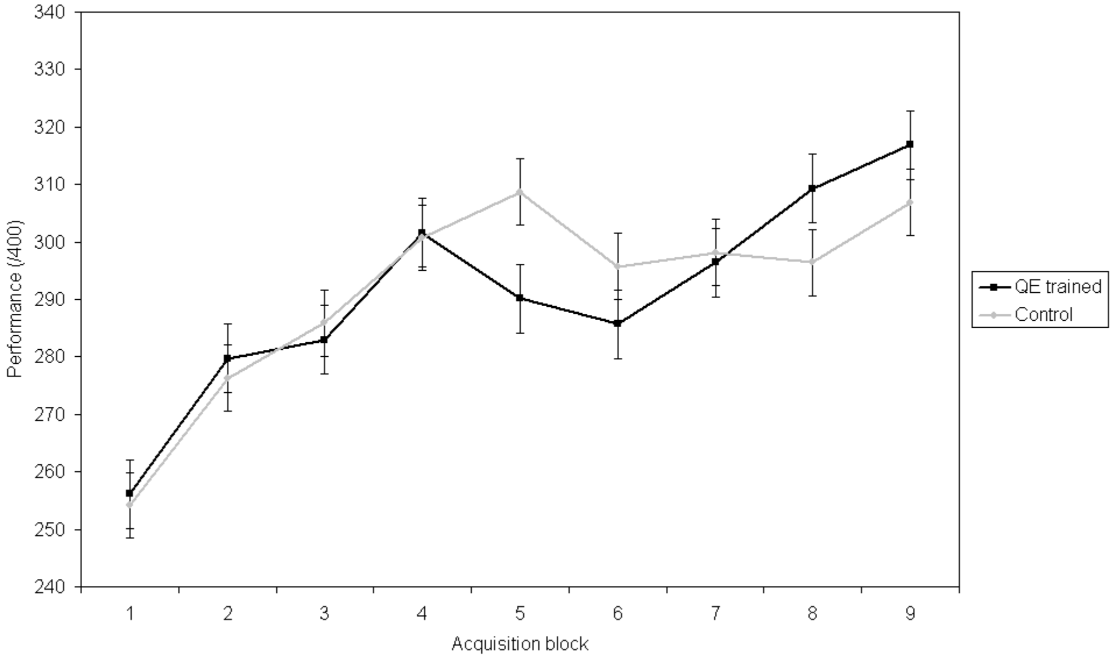


***Figure 7.1:*** *Acquisition phase performance data showing performance in each learning block of 40 putts for both the QE trained and Control groups.*

***Table 7.2:*** *Mean (standard deviation) scores from MRF-3 across pressure and retention tests.*

| | **Retention 1** | | **Stress** | | **Retention 2** | |
|---|---|---|---|---|---|---|
| | **QE trained** | **Control** | **QE trained** | **Control** | **QE trained** | **Control** |
| **Cognitive** | 2.77 | 2.22 | 6.2 | 6.74 | 3.31 | 2.68 |
| **Anxiety** | (0.91) | (0.52) | (1.2) | (1.86) | (1.25) | (0.97) |
| **Somatic** | 2.57 | 2.38 | 5.75 | 5.41 | 2.65 | 3.18 |
| **Anxiety** | (0.44) | (1.05) | (1.34) | (0.97) | (1.47) | (1.43) |
| **Self** | 7.22 | 6.8 | 3.25 | 2.17 | 6.18 | 6.65 |
| **Confidence** | (1.36) | (1.14) | (0.97) | (1.39) | (2.34) | (1.49) |

**Pre-Test and Test Phase Performance**

ANOVA revealed significant main effects for group, $F(1,12) = 4.99$, $p < .05$, $\eta_p^2 = .29$ and test, $F(3,36) = 24.15$, $p < .001$, $\eta_p^2 = .67$. These findings were qualified by a significant interaction effect, $F(3,36) = 3.96$, $p < .05$, $\eta_p^2 = .25$. Follow up t-tests showed that there were no significant performance differences between groups for pre-test ($p = .74$), retention test 1 ($p = .12$), or retention test 2 ($p = .12$), suggesting that the degree of learning was similar for both groups. However, the control group did perform significantly worse than the QE trained group in the pressure test ($p < .005$). Within groups, the QE trained group displayed significant improvements in performance between pre-test and retention test 1 ($p < .001$) but no significant differences between retention test 1 and the pressure test ($p = .32$) or retention test 2 and the pressure test ($p = .55$). There was also no significant difference between retention test 1 and retention test 2 ($p = .39$) indicating that no further learning had occurred during the test phase. The Control group displayed significant improvements in performance between pre-test and retention test 1 ($p < 0.05$) but reductions in performance between retention test 1 and the pressure test ($p < .01$) and retention test 2 and pressure test ($p < .01$). The control group also displayed no significant difference between retention test 1 and retention test 2 ($p = .58$). Pre-test and test phase performance data are presented in Figure 7.2.

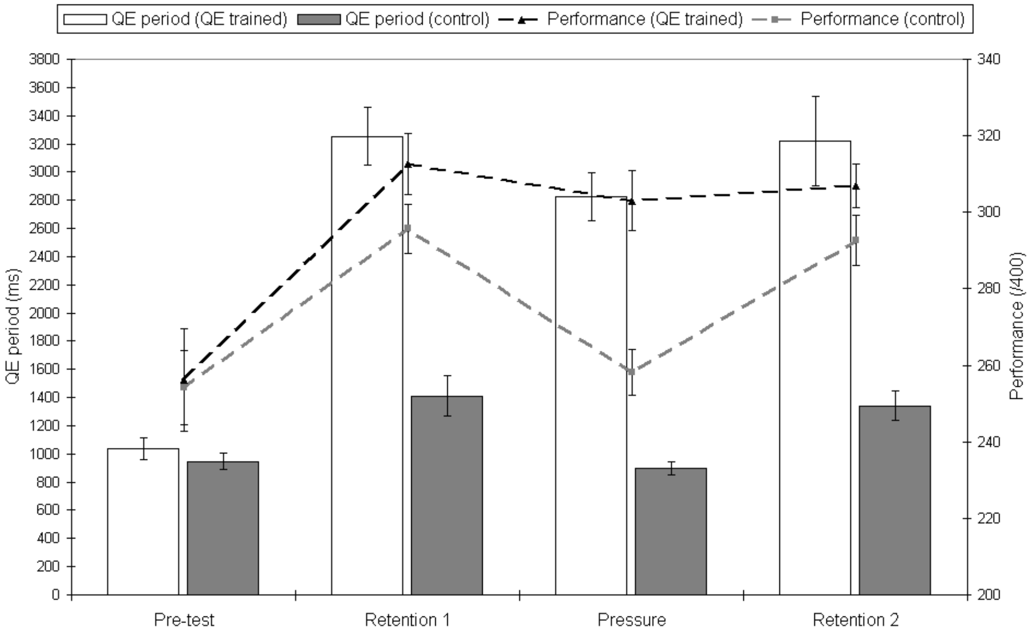


***Figure 7.2:*** *Putting performance (score/400) and QE (ms) for QE trained and Control group across the 4 tests (pre-test, retention test 1, pressure test & retention test 2).*

**Pre-Test and Test Phase QE**

ANOVA revealed a significant main effect for group $F(1,12) = 81.99$, $p < .001$, $\eta_p^2 = .87$ and test, $F(3,36) = 41.13$, $p < .001$, $\eta_p^2 = .77$. This was qualified by a significant interaction effect $F(3,36) = 21.55$, $p < .001$, $\eta_p^2 = .64$. Follow up t-tests revealed no significant QE differences between groups for pre-test ($p = .38$), however there was a significant difference between groups at retention test 1 ($p < .01$), the pressure test ($p < .01$) and retention test 2 ($p < .01$). Within groups, the QE trained group displayed a significant increase in QE from pre-test to retention test 1 ($p < .001$), and a significant decrease in QE from retention test 1 to the pressure test ($p < .05$), but not between retention test 2 and the pressure test ($p = .26$). There was also no significant difference in QE between retention test 1 and retention test 2 ($p = .87$). The control group displayed significant improvements in QE from pre-test to retention test 1 ($p < .05$), but a significant decrease in QE from retention 1 ($p < .01$) and retention test 2 ($p < 0.05$) to the pressure test. There was also no significant difference in QE for the Control group between retention test 1 and retention test 2 ($p = .76$). Pre-test and test phase QE data are presented in Figure 7.2.

### Regression Analysis

Results from the regression analysis revealed that QE period predicted 36% of the variance in performance during the test phase ($R^2$=.358, $\beta$= .60, $p$ < .001).

## 7.4. Discussion

The aim of this research was to examine the efficacy of a QE training regime aimed at optimizing the learning and performance under pressure of a golf-putting task. Previous research has highlighted the benefits of focusing externally during the acquisition of a motor skill. QE training is therefore a practical technique to guide an external focus of visual attention whilst also guiding its timing in relation to critical movements (visuo-motor control).

### Learning

There were no differences in the performance levels of both groups at baseline (pre-test), indicating that both groups started from similar novice levels of performance. Results revealed a significant improvement in performance for both groups from pre-test to retention test 1, indicating that a degree of learning had occurred (Figure 7.2). The absence of any significant differences in performance between retention tests 1 and 2 for each group suggests some level of stability of learning had been attained. However, it is unlikely that full automaticity has been achieved for these participants after only 480 repetitions (see Masters, 1992; Mullen & Hardy, 2000). Although the QE trained group demonstrated better performance in retention tests 1 and 2 than their Control group counterparts, this difference was not significant (see Figure 7.2). The results from the acquisition phase (Figure 7.1) also suggest that both groups' performance had improved in a similar manner as a result of training.

The QE data (Figure 7.2) revealed that both groups had similar QE durations at baseline (pre-test), suggesting that any subsequent changes in duration should be the result of the training instructions provided. As expected, the QE trained group had longer QE durations compared to their Control group counterparts throughout the test conditions. Interestingly, while the significant increase in QE duration for the QE trained participants from pre-test to retention test 1 was expected, there was also a significant increase in QE duration for the Control group. Despite receiving no explicit instructions related to gaze control, these participants appear to have developed more effective visuo-motor control through discovery learning over repeated skill attempts. However, the mean QE at retention 1 test for the Control group (1411.43ms, *SD* = 372.86) is still significantly lower than that of the QE trained participants in the current study (3521.86ms, *SD* = 540.60) and is more representative of the QE duration of less expert putters (i.e., between 1 and 1.5 seconds; as reported in Vickers, 2007).

In contrast to the predictions of hypothesis 1 and also the findings of the previous study (study 3, chapter 6), the QE trained group did not perform better than the control group in retention tests 1 and 2; despite having significantly longer QE periods (see Figure 7.2). It cannot therefore be stated that the QE training programme expedites the learning of golf putting for novice participants. However, the regression analysis did at least suggest that longer QE periods are indicative of superior performance. Furthermore, although differences in performance in the retention tests were non-significant, they were in the predicted direction. The lack of statistical difference is likely due to individual variations in performance within the groups and the lack of power caused by the relatively small sample size. Indeed, this explanation is supported by a subsequent analysis of the data at an individual level. The top three performance scores during retention test 1 (mean, 333.33, *SD* = 9.29) were from participants from the QE trained group with long mean QE durations (mean, 3561.33ms, *SD* = 326.35). In contrast, the bottom three performance scores were from participants from the Control group (mean, 279.67, *SD* = 5.03), who had much shorter mean QE durations (mean, 1372.00, *SD* = 267.82).

**Pressure Effects**

The MRF data supports the effectiveness of the anxiety manipulation, in that both groups were significantly more anxious during the pressure test than the retention tests. The reported anxiety levels are similar to those found in other laboratory (e.g., Wilson et al., 2007b; Wilson et al., 2009; studies 1, 2 & 3) and competitive (e.g., Krane, 1994; Smith et al., 2001) environments. While there were no group-differences in the level of anxiety reported by the participants, the effect of this anxiety on each group's performance was different, as hypothesized (hypothesis 2). Specifically, while the Control group performed significantly worse in the pressure test than the retention tests, the QE trained group managed to maintain pressure test performance at retention test 1 levels (Figure 7.2).

Although the interaction effect found for the performance data supports our prediction that QE training may act in some way to insulate the performer from the negative effects of anxiety, the actual QE data results are not fully supportive of our hypotheses. Follow up tests on the QE data revealed that there was a significant decrease in QE duration from retention test 1 to the pressure test for both the Control *and* QE trained groups (see Figure 7.2). This finding is in accord with recent research testing attentional control theory (Eysenck et al., 2007), which has demonstrated that anxiety impairs visual-attentional control and acts to cut short the QE period of performers (see studies 1, 2 & 3; Behan & Wilson, 2008; Wilson et al., 2009). However, if QE training did not help anxious participants to maintain attentional control at retention test levels, how was performance maintained under pressure by these participants?

A re-examination of the QE data in Figure 7.2 reveals a potential explanation, similar to that given for confounding QE & performance results in study 3 (chapter 6). The control group displayed a significant reduction in QE from retention to pressure test (of 482ms), reducing their average QE to 894ms. Previous research has demonstrated that durations of less than one second are insufficient to produce consistently accurate performance (Vickers, 1992; Vickers, 2007). Although the QE trained group also displayed a significant reduction in QE (of 410ms), this only reduced their QE to an average of 2.8 seconds, a figure that previous research has shown to be indicative of accurate performance (Vickers, 1992; Vickers, 2007). It is therefore suggested that despite anxiety significantly reducing the QE period, this remained within an optimal zone and above a critical threshold for performance to be maintained (see Behan & Wilson, 2008). Results from the previous study showed that under pressure the control group suffered deterioration in performance; however this was not accompanied by a reduction in the QE period. A floor effect was proposed, whereby QE periods were already low, and therefore anxiety influenced performance through alternative mechanisms. It seems that for the QE to act to insulate or protect a performer from the debilitating effects of anxiety it must be within an optimal zone. Equally for performance to be influenced by anxiety causing a reduction in performance, this reduction must take the QE below a critical threshold and out of an optimal zone.

One concern with our interpretation of the performance results being related to changes in target-directed gaze control, is that both groups also received technical instructions; with the QE trained group effectively receiving additional (as opposed to distinct) training instructions. Therefore, the superior performance under pressure of the QE trained group may have been simply due to them receiving a greater volume of instruction (both technical and gaze related) and this is acknowledged as a limitation of the study. Subsequent research should therefore attempt to replicate our findings by adopting distinctly different training protocols to avoid the volume of training received potentially confounding results.

The rationale for our decision to include both technical and gaze related coaching points for the QE trained group was based on Masters' (1992) conscious processing (reinvestment) hypothesis, and concerns with providing explicit technical instructions to only the control group. A consistent finding in the golf putting literature (see Masters, 1992; Mullen & Hardy, 2000; Wilson et al., 2007b) is that performers are likely to choke under pressure if they reinvest in the explicit knowledge base underlying skilled performance. Indeed the results of our control group support Masters' predictions that explicit learning may cause performers to choke under pressure. However, the QE trained group were able to maintain performance despite being provided with the same explicit instructions. This finding suggests that QE training may help performers maintain a focus on the critical stimuli underpinning optimal performance and away from task-unproductive cues (like movement mechanics).

An alternative explanation is that QE training might create a form of implicit learning, where learners are partially protected from developing explicit rules by focusing only on the external target, and not movement control. However, as the number of explicit rules generated by both groups was not assessed (Masters & Maxwell, 2008), it is not possible to determine if QE training does act to reduce the accrual of explicit knowledge (cf. analogy learning, Lam et al., 2009). Whatever the specific mechanisms, it is evident that novice golfers were able to maintain performance despite significant increases in self-reported anxiety when directed to attend to a single, external cue. Future research should examine the degree to which QE training may aid the accrual of implicit knowledge, to better understand the mechanisms through which QE training may expedite robust skill learning.

### Implications

From an applied perspective the findings of this study have some important implications. The benefits to performance of QE training highlighted in this study offer an insight into a potential future direction for golf coaching. Much of the guidance currently given by coaches focuses upon the mechanics of the movement and draws an individual's attention inwards, something that has been shown to be counterproductive (Wulf, 2007). However, difficulties may be encountered when attempting to direct a performer's focus of attention to external sources (Bell & Hardy, 2009) and away from explicit movement rules (Masters & Maxwell, 2008). QE training may act as a practical and easily applicable training regime that acts to focus an individual's attention correctly, and help optimally coordinate gaze and motor control.

From a sport psychology perspective, a key goal is to help performers deal with the emotional and cognitive factors inherent in performing in ego-threatening situations (e.g., Hardy, Jones, & Gould, 1996; Zinsser, Bunker, & Williams, 2006). Pre-performance routines, consisting of behavioral and cognitive elements, have been proposed as a useful strategy for maintaining concentration and perceptions of control in pressurized environments (Moran, 1996). As discussed previously (chapter 2), Singer's five step strategy has been shown to facilitate learning and performance in a number of laboratory and field studies (see Singer, 2000; 2002). It focuses on creating the conditions for a "just do it" performance state, and emphasises that optimally focused attention is best achieved by selecting one, appropriate external cue. The QE may be seen as a part of the pre-performance routine, helping the performer focus on what they can control (an external, process-related cue) rather than on non-productive (internal) thoughts and emotions (see Wilson & Richards, 2010).

As previously discussed an important consideration when attempting to guide attention via directing external fixations is the degree to which the location of overt gaze is reflective of the target of covert attention. Some practitioners (e.g., Singer, 2000; Vickers, 2007) suggest that directing attention externally via gaze control might make it more difficult for performers to also focus on internal thoughts. Indeed, neuroscience research suggests that there is substantial overlap between the areas of the cortex involved in shifting gaze and shifting covert attention (e.g., Corbetta, 1998; Shipp, 2004), and that it is difficult to shift the point of gaze without shifting attention (Henderson, 2003). However, practitioners must recognize that while gaze may be directed to the external cue, covert attentional shifts (e.g., cognitive intrusions; Sarason, 1998) may still take place during the QE period. Any psychological training programme aiming to help athletes cope with performing in pressure environments should therefore also consider the impact of these internal thoughts and emotions (see Zinsser et al., 2006).

## 7.5. Conclusions

To conclude, the current study investigated the efficacy of a QE training regime, aimed at optimizing the learning and subsequent maintenance of performance under pressure of golf putting. Results indicated that QE training acted to protect performers from the adverse effects of anxiety by maintaining effective QE fixation durations and attentional control. The group data did not support the prediction that the QE trained participants would show significantly improved learning compared to their control group counterparts. However, an examination of *individual* performance and QE data revealed supportive results for the best and worst performing participants. These results suggest that future research on potential expediency of learning benefits from QE training is warranted. From an applied perspective, QE training may provide a useful method to guide visuo-motor skill training and a psychological technique to aid performance under pressure.

## 7.6. Directions for Future Research

Collectively results from both studies 3 and 4 (chapters 6 & 7) offer support for the role of QE training in the expediency of learning and robustness under pressure. Future research should examine the benefits of QE training in a wide variety of sports to establish sports specific differences in the duration of optimal QE periods, and also any skill specific effects that anxiety may have (e.g. disruption of LSH, as in study 2). A word of caution is that, unlike in previous QE training studies, (e.g., Harle and Vickers, 2001; Vickers & Adolphe, 1997) studies 3 and 4 (chapters 6 & 7) did not analyse the transfer effects to 'real' competition. Williams and Grant (1999), state that, "few studies have attempted to determine whether the pre- to- post test improvement observed in clinical settings transfer to the sport domain" (p. 198). The ability to perform with accuracy and consistency whilst in highly pressurised environments is essential for success in sport and is of interest to both theorists and applied sport psychologists. Therefore, a limitation is that the transfer of the potential benefits of training the QE to the competitive world of golf cannot be made. Future research should attempt to test the efficacy of QE training for competitive golfers and assess performance both under laboratory conditions and on the course.

# Chapter 8 (Study 5): Quiet Eye Training Facilitates Competitive Putting Performance in Elite Golfers.

-Submitted as: Vine, S.J., Moore, L.J. & Wilson, M.R. (under review). Quiet eye training facilitates competitive putting performance in elite golfers, *Frontiers in Movement Science and Sports Psychology*.

-This research was funded by a business voucher from the Economic and Social Research Council's capacity building cluster in Sport, Leisure and Tourism, based at the University of Exeter (RES-187-24-0002).

## 8.1. Introduction

Given its relative importance within the game of golf it is unsurprising that much research has focused on improving accuracy in golf putting (Hellstrom, 2009a). Requiring precise and accurate movements and often performed under conditions of high pressure, the golf putt is a skill particularly susceptible to breakdown (Gucciardi et al., 2010). A major focus for research examining the acquisition and performance of far-aiming skills, like putting, has been the control of gaze. Research has revealed proficiency related differences in gaze control, with experts demonstrating more efficient gaze strategies across a range of sport skills (see Mann et al. 2007 for a review). Gaze control has also been shown to be susceptible to change under heightened levels of anxiety, with less efficient gaze leading to reductions in performance (see Janelle 2002; Wilson 2008 for reviews). Researchers have therefore suggested that training interventions, designed to guide optimal gaze control, may facilitate performance in highly pressurised environments (Behan and Wilson 2008; Vickers and Williams 2007). The current study aimed to assess the utility of a gaze training intervention aimed at improving golf putting among low handicap golfers.

The control of gaze has been shown to be an important determinant of accuracy in the execution of motor tasks (Land 2009; Vickers 2009). Vickers (1992) was the first to assess the gaze control of expert and novice golfers whilst performing golf putts. Vickers highlighted proficiency differences in gaze control during the alignment and execution phase of the putt. Most notably, experts kept their eyes steady on the back of the ball for around two seconds prior to the initiation of the back swing and maintained this fixation until the putter contacted the ball. Their gaze would then remain steady in the same location for around 300-500ms after the ball had been struck. This aiming fixation was later termed the quiet eye (QE; Vickers 1996).

From an applied perspective, such insights into the psychomotor processes underpinning skilled performance may guide the development of innovative training interventions to optimise gaze control and facilitate accurate and efficient motor task performance. Research by Vickers and colleagues has shown that skilled performers can be taught to develop longer and more effective QE periods, with subsequent improvements in performance (Adolphe et al. 1997; Harle and Vickers 2001). For example, Harle and Vickers (2001) examined the effect of a QE training regime aimed at improving the gaze control and free-throw accuracy of near-elite basketball players. Results showed that not only did the QE trained team significantly increase their QE durations from an average of 300ms to 900ms and free-throw percentages by 12% in a laboratory setting, but they improved their competitive free-throw percentage by 22.6% after two seasons.

Research examining disruptions in gaze control during pressurised performance may provide additional information as to how training interventions can facilitate performance (Wilson 2008). Effective attentional control, as indexed by the QE, is negatively impacted by anxiety, causing subsequent performance degradation in far aiming tasks (see studies 1 & 2; Behan and Wilson 2008; Vickers and Williams 2007; Wilson et al. 2009; Wood and Wilson 2010). However, Vickers and Williams found that elite biathletes who managed to maintain their QE durations under pressure were less susceptible to choking. The authors suggested that by allocating attention externally to critical task information (via the QE) the biathletes were insulated from the normally debilitating effects of anxiety.

This finding raises fascinating questions about whether performers can be taught to maintain effective attentional control under pressure, via QE training (Wilson et al. 2010). In line with this notion, study 4 examined the effects of a QE training regime aimed at optimising the gaze control, learning and performance under pressure of novice golfers in a putting task. Consistent with the work of Vickers and colleagues, the results revealed that the QE trained golfers displayed significantly longer and more effective QE durations, as well as more accurate putting performance post-training when compared to pre-training. Furthermore, the authors found that the elevated anxiety encountered in a subsequent pressure test had a different effect on the gaze control and performance of QE trained and control groups. Specifically, the control group displayed significantly shorter QE durations and performed significantly worse in a pressure test than their QE trained counterparts. Thus, the results indicate that QE training acted to protect performers from the adverse effects of anxiety upon performance by maintaining effective QE durations.

### Aims & Hypotheses

The aims of this research were to replicate the findings of study 4, using a brief QE intervention aimed at training optimal visuo-motor control of elite golfers in a laboratory setting and under conditions of heightened anxiety (pressure test). Furthermore, the research aimed to examine whether the QE training would result in improvements in *real* competitive putting performance. In line with previous research it was predicted that participants in a QE trained group would perform significantly better in laboratory based retention and pressure tests, compared to those in a control group, due to more optimal gaze control (QE). Furthermore, this in turn, was expected to contribute to participants in the QE trained group performing significantly better in *real* competitive settings, compared to those in a control group. Specifically, it was hypothesised that:

1. The QE trained group would demonstrate significantly better performance and gaze control (longer QE durations) in a laboratory based retention test, compared to their control group counterparts.
2. The QE trained group would demonstrate significantly better performance and gaze control (longer QE durations) in a laboratory based pressure test, compared to their control group counterparts.
3. The QE trained group would demonstrate significantly greater improvements in competitive performance pre- to post- training, compared to the control group.

## 8.2. Methods

### Participants

22 elite male golfers (mean age, 20.95, *SD* = 2.66) with an average handicap of 2.78 (*SD* = 2.24) volunteered to take part in the study. All participants currently held a handicap less than 6 and thus, were identified as elite (as Karlsen et al. 2008). All were right handed, reported normal or corrected vision and were individually tested. Written information was provided and written consent was gained from all participants (see appendices 1 & 6). Local ethics committee approval was obtained prior to the start of testing.

### Apparatus

Straight putts were taken from three, ten feet (3.05m) locations to a regulation hole (10.80cm diameter) on an artificial putting green (length = 6m, width = 2.5m). All participants used their own golf putters and standard size (4.27cm diameter) white golf balls. Gaze was measured using an Applied Science Laboratories (ASL; Bedford, MA) Mobile Eye Tracker.

### Measures

***Experimental Performance.*** Two measures of experimental putting performance were calculated; performance outcome (percentage of putts holed) and performance error (the distance that the ball finished from the hole, in cm). Zero was recorded and used in the calculation of average performance error on trials where the putt was holed. These measures are similar to those utilised in previous golf putting research (e.g. Cooke et al. in press; Wilson and Pearcy 2009; Wilson et al., 2007b).

***Competitive Performance****.* Two measures of competitive putting performance were derived from putting statistics kept by the participants over twenty competitive rounds (before and after the laboratory-based training session). Participants recorded the number of putts taken per hole, whether they had a putt at a distance of 6 to 10 feet on each hole and if they were successful with that putt on a putting scorecard (see appendix 7). These data were used to calculate measures including average number of putts per round and the percentage of putts holed from 6-10 feet. A low number of putts per round and a high percentage of putts holed from 6-10 feet represented better performance (see Pelz, 2000).

***State Anxiety.*** (see section 3.5).

***QE Duration*****.** (see section 3.4).

**Procedure**

After reading the written information introducing the study (appendix 6) and being informed of their right to withdraw from the study at any time, participants provided informed consent (appendix 1). Next, participants were provided with putting scorecards (appendix 7) and recorded their competitive putting performance for ten competition rounds (over a maximum of three months). This data acted as a baseline (pre-training) measure. Upon completion of these ten rounds participants attended the laboratory individually for training and the first testing session.

On arrival participants were randomly assigned to either a QE training or control group. Next, participants were given the chance to take ten practice putts and familiarise themselves with the surroundings. Participants were then fitted with the eye-tracker and calibration took place. During calibration participants adopted their putting stance and were then asked to fixate in turn on one of four golf balls placed in a square on the green approximately half a metre in front of their feet. As in studies 3 and 4 calibration checks were performed every 10 putts to ensure the eye-tracker had not been knocked or altered, and if necessary the line of gaze was re-calibrated before proceeding with the testing protocol.

Following calibration, participants took a further ten practice putts to become familiar with putting whilst wearing the eye-tracker. Next, participants took twenty putts (two blocks of ten), during which experimental performance and gaze behaviour (QE) were recorded. This data acted as a baseline (pre-test) measure. Participants then began their assigned training regime (QE or control) (see 'Training Protocol' section). In both training regimes participants took a further twenty putts (four blocks of five putts), during which experimental performance and gaze behaviour were measured. Following cessation of the training regimes participants were provided with more putting scorecards (appendix 7) and dates were arranged for them to return to the laboratory.

After recording their putting performance for another ten competitive rounds (again over a maximum of 3 months), participants returned to the laboratory for a second testing session. Familiarisation and calibration were repeated in the same manner as during their first visit. Following calibration, participants completed twenty putts in a retention task and a further fifteen putts in a pressure test (high anxiety; see 'Pressure Manipulation' section). Anxiety levels (MRF-3), experimental performance, and gaze behaviour were recorded throughout these series of putts. Finally, participants were thanked and debriefed about the aims of the study, and offered feedback if requested.

### Training Protocol

The training regimes were adapted from previous QE training research (Harle and Vickers 2001; Vickers 2007; studies 3 & 4). Both training groups started by viewing one video of their own gaze data from putts taken during the pre-test and were asked to verbalise what they noticed with regard to their gaze control. Next, after taking five putts, during which performance and gaze control measures were recorded, both groups viewed a video of their gaze control alongside that of an elite prototype who exhibited the critical QE as found in past gaze research (Vickers 1992; Vickers 2007). The participants video was shown and the expert video then shown and participants were asked to verbalise differences that they had noticed. At this stage only the QE trained group were directed by the researcher towards key differences between their gaze control and that of the elite prototype. This consisted of highlighting the key QE features (long fixation on hole, saccades between ball and hole, lengthy final fixation prior to backswing, dwell of final fixation after ball has gone). No such feedback or guidance was given to the control group.

Furthermore, consistent with previous QE training research (e.g. Harle and Vickers 2001; studies 3 & 4), the following points adapted from Vickers (2007) were stressed:

1. Assume your stance and align the club so the gaze is on the back of the ball.
2. After setting up over the ball, fix your gaze on the hole. Fixations towards the hole should be made no more than 3 times.

3. The final fixation should be a QE on the back of the ball. The onset of the QE should occur before the stroke begins and last for 2 to 3 seconds.
4. No gaze should be directed to the club head during the backswing or fore swing.
5. The QE should remain on the green for 200 to 300ms after the club contacts the ball.

Next, the QE trained group were asked to improve aspects of their gaze control based on these feedback points and what they had learned from viewing the elite prototype. Both groups then performed a further fifteen putts, during which performance and gaze control measures were recorded.

### Pressure Manipulation

Consistent with previous research several techniques were used to create high levels of cognitive anxiety for the pressure test (see section 3.5).

### Data Analysis

A subset of shots (every fourth) was selected for analysis (see section 3.2.2). Due to a digital storage device failure video data from the eye tracker for 5 of the QE trained participants was lost, and subsequently could not be analysed.

### Statistical Analysis

Test phase (retention test and pressure test) anxiety data were subjected to a 2 (Group: QE trained, control) x 2 (Test: retention, pressure) mixed design analysis of variance (ANOVA). Pre-test and test phase performance and QE data were subjected to a 2 (Group: QE trained, control) x 3 (Test: pre-test, retention, pressure) mixed design analysis of variance (ANOVA). Competitive performance measures were subjected to a 2 (Group: QE trained, control) x 2 (Time: Pre-training, Post-training) mixed design analysis of variance (ANOVA). Significant main and interaction effects were followed up with Bonferroni corrected post hoc t-tests and simple t-tests, respectively. Effect sizes were calculated using Partial Eta squared ($\eta_p^2$) for omnibus comparisons. Linear regression analysis was also performed on the QE and performance error data for the test phase to assess the degree to which QE durations predicted variance in performance.

## 8.3. Results

### Anxiety

ANOVA revealed a significant main effect for test ($F(1, 20) = 265.55$, $p < .001$, $\eta_p^2 = .93$), with anxiety being significantly higher during the pressure test than the retention test ($t(21) = -16.75$, $p < .001$). There was no significant main effect for group ($F(1, 20) = 1.29$, $p = .27$, $\eta_p^2 = .06$), and no significant interaction effect ($F(1, 20) = .13$, $p = .73$, $\eta_p^2 = .01$), indicating that both groups reported comparable levels of anxiety. While cognitive anxiety was the main focus of analysis, the self-report data from all 3 MRF-3 scales are presented in Table 8.1.

***Table 8.1:*** *Mean (standard deviation) scores from MRF-3 questionnaire for QE trained and Control groups across the test phase.*

| | Retention Test | | Pressure Test | |
|---|---|---|---|---|
| | QE Trained | Control | QE Trained | Control |
| Cognitive Anxiety | 3.04<br>(0.94) | 3.40<br>(0.88) | 7.17<br>(0.54) | 7.35<br>(0.82) |
| Somatic Anxiety | 3.04<br>(0.50) | 3.40<br>(1.35) | 6.88<br>(0.77) | 7.00<br>(0.75) |
| Self Confidence | 9.00<br>(0.93) | 7.75<br>(1.77) | 4.92<br>(1.22) | 3.20<br>(0.89) |

### QE

ANOVA revealed a significant main effect for test ($F(2, 30) = 3.50$, $p < .05$, $\eta_p^2 = .19$), and group ($F(1, 15) = 9.48$, $p < .01$, $\eta_p^2 = .39$). This was accompanied by a significant interaction effect ($F(2, 30) = 5.82$, $p < .01$, $\eta_p^2 = .28$). Follow-up t-tests revealed no significant QE differences between groups for pre-test ($t(15) = -.40$, $p = .70$), or retention test ($t(15) = 1.84$, $p = .09$). However, the QE trained group (mean = 2794.31, $SD = 1136.11$) did display significantly longer QE durations than the control group (mean = 1404.74, *SD* = 489.48) during the pressure test ($t(7.58) = 3.04$, $p < .05$). Pre-test and test phase QE data are presented in Figure 8.1.

### Percentage Putts Holed (laboratory)

ANOVA revealed no significant main effect for test ($F(1.37, 27.43) = .55$, $p = .52$, $\eta_p^2 = .03$). However, there was a significant main effect for group ($F(1, 20) = 8.64$, $p < .01$, $\eta_p^2 = .30$), and a significant interaction effect ($F(1.37, 27.43) = 5.97$, $p < .05$, $\eta_p^2 = .23$). Follow-up t-tests showed that there were no significant differences between groups for pre-test ($t(20) = .14$, $p = .89$), or retention test ($t(20) = 2.35$, $p = .087$). However the QE trained group (mean = 60%, *SD* = 15%) did hole a significantly higher percentage of putts than the control group during the pressure test (mean = 36%, *SD* = 15%; $t(20) = 3.75$, $p < .005$). Pre-test and test phase percentage holed data are presented in Figure 8.1.

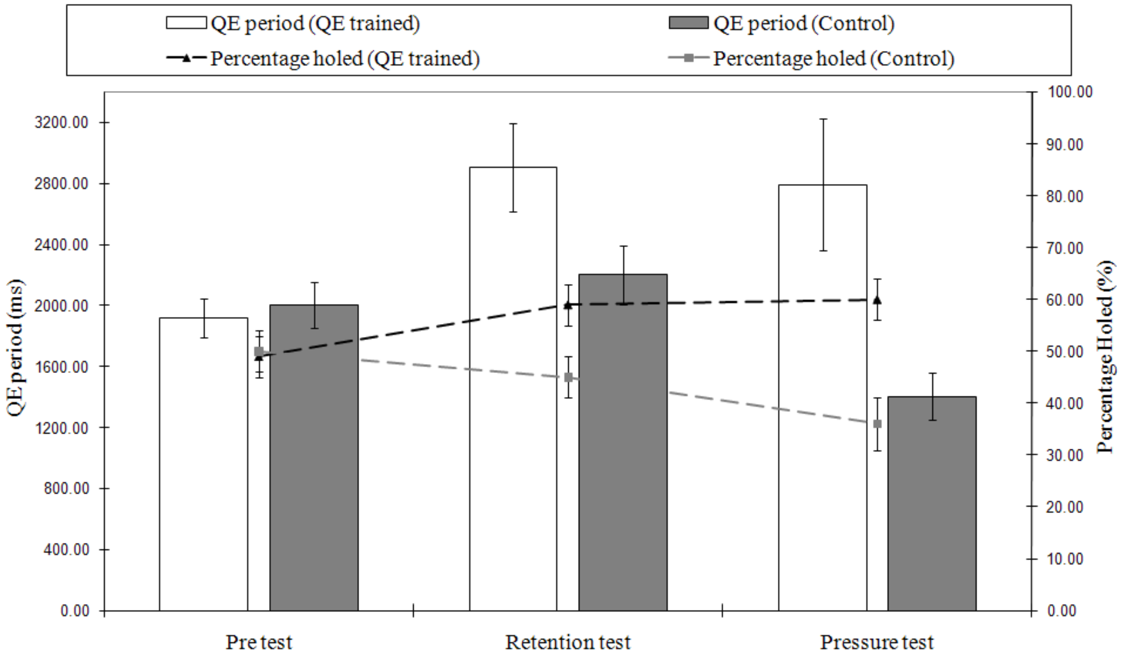


***Figure 8.1***: *QE period (ms) and percentage holed (%) for QE trained and Control groups for pre-test, retention test and pressure test.*

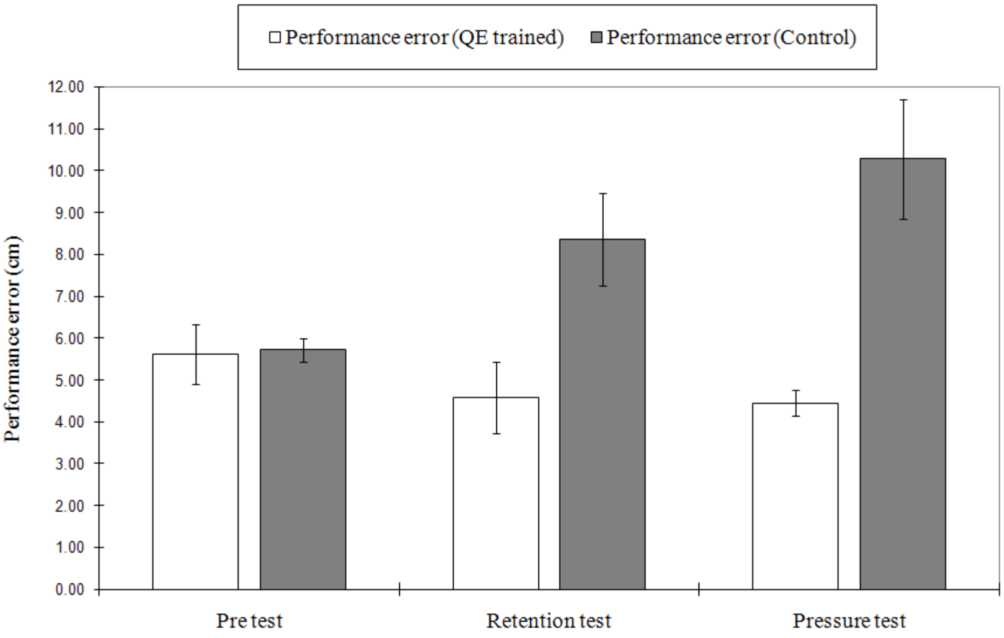


***Figure 8.2***: *Performance error (cm) for QE trained and Control groups for pre-test, retention test and pressure test.*

**Average Performance Error (laboratory)**

ANOVA revealed no significant main effect for test ($F(2, 40) = 1.97$, $p = .15$, $\eta_p^2 = .09$). However, there was a significant main effect for group ($F(1, 20) = 21.58$, $p < .001$, $\eta_p^2 = .52$), and a significant interaction effect ($F(2, 40) = 5.77$, $p < .01$, $\eta_p^2 = .22$). Follow-up t-tests revealed no significant differences between groups for pre-test ($t(14.33) = .13$, $p = .90$). However, the QE trained group (mean = 4.58, *SD* = 2.98) did perform significantly better than the control group (mean = 8.37, *SD* = 3.51) during the retention test ($t(20) = 2.74$, $p < .05$). Furthermore, the QE trained group (mean = 4.45, *SD* = 1.04) performed significantly better than the control group (mean = 10.28, *SD* = 4.49) during the pressure test ($t(9.81) = 4.01$, $p < .005$). Pre-test and test phase average performance error data are presented in Figure 8.2.

**Regression Analysis**

Results from the regression analysis revealed that QE duration predicted 43% of the variance in average performance error during the test phase ($R^2 = .43$, $\beta = 13.93$, $p < .005$).

## Competitive Performance

***Putts per Round***. ANOVA revealed no significant main effect for group ($F(1, 20) = 2.20$, $p = .15$, $\eta_p^2 = .10$). However, there was a significant main effect for time ($F(1, 20) = 13.92$, $p < .005$, $\eta_p^2 = .41$), and a significant interaction effect ($F(1, 20) = 11.70$, $p < .005$, $\eta_p^2 = .37$). Follow-up t-tests revealed no significant differences between groups at pre-training ($t(20) = -55$, $p = .59$), however, the QE trained group (mean = 27.61, SD = 1.93) did display significantly fewer putts per round than the control group (mean = 29.89, SD = 3.11) at post-training ($t\ (20) = 2.11$, $p < .05$). Within groups, the QE trained group displayed a significant reduction in putts per round from pre-training to post-training ($t(11) = 6.18$, $p < .001$), whilst the control group displayed no significant difference in performance between pre-training and post-training ($t(9) =.18$, $p = .86$). Putts per round data are presented in Figure 8.3.

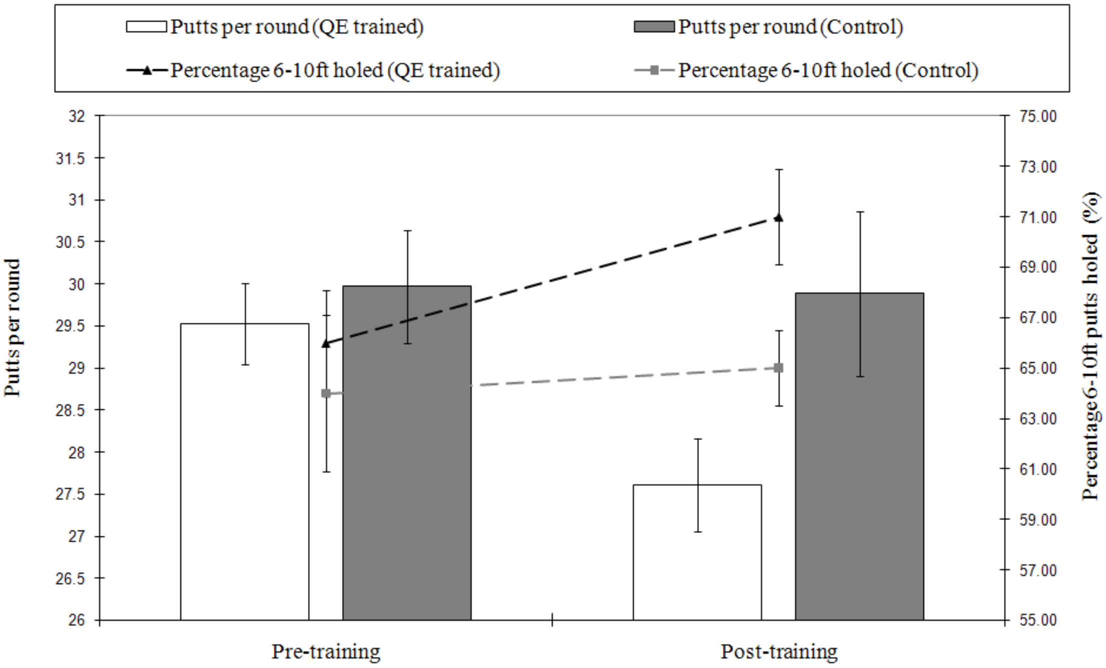


***Figure 8.3****: Competitive performance; putts per round and percentage 6-10ft putts holed (%) for QE trained and control groups pre training and post training.*

***Percentage 6-10ft Putts Holed.*** ANOVA revealed no significant main effect for group ($F(1, 20) = 1.75$, $p = .20$, $\eta_p^2 = .08$), and no significant interaction effect ($F(1, 20) = 2.33$, $p = .14$, $\eta_p^2 = .10$). However, there was a significant main effect for time ($F(1, 20) = 5.36$, $p < .05$, $\eta_p^2 = .21$). Follow up tests revealed no significant difference between groups at pre-training ($p$ = .686) however the QE trained group holed significantly more putts from 6-10 ft than the control group post training ($p < 0.05$).

## 8.4. Discussion

The purpose of the present study was to examine the effectiveness of a QE training intervention aimed at optimising the gaze control and putting performance of elite golfers in a laboratory setting and under conditions of heightened anxiety. Furthermore, the present study aimed to test whether the potential benefits of training the QE translated into improvements in *real* competitive putting performance.

### Hypothesis 1: Retention

There were no differences in the performance levels (percentage holed or average performance error) of both groups at baseline (pre-test), indicating that both groups started from similar levels of performance. Contrary to the predictions of hypothesis 1, although the QE trained group holed more putts than their Control group counterparts during the retention test (45% vs. 59%) this difference was not statistically significant (Figure 8.1). However the QE trained group did exhibit significantly lower average performance error than the Control group (4.58cm vs. 8.37cm; Figure 8.3), reflecting that they consistently left the ball closer to the hole on misses, demonstrating superior distance control, a strong determinant of putting proficiency (Tierney and Coop, 1998).

The QE data (Figure 8.1) revealed that both groups had comparable QE durations at baseline (pre-test), suggesting that any subsequent changes in duration should be the result of the training provided. As expected, while the Control group displayed no significant change in QE from pre-test to retention test ($p$ = .31), the QE trained group displayed a significant increase ($p < .05$) in QE duration, supporting the effectiveness of the training intervention (Figure 8.1). However, in contrast to the predictions of hypothesis 1, although the QE trained group displayed longer mean QE durations than the Control group (2817ms vs. 2203ms) during the retention test, this difference was not statistically significant (Figure 8.1).

Although differences in the percentage of putts holed and QE duration in the retention test were non-significant, they were in the predicted direction. The regression analysis adds further support to the importance of longer QE periods in putting, with longer QE periods being strongly predictive of better distance and line judgments (less error). Results from study 4 (chapter 7) revealed significant differences between QE-trained and control groups; however this used novice performers and was carried out over a longer period (400 putts of training). The lack of statistical difference in the current study is therefore likely due to a ceiling effect resulting from the use of elite golfers, large within group variations in performance and the lack of statistical power caused by the relatively small sample size.

**Hypothesis 2: Pressure**

The purpose of the pressure test was to examine if QE training might offer further benefits in terms of helping golfers maintain their effective QE durations even when under pressure (see study 4, chapter 7). The MRF-3 data supports the effectiveness of the anxiety manipulation, indicating that both groups experienced significantly more cognitive anxiety during the pressure test than the retention test (Table 8.1). The anxiety levels are similar to those reported in previous research in both laboratory and competitive settings (e.g. Krane 1994; Smith et al. 2001; Wilson et al. 2007; studies 1, 2, 3 & 4).

Consistent with the predictions of hypothesis 2, while both groups experienced comparable levels of anxiety, this had differential effects on their gaze control and performance. Specifically, while there were non-significant differences in QE at retention, the Control group displayed significantly shorter QE durations (Mean = 1404ms) than the QE trained group (Mean = 2984ms; Figure 8.1) under pressure. This reduction in the efficiency of goal-directed control when anxious is consistent with the predictions of attentional control theory (Eysenck et al. 2007) which has previously been tested using the QE in basketball free-throw shooting (studies 1 & 2, chapters 4 & 5) and soccer penalty shooting (Wood and Wilson 2010). Eysenck et al. argue that anxious individuals are more distractible, as anxiety increases the influence of the stimulus-driven attentional system at the expense of goal-directed control.

The impairment of effective attentional control (QE) experienced by the Control group resulted in subsequent performance degradation; or choking (Gucciardi et al. 2010). Specifically, the Control group only holed an average of 36% of putts during the pressure test (compared to 45% at retention), while the QE trained group holed an average of 60% (up from 55% at retention; Figure 8.1). Moreover, the Control group also exhibited significantly greater performance error than the QE trained group during the pressure test (Figure 8.2). Thus, consistent with the study by Vickers and Williams (2007) individuals who maintained or increased their QE periods under pressure, were able to maintain or exceed performance from non-pressure performance levels. More importantly, the results mirror findings from study 4 (chapter 7), revealing that performers can be trained to maintain effective QE periods. In that study, the Control group also performed significantly worse in the pressure test than the QE trained group, holing significantly fewer putts and missing by a greater distance.

### Hypothesis 3: Competitive Performance

There were no differences in the competitive performance levels (putts per round or percentage of 6-10ft putts holed) between both groups at baseline (pre-training), indicating that both groups started from similar levels of putting performance. In line with the predictions of hypothesis 3, the QE trained group made significantly fewer putts per round than the Control group at post-training (27.6 vs. 29.9; Figure 8.3), demonstrating a positive transfer of training to competitive play (see Adolphe et al. 1997; Harle and Vickers 2001). Specifically, the performance data revealed that while the Control group displayed no change in performance following training, the QE trained group reduced their mean number of putts per round by 1.92 shots and holed 5% more putts from 6 to 10 feet (Figure 8.3).

There may be a number of mechanisms by which the QE impacts upon performance in this way, consisting of both visuo-motor control and psychological control elements. First, as highlighted for simple reaching and grasping tasks (e.g., Neggers and Bekkering 2000); well-learned visually guided tasks (Land 2009); and sport skills (Vickers 2009), the motor system tends to be more accurate when provided with timely information about targets from the gaze system. In effect, by holding a ball focused QE throughout the putting stroke and through impact, golfers are able to ensure a more accurate contact with the sweet spot of the putter, ensuring more consistent ball strike. Second, the QE may provide the ‘external focus of attention’ described by Wulf and colleagues (see Wulf 2007) or the ‘external cue’ described in Singer’s (2002) 5-step pre-performance routine. Singer advocates focusing on an external cue to prevent athletes from focusing on internal or external distracters, negative thoughts, or the mechanics of skill execution (Singer, 2002). As the stimulus-driven attentional system is more active when performers are anxious (Eysenck et al., 2007), such internal and external distracters are more likely to influence pressure putts. The QE may therefore also help provide a focus on what is controllable (ball strike) rather than what is not (a successful outcome) when golfers are under pressure.

## Implications

The current study meets the call of Williams and Grant (1999) for research to attempt to determine whether pre-post differences in clinical settings transfer to the sporting domain. In this sense the current study furthers the work in study 4 (chapter 7) and shows that the benefits of QE training may transfer to the ‘real’ competitive world of golf, and to experienced golfers as well as novices. The findings of the present study suggest that the QE strategy is easily incorporated as part of a pre-performance routine that can be learned quickly and applied on the course. Pre-performance routines (task relevant behavioural and cognitive routines) have long been posited as a useful strategy for maintaining effective concentration in pressurised environments (e.g. Moran 1996) and for alleviating choking (Mesagno, Marchant & Morris, 2008). Indeed golfers themselves have identified attentional control, the ability to maintain concentration and resist distraction, as a critical psychological skill for optimal performance (Bois, Sarrazin, Southan & Boice, 2009; Hellstrom 2009b).

It has been highlighted that at high levels of golf, even minor improvements in performance can make a major difference (Cohn, Rotella & Lloyd, 1990). When compared to putting statistics from the current PGA Tour season the magnitude of the recorded improvements for these golfers are substantiated. For example, according to the 2010 PGA Tour putts per round statistics, if a golfer ranked last (195th), experienced an improvement of 1.92 putts per round, he would climb 167 places to 28th in the rankings for this statistic (PGA Tour Putting Statistics 2010). Furthermore, as research has shown that a low number of putts per round is strongly associated with better overall golf performance (lower scores) and higher earnings on the PGA Tour (see Hellstrom 2009a for a review), this improvement is likely to be highly beneficial to a golfer. However, it should be noted that the putts per round measure of performance may have been influenced by the participants' short game performance (i.e. chip, pitch or bunker shots) and should be acknowledged as a limitation. Therefore, future research should perhaps adopt the putts per greens reached in regulation (GIR; the number of greens reached in two shots (or less) than par for the hole) as a more sensitive measure of competitive putting performance (see Hellstrom 2009a).

## 8.5. Conclusion

To conclude, the current study investigated the effectiveness of a QE training intervention aimed at optimising the gaze control and performance of elite golfers in both a laboratory-based putting task and 'real' competitive performance. Consistent with previous research and predictions, the QE intervention acted to insulate golfers from the debilitating effects of anxiety upon performance by ensuring they maintained effective gaze control (QE durations) in a pressurised environment. Moreover, the QE trained group reported significantly improved performance in a competitive setting, with an improvement in competitive putting performance of 1.92 putts per round and 6% more holed putts from 6 to 10 feet. From an applied perspective, the findings suggest that QE training may provide a useful psychological technique, as part of a pre performance routine to aid performance under pressure and improve performance in competitive environments.

# Chapter 9. General Discussion

The initial aim of this series of studies was to examine the influence of cognitive anxiety upon visual attentional control during the execution of the free throw, a skill classified as a far aiming targeting task. In study 1 (chapter 4) the QE was adopted as an objective measure of optimal visuo-motor control and the attentional control theory (ACT; Eysenck et al, 2007) was examined as a theoretical framework for understanding the disruption of attentional processes due to heightened anxiety. Study 2 (chapter 5), involved a re-analysis of the data from study 1, and examined the influence of anxiety upon a form of visuo-motor control which has been specifically affirmed for the basketball free throw; the location suppression hypothesis (LSH). Study 3 (chapter 6) then examined the utility of a QE training regime, aimed at improving robustness against anxiety by guiding optimal visuo-attentional control. The free-throw was again adopted and subjects were exposed to a weeklong intervention which guided a lengthy QE fixation and suppression of vision. Findings were discussed from what Vickers (2007) describes as the cognitive neuroscience perspective of the QE. In study 4 & 5 (chapters 7 & 8) a golf task was adopted, to examine the utility of QE training in a different visuo-motor task with different attentional requirements. QE training aimed at improving the expediency of learning among novices (study 4) and the mastery of skills among experts (study 5) was assessed. Results were discussed from a more applied sport psychology perspective.

Studies within this thesis have made a significant addition to the sports psychology, attention and motor learning literature. These additions include (1) a greater understanding of visual attentional control in targeting tasks and the influence of anxiety upon visual attentional control; (2) evidence to support the use of the ACT as a theoretical framework for understanding the influence of anxiety on attentional processes when executing visuo-motor skills; (3) evidence to support the notion of QE training to improve the learning and subsequent robustness of visuo-motor skills, specifically in highly anxious environments; and finally (5) evidence to support the use of QE training among an expert population to improve performance and robustness under pressure in competitive environments.

The proceeding section offers a discussion of how findings within this thesis collectively contribute to the literature base.

## 9.1. Summary and Discussion of Findings

### 9.1.1. The Influence of Anxiety on Visual Attentional Control, Support for the ACT

The results from study 1 and 2 (chapters 4 & 5) support findings from previous research highlighting the important role of the QE in free throw shooting (Harle & Vickers, 2001; Vickers, 1996) and jump shots (Oudejans et al., 2005). Specifically performers displayed significantly longer QE durations on hits than on misses. Results show that the QE period was significantly reduced in the high threat condition (34%). QE offset was also changed under anxious conditions; meaning that the QE was initiated at the same point, but was cut short as a result of anxiety. Furthermore performers switched from suppressing vision by blinking or allowing eye to move freely, to fixating the occluding ball and hands. Instead of adopting the optimal LSH attentional strategy, anxious participants' attention appears to have been 'captured' by the ball as it occluded the target. The disruptions in visual attentional control (QE) led to deterioration in performance. This result is in conjunction with previous research highlighting that visual attentional disruptions lead to breakdown in visuo-motor performance (Janelle, 2002; Behan & Wilson, 2008).

In accordance with the cognitive neuroscience perspective of the QE, a reduced period of cognitive preprogramming may prevent the optimal organisation of neural pathways needed for accuracy. Corbetta & Shulman (2002) propose that cognitive (top-down) factors such as knowledge, expectation and current goals interact with sensory (bottom-up) factors, such as visual and auditory inputs, during the control of attention. The QE may help maintain effective goal-driven attentional control, while reducing the impact of the stimulus-driven attentional system, leading to improved performance.

A reduction in QE duration, as a result of heightened pressure, may reflect an impairment of attentional control in terms of the mechanisms highlighted by Eysenck et al. (2007). Whilst longer QE periods allow performers an extended duration of programming (goal directed control) and minimize distraction from other environmental cues (stimulus-driven control); anxiety causes an increased influence of the stimulus driven attentional system, shortening the QE and leading to less accurate performance. ACT suggests that anxiety causes a disruption in attentional control as an individual's processing resources are more likely to be diverted away from task relevant stimuli and towards more salient task irrelevant stimuli. This is assumed to be the case irrespective of whether these stimuli are external (e.g., environmental distractors) or internal (e.g., worrying thoughts). While study 2 provides support for a diversion of attention towards external distractions (i.e., the ball) future research should examine *how* and *why* internal distractions influence visual attentional control.

Findings from studies 1 and 2 support those of other researchers suggesting that there is both an optimal visual attentional control strategy in far aiming tasks, and that this strategy is impaired under anxious conditions. Results also support the notion that the QE is an objective measure of the efficiency of visual attentional control. Following these results studies 3, 4 and 5 met the calls of researchers to examine the utility of a QE training programme to help performers to enhance optimal visual attentional control, maintain it when anxious and therefore improve the quality and robustness of performance.

### 9.1.2. QE Training

#### Learning Effects

Results from studies 3 and 4 (chapters 6 & 7) support the use of QE training to enhance visual attentional control; specifically QE trained groups had significantly longer QE durations than control groups. In study 3 improved QE was accompanied by improved performance among the QE trained group, suggesting that QE training had enhanced the expediency of learning. Although previous research has examined the impact of attentional focus training on the expediency of motor skill learning (Wulf, 2007; Lam et al., 2009) these are the first results to implicate the beneficial role of QE training. From a cognitive neuroscience perspective QE training likely promoted an effective form of goal-directed attentional control (Corbetta et al., 2008) that enabled an efficient neural network for specialized motor planning that integrates visual information with motor commands (Janelle et al., 2000; Land, 2009). However several other theoretical approaches to the learning and mastery of motor skills point to the role of attention (see study 1, chapter 4). Both Wulf and colleagues (see Wulf, 2007) and Singer (2000, 2002) propose that an external focus of attention can aid the learning and robustness of skills, by preventing an inward focus of attention. In this sense it may be that QE training simply provides a functional way to optimise external attention. An alternative explanation is that QE training might create a form of implicit learning, where learners are partially protected from developing explicit rules by focusing only on the external target, and not movement control (see Lam et al., 2009). However, as we did not assess the number of explicit rules generated by both groups (Masters & Maxwell, 2008), it is not possible to determine if QE training does act to reduce the accrual of explicit knowledge (cf. analogy learning, Lam et al., 2009).

### Pressure Effects

Performance data from the pressure tests in study 3 and 4 offer support for the notion that QE training may protect individuals from the negative influence of anxiety. QE trained groups managed to maintain performance at retention test levels, whereas control groups displayed a significant reduction in performance. These findings were supported by gaze behaviour data as experts managed to maintain their QE above a critical threshold required for accurate performance.

In study 3 reductions in performance displayed by the control group when under pressure were not coupled with reductions in QE. A potential explanation comes from the particularly low QE durations of the control group. As they had received no training the QE durations during the retention test conditions were already low (~375 ms), and of similar durations to those reported in studies 1 and 2 for performers who ‘choked’ under pressure. It may have been the case that, despite a non significant drop in QE, the durations were already low, pointing to a ‘floor effect’ (see study 1, chapter 4).

Overall results point to the role of QE training in the prevention of performance deterioration by maintaining the QE above a critical threshold required for accurate performance. Findings from both study 3 & 4 are pointing towards an optimal duration of the QE period, which has been suggested in previous research (Williams et al, 2002a; Behan & Wilson, 2008).

### 9.1.3. QE Training Among Experts

Study 5 (chapter 8) examined a brief QE training intervention among an expert population of golfers. Although the QE trained group displayed significant improvements in QE as a result of the intervention, in a laboratory based retention test, both the QE trained and control group displayed similar QE durations. QE trained and control groups also had similar levels of performance, as measured by the number of putts holed. However, although performance (as measured by number holed) was not significantly different, average performance error was. This suggests that the QE training had in some way influenced the distance control of the QE trained group, likely due to a lengthy fixation on the hole. Future research may wish to focus on an examination of gaze behaviours towards the hole and other abstract targets, rather than gaze behaviours on the ball (see Lier, Kamp & Salvesbherg, 2008).

Results from study 5 (chapter 8) provide support for previous findings within this thesis. Firstly expert golfers who had received a brief QE training intervention performed significantly better and displayed significantly longer QE periods, than their control group counterparts, in a high anxious condition. This supports findings from studies 3 and 4 (chapters 6 & 7) showing that QE training enables performers to maintain optimal goal directed visual attentional control. In contrast the control group displayed deterioration in visual attentional control and performance under pressure.
Among a skilled population the benefits of QE training may only be evident under anxious or pressurised conditions. Given that both the QE trained and control group consisted of elite golfers, it is unsurprising that their QE durations and performance were similar at retention. In this sense a relatively short QE training intervention may have equipped the experts with a strategy that could be implemented at times when it was needed most, allowing for maintenance of the normal neurological processes and therefore higher levels of performance.

### Competitive Performance

Study 5 (chapter 8) meets the call of Williams and Grant (1999) for research to attempt to determine whether pre-post differences in clinical settings transfer to the sporting domain. In this sense the current study furthers the work in study 4 and shows that the benefits of QE training may be effective among an expert population and transfer to the 'real' competitive world of golf. Specifically the performance data revealed that while the Control group displayed no change in performance following training, the QE trained group reduced their mean number of putts per round by 1.92 shots and holed 6% more putts from 6 to 10 feet (Figure 8.2). This corroborates previous findings showing that QE training can lead to improvements in competitive performance (Adolphe et al., 1997; Harle & Vickers, 2001). Although gaze data was not collected during the competitive rounds of golf (as will be discussed in section 9.3) it is assumed that performance was superior for the QE trained group due to more effective visual attentional control (QE). Again it seems that QE training had equipped participants with a strategy that can be adopted during times of pressure.

## 9.2. Implications

Janelle (2002) has previously suggested that attentional control is one of the most critical psychological skills to perform effectively in sports. The studies in this thesis help further our understanding of how attentional control and skilled performance might break down under pressure. Results corroborate findings from previous research (Adolphe et al., 1997; Harle & Vickers, 2001) demonstrating that performers can be taught to develop a longer QE period, with subsequent improvements to performance. Furthermore the findings in this thesis are the first to highlight the benefits of QE training among novice performers. This has implications for both scientific enquiry and applied practice in motor learning.

The benefits of QE training highlighted in this study offer an insight into a potential future direction for motor skill coaching. Much of the guidance currently given by coaches focuses upon the mechanics of the movement and draws an individual's attention inwards, something that has been shown to be counterproductive (Wulf, 2007). However, difficulties may be encountered when attempting to direct a performer's focus of attention to external sources (Bell & Hardy, 2009) and away from explicit movement rules (Masters & Maxwell, 2008). QE training may act as a practical and easily applicable training regime that acts to focus an individual's attention correctly, and help optimally coordinate gaze and motor control.

Results from this thesis may also have implications for the training of skills in non sporting environments. For example Wilson, McGrath, Vine et al. (2010a) have examined differences in the visual control of expert and novice laparoscopic surgeons using virtual reality simulators. Subjects performed a task whereby ten flashing balls set at different heights and depths, must be touched using two instruments, one held in each hand. Expert performers appear to maintain an anchored fixation on the target (flashing ball) whilst manoeuvring the tool, where as novice performer tend to switch visual attention between the target and the tools. These findings suggest that gaze control parameters predict proficiency in generic visuo-motor skills (such as laparoscopic surgery) as well as sporting specific tasks. In this sense training novice laparoscopic surgeons to adopt the visual control pattern of expert surgeons may expedite learning and lead to more robust skills. This would have particular relevance to surgical training as skills robust from distraction, pressure and time constraints are essential for safety (see Wilson, McGrath & Coleman, 2010b). Future research examining visual attentional control in non-sporting environments is therefore warranted.

While study 5 (chapter 8) provides no support for previous research which has shown that QE training aids expert performance (Adolphe et al., 1997; Harle & Vickers, 2001), results are the first to show that QE training can help expert performers to maintain high levels of performance in, the inevitably pressurised, competitive setting. Pre-performance routines (task relevant behavioural and cognitive routines) have been posited as a useful strategy for maintaining effective concentration in pressurised environments (e.g. Moran, 1996) and may act to alleviate choking (Mesagno, Marchant, & Morris, 2008). Indeed golfers themselves have identified attentional control, the ability to maintain concentration and resist distraction, as a critical psychological skill for optimal sport and golf performance (Bois et al., 2009; Hellstrom, 2009b). The findings of the present study suggest that the QE strategy could be incorporated as part of a pre-performance routine to produce high levels of performance and reduce performance deterioration under pressure. Furthermore, the findings highlight the QE as an effective strategy that can be applied specifically at the point of pressure (Hill et al., 2010). Future research is encouraged to replicate these findings in a wide range of sporting tasks (e.g. basketball free-throw, rifle shooting, archery).

Previous research has suggested that there may be a specific optimal QE duration for each sporting task (Behan & Wilson, 2008). Results from this thesis support this notion. In basketball it appears that the QE occurs early in the movement phase, and is then stopped by the ball and hands entering the field of view. The skilled performers used in study 1 and 2 appear to display QE durations above 600ms on successful shots, and this is befitting with previous research (see Vickers, 2007). In study 3, the QE trained free throwers displayed QE durations of ~500-575ms (during retention and pressure tests) and subsequently outperformed their control group counterparts who displayed QE durations of ~300-375ms.

In golf it appears that QE durations above 1000ms are important for accurate performance. In study 4 the control group displayed QE durations of approximately 1200-1500ms during retention tests, in which the matched the performance of a QE trained group who displayed QE durations of approximately 3200-3500ms. This therefore highlights that QE durations have an upper limit after which they fail to benefit performance any further. Interestingly, in study 3 the control group displayed a reduction in QE below 1000ms, which lead to a significant reduction in performance. Future research should attempt to establish the optimal thresholds of QE for different sporting tasks, something that will be discussed later in this chapter.

The yips, a colloquial term for a psycho neuromuscular dysfunction occurring during putting, can be a problem for both novice and expert golfers (Smith et al., 2000). The Yips is characterised by jerks and tremors prior to or during the putting stroke and is considered as a golf specific form of ‘choking’ (Otten, 2009). QE training may be a plausible intervention for the alleviation of the Yips, by preventing a golfer from trying to exert conscious control over skills that are normally performed automatically (Kremer & Moran, 2008).

From a theoretical perspective it is clear that ACT provides a useful framework by which visual attentional control in stressful environments can be examined. While there have been few studies within the cognitive psychology literature which have tested its main predictions, research examining ACT should continue to adopt ‘process pure’ tasks which assess inhibition and shifting functions of attention (e.g. Derakshan et al., 2009). Studies from the sports literature which have examined ACT have assessed state anxiety whereas studies within the cognitive psychology literature tend to asses trait anxiety. Future research examining state anxiety and the disruption of attention within a sporting environment is therefore warranted. Furthermore studies adopting sporting tasks have revealed that alterations in visual attentional control lead to a deterioration in performance (as studies 1 & 2; see Wilson et al., 2009). This is in contrast to studies adopting ‘process pure’ tasks (e.g., anti-saccade tasks) for which visual attentional disruptions tend not to lead to deteriorations in performance (see Derekshan et al., 2009). This likely represents the importance of the timely coordination of visual attention and actions for the accurate execution of complex skills. Given the heavy reliance of sports skills on visual attentional control they provide interesting tasks for which to examine ACT.

The QE, as an objective measure of visual attentional control, is an interesting and useful variable to utilise in studies examining ACT. The results of this thesis provide evidence that anxiety causes a disruption in ‘general’ goal-directed attentional control. For example study 1 & 2 (chapters 4 & 5) suggest that attention is disrupted (shortened QE) as a result of internal threat (worrisome thoughts), however the process by which internal threat breakdowns the QE is not clear. Why do worrisome thoughts cause a change in the QE fixation? To understand more about how the detection of threat causes a disruption in visual attention, research should examine the process by which attention is directed towards salient or threatening stimuli within the external environment. Therefore, studies should adopt tasks in which the attentional avoidance of threatening stimuli (inhibition) is essential for successful performance. For example previous research in football penalty kicking has shown that anxious individuals tend to fixate the salient and threatening stimulus (the goalkeeper) at the expense of goal-driven task-relevant stimuli (the optimal scoring zones just inside the post of the goal) (Wilson et al., 2009). Wood and Wilson (2010) therefore examined the influence of a distracting goalkeeper (waving his arms) on the performance of penalty takers when anxious. Results offered support for the ACT as shifts in attentional control from a target-focused, top-down attentional strategy (goal focused), to a stimulus-driven (goalkeeper-focused) bottom-up attentional strategy significantly reduced performance. A problem with this research is the degree to which the goalkeeper is considered a threatening stimuli, research needs to adopt tasks with which the external distraction is also deemed threatening (see Nieuwenhuys & Oudejans, 2009).

## 9.3. Limitations and Directions for Future Research

In contrast to the small amount of literature examining LSH (Williams et al., 2002a; Vickers et al., 2000) the current results suggest that LSH is a valid measure of negative attentional control in free-throw shooting. Future research therefore needs to continue to examine the LSH in basketball in order to further our understanding of how and why attentional control is disrupted and performance degraded in anxious conditions. However, as the LSH may be a very specific attentional strategy which is relevant only to skills where the target is fully occluded during the completion of the motor act (see Williams et al., 2002a), it is important that researchers also attempt to determine objective measures of effective attentional control for other skills.

This thesis adopted two visuo-motor tasks (basketball free throw and the golf putt) for which the QE has been previously defined. Future research should also attempt to define the specific QE period for other sporting tasks. As Janelle et al. (2000) suggest optimal durations and locations of QE may exist for each different sporting task. Furthermore, research should attempt to understand the specific mechanisms underlying the QE. Results offer strong support for the benefits of a QE fixation in accurate visuo-motor skills execution, however the mechanisms underlying its positive influence on performance are not fully understood (Wilson, 2008). As the mechanisms underlying the QE are yet to be fully understood, future research should remain open to alternative perspectives on how the QE works. To explain the above findings the QE was considered from a cognitive neuroscience perspective (see chapter 2). This perspective implicates the role of cognitive pre programming and the organisation of neural networks in the accurate execution of skills and draws upon evidence from the cognitive neuroscience literature (e.g. Posner & Raichle, 1994;

Corbetta & Schulman, 2002). Future research should consider other theoretical approaches to the expediency of motor skill learning within the sports psychology and motor learning literature to aid the understanding of *how* QE training may work.

The QE is proposed as a period of cognitive pre-programming, whereby experts display longer fixations to extract critical information and programme accurate movement responses. However, this confounds research from the visual search literature suggesting that expert performers can extract critical information more quickly and efficiently than novices (Williams et al., 1994a). Although the cognitive neuroscience perspective of the QE is commonly adopted within the literature, research should examine the extent to which the QE is in fact representative of a period of cognitive pre-programming. To identify the attentional processes involved in the QE, research should adopt alternative measures such as Electroencephalography (EMG; see Janelle et al., 2000) Transcranial magnetic stimulation (TMS; see Moran, 2009) or Magnetic resonance imagery (MRI; see Milton et al., 2007). A recent interest in sporting environments from cognitive psychologists should allow for the adoption of such measures (Moran, 2009), providing a more detailed analysis of the neural mechanisms involved in the planning of visually guided actions (Milton et al., 2007).

In conjunction with the use of the above measures research should also consider experimentally manipulating the timing and duration of the QE, to aid the understanding of *how* or *why* it works. Previous research has adopted this approach using a billiards task (Williams et al., 2002a) in which performers were asked to close their eyes so that viewing time was reduced. Results showed that when the available viewing time was shortened, although QE was also shortened, expert performers managed to maintain a QE duration that was sufficient to maintain performance. In contrast less expert performers displayed a reduced QE and a subsequent reduction in performance. Experts appear to have reduced the time needed to prepare for and ‘line up’ the shot to enable them enough time for a lengthy final fixation on the cue ball (QE). To further these interesting findings research needs to experimentally shorten (and lengthen) QE until performance suffers, so that optimal thresholds can be found. As results from the Williams et al., (2002a) study suggest, performers can, if needed to, adopt much more succinct and efficient QE periods whilst still maintaining performance. Therefore although the performers of closed self paced skills may ‘self select’ a lengthy QE duration, the same motor response production may be possible with much shorter QE durations. These findings would therefore suggest that the cognitive pre-programming approach may not fully explain the benefits of a QE fixation.

An alternative approach to examine the ‘cognitive pre-programming’ explanation for the QE would be to manipulate the complexity of the sporting task. Again Williams et al., (2002a) adopted this approach by increasing the complexity of a billiards shot. Their results found that as the complexity of the shot increased the QE was lengthened. If the QE reflects a period of pre-programming then more complex tasks should be characterised by longer QE periods. However, although the task was more complex (i.e. striking billiards balls off of cushions instead of having a direct shot), the motor action it’s self was almost identical (i.e. the delivery of a cue towards a cue ball). Therefore while choice of shot (i.e. which angle to strike the ball at and which part of the cushion to contact) may have required good decision making skills, I would argue that the final motor action would not require any longer ‘pre-programming’. It may therefore be that the longer QE period simply reflects a longer period of quiescence needed for the preparation of a more daring or difficult shot (sport psychology perspective; see chapter 2), which would relax the performer and allow for an automatic motor response (see Janelle et al., 2000).

In order to understand the role of the QE, future research should attempt to increase the complexity of the motor action it’s self. If the motor response required to be accurate is more complex, then longer QE periods would be required to pre-programme this movement. For example the simple task of throwing a ball towards a target could be made more complex by asking performers to place a spin on the ball. The constraints of the task are the same, but the production of a spinning action should require more pre-programming and therefore longer QE periods. Future QE training studies could consider including additional groups (as well as QE trained and movement trained) to understand *how* QE training influences performance. For example a group could be trained to maintain the same focus of visual attention (i.e. stable before the final motor action) but on a location which is not relevant to the task (i.e. a random location on the green when putting).

An alternative approach to the cognitive neuroscience perspective of the QE is that QE may simply promote a more general focus of outward or external attention (Wulf, 2007; Singer, 2000) or acts as a form of implicit learning (Lam et al., 2009). Research should focus on examining the relationship between variables adopted by different motor learning theorists (such as the accrual of explicit knowledge, self report measures of the direction of overt attention). Research should also consider that this relationship may be bi-directional. For example while QE training may promote implicit learning, implicit learning may also prevent an inward focus of attention and promote efficient external visual attentional control.

While the studies in this thesis adopted a cognitive psychology approach to examining the QE, alternative modes of design and analysis may offer further insight into *how* and *why* the QE works. For example the ecological psychology view of the QE (see chapter 2) could be adopted to explain the benefits of the QE. Although the coding rules and frameworks applied to this data do not promote an ecological viewpoint, future research should consider examining gaze behaviour data from both the ecological psychology and cognitive neuroscience perspectives (see Vickers, 2009).

An interesting suggestion made in previous research (Janelle, 2002) is that QE training may act to craft a change in the mechanics of a skill, leading to greater accuracy. Although the temporal phases of movement were calculated throughout each of the studies within this thesis, no specific predictions were made and no data was analysed. A more detailed analysis of putter acceleration and kinematics is needed to examine this idea (e.g., Cooke, Kavussanu, McIntyre, & Ring, in press). Subsequent studies might seek to adopt such measures to determine if more effective attentional control might influence processes underpinning performance (e.g., more consistent putter head position at contact). However, it is not clear that even detailed kinematic analyses would provide more insight into the processes underlying putting performance under pressure. For example, despite assessing a wide range of kinetic and kinematic variables, Mullen and Hardy (2000) found no conclusive ‘process’ changes due to pressure, despite putting performance being significantly impaired. Furthermore, recent research by Karlsen, Smith and Nilsson (2008) found that the putting stroke itself may have limited influence on the amount of putts holed. These authors found that the direction variability in the putting strokes of elite players was very low and should relate to 95% of 4m putts being holed (given perfect conditions). However, statistics from the Professional Golf Association (PGA) Tour for the 2009 season reveal that the percentage of putts holed from ten to fifteen feet is less than 30% (PGA Tour Putting Statistics, 2009).

A limitation of this thesis is the relatively low sample sizes adopted in each study. Resources limitations, participant drop out and time constraints meant that it was not possible to test more participants, particularly in the training studies. Future research replicating these studies or adopting a similar design should strive to increase the sample size to give clearer and potentially stronger findings. In contradiction to this suggestion, QE and anxiety related research adopting a single subject design is also interesting. Examining how an individual experiences pressure and adopts specific behavioural strategies during competitive performance may provide new and more detailed insights into visual attentional control and the anxiety performance relationship. Although every attempt was made to recruit golfers with a low handicap, an average handicap of 2.78 cannot be considered fully elite. For a clearer understanding of the benefits of QE among elite athletes in the competitive setting studies would ideally recruit golfers who are participating in the world's best competitions (PGA tour), single subject design research is the most likely way that this will be achieved.

A weakness of the current study is that no evidence of gaze control during competitive performance was obtained. Gaze data would be necessary to establish whether improvements in performance were attributable to efficient gaze control when playing in pressurised competition. However, owing to the practical limitations of wearing eye trackers whilst competing this was not possible. Although competitive settings are generally accepted as pressurised environments, the current study did not assess the golfer's levels of anxiety during performance. Therefore, future research is encouraged to include self-rated (e.g., MRF-3) and psycho physiological (e.g., heart rate) measures of anxiety throughout performance to evaluate whether the QE training regime is effective in improving performance for high pressure putts in a competitive settings. Advances in the technology and a reduction in the costs of eye trackers may lead to an increase in the popularity in the use of eye trackers in both academic and sporting environments. This would inevitably lead to more ecological validity as eye movement data could be collected more frequently and at the specific points of competition pressure. Similarly, the analysis of performance adopted in both study 4 and 5 (number holed and error) do not allow for an analysis of *how* the putt was missed, i.e. too long or too short. A more detailed analysis of putting performance, particularly when in the competitive environment, would be an interesting addition to future research.

A further limitation of the studies within this thesis is that overt visual attention was measured and manipulated, however covert shifts of attention were not assessed. There is a difficulty in both manipulating and assessing the location of covert attention. While self report measures of focus of attention have been used (see Wulf 2007) it is unlikely that performers can accurately recall focus of attention through introspection. While there is strong evidence suggesting that during manually aiming tasks it is unlikely that the location of overt and covert attention differ (see section 2.2) it must still be considered that whilst gaze may be directed to the external cue, covert attentional shifts (e.g., cognitive intrusions; Sarason, 1998) may still take place during the QE period. Any psychological training programmes aiming to help athletes cope with performing in pressure environments should therefore also consider the impact of these internal thoughts and emotions (see Zinsser et al., 2006).

## 9.4. Final Conclusions & Summary of Future Research Questions

The series of studies in this thesis provide support for the predictions of ACT and suggest that the negative influence of anxiety on performance is likely due to disruptions in attentional control. This supports suggestions from previous research that attentional control is one of the most critical psychological skills to perform effectively in sports (Janelle, 2002; Moran, 2009). Support is also found for research highlighting the potential for visual attentional training to aid performance in anxious conditions (Behan & Wilson, 2008).

While there are a number of limitations of the current study which have been highlighted, there are clear directions for future scientific enquiry and implications for the training of skills in sporting (Milton et al., 2007) and non-sporting (Wilson et al., 2010b) environments. Potential directions for future research are summarised below:

- Examine the ACT as a theoretical framework for interpreting gaze related results.
- Examine the specific predictions of the ACT in sporting tasks (e.g. trait anxiety differences and switching and inhibition functions).
- Define the optimal QE durations for specific sporting tasks.
- Examine the mechanisms underlying the QE (e.g. cognitive pre-programming; task and motor skill complexity)
- Adopt neural imaging techniques to examine attentional processes during the QE period.
- Examine the benefits of QE training in 'real world' sporting and not sporting tasks.

While a vast amount of further research is needed, the degree to which this line of enquiry may impact upon applied practise is summarised nicely by Yarrow and colleagues: "an understanding of the neural mechanisms that distinguish elite sportspeople from others not only provides a rational basis for refining future training strategies, but may also open up the possibility of predictive physiological profiling and, in time, genotyping to foretell the likelihood of success at the highest level" (Yarrow et al., 2009, p. 594).

# References

Abernethy, B. (1988). Visual search in sport and ergonomics: It's relationship to selective attention and performer expertise. *Human Performance, 4*, 205-35.

Abernethy, B. (1990). Expertise, visual search, and information pick up in squash. *Perception, 19*, 63-77.

Abrams, R.A., Meyer, D.E. & Kornblum, S. (1990). Eye-hand coordination and oculomotor control in rapid aimed limb movements. *Journal of Experimental Psychology, 15(3)*, 529-543.

Adolphe, R.M., Vickers, J.N., & LaPlante, G. (1997). The effects of training visual attention on gaze behaviour and accuracy: A pilot study. *International Journal of Sports Vision*, *4*, 28-33.

Ansari, T. L., Derakshan, N., & Richards, A. (2008). Effects of anxiety on task switching: Evidence from the mixed antisaccade task. *Cognitive, Affective, & Behavioural Neuroscience, 8(3),* 229-238.

Apter, M.J. (1982). *The Experience of Motivation: The Theory of Psychological Reversals*. London and New York: Academic Press.

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

Bakker, F.C., Oudejans, R.D., Binsch, O., & Van der Kamp, J. (2006). Penalty shooting and gaze behaviour: Unwanted effects of the wish not to miss. *International Journal of Sport Psychology, 37*, 265-280.

Ballard, D.H., & Hayhoe, M.M. (2009). Modelling the role of task in the control of gaze. *Visual Cognition, 17*, 1185-1204.

Bar-Haim, Y., Lamy, D., Pergamin, L., Bakermans-Kranenburg, M.J., & Van IJzendoorn, M.H. (2007). Threat-related attentional bias in anxious and non-anxious individuals: A meta-analytic study. *Psychological Bulletin, 133*, 1-24.

Baumeister, R. F. (1984). Choking under pressure: Self-consciousness and paradoxical effects of incentives on skilful performance. *Journal of Personality and Social Psychology, 46***,** 610-620.

Beckering, H., Adam, J.J., Kingma, H., Huson, A., & Whiting, H.T. (1994). Reaction time latencies of eye and hand movements in single and dual task conditions. *Experimental Brain Research, 97*, 471-476.

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.

Beilock, S.L., & Gray, R. (2007). Why do athletes choke under pressure? In G. Tenenbaum & R.C. Eklund. (Eds.), *Handbook of sports psychology* (3rd ed., pp. 425-444). Hoboken: New Jersey. Wiley & Sons.

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

Binsch, O., Oudejans, R. R. D., Bakker, F.C. & Savelsbergh, G.J.P. (2009). Unwanted effects in aiming actions: The relationship between gaze behavior and performance in a golf putting task. *Psychology of Sport and Exercise 10(6),* 628-635.

Bois, J.E., Sarrazin, P.G., Southon, J., & Boiche, J.C.S. (2009). Psychological characteristics and their relation to performance in professional golfers. *Sport Psychology, 23*, 252-270.

Boutcher, S.H. (2002). Attention and sport performance. In T. Horn (Ed.), *Advances in sport psychology*, 2nd Edition (pp. 441-457). Champaign, IL: Human Kinetics.

Branch, J. (2009). *For free throws, fifty years of practice is no help*. Published 3rd March, 2009, New York Times: http://www.nytimes.com/2009/03/04/sports/basketball/04freethrow.html.

Bridgeman, G., Hendry, D. & Start, L. (1975). Failure to detect displacement of visual world during saccadic eye movements. *Vision Research, 15,* 719-722.

Burton, D. (1988). Do anxious swimmers swim slower? Re examining the elusive anxiety- performance relationship. *Journal of Sport & Exercise Psychology, 10*, 45-61.

Calvo, M. G. (1985). Effort, aversive representations and performance in test anxiety. *Personality and Individual Differences, 6*, 563-571.

Calvo, M. G., Eysenck, M. W., Ramos, P. M. & Jimenez, A. (1994). Compensatory reading strategies in test anxiety. *Anxiety, Stress & Coping: An International Journal,* 7, 99-116.

Carl, J. R. & Gellman, R.S. (1987). Human smooth pursuit: stimulus-dependent responses. *Journal of Neurophysiology, 57(5),* 1446-1463.

Causer, J., Bennett, S.J., Holmes, P.S., Janelle, C.M., & Williams, A.M. (2010). Quiet eye duration and gun motion in elite shotgun shooting. *Medicine & Science in Sports & Exercise, 42(8),* 1599-1608.

Cheng, W-N.K., Hardy, L., & Markland, D. (2009). Towards a three-dimensional conceptualization of performance anxiety: Rationale and initial measurement development. *Psychology of Sport and Exercise, 10*, 271-278.

Cockerill, I.M. & MacGillivary, W.W. (1981). *Vision and sport*, Cheltenham: Stanley Thornes.

Cohn, P. J., Rotella, R. J., & Lloyd, J. W. (1990). Effects of a cognitive-behavioral intervention on the pre-shot routine and performance in golf. *The Sports Psychologist, 4*, 33-47.

Cooke, A., Kavussanu, M., McIntyre, D. & Ring, C. (in press). Psychological, muscular and kinematic factors mediate performance under pressure. *Psychophysiology*.

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

Corbetta, M. (1998). Frontoparietal cortical networks for directing attention and the eye to visual locations: Identical, independent, or overlapping. *Proceedings of the National Academy of Sciences of the United States of America, 95,* 831–838.

Corbetta, M., Patel, G., & Schulman, G.L. (2008). The reorienting system of the human brain: From environment to theory of mind. *Neuron, 58*, 306-324.

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

Cox, R. H., Russell, W. D. & Robb, M. (1998). Development of a CSAI-2 short form for assessing competitive state anxiety during and immediately prior to competition. *Journal of Sport Behaviour, 21***,** 30-40.

De Oliveira, R.F., Oudejans, R.D.D, & Beek, P.J. (2006). Late information pick up is preferred in basketball jump shooting. *Journal of Sports Sciences, 24,* 933-940.

Derakshan, N., Ansari, T.L., Hansard, M., Shoker, L., & Eysenck, M.W. (2009). Anxiety, inhibition, efficiency and effectiveness: An investigation using the anti saccade task. *Experimental Psychology, 56(1),* 48-55.

Easterbrook, J. A. (1959). The effect of emotion on cue utilization and the organization of behavior. P*sychological Review, 66,* 183 – 201.

Ericsson, K.A. (2003). The development of elite performance and deliberate practice: An update from perspective of the expert performance approach. In J. Starkes & K.A. Ericsson (Eds.) *Expert performance in sport: Recent advances in research on sport expertise* (pp. 49-81). Champaign, IL: Human Kinetics.

Eysenck, M.W. (1984). *A Handbook of Cognitive Psychology*, London: Erlbaum.

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

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

Eysenck, M.W., Derakshan, N., Santos, R., & Calvo, M.G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion, 7,* 336–353.

Fisher, A.C. (1976). *Psychology of Sport*. Palo Alto, CA: Mayfield.

Gibson, J.J. (1979). *The ecological approach to visual-perception*. Boston: Houghton Mifflin.

Gould, D.R. & Krane, V. (1992). The arousal-athletic performance relationship: Current status and future directions, in T.S. Horn (Ed.), *Advances in Sports Psychology*, Champaign IL: Human Kinetics.

Gucciardi, D. F. & Dimmock, J.A. (2008). Choking under pressure in sensorimotor skills: Conscious processing or depleted attentional resources? *Psychology of Sport & Exercise 9(1)*, 45-59.

Gucciardi, D.F., Longbottom, J.L., Jackson, B., and Dimmock, J.A. (2010). Experienced golfer's perspectives on choking under pressure. *The Journal of Sport & Exercise Psychology 32*, 61-83.

Hackman, B.B. & Guilford, J.P. (1936). A study of the visual fixation method of measuring attention value. *Journal of Applied psychology, 20(1*), 44-59.

Hanin, Y.L. (1980). A study of anxiety in sports. In W.F. Straub (Ed.), *Sport Psychology: An Analysis of Athlete Behaviour*. Ithaca, NY: Movement Publications.

Hanton, S., Neil, R., & Mellalieu, S.D. (2008). Recent developments in competitive anxiety direction and competition stress research. *International Review of Sport and Exercise Psychology, 1*, 45-57.

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

Hardy, L. (1990). A catastrophe model of performance in sport. In G. Jones & L.Hardy (Eds.), *Stress and Performance in Sport*. Chichester: Wiley.

Hardy, L., Jones, G., & Gould, D. (1996). *Understanding psychological preparation for sport: Theory and practice of elite performers.* Chichester: Wiley.

Hardy, L. & Upton, G. (1992). Interactive effects of cognitive anxiety and physiological arousal upon golfers. *Journal of Sports Sciences, 10***,** 612.

Hellstrom, J. (2009a). Competitive elite golf: a review of the relationships between playing results, technique and physique. *Sports Medicine, 39*, 723-741.

Hellstrom, J. (2009b). Psychological hallmarks of skilled golfers. *Sports Medicine, 39*, 845-855.

Helsen, W.F. & Pauwels, J.M. (1993). A cognitive approach to visual search in sport. In *Visual Search II*, pp. 379-388. London: Taylor & Francis.

Helsen, W.F. & Starkes, J.L. (1999). A mulitdimenasional approach to skills perception and performance in sport. *Applied Cognitive Psychology, 13*, 1-27.

Henderson, J.M. (2003). Human gaze control during real-world scene perception. *Trends in Cognitive Sciences, 7,* 498–504.

Hill, D. M., Hanton, S., Matthews, S. & Flemming, S. (2010). Choking in sport: a review. *International Review of Sport & Exercise Psychology 3(1*), 24-39.

Hoffman, H.G. (2004). Virtual reality therapy. *Scientific American, August*, 58-65.

Howell, D.C. (2002). *Statistical methods for psychology* (5th ed.). Boston MA: PWS-Kent.

Hull, C.L. (1943). *Principles of behaviour*. New York: Appleton-Century.

James W. (1890). *Principles of psychology*. New York: Holt.

Janelle, C.M. (1999). Ironic mental processes in sport: Implications for sport psychologists. *The Sport Psychologist, 13,* 201-220.

Janelle, C. M. (2002). Anxiety, arousal and visual attention: A mechanistic account of performance variability. *Journal of Sports Sciences, 20,* 237 – 251.

Janelle, C.M., & Hatfield, B. (2008). Visual attention and brain processes that underlie expert performance: Implications for sport and military psychology. *Military Psychology*, *20*, 117–134.

Janelle, C. M. & Hillman, C. H. (2003). Expert performance in sport: current perspectives and Critical issues. In K. A. Ericsson and J. Starkes (Eds.), recent advances in research on sport expertise (pp. 19-48). Champaign, IL: Human Kinetics.

Janelle, C.M., Hillman, C.H., Apparies, R.J., Murray, N.P., Meili, L., Fallon, E.A., & Hatfield, B.D. (2000). Expertise differences in cortical activation and gaze behavior during rifle shooting. *Journal of Sport & Exercise Psychology, 22*,167-182.

Janelle, C.M., Singer, R.N., & Williams, A.M. (1999). External distraction and attentional narrowing: Visual search evidence. *Journal of Sport & Exercise Psychology, 21,* 70-91.

Johansson, R. S., Westling, G., Backstrom, A., & Flanagan, J.R. (2001). Eye-hand coordination in object manipulation. *Journal of. Neuroscience, 21*(17), 6917-6932.

Jones, G. (1995). More than just a game: Research developments and issues in competitive anxiety in sport. *British Journal of Psychology, 86*, 449-478.

Just, M. A. & Carpenter, P.A. (1976). Eye fixations and cognitive processes. *Cognitive Psychology 8(4),* 441-480.

Kahneman, D. (1973). *Attention and effort.* Englewood Cliffs, NJ: Prentice-Hall.

Karlsen, J., Smith, G., & Nilsson, J. (2008). The stroke has only a minor influence on direction consistency in golf putting among elite players. *Journal of Sports Sciences*, *26*, 243-250.

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

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

Kremer, J., and Moran, A. (2008). *Pure Sport: Practical Sport Psychology*. Routledge, UK.

Kuhn, G., Tatler, B., Findlay, J. & Cole, G. (2008). Misdirection in magic: Implications for the relationship between eye gaze and attention. *Visual Cognition, 16,* 391-405.

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

Land, M.F. (2009). Vision, eye movements, and natural behavior. *Visual Neuroscience, 26,* 51-62.

Land, M.F., Mennie, N., & Rusted, J. (1999). The roles of vision and eye movements in the control of activities of daily living. *Perception, 28,* 1311–1328.

Lazarus, R. S. (1996). The role of coping in the emotions and how coping changes over the life course. In Magai, C. & Mcfadden, S. H. (Eds.) *Handbook of Emotion, Adult Development and Aging.* San Diego, CA, Academic Press.

Lier, W. V., Kamp J. V. & Salvesbherg D. (2008). Gaze in golf putting; effects of slope. *International Journal of Sports Psychology 39*, 1-18.

Lundqvist, C. & Hassmann, P. (2005). Competitive State Anxiety Inventory-2 (CSAI-2): Evaluating the Swedish version by confirmatory factor analyses. *Journal of Sports Sciences, 23(7),* 727-736.

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

Martell, S. G. & J. N. Vickers. (2004). Gaze characteristics of elite and near-elite athletes in ice hockey defensive tactics. *Human Movement Science 22(6),* 689-712.

Martens, R. (1971). Internal-external control and social reinforcement effects on motor performance. *Research Quarterly, 42*, 107-113

Martens, R., Burton, D., Vealey, R., Bump, L., & Smith, D. (1990). Development of the CSAI-2. In R. Martens, R. Vealey & D. Burton (Eds.), *Competitive anxiety in sport* (pp. 127-140). Champaign IL: Human Kinetics.

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

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

McPherson, S. L. & J. N. Vickers (2004). Cognitive control in motor expertise. *International Journal of Sport and Exercise Psychology, 2*, 274-300.

Mesagno, C., Marchant, D., & Morris, T. (2008). A pre-performance routine to alleviate choking in "choking-susceptible" athletes. *Sport Psychology, 22*, 439-459.

Meshkati, N., Hancock, P. A., Rahimi, M. & Dawes, S. M. (1995). Techniques in mental workload assessment. In Wilson, J. R. & Corlett, E. N. (Eds.), *Evaluation of human work: A practical ergonomics methodology, (*2nd edition), Philadelphia, Taylor and Francis.

Milner, D.A. & Goodale, M.A. (1995). *The visual brain in action.* Oxford: Oxford

University Press.

Milton, J., Solodkin, A., Hlustik, P., & Small, S.L. (2007). The mind of expert motor performance is cool and focused. *Neuroimage, 35*, 804-813.

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.

Moran, A.P. (1996). T*he psychology of concentration in sports performers: A cognitive analysis,* Hove: Psychology Press.

Moran, A. (2004). *Sport and exercise psychology: a critical introduction.* Routledge, UK.

Moran, A. (2009). Cognitive psychology in sport: Progress and prospects. *Psychology of Sport and Exercise*. 10(4), 420-426.

Moran, A., Byrne, A. & McGlade, N. (2002). The effects of anxiety and strategic planning on visual search behaviour. *Journal of Sports Sciences, 20*, 225-236.

Mulder, G. (1986). The concept and measurement of mental effort. In Hockey, G. R. J., Gaillard, A. W. K. & Coles, M. G. H. (Eds.) *Energetics and human information processing.* Dordrecht, Netherlands, Martinus Nijhoff.

Mullen, R. & Hardy, L. (2000). State anxiety and motor performance: Testing the conscious processing hypothesis. *Journal of Sports Sciences, 18,* 785–799.

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

Murray, N. P., & Janelle, C. M. (2007). Event-related potential evidence for the processing efficiency theory. *Journal of Sports Sciences, 25,* 161 – 171.

Murphy, S., Greenspan, M., Jowdy, D. & Tammen, V. (1989). *Development of a brief rating instrument of competitive anxiety: Comparison with the CSAI-2*. Paper presented at the meeting of the Association of the Advancement of Applied Sports Psychology, Seattle,WA.

Neggers, S.F. & Bekkering, H. (2000). Coordinated control of eye and hand movements in dynamic reaching. *Human Movement Science, 21,* 349-376.

Neggers, S.F. & Bekkering, H. (2001). Gaze anchoring to a pointing target is present during the entire pointing movement and is driven by a non visual signal. *Journal of Neurophysiology, 86,* 961-970.

Nieuwenhuys, A., & Oudejans, R.R.D. (2009). Effects of anxiety on handgun shooting behaviour of police officers: A pilot study. *Anxiety, Stress and Coping, 22*, 1–9.

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 & Exercise Psychology, 30,* 171-185.

Norman, D.A. (1969). Memory and attention, New York: Wiley.

Nougier, V., Azemar, G. & Stein, J.F. (1992). Covert orienting to central visual cues and sport practice relations in the development of visual attention. *Journal of Experimental and Child Psychology, 54*, 315-333.

Ohman, A., Flykt, A. & Esteves, F. (2001). Emotion drives attention: detecting the snake in the grass. *Journal of experimental psychology: general, 130(3),* 466-478.

Orlick, T. (1990). *In pursuit of excellence*. Champaign, Illinois: Leisure Press.

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

Oudejans, R. R. D., Koedijker, J., Bleijendaal, I., & Bakker, F. C. (2005). The education of attention in aiming at a far target: Training visual control in basketball jump shooting. *International Journal of Sport & Exercise Psychology, 3,* 197 – 221.

Oudejans, R. R. D., van de Langenberg, R. W., & Hutter, R. I. (2002). Aiming at a far target under different viewing conditions: Visual control in basketball jump shooting. *Human Movement Science, 21*, 457 – 480.

Panchuk, D. & J. N. Vickers. (2006). Gaze behaviors of goaltenders under spatial-temporal constraints. *Human Movement Science 25(6),* 733-752.

Panchuk, D. & J. N. Vickers. (2009). Using spatial occlusion to explore the control strategies used in rapid interceptive actions: Predictive or prospective control? *Journal of Sports Sciences 27(12*), 1249 - 1260.

Parfitt, G. & Pates, J. (1999). The effects of cognitive and somatic anxiety and self-Confidence on components of performance during competition. *Journal of Sports Sciences 17(5*), 351-356.

Pelz, D. (1994). A study of golfers' ability to read greens. In A.J. Cochran & M.R.

Pelz, D. (2000). *Dave Pelz's putting bible*. New York: Doubleday.

Farally (Eds.), *Science and Golf II: Proceedings of the World Congress of Golf* (pp. 181-185). London: E&F Spon.

PGA Tour Putting Statistics (2009). http://www.pgatour.com/r/stats/info/?405.

PGA Tour Putting Statistics (2010). Accessed May 25th :http://www.pgatour.com/r/stats/info/?343.

Planer, P.M. (1994). *Sports Vision Manual*, Harrisburg PA: International Academy of Sports Vision.

Poolton, J.M., Masters, R.S.W., & Maxwell, J.P. (2005). The relationship between initial errorless learning conditions and subsequent performance. *Human Movement Science*, *24*, 362-378.

Poolton, J.M., Maxwell, J.P., Masters, R.S.W., & Raab, M. (2006). Benefits of an external focus of attention: Common coding or conscious processing? *Journal of Sports Sciences*, *24*, 89-99.

Posner, M.I. (1908). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*, 3-25.

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

Posner, M. I., & Rothbart, M. K. (1998). Attention, self-regulation, and consciousness. *Philosophical Transactions of the Royal Society of London, 353*, 1915-1927.

Power, M.J. & Dalgleish, T. (1997). *Cognition and emotion: From order to disorder.* Hove, England: Psychology Press.

Ripoll, H., Kerlirzin, Y., Stein, J.F. & Reine, B. (1995). Analysis of information processing, decision making and visual strategied in complex solving sport situations. *Human Movement Science 14(3),* 325-349.

Salmoni, A.W., Schmidt, R.A., & Walter, C.B. (1984). Knowledge of results and motor learning: A review and critical reappraisal. *Psychological Bulletin, 95,* 355-386.

Sarason, I.G. (1988). Anxiety, self-preoccupation and attention. *Anxiety Research, 1*, 3-7.

Sarlegna, F., Blouin, J., Bresciani, J.P., Bourdin, C., Vercher, J.L., & Gauthier, G.M. (2003).Target and hand position information in the online control of goal-directed arm movements. *Experimental Brain Research, 151,* 524-535.

Schmidt, R.A. (1988). Motor control and learning: A behavioural emphasis, (2nd edition), Champaign IL: Human kinetics.

Schmidt, R. A., & Lee, T. D. (1999). *Motor control and learning: A behavioural emphasis.* Champaign, IL: Human Kinetics.

Setchenov, I.M. (1935). On the question of sensitive stimuli on human muscular work. In *Setchenov selected works* (pp. 246-260), Moscow: state publishing house for biological and medical literature.

Shinoda, H., Hayhoe, M. M., & Shrivastava, A. (2001). What controls attention in natural environments? *Vision Research, 41,* 3535 – 3545.

Shipp, S. (2004). The brain circuitry of attention. *Trends in Cognitive Science, 8,* 223-230.

Singer, R.N. (1988). Strategies and meta strategies in learning and performing self-paced athletic skills. *The Sports Psychologist*, *2*, 49-68.

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

Singer, R.N. (2002). Pre performance state, routines and automaticity: What does it take to realise expertise in self paced events? *Journal of Sport and Exercise Psychology, 24*, 359-375.

Singer, R.N., Cauraugh, J.H., Chen, D., Steinberg, G.M. & Frehlich, S.G. (1996). Visual search, anticipation and reactive comparisons between highly skilled and beginning tennis players. *Journal of Applied Sports Psychology 8*, 9-26.

Smith, A., Malo, S., Laskowski, E., Sabick, M., Cooney, W., Finnie, S., et al. (2000). A multidisciplinary study of the 'yips' phenomenon in golf: An exploratory analysis. *Sports Medicine, 30*(6), 423-437.

Smith, E. E., and Kosslyn, S. M. (2007). *Cognitive Psychology: Mind and Brain*. Upper Saddle River, NJ: Pearson/Prentice-Hall.

Smith, N. C., Bellamy, M., Collins, D. J., & Newell, D. (2001). A test of processing efficiency theory in a team sport context. *Journal of Sports Sciences, 19*, 321–332.

Starkes, J. L., & Allard, F. (1993). *Cognitive issues in motor control*. Amsterdam: North- Holland.

Starkes, J. L., & Ericsson, K.A. (Eds.). (2003). *Expert performance in sports: Advances in research on sport expertise*. Champaign, IL: Human Kinetics.

Thomas, J. R. & Nelson, J.K. (2001). *Research methods in physical activity* (4th edition.), Champaign, IL: Human Kinetics Publishers.

Thomas, O., Hanton, S. & Jones, G. (2002). An alternative approach to short-form self-report assessment of competitive anxiety: A research note. *International Journal of Sport Psychology, 33*, 325-336.

Tierney, D.E. & Coop, R.H. (1998). A bivariate probability model for putting proficiency. In *Science and Golf III: Proceedings of the 1998 World Scientific Congress of Golf*, eds. M.R. Farally and A.J. Cochran (Eds.), (pp. 385-394), Champaign, IL: Human Kinetics.

Treisman, A. (1993). The perception of features and objects. In A. Baddeley & L. Weiskrantz (Eds), *Attention: Selection, awareness and control* (pp. 5-35). Oxford: Clarendon Press University.

Ungerleider, L.G. & Mishkin, M. (1982). Two cortical visual systems. In D.J. Ingle, M.A. Goodale & R.J.W. Mansfield (Eds.), *Analysis of visual behavior*, Cambridge MA: MIT Press.

Vickers, J.N. (1988). Knowledge structures of elite novice gymnasts. *Human Movement Science, 7*, 4-72.

Vickers, J.N. (1992). Gaze control in putting. *Perception*, *21*, 117-132.

Vickers, J.N. (1996). Visual control when aiming at a far target. *Journal of Experimental Psychology: Human Perception and Performance, 2,* 324–354.

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

Vickers, J.N. (2009). Advances in coupling perception and action: The quiet eye as a bidirectional link between gaze, attention, and action. *Progress in Brain Research*, *174*, 279-288.

Vickers, J.N., & Adolphe, R.A. (1997). Gaze behaviour during a ball tracking and aiming skill. *International Journal of Sports Vision*, *4*, 18-27.

Vickers, J.N., Rodriques, S.T. & Edowrthy, G. (2000). Quiet eye accuracy in the dart throw. *International Journal of Sports Vision, 6*, 30-36.

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.

Viviani, P. (1990). Eye movements in visual search: Cognitive, perceptual and motor control aspects. *Reviews of Oculomotor Research, 4,* 353 – 393.

Wegner, D. M. (1994). Ironic processes of mental control. *Psychological Review*, *101*, 34-52.

Weierich, M. R., Treat, T.A. & Hollingworth, A. (2008). Theories and measurement of visual Attentional processing in anxiety. *Cognition & Emotion, 22(6),* 985 - 1018.

Weinberg, R.S. (1979). Anxiety and motor performance: Driver theory versus cognitive theory. *International Journal of Sports Psychology, 10*, 112-121.

Williams, A. M., Davids, K. & Burwitz, L. & Williams, J.G. (1994b). Visual search strategies of experienced and inexperienced soccer players. *Research Quarterly for Exercise and Sport, 65*, 127-135.

Williams, A. M., Davids, K. & Burwitz, L. (1994a). Ecologocal validity and visual search research in sport, *Journal of Sport and Exercise Psychology*, s16- 22.

Williams, A. M., Davids, K. & Williams, J. G. (1999). *Visual Perception and Action in Sport,* London, E & FN Spon.

Williams, A. M., & Elliott, D. (1999). Anxiety, expertise, and visual search strategy in karate. *Journal of Sport and Exercise Psychology, 21,* 362 – 375.

Williams, A.M., & Ford, P.R. (2008). Expertise and expert performance in sport. *International Review of Sport and Exercise Psychology*, *1***,** 4-18.

Williams, A.M. & Grant, A. (1999). Training perceptual skill in sport. *International Journal of Sport Psychology, 30,* 194-220.

Williams, A. M., Singer, R. N., & Frehlich, S. G. (2002a). Quiet eye duration, expertise, and task complexity in near and far aiming tasks. *Journal of Motor Behavior, 34,* 197 – 207.

Williams, A. M., Vickers, J. N., & Rodrigues, S. T., (2002b). The effects of anxiety on visual search, movement kinematics, and performance in table tennis: A test of Eysenck and Calvo's processing efficiency theory. *Journal of Sport and Exercise Psychology, 24,* 438 – 455.

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

Wilson, M., Chattington, M., Marple-Horvat, D. E., & Smith, N. C. (2007a). A comparison of self-focus versus attentional explanations of choking. *Journal of Sport and Exercise Psychology, 29,* 439 – 456.

Wilson, M., McGrath, J., & Coleman, M. (2010b). Developing basic eye-hand coordination skills for laparoscopic surgery using gaze training. *British Journal of Urology – International, 105,* 1356-1358.

Wilson, M.R., McGrath, J., Vine, S.J., Brewer, J., Defriend, D, and Masters, R.S.W. (2010a). Psycho motor control in a virtual laparoscopic surgery training environment: Gaze control parameters differentiate novices from experts. *Surgical Endoscopy, 24(10).* 2458.

Wilson, M.R., & Pearcey, R. (2009). On the right line: The visuomotor control of straight and breaking golf putts. *Perceptual and Motor Skills, 109,* 1-8.

Wilson, M.R., & Richards, H. (2010). Putting it together: Skill packages for pressure performance. In D. Collins, A. Abbott, & H. Richards (Eds.), *Performance Psychology (pp. 333-356)* Edinburgh, UK: Elsevier.

Wilson, M. & Smith, N.C. (2007). A test of the predictions of processing efficiency theory during elite team competition using the Thought Occurrence Questionnaire for Sport. *International Journal of Sport Psychology, 38(3),* 245-262.

Wilson, M., Smith, N. C., Chattington, M., Ford, M., & Marple-Horvat, D. E. (2006). The role of effort in moderating the anxiety – performance relationship: Testing the prediction of processing efficiency theory in simulated rally driving. *Journal of Sports Sciences, 24,* 1223 – 1233.

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

Wilson, M., Stephenson, S., Chattington, M., & Marple-Horvat, D.E. (2007a). Eye movements coordinated with steering benefit performance even when vision is denied. *Experimental Brain Research, 76,* 397-412.

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

Wine, J. (1971). Test anxiety and direction of attention. *Psychological Bulletin, 76*, 92-104.

Wood, G. & Wilson, M.R. (2010). Goalkeeper distractions increase the likelihood of missing a penalty kick. *Journal of Sports Sciences, 28,* 937-946.

Woodman, T. & Davis, P.A. (2008). The role of repression in the incidence of ironic errors. *The Sport Psychologist, 22,* 183-196.

Woodman, T., & Hardy, L. (2001). Stress and anxiety. In R. N. Singer, H. A. Hausenblas, & C.M. Janelle (Eds.), *Handbook of sport psychology* (pp. 127 – 170). New York: Wiley.

Woodman, T. & Hardy, L. (2003). The relative impact of cognitive anxiety and self-confidence upon sport performance: a meta-analysis. *Journal of Sports Sciences 21(6),* 443-457.

Woods, D.L. (1990). The physiological basis of selective attention: Implications of event-related potential studies, In J.W. Rohrbaugh, R. Parasurasman & R. Johnson (Eds.), Event- related brain potentials, New York: Oxford University Press.

Wulf, G. (2007). *Attention and motor skill learning. Champaign, IL: Human Kinematics.*

Wulf, G., Lauterbach, B., & Toole, T. (1999). The learning advantages of an external focus of attention in golf. *Research Quarterly for Exercise and Sport*, *70*, 120-126.

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

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

Yarrow, K., Brown, P., & Krakauer, J.W. (2009). Inside the brain of an elite athlete: The neural processes that support high achievement in sports. *Nature Reviews Neuroscience, 10*, 585-596.

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

Yiend, J. (2010). The effects of emotion on attention: A review of attentional processing of emotional information. *Cognition & Emotion, 24(1),* 3 - 47.

Zachary, T., Wulf, G., Mercer, J., & Bezodis. (2005). Increased movement accuracy and reduced EMG activity as the result of adopting an external focus of attention. *Brain Research Bulletin*, *67*, 304-307.

Zinsser, N., Bunker, L.K., & Williams, J.M. (2006). Cognitive techniques for improving performance and building confidence. In JM Williams (Ed.) *Applied sport psychology: Personal growth to peak performance* (5th ed., pp. 349-381). Mountain View, CA: Mayfield.

# Appendix 1. Informed Consent Form

**School of Sport and Health Sciences**

The influence of different conditions on aiming behaviour and performance in basketball free throw shooting.

**INFORMED CONSENT FORM FOR**

NAME: ________________________________ D.O.B: ______________

DATE: ________________________________ TIME: ______________

**GENERAL**

1. **I confirm that**:

a) I am willing to take part in the above named experiment as a volunteer subject.

b) I am not pregnant, not receiving psychiatric treatment, and I have had no significant illness or injury, which may be exaggerated by my participation in the above named experiment.

c) I have/will inform the person in control of the experiment of any temporary medical condition from which I am suffering or have suffered recently which may be worse by my participation.

**2. I understand that**

a) The person in control of the experiment explained to me the nature and purpose of the experiment and informed me of any foreseeable risk to my health as a result of my participation.

b) I am free to withdraw from my experiment at any time without the need to give a reason.

c) I agree to terminate any experiment if the person in control feels it is advisable to do so.

d) Any information collected during the course of the study will be treated as confidential in accordance with the Data Protection Act. The information will be kept for a time up to publication of the data in an academic journal and for a period of 5 years thereafter. At all times my anonymity will be preserved

I agree to take part in this project.

……………………………………………………………… ………………………………

(Signature of participant) (Date)

This project has been reviewed and approved by the Ethics Committee of the school of Sport and Health Sciences.

# Appendix 2. The Mental Readiness Form

## (MRF-3; Krane. 1994)

The 3 questions below are designed to assess your performance state. Please indicate one number on each scale that you feel represents most closely how you feel **RIGHT NOW.**

3) My thoughts are:

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |

**NOT WORRIED** **WORRIED**

2) My body feels:

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |

**NOT TENSE** **TENSE**

1) I am feeling:

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |

**NOT CONFIDENT** **CONFIDENT**

# Appendix 3. Information sheet for studies 1 and 2

UNIVERSITY OF EXETER

## SCHOOL OF SPORT AND HEALTH SCIENCES

## PARTICIPANTS INFORMATION SHEET (Performance Study)

You are invited to take part in a research study. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

### What is the purpose of the study?

The purpose of the study is to investigate the effects of various conditions on aiming behaviour and performance of basketball free throw shooting

### Who is suitable to take part in this study?

We are looking for individuals who play basketball to a club or university level, who are not pregnant, do not receive psychiatric treatment or suffer from an injury, disease or symptoms of disease (including heart disease, chest pain, dizziness or feinting, high or low blood pressure, bone or joint problems), which may be exaggerated by vigorous exercise.

### What am I expected to do in this study?

You will be asked to perform a number of free-throws in different conditions while wearing an eye-tracking device. You will attend the laboratory on one occasion and carry out approximately 50 free throws (including warm-up throws). These will be split up into blocks of ten free throws. You will be asked to perform your best and try and make as many shots as you can. There will be no time pressure and you will be asked to take the free-throws as you normally would.

### What am I going to gain by participating in the study?

You will be briefed after the experiment about the way in which you coordinate your aiming and your free-throw action. This should enable you to improve your free-throw technique and hence, your free-throw percentages in matches.

**Confidentiality**

All information that is collected about you during the course of the research will be kept strictly confidential. Your identity will not be revealed in any publication of the results.

If you have any enquiries please do not hesitate to contact myself Samuel Vine (s.vine @exeter.ac.uk).

Thank you very much for taking time to consider this invitation.

The Ethics Committee of the School of Sport and Health Sciences has reviewed and approved this project.

# Appendix 4. Information Sheet for study 3

**SCHOOL OF SPORT AND HEALTH SCIENCES**

PARTICIPANTS INFORMATION SHEET (Training Study)

You are invited to take part in a research study. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

### What is the purpose of the study?

The purpose of the study is to investigate how we learn motor skills, particularly throwing and aiming motor skills

### Who is suitable to take part in this study?

We are looking for individuals who are involved in sport but do not play basketball and who are not pregnant, do not receive psychiatric treatment or suffer from an injury, disease or symptoms of disease (including heart disease, chest pain, dizziness or feinting, high or low blood pressure, bone or joint problems), which may be exaggerated by vigorous exercise.

### What am I expected to do in this study?

You will practice the skill of free-throw shooting over 3 sessions in the laboratory in Barings Court. In each session you will complete 120 free throws (4 blocks of 30, with 2 minutes rest between blocks). You will wear an eye tracker for all throws and an external video camera will also film the movement phases of each throw. At some point the following week you will be asked to attend the laboratory for one final time and carry out approximately 120 free throws (including warm-up throws). You will be asked to perform a number of free-throws in different conditions while wearing the eye-tracking device. On all occasions you will be asked to perform your best and try and make as many shots as you can.

## Confidentiality

All information that is collected about you during the course of the research will be kept strictly confidential. Your identity will not be revealed in any publication of the results.

If you have any enquiries please do not hesitate to contact myself Sam Vine (s.vine@ex.ac.uk)

Thank you very much for taking time to consider this invitation.

The Ethics Committee of the School of Sport and Health Sciences has reviewed and approved this project.

# Appendix 5. Information Sheet for study 4

## SCHOOL OF SPORT AND HEALTH SCIENCES

## PARTICIPANTS INFORMATION SHEET (Training Study)

You are invited to take part in a research study. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

### What is the purpose of the study?

The purpose of the study is to investigate how we learn motor skills, particularly aiming motor skills

### Who is suitable to take part in this study?

We are looking for individuals who are involved in sport but do not play golf and who are not pregnant, do not receive psychiatric treatment or suffer from an injury, disease or symptoms of disease (including heart disease, chest pain, dizziness or feinting, high or low blood pressure, bone or joint problems), which may be exaggerated by vigorous exercise.

### What am I expected to do in this study?

You will practice the skill of putting over 3 sessions in the laboratory in Baring Court. In each session you will complete 120 putts (4 blocks of 30, with 2 minutes rest between blocks). You will wear an eye tracker for all putts and an external video camera will also film the movement phases of each putt. At some point the following week you will be asked to attend the laboratory for one final time and carry out approximately 120 putts (including warm-up throws). You will be asked to perform a number of putts in different conditions while wearing the eye-tracking device. On all occasions you will be asked to perform your best and try and make as many shots as you can.

### What am I going to gain by participating in the study?

You will be briefed after the experiment about the way in which you coordinate your aiming and your free-throw action. This information might benefit you in your other sporting activities.

### Confidentiality

All information that is collected about you during the course of the research will be kept strictly confidential. Your identity will not be revealed in any publication of the results.

If you have any enquiries please do not hesitate to contact myself Samuel Vine (s.vine@ex.ac.uk)

Thank you very much for taking time to consider this invitation.

The Ethics Committee of the School of Sport and Health Sciences has reviewed and approved this project.

# Appendix 6. Information Sheet for study 5

UNIVERSITY OF EXETER

## SCHOOL OF SPORT AND HEALTH SCIENCES- INFORMATION SHEET

You are invited to take part in a research study. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

### What is the purpose of the study?

The purpose of the study is to investigate a new training technique used to improve the putting performance of golfers when putting. The training technique hopes to improve the accuracy of the performer, but also to improve their ability to cope with pressure.

### Who is suitable to take part in this study?

We are looking for golfers who have a low handicap and are willing to commit a small amount of their time. We are looking for people who do not receive psychiatric treatment or suffer from an injury, disease or symptoms of disease (including heart disease, chest pain, dizziness or feinting, high or low blood pressure, bone or joint problems), which may be exaggerated by vigorous exercise.

### What am I expected to do in this study?

- Record your own putting performance during your normal rounds of golf. We will provide a score sheet on which you can write down your scores and some other simple information about your putting performance.
- You will then be asked to come into the School of Sport and Exercise Science at the University of Exeter and take some simple putts on our artificial indoor putting green whilst wearing an eye tracker.

- You will then be introduced to a training strategy aimed at improving your putting performance and shown how to implement this into your game.
- We will then ask you to continue to record your own putting performance during your normal rounds of golf.
- We will finish with a final session on the artificial putting surface once again wearing an eye tracker.

### What am I going to gain by participating in the study?

You will be introduced to a ground breaking new training strategy that has been shown in research around the world to improve aiming performance in a variety of skills. You will also be given detailed feedback about your putting action and your visual aiming strategy. There will also be an opportunity at the end of the study to compete for a cash prize in a putting competition.

### Confidentiality

All information that is collected about you during the course of the research will be kept strictly confidential. Your identity will not be revealed in any publication of the results.

If you have any enquiries please do not hesitate to contact myself Samuel Vine (s.vine@ex.ac.uk)

Thank you very much for taking time to consider this invitation.

The Ethics Committee of the School of Sport and Health Sciences has reviewed and approved this project.

# Appendix 7. Performance Score Card for study 5

UNIVERSITY OF EXETER

Name:_____________E-mail_________

Mobile number:____________________

Handicap:________________

Golf course:______________

Competition:_____________

Gross Score:______________

Rate your putting performance (1-10)

(10 = Your best)________

(1 = Your worst)________

| Hole | Putts taken | 6-10ft Putt (Y/N) | Successful (Y/N) |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 10 | | | |
| 11 | | | |
| 12 | | | |
| 13 | | | |
| 14 | | | |
| 15 | | | |
| 16 | | | |
| 17 | | | |
| 18 | | | |

TOTAL________________________________________________________________

# Appendix 8. Statistical Analysis Outputs (SPSS)

General Linear Model

Fixation Count (Study 1, Chapter 4)

Tests of Within-Subjects Effects

Measure:MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| threat | Sphericity Assumed | 39.690 | 1 | 39.690 | 32.444 | .000 |
| | Greenhouse-Geisser | 39.690 | 1.000 | 39.690 | 32.444 | .000 |
| Error(threat) | Sphericity Assumed | 11.010 | 9 | 1.223 | | |
| | Greenhouse-Geisser | 11.010 | 9.000 | 1.223 | | |
| outcome | Sphericity Assumed | 5.290 | 1 | 5.290 | 6.096 | .036 |
| | Greenhouse-Geisser | 5.290 | 1.000 | 5.290 | 6.096 | .036 |
| Error(outcome) | Sphericity Assumed | 7.810 | 9 | .868 | | |
| | Greenhouse-Geisser | 7.810 | 9.000 | .868 | | |
| trial | Sphericity Assumed | 4.390 | 9 | .488 | .868 | .557 |
| | Greenhouse-Geisser | 4.390 | 4.199 | 1.046 | .868 | .496 |
| Error(trial) | Sphericity Assumed | 45.510 | 81 | .562 | | |
| | Greenhouse-Geisser | 45.510 | 37.789 | 1.204 | | |
| threat * outcome | Sphericity Assumed | 9.610 | 1 | 9.610 | 4.703 | .058 |
| | Greenhouse-Geisser | 9.610 | 1.000 | 9.610 | 4.703 | .058 |
| Error(threat*outcome) | Sphericity Assumed | 18.390 | 9 | 2.043 | | |
| | Greenhouse-Geisser | 18.390 | 9.000 | 2.043 | | |
| threat * trial | Sphericity Assumed | 3.910 | 9 | .434 | .720 | .689 |
| | Greenhouse-Geisser | 3.910 | 2.984 | 1.310 | .720 | .548 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Error(threat*trial) | Sphericity Assumed | 48.890 | 81 | .604 | | |
| | Greenhouse-Geisser | 48.890 | 26.854 | 1.821 | | |
| outcome * trial | Sphericity Assumed | 1.510 | 9 | .168 | .390 | .937 |
| | Greenhouse-Geisser | 1.510 | 5.131 | .294 | .390 | .858 |
| Error(outcome*trial) | Sphericity Assumed | 34.890 | 81 | .431 | | |
| | Greenhouse-Geisser | 34.890 | 46.181 | .756 | | |
| threat * outcome * trial | Sphericity Assumed | 2.790 | 9 | .310 | 1.059 | .402 |
| | Greenhouse-Geisser | 2.790 | 4.489 | .622 | 1.059 | .393 |
| | Greenhouse-Geisser | 23.710 | 40.399 | .587 | | |

General Linear Model

QE period duration (Study 1, Chapter 4)

Tests of Within-Subjects Effects

Measure:MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| threat | Sphericity Assumed | 2360832.250 | 1 | 2360832.250 | 12.106 | .007 |
| | Greenhouse-Geisser | 2360832.250 | 1.000 | 2360832.250 | 12.106 | .007 |
| Error(threat) | Sphericity Assumed | 1755130.250 | 9 | 195014.472 | | |
| | Greenhouse-Geisser | 1755130.250 | 9.000 | 195014.472 | | |
| accuracy | Sphericity Assumed | 7352232.250 | 1 | 7352232.250 | 30.129 | .000 |
| | Greenhouse-Geisser | 7352232.250 | 1.000 | 7352232.250 | 30.129 | .000 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Error(accuracy) | Sphericity Assumed | 2196190.250 | 9 | 244021.139 | | |
| | Greenhouse-Geisser | 2196190.250 | 9.000 | 244021.139 | | |
| trial | Sphericity Assumed | 294636.250 | 9 | 32737.361 | .834 | .587 |
| | Greenhouse-Geisser | 294636.250 | 4.423 | 66616.469 | .834 | .522 |
| Error(trial) | Sphericity Assumed | 3180386.250 | 81 | 39264.028 | | |
| | Greenhouse-Geisser | 3180386.250 | 39.806 | 79897.426 | | |
| threat * accuracy | Sphericity Assumed | 324330.250 | 1 | 324330.250 | 1.931 | .198 |
| | Greenhouse-Geisser | 324330.250 | 1.000 | 324330.250 | 1.931 | .198 |
| Error(threat*accuracy) | Sphericity Assumed | 1511272.250 | 9 | 167919.139 | | |
| | Greenhouse-Geisser | 1511272.250 | 9.000 | 167919.139 | | |
| threat * trial | Sphericity Assumed | 361650.250 | 9 | 40183.361 | 1.331 | .234 |
| | Greenhouse-Geisser | 361650.250 | 3.831 | 94388.762 | 1.331 | .279 |
| Error(threat*trial) | Sphericity Assumed | 2445312.250 | 81 | 30189.040 | | |
| | Greenhouse-Geisser | 2445312.250 | 34.483 | 70912.588 | | |
| accuracy * trial | Sphericity Assumed | 207870.250 | 9 | 23096.694 | .605 | .789 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Greenhouse-Geisser | 207870.250 | 4.088 | 50845.798 | .605 | .665 |
| Error(accuracy*trial) | Sphericity Assumed | 3091032.250 | 81 | 38160.892 | | |
| | Greenhouse-Geisser | 3091032.250 | 36.794 | 84008.602 | | |
| threat * accuracy * trial | Sphericity Assumed | 95352.250 | 9 | 10594.694 | .325 | .964 |
| | Greenhouse-Geisser | 95352.250 | 4.022 | 23709.365 | .325 | .860 |
| Error(threat*accuracy*trial) | Sphericity Assumed | 2637570.250 | 81 | 32562.596 | | |
| | Greenhouse-Geisser | 2637570.250 | 36.195 | 72870.291 | | |

T-Test
Anxiety, Performance & Eye tracker influence (Study 1 & 2, Chapter 4 & 5)

Paired Samples Test

| | | Paired Differences | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 95% Confidence Interval of the Difference | | | | |
| | | Mean | Std. Deviation | Std. Error Mean | Lower | Upper | t | df | Sig. (2-tailed) |
| Pair 1 | Wout_ET - With_ET | -5.00000 | 18.40894 | 5.82142 | -18.16896 | 8.16896 | -.859 | 9 | .413 |
| Pair 2 | Anx_LP - Anx_HP | -1.77700 | 1.08604 | .34344 | -2.55391 | -1.00009 | -5.174 | 9 | .001 |
| Pair 3 | Perf_LP - Perf_HP | 18.10000 | 10.37572 | 3.28109 | 10.67766 | 25.52234 | 5.516 | 9 | .000 |

General Linear Model

Mean fixation duration (Study 1, Chapter 4)

Tests of Within-Subjects Effects

Measure:MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| threat | Sphericity Assumed | 3429904.000 | 1 | 3429904.000 | 63.983 | .000 |
| | Greenhouse-Geisser | 3429904.000 | 1.000 | 3429904.000 | 63.983 | .000 |
| Error(threat) | Sphericity Assumed | 482456.000 | 9 | 53606.222 | | |
| | Greenhouse-Geisser | 482456.000 | 9.000 | 53606.222 | | |
| accuracy | Sphericity Assumed | 198916.000 | 1 | 198916.000 | 7.402 | .024 |
| | Greenhouse-Geisser | 198916.000 | 1.000 | 198916.000 | 7.402 | .024 |
| Error(accuracy) | Sphericity Assumed | 241844.000 | 9 | 26871.556 | | |
| | Greenhouse-Geisser | 241844.000 | 9.000 | 26871.556 | | |
| trial | Sphericity Assumed | 36404.000 | 9 | 4044.889 | .754 | .659 |
| | Greenhouse-Geisser | 36404.000 | 4.062 | 8962.565 | .754 | .564 |
| Error(trial) | Sphericity Assumed | 434796.000 | 81 | 5367.852 | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Greenhouse-Geisser | 434796.000 | 36.556 | 11893.953 | | |
| threat * accuracy | Sphericity Assumed | 10816.000 | 1 | 10816.000 | .367 | .560 |
| | Greenhouse-Geisser | 10816.000 | 1.000 | 10816.000 | .367 | .560 |
| Error(threat*accuracy) | Sphericity Assumed | 265584.000 | 9 | 29509.333 | | |
| | Greenhouse-Geisser | 265584.000 | 9.000 | 29509.333 | | |
| threat * trial | Sphericity Assumed | 57296.000 | 9 | 6366.222 | 1.431 | .189 |
| | Greenhouse-Geisser | 57296.000 | 4.827 | 11870.574 | 1.431 | .234 |
| Error(threat*trial) | Sphericity Assumed | 360344.000 | 81 | 4448.691 | | |
| | Greenhouse-Geisser | 360344.000 | 43.441 | 8295.111 | | |
| accuracy * trial | Sphericity Assumed | 59924.000 | 9 | 6658.222 | .983 | .460 |
| | Greenhouse-Geisser | 59924.000 | 4.177 | 14345.145 | .983 | .431 |
| Error(accuracy*trial) | Sphericity Assumed | 548516.000 | 81 | 6771.802 | | |
| | Greenhouse-Geisser | 548516.000 | 37.596 | 14589.854 | | |
| threat * accuracy * trial | Sphericity Assumed | 59904.000 | 9 | 6656.000 | 1.045 | .412 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Error(threat*accuracy*trial) | Sphericity Assumed | 515696.000 | 81 | 6366.617 | | |
| | Greenhouse-Geisser | 515696.000 | 33.084 | 15587.682 | | |

General Linear Model

QE onset (Study 1 & 2, Chapter 4 & 5)

Tests of Within-Subjects Effects

Measure:MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| threat | Sphericity Assumed | 1535121.000 | 1 | 1535121.000 | 2.427 | .154 |
| | Greenhouse-Geisser | 1535121.000 | 1.000 | 1535121.000 | 2.427 | .154 |
| Error(threat) | Sphericity Assumed | 5691729.000 | 9 | 632414.333 | | |
| | Greenhouse-Geisser | 5691729.000 | 9.000 | 632414.333 | | |
| accuracy | Sphericity Assumed | 4330561.000 | 1 | 4330561.000 | 9.984 | .012 |
| | Greenhouse-Geisser | 4330561.000 | 1.000 | 4330561.000 | 9.984 | .012 |
| Error(accuracy) | Sphericity Assumed | 3903729.000 | 9 | 433747.667 | | |
| | Greenhouse-Geisser | 3903729.000 | 9.000 | 433747.667 | | |
| trial | Sphericity Assumed | 1261521.000 | 9 | 140169.000 | 1.183 | .317 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Greenhouse-Geisser | 1261521.000 | 4.638 | 271994.065 | 1.183 | .333 |
| Error(trial) | Sphericity Assumed | 9595569.000 | 81 | 118463.815 | | |
| | Greenhouse-Geisser | 9595569.000 | 41.742 | 229875.754 | | |
| threat * accuracy | Sphericity Assumed | 811801.000 | 1 | 811801.000 | 4.135 | .073 |
| | Greenhouse-Geisser | 811801.000 | 1.000 | 811801.000 | 4.135 | .073 |
| Error(threat*accuracy) | Sphericity Assumed | 1767049.000 | 9 | 196338.778 | | |
| | Greenhouse-Geisser | 1767049.000 | 9.000 | 196338.778 | | |
| threat * trial | Sphericity Assumed | 432249.000 | 9 | 48027.667 | .558 | .828 |
| | Greenhouse-Geisser | 432249.000 | 3.653 | 118326.605 | .558 | .680 |
| Error(threat*trial) | Sphericity Assumed | 6975801.000 | 81 | 86121.000 | | |
| | Greenhouse-Geisser | 6975801.000 | 32.877 | 212177.818 | | |
| accuracy * trial | Sphericity Assumed | 643449.000 | 9 | 71494.333 | .594 | .798 |
| | Greenhouse-Geisser | 643449.000 | 3.749 | 171613.087 | .594 | .659 |
| Error(accuracy*trial) | Sphericity Assumed | 9747561.000 | 81 | 120340.259 | | |
| | Greenhouse-Geisser | 9747561.000 | 33.745 | 288861.542 | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| threat * accuracy * trial | Sphericity Assumed | 1203889.000 | 9 | 133765.444 | .936 | .499 |
| | Greenhouse-Geisser | 1203889.000 | 3.905 | 308312.912 | .936 | .453 |
| Error(threat*accuracy*trial) | Sphericity Assumed | 1.157E7 | 81 | 142856.309 | | |
| | Greenhouse-Geisser | 1.157E7 | 35.143 | 329266.237 | | |

General Linear Model

Occlusion onset (Study 2, Chapter 5)

Tests of Within-Subjects Effects

Measure:MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| condition | Sphericity Assumed | 16000.000 | 1 | 16000.000 | 4.737 | .058 |
| | Greenhouse-Geisser | 16000.000 | 1.000 | 16000.000 | 4.737 | .058 |
| Error(condition) | Sphericity Assumed | 30400.000 | 9 | 3377.778 | | |
| | Greenhouse-Geisser | 30400.000 | 9.000 | 3377.778 | | |
| accuracy | Sphericity Assumed | 2560.000 | 1 | 2560.000 | .935 | .359 |
| | Greenhouse-Geisser | 2560.000 | 1.000 | 2560.000 | .935 | .359 |
| Error(accuracy) | Sphericity Assumed | 24640.000 | 9 | 2737.778 | | |
| | Greenhouse-Geisser | 24640.000 | 9.000 | 2737.778 | | |
| condition * accuracy | Sphericity Assumed | 160.000 | 1 | 160.000 | .091 | .770 |
| | Greenhouse-Geisser | 160.000 | 1.000 | 160.000 | .091 | .770 |
| Error(condition*accuracy) | Sphericity Assumed | 15840.000 | 9 | 1760.000 | | |
| | Greenhouse-Geisser | 15840.000 | 9.000 | 1760.000 | | |

General Linear Model

Composite measure of suppressed vision (Study 2, Chapter 5)

Tests of Within-Subjects Effects

Measure:MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| condition | Sphericity Assumed | 108160.000 | 1 | 108160.000 | 7.295 | .024 |
| | Greenhouse-Geisser | 108160.000 | 1.000 | 108160.000 | 7.295 | .024 |
| Error(condition) | Sphericity Assumed | 133440.000 | 9 | 14826.667 | | |
| | Greenhouse-Geisser | 133440.000 | 9.000 | 14826.667 | | |
| accuracy | Sphericity Assumed | 640.000 | 1 | 640.000 | .545 | .479 |
| | Greenhouse-Geisser | 640.000 | 1.000 | 640.000 | .545 | .479 |
| Error(accuracy) | Sphericity Assumed | 10560.000 | 9 | 1173.333 | | |
| | Greenhouse-Geisser | 10560.000 | 9.000 | 1173.333 | | |
| condition * accuracy | Sphericity Assumed | 160.000 | 1 | 160.000 | .050 | .828 |
| | Greenhouse-Geisser | 160.000 | 1.000 | 160.000 | .050 | .828 |
| Error(condition*accuracy) | Sphericity Assumed | 28640.000 | 9 | 3182.222 | | |
| | Greenhouse-Geisser | 28640.000 | 9.000 | 3182.222 | | |

General Linear Model

Anxiety (Study 3, Chapter 6)

Tests of Within-Subjects Effects

Measure:MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| test | Sphericity Assumed | 160.074 | 2 | 80.037 | 77.482 | .000 |
| | Greenhouse-Geisser | 160.074 | 1.835 | 87.227 | 77.482 | .000 |
| test * Group | Sphericity Assumed | .083 | 2 | .041 | .040 | .961 |
| | Greenhouse-Geisser | .083 | 1.835 | .045 | .040 | .951 |
| Error(test) | Sphericity Assumed | 28.923 | 28 | 1.033 | | |
| | Greenhouse-Geisser | 28.923 | 25.692 | 1.126 | | |

Tests of Between-Subjects Effects

Measure:MEASURE_1

Transformed Variable:Average

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Intercept | 777.630 | 1 | 777.630 | 1434.521 | .000 |
| Group | .141 | 1 | .141 | .260 | .618 |
| Error | 7.589 | 14 | .542 | | |

General Linear Model

QE period (Study 3, Chapter 6)

Tests of Within-Subjects Effects

Measure:MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| test | Sphericity Assumed | 100517.293 | 3 | 33505.764 | 5.429 | .003 |
| | Greenhouse-Geisser | 100517.293 | 2.026 | 49625.406 | 5.429 | .010 |
| test * Group | Sphericity Assumed | 77337.793 | 3 | 25779.264 | 4.177 | .011 |
| | Lower-bound | 77337.793 | 1.000 | 77337.793 | 4.177 | .060 |
| Error(test) | Sphericity Assumed | 259230.602 | 42 | 6172.157 | | |
| | Greenhouse-Geisser | 259230.602 | 28.357 | 9141.585 | | |

Tests of Between-Subjects Effects

Measure:MEASURE_1

Transformed Variable:Average

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Intercept | 1.237E7 | 1 | 1.237E7 | 890.480 | .000 |
| Group | 456046.973 | 1 | 456046.973 | 32.837 | .000 |
| Error | 194433.617 | 14 | 13888.116 | | |

General Linear Model

Performance (% accuracy) (Study 3, Chapter 6)

Tests of Within-Subjects Effects

Measure:MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| test | Sphericity Assumed | 9012.293 | 3 | 3004.098 | 69.299 | .000 |
| | Greenhouse-Geisser | 9012.293 | 1.778 | 5067.751 | 69.299 | .000 |
| test * Group | Sphericity Assumed | 1069.949 | 3 | 356.650 | 8.227 | .000 |
| | Greenhouse-Geisser | 1069.949 | 1.778 | 601.649 | 8.227 | .002 |
| Error(test) | Sphericity Assumed | 1820.695 | 42 | 43.350 | | |
| | Greenhouse-Geisser | 1820.695 | 24.897 | 73.129 | | |

Tests of Between-Subjects Effects

Measure:MEASURE_1

Transformed Variable:Average

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Intercept | 172900.035 | 1 | 172900.035 | 2370.904 | .000 |
| Group | 1255.816 | 1 | 1255.816 | 17.220 | .001 |
| Error | 1020.961 | 14 | 72.926 | | |

General Linear Model

Acquisition data (Study 4, Chapter 7)

Tests of Within-Subjects Effects

Measure:MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| block | Sphericity Assumed | 44569.683 | 8 | 5571.210 | 9.548 | .000 |
| | Greenhouse-Geisser | 44569.683 | 3.599 | 12385.148 | 9.548 | .000 |
| block * Group | Sphericity Assumed | 4891.143 | 8 | 611.393 | 1.048 | .406 |
| | Greenhouse-Geisser | 4891.143 | 3.599 | 1359.164 | 1.048 | .389 |
| Error(block) | Sphericity Assumed | 56013.841 | 96 | 583.478 | | |
| | Greenhouse-Geisser | 56013.841 | 43.184 | 1297.107 | | |

Tests of Between-Subjects Effects

Measure:MEASURE_1

Transformed Variable:Average

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Intercept | 1.108E7 | 1 | 1.108E7 | 7451.352 | .000 |
| Group | 4500.071 | 1 | 4500.071 | 3.027 | .107 |
| Error | 17840.730 | 12 | 1486.728 | | |

General Linear Model

Anxiety (Study 4, Chapter 7)

Tests of Within-Subjects Effects

Measure:MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| test | Sphericity Assumed | 131.008 | 2 | 65.504 | 58.760 | .000 |
| | Greenhouse-Geisser | 131.008 | 1.496 | 87.573 | 58.760 | .000 |
| test * Group | Sphericity Assumed | 2.985 | 2 | 1.492 | 1.339 | .281 |
| | Greenhouse-Geisser | 2.985 | 1.496 | 1.995 | 1.339 | .279 |
| Error(test) | Sphericity Assumed | 26.754 | 24 | 1.115 | | |
| | Greenhouse-Geisser | 26.754 | 17.952 | 1.490 | | |

Tests of Between-Subjects Effects

Measure:MEASURE_1

Transformed Variable:Average

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Intercept | 668.804 | 1 | 668.804 | 324.812 | .000 |
| Group | .461 | 1 | .461 | .224 | .645 |
| Error | 24.709 | 12 | 2.059 | | |

General Linear Model

QE period (Study 4, Chapter 7)

Tests of Within-Subjects Effects

Measure:MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| test | Sphericity Assumed | 1.617E7 | 3 | 5388651.065 | 41.134 | .000 |
| | Greenhouse-Geisser | 1.617E7 | 2.164 | 7470913.385 | 41.134 | .000 |
| test * Group | Sphericity Assumed | 8471099.911 | 3 | 2823699.970 | 21.555 | .000 |
| | Greenhouse-Geisser | 8471099.911 | 2.164 | 3914823.514 | 21.555 | .000 |
| Error(test) | Sphericity Assumed | 4716054.643 | 36 | 131001.518 | | |
| | Greenhouse-Geisser | 4716054.643 | 25.966 | 181622.633 | | |

Tests of Between-Subjects Effects

Measure:MEASURE_1

Transformed Variable:Average

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Intercept | 1.950E8 | 1 | 1.950E8 | 555.371 | .000 |
| Group | 2.878E7 | 1 | 2.878E7 | 81.996 | .000 |
| Error | 4212606.214 | 12 | 351050.518 | | |

General Linear Model

Performance (error) (Study 4, Chapter 7)

Tests of Within-Subjects Effects

Measure:MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| test | Sphericity Assumed | 20975.143 | 3 | 6991.714 | 24.150 | .000 |
| | Greenhouse-Geisser | 20975.143 | 1.641 | 12783.103 | 24.150 | .000 |
| test * Group | Sphericity Assumed | 3441.929 | 3 | 1147.310 | 3.963 | .015 |
| | Greenhouse-Geisser | 3441.929 | 1.641 | 2097.651 | 3.963 | .043 |
| Error(test) | Sphericity Assumed | 10422.429 | 36 | 289.512 | | |
| | Greenhouse-Geisser | 10422.429 | 19.690 | 529.321 | | |

Tests of Between-Subjects Effects

Measure:MEASURE_1

Transformed Variable:Average

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Intercept | 4546320.286 | 1 | 4546320.286 | 4261.272 | .000 |
| Group | 5323.500 | 1 | 5323.500 | 4.990 | .045 |
| Error | 12802.714 | 12 | 1066.893 | | |

General Linear Model

Anxiety (Study 5, Chapter 8)

Tests of Within-Subjects Effects

Measure:MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| test | Sphericity Assumed | 177.834 | 1 | 177.834 | 265.547 | .000 |
| | Greenhouse-Geisser | 177.834 | 1.000 | 177.834 | 265.547 | .000 |
| test * Group | Sphericity Assumed | .084 | 1 | .084 | .125 | .728 |
| | Greenhouse-Geisser | .084 | 1.000 | .084 | .125 | .728 |
| Error(test) | Sphericity Assumed | 13.394 | 20 | .670 | | |
| | Greenhouse-Geisser | 13.394 | 20.000 | .670 | | |

Tests of Between-Subjects Effects

Measure:MEASURE_1

Transformed Variable:Average

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Intercept | 1197.959 | 1 | 1197.959 | 1927.981 | .000 |
| Group | .800 | 1 | .800 | 1.288 | .270 |
| Error | 12.427 | 20 | .621 | | |

General Linear Model

Laboratory Performance (% holed) (Study 5, Chapter 8)

Tests of Within-Subjects Effects

Measure:MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| test | Sphericity Assumed | .016 | 2 | .008 | .552 | .580 |
| | Greenhouse-Geisser | .016 | 1.371 | .012 | .552 | .517 |
| test * Group | Sphericity Assumed | .174 | 2 | .087 | 5.967 | .005 |
| | Greenhouse-Geisser | .174 | 1.371 | .127 | 5.967 | .014 |
| Error(test) | Sphericity Assumed | .582 | 40 | .015 | | |
| | Greenhouse-Geisser | .582 | 27.429 | .021 | | |

Tests of Between-Subjects Effects

Measure:MEASURE_1

Transformed Variable:Average

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Intercept | 16.164 | 1 | 16.164 | 526.990 | .000 |
| Group | .265 | 1 | .265 | 8.635 | .008 |
| Error | .613 | 20 | .031 | | |

General Linear Model

Laboratory Performance (Average error) (Study 5, Chapter 8)

Tests of Within-Subjects Effects

Measure:MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| test | Sphericity Assumed | 31.338 | 2 | 15.669 | 1.967 | .153 |
| | Greenhouse-Geisser | 31.338 | 1.654 | 18.942 | 1.967 | .162 |
| test * Group | Sphericity Assumed | 91.968 | 2 | 45.984 | 5.771 | .006 |
| | Greenhouse-Geisser | 91.968 | 1.654 | 55.589 | 5.771 | .010 |
| Error(test) | Sphericity Assumed | 318.702 | 40 | 7.968 | | |
| | Greenhouse-Geisser | 318.702 | 33.088 | 9.632 | | |

Tests of Between-Subjects Effects

Measure:MEASURE_1

Transformed Variable:Average

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Intercept | 2766.826 | 1 | 2766.826 | 347.854 | .000 |
| Group | 171.649 | 1 | 171.649 | 21.580 | .000 |
| Error | 159.079 | 20 | 7.954 | | |

General Linear Model

Course Performance- Putts per round (Study 5, Chapter 8)

Tests of Within-Subjects Effects

Measure:MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| time | Sphericity Assumed | 10.911 | 1 | 10.911 | 13.924 | .001 |
| | Greenhouse-Geisser | 10.911 | 1.000 | 10.911 | 13.924 | .001 |
| time * Group | Sphericity Assumed | 9.165 | 1 | 9.165 | 11.696 | .003 |
| | Greenhouse-Geisser | 9.165 | 1.000 | 9.165 | 11.696 | .003 |
| Error(time) | Sphericity Assumed | 15.672 | 20 | .784 | | |
| | Greenhouse-Geisser | 15.672 | 20.000 | .784 | | |

Tests of Between-Subjects Effects

Measure:MEASURE_1

Transformed Variable:Average

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Intercept | 37327.148 | 1 | 37327.148 | 4063.666 | .000 |
| Group | 20.224 | 1 | 20.224 | 2.202 | .153 |
| Error | 183.712 | 20 | 9.186 | | |

General Linear Model

Course Performance - % 6-10ft putts holed (Study 5, Chapter 8)

Tests of Within-Subjects Effects

Measure:MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| time | Sphericity Assumed | .012 | 1 | .012 | 5.363 | .031 |
| | Greenhouse-Geisser | .012 | 1.000 | .012 | 5.363 | .031 |
| time * Group | Sphericity Assumed | .005 | 1 | .005 | 2.329 | .143 |
| | Greenhouse-Geisser | .005 | 1.000 | .005 | 2.329 | .143 |
| Error(time) | Sphericity Assumed | .046 | 20 | .002 | | |
| | Greenhouse-Geisser | .046 | 20.000 | .002 | | |

Tests of Between-Subjects Effects

Measure:MEASURE_1

Transformed Variable:Average

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Intercept | 19.336 | 1 | 19.336 | 2230.202 | .000 |
| Group | .015 | 1 | .015 | 1.751 | .201 |
| Error | .173 | 20 | .009 | | |