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Neuroscience of the Quiet Eye in Golf Putting

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Over 50 refereed publications have been published on the quiet eye (QE, Vickers, 1996) in a wide range of motor tasks. Mean quiet eye duration in the golf putt is longer for highly skilled golfers (handicap less than 4), averaging 2.5–3.0 s, compared with 1.0–1.5 s for those with lower skill levels. A long duration QE not only helps organize and sustain the neural networks underlying the organization and control of the putt, but also may insulate the golfer from the normally debilitating effects of distracting thoughts, high arousal and high pressure. Research from neuroscience using electroencephalograph (EEG) and imaging are beginning to identify the neural structures underlying QE focus of attention. QE training in the golf putt has proven to be effective and has been shown to increase performance under high pressure.

Keywords: performance under pressure, vision, attention, brain, quiet eye, focus

Golf putting requires precise control of physical actions and vision is essential in providing the information the movement systems needs to perform at a high level. Vision and focus of attention play a critically important role as the ability to direct the gaze (i.e., the eyes, the head, and the body) to optimal areas of the golf environment at the appropriate time is one characteristic of elite putting performance. One variable that has been consistently found to discriminate elite performers from their near-elite and novice counterparts is the quiet eye. In this paper the quiet eye is defined and the neural pathways of the visual-motor system are explained. Following there is a presentation of the results of recent neural imaging studies conducted during long duration movements which show increased activation of a frontal area that is central to both focus of visual attention and precise motor control. Following this, there is an explanation how QE training not only improves the performance of novice golfers, but also is of assistance to elite golfers in improving their accuracy during competition.

The quiet eye (QE) is a perceptual-motor variable applicable to a wide range of motor skills (for review see Mann, Williams, Ward & Janelle, 2007; Vickers, 2007). The QE is defined as the final fixation or tracking gaze located on a specific location or object in the visuo-motor workspace within 3° of visual angle (or less) for more than 100 ms (Vickers, 1996; Vickers, 2007). The QE onset occurs before

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a final critical movement in the task and offset when the gaze deviates off the location or object by more 100 ms. The onset of the QE in elite athletes occurs earlier and the duration is longer compared to near-elite or non-elites. It is also earlier and longer during higher levels of performance (success, fail). The QE in the golf putt is the final fixation located on the top or back of the ball within 1° of visual angle for more than 100 ms. The QE onset occurs before the onset of the backswing and QE offset when the gaze deviates off the top or back of the ball by more than 100 ms. QE research in golf has grown over the years with some of the major studies shown in Table 1. Across the studies (with one exception), QE duration of low handicap golfers averaged between 2.0-3.0 seconds compared to 1-1.5 seconds for high handicap or lower skilled golfers (Vickers, 2007, 1992; Vine & Wilson, 2011; Vine, Moore & Wilson, 2011; Mann, Coombes, Mousseau, & Janelle, 2011). The one exception is Van Lier, van der Kamp & Savelsbergh (2010) who found a QE of 1080 ms that did not differ due to expertise or accuracy. It appears the authors defined the QE as the final fixation before the ball was contacted, instead of the final fixation that had an onset prior to the backstroke.

Neural Pathways and Visuo-Motor Control of the Quiet Eye

Humans see with clear acuity when light falls on a small region of the retina called the fovea. Because of this humans are able to see with full acuity over a relatively small visual angle of 3° (Coren, Ward, & Enns, 2004). Elite golfers control their gaze precisely to process critical aspects of the ball, hole, breakpoint and other locations with full acuity. Researchers who use mobile eye trackers measure the location of the gaze in space over this small visual angle, with two eye movements, fixations and saccades being of greatest interest. A fixation occurs when the gaze is held stable on an object (ball, club head, part of green, hole or other location) within 3° of visual angle for 100 ms or longer (Carpenter, 1988). The 100 ms threshold is the minimum amount of time needed to recognize or become aware of a stimulus. Saccades occur when the eyes move quickly from one fixated location to another, for example when looking from the hole to the ball when putting. During fixations information is processed by the brain, but during saccades it is suppressed.

During the QE visual information is registered first by the retina, then passes rapidly through the optic nerve, the lateral geniculate nucleus, and the optic/straite

Table 1 Mean Quiet Eye Duration of Low and Handicap Golfers as Found in Selected Studies.

Studies	Low Handicap	High Handicap
Vickers, 1992	2200 ms	900 ms
Vickers & Crews, 2004	2210 ms	1680 ms
VanLier et al., 2009**	1080 ms	1100 ms
Mann et al., 2011**	3300 ms	2900 ms
Vine et al., 2011	2794 ms	1405 ms
Mean QU Duration	2317	1597

** est. 1 s for stroke duration

radiations to the visual/cortex occipital lobe at the back of the head. Located in the occipital cortex are visual sensors that begin the processing of registering and interpreting what the golfer sees, with specific detectors for initial registration (V1), shape (V2), angles (V3), motion (V3a), color (V4), V5 (motion with direction), depth and self motion (V6) and depth of stereo motion (V7) (Carter, 2009; Kolb & Whishaw, 2009; Corbetta, Patel, & Shulman, 2008; Corbetta, & Shulman, 2002). During a long duration QE the gaze is stable for 2-3 seconds depending on the distance of the putt; therefore, from the outset of the fixation the golfer perceives a constant and relatively stable stream of information about the ball and its location relative to the club face and intended target as determined before onset. Extensive testing of golfers has shown that only highly skilled golfers are consistently able to hold the QE stable on the ball for about one second before the backswing, one second during the stroke, and a half second after contact. Instead, for lower skilled golfers it is more common for the gaze to shift once the stroke begins as indicated by higher fixation rates to more locations (Vickers, 1992; Vickers, 2004) therefore, the brain registers information from multiple sources using the V1-V7 sensors. Instead of receiving input about one location re the position of the ball and its relationship to the intended target as occurs with elite golfers, lower skilled golfers take more information from many sources and therefore may be unable to maintain the precise alignment of the club face on the ball that must occur in order for high levels of putting accuracy to occur (Pelz, 2000).

Role of Dorsal Attention Network (DAN) and Ventral Attention Networks (VAN)

Once an object is perceived by the visual cortex, visual information moves rapidly forward in the brain, along two routes (Corbetta, Patel, & Shulman, 2008; Corbetta, & Shulman, 2002; Milner & Goodale, 1995). The dorsal attention network (DAN) projects from the occipital lobe to parietal lobe and forward to the frontal lobe in a journey that goes over the top of your head to the frontal lobe, while the ventral attention network (VAN) projects forward along the sides of the head through the temporal lobes to the frontal areas (Corbetta, Patel, & Shulman, 2008; Corbetta, & Shulman, 2002). The primary function of the DAN is to sustain spatial focus of attention on one location, thereby blocking out competing stimuli that may intrude from the VAN system. The VAN includes the hippocampus and amygdala, which are located on the inside of the temporal lobe on each the side of the head. The hippocampus is responsible for recording memories and the amygdala for emotional control and regulation. Imagine for example, that a golfer has had a particularly bad experience. This would be dually registered by the hippocampus and amygdala. When a long duration QE is maintained on an optimal location a mental buffer or barrier is created that prevents intruding thoughts or bad experiences arising in the hippocampus and amygdala from distracting attention and leading to higher levels of anxiety. Evidence in support of this is provided in studies by Land (2009), Corbetta, Patel, & Shulman, (2008), and Corbetta, & Shulman, 2002, which show the VAN network is activated when visual attention switches from one location to another. We can speculate that when the QE duration is lower the DAN system has been deactivated and the gateway is opened to potentially harmful memories and emotions that contribute to higher levels of anxiety and lower levels of performance.

Evidence in support of this speculation comes from QE studies conducted under conditions of high pressure and/or anxiety which show that when the QE duration declines, performance also decreases. This has been shown in table tennis (Williams, Vickers & Rodrigues, 2002), shooting (Vickers & Williams, 2007; Causer, Holmes, Smith & Williams, 2011) basketball shooting and golf (Vine, Moore & Wilson, 2011; Wilson, Vine & Wood, 2009).

Both the DAN and VAN send information to the frontal lobes, where the stroke is planned, initiated and controlled. Only recently have imaging studies provided some insight into the role of the frontal areas during long duration movements like the putt. This is due to the vast majority of EEG and MRI studies concentrating on the preparation of the stroke and/or the use of tasks that require rapid movements (such as a key press). In contrast, studies by Swinnen and colleagues have succeeded in imaging the brain not only before, but during, long duration movements with time spans similar to the one second found in the putting stroke. Callaert et al. (2011) have shown that a new dorsal spatial attention frontal area is activated during long duration movement planning and control, irrespective of which hand is used, having the eyes open or closed, or whether feedback is available or not. The dorsal spatial attention frontal area is located in the right inferior, medial and superior frontal gyrus and activated when spatial information must be continuously exploited to maintain accurate long duration movements.

Quiet Eye Training

QE training studies are designed to help novices acquire the quiet eye characteristics of experts (Vickers, 2009, 2007). Table 2 provides an overview of some studies completed to date, in the volleyball serve reception (Adolphe, Vickers & LaPlante, 1997), basketball free throw (Harle & Vickers, 2001), golf putt (Vickers, 2007; Vine, Moore & Wilson, 2011) and skeet shooting (Causer et al., 2011). Using this approach, Vine, Moore and Wilson (2011) randomly placed 22 elite golfers into 2 groups (QE trained; Control) based on their handicaps. Changes in putting performance and QE duration were determined during a pretest, a posttest under pressure in the laboratory and a follow-up transfer test of 10 rounds of competitive golf. Although both groups had similar accuracy and QE scores in the pretest, the QE-trained group was significantly more accurate and lagged the ball closer to the hole than the Control group during the pressure test. They also increased the QE duration by 800 ms while the control group decreased their QE duration by 400 ms. Over the course of 10 competitive rounds the QE-trained group made 1.9 fewer putts per round ($p < .05$) compared with their pretest while the Control group showed no change in their putting statistics.

Neuroplasticity in Golf

The concluding topic now considers the type of neural structures that may change as a result of QE training. Jancke, Koeneke, Hoppe, Rominger and Hanggi (2009) scanned 40 golfers using MRI: 10 professional golfers (handicap 0), 10 highly-skilled golfers (handicap range 1–14); 10 golfers at the intermediate level (handicaps 15 and 36), and 10 individuals with no golf experience. Significant differences were found between the two high skilled groups (handicap range 0–14) when compared with the lower skilled (handicap range 15–36 plus novices). Specifically, changes

Table 2 Selected Quiet Eye Training Studies by Sport, Skill Level and Increase in Performance with and without Quiet Eye Training.

Study	Sport & Task	Skill Level	QE Trained	Control
Adolphe et al. 1997	Volleyball	Team Canada	+7%	0
Harle & Vickers 2001	Basketball	Varsity	+23%	+6%
Ouedjans et al., 2005	Basketball	Professional	+14%	0%
Vine et al., 2011	Golf Putt	Low Handicap	-1.9 putts/ round	0/round
Causer et al., 2011	Skeet Shooting	Olympic	+5%	0%
Vine et al., 2011	Basketball	Novices	+34%	+23%

occurred primarily in the dorsal premotor and parietal cortex, the area also identified by Callaert et al. The authors concluded that extensive practice in golf, which is necessary to achieve a handicap ranging from 0 to 14, leads to significant changes in the dorsal spatial attention frontal area. In a follow-up study, Bezzola, Merillat, Gaser and Jancke (2011) trained novice golfers using 40 hours of golf practice and play and compared with a control group with no experience in golf. The pre-/post MRI showed significant increases in the dorsal spatial attention frontal area of the trained group that were not present in the control group. In particular there were changes in the parietal-occipital junction (POJ) which is functionally and anatomically connected to the visual system. Increases in gray matter in this area provide an additional clue why a long duration QE is essential to golf success; it assists and establishes, in a consistent manner, visuospatial attention control that is associated with enhanced spatial learning and body perception/control. Similar results have been shown for elite ballet dancers (Hangii, et al 2010).

Recently Wood & Wilson (2012) have established that when athletes receive QE training this endows them with a higher sense of perceived control and confidence. In a study of skilled penalty takers in soccer, not only did the QE trained group increase their QE duration on locations further from the goalkeeper, but they also were more accurate to these locations than a control group in both a laboratory based retention test and a high stress shootout. Perceived control was determined from a questionnaire developed by the authors based on the work of Jordet et al. (2006) that assessed perceptions of contingency and competence. The authors are the first to show that QE training not only increases QE duration and performance but also positively alters control beliefs when performing under high pressure.

In summary, a long duration QE is an objective measure of a golfer's ability to detect the critical cues underlying putting success and maintain visual focus under conditions of high anxiety and pressure. The QE prevents a loss of visual focus and task relevant attention by providing the information the brain needs to control the hands and club face as precise contact with the ball is made. In support of this notion, MRI studies of subjects, including golfers, show increased activation of a neural area within the dorsal spatial attention frontal network and decreased activation in ventral temporal areas, areas central to attention switching and emotional activation. A long duration QE appears to help maintain focus on the task at hand while at the same time blocking out destructive thoughts known to lead to lower levels of performance.

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