Title: An occlusion paradigm to assess the importance of the timing of the quiet eye fixation.

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RUNNING HEAD: Quiet eye supports late visual information pick up in golf putting.

TITLE: An occlusion paradigm to assess the importance of the timing of the quiet eye fixation.

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Abstract

The aim of the study was to explore the significance of the ‘timing’ of the quiet eye, and the relative importance of late (online control) or early (pre-programming) visual information for accuracy. Twenty-seven skilled golfers completed a putting task using an occlusion paradigm with three conditions: early (prior to backswing), late (during putter stroke), and no (control) occlusion of vision. Performance, quiet eye, and kinematic variables relating to the swing were measured. Results revealed that providing only early visual information (occluding late visual information) had a significant detrimental effect on performance and kinematic measures, compared to the control condition (no occlusion), despite quiet eye durations being maintained. Conversely, providing only late visual information (occluding early visual information) was not significantly detrimental to performance or kinematics, with results similar to those in the control condition. These findings imply that the visual information extracted during movement execution – the late proportion of the quiet eye - is critical when golf putting. The results challenge the predominant view that the QE serves only a pre-programming function. We propose that the different proportions of the QE (before and during movement) may serve different functions in supporting accuracy in golf putting.

Keywords: On-line control, Pre-programming, Occlusion paradigm, golf putting.

Introduction

Practically all eye movements made in naturalistic goal-directed actions can be interpreted as acquiring information to guide a forthcoming action (Tatler et al., 2011). In order to produce accurate goal-directed movements, the motor system requires accurate and timely visual information about targets critical to task completion. Research has demonstrated that fixations are tightly coupled, temporally and spatially, to the motor actions of the task (see Ballard & Hayhoe, 2009; Land 2009 for reviews). Specifically, gaze tends to move to the target in advance of movement initiation and remains stable as the movement unfolds, a strategy that has been proposed to simplify the computational problem for the central nervous system (Neggers & Bekkering, 2002). In sport, this stable gaze strategy has been termed quiet eye (QE; Vickers, 1996) and its duration has been shown to reliably discriminate between better and poorer performance across a wide range of skills (Vickers, 2007).

The QE is defined for a given motor task as the final fixation (or tracking gaze) to a relevant target, with an onset that occurs before the critical phase of the motor task and an offset that occurs when this final gaze deviates off the target (Vickers, 1996, 2007). It is proposed that during this period, visually acquired goal position information can be efficiently passed to the motor control system, resulting in movement kinematics and patterns of muscle activation that are more effective for successful skill performance (Moore, Vine, Cooke, Ring & Wilson, 2012a).

While there is strong support for an important role of QE in underpinning expertise (e.g. see meta-analysis by Mann, Williams, Ward & Janelle, 2007), to date the literature suffers from a lack of specificity about this role. The predominant explanation for positive QE effects is a pre-planning one, with QE postulated to functionally represent a critical period of cognitive processing during which the parameters of the movement such as force, direction, and velocity are fine-tuned and programmed (Vickers, 1996; Williams, Singer & Frehlich, 2002). For example, Mann and colleagues found that QE duration was closely associated with the Bereitschaftspotential, a pre-motor readiness potential, in a golf-putting task. The authors inferred that the QE period serves an important preparatory motor programming function and allows time for the brain to coordinate the neural structures involved in movement preparation (Mann, Coombes, Mousseau & Janelle, 2011).

However, even within the same task (i.e. golf putting) there are findings that point to a more important role for online control. First, Vickers' (1992) original research suggested that the QE should be maintained throughout the execution of a golf putt, with a dwell period maintained after contact (Vickers, 2007). This dwell period can offer no functional benefit in terms of pre-planning, but instead likely reflects online control of putter-ball contact (e.g., Wilson & Pearcey, 2009). Additionally, Vine, Lee, Moore & Wilson (2013) recently revealed that when golfers missed a short putt, it was due to the QE attenuating early (i.e. before contact). In this study a 'shoot out' design was adopted whereby participants were required to putt from 5ft until they missed. The early (pre-programming; before movement) and the late (online control; during movement) proportions of the QE were calculated. Interestingly, the final missed putt was accompanied by a shortening of the late (online control) QE, when compared with the first and penultimate putts. However the early (pre-programming) QE was similar across all putts. The authors concluded that this reflected the breakdown of the online control of the putt, and highlighted the importance of the QE to support the online control of movement. In addition, Oudejans, van de Langenberg & Hutter (2002) found that only the use of late visual information was necessary to produce accurate basketball jump shots (in comparison to early visual information). These findings were contrary to Vickers' (1996) results that experts preferred to initiate an early QE (prior to movement initiation) that was terminated early to avoid distraction from the ball moving in front of their face.

The aim of this study was therefore to initiate enquiry into the relative importance of the processes proposed to underpin the positive relationship between QE duration and golf putting performance, by manipulating the availability of visual information during putting, using an occlusion paradigm (cf. Oudejans et al., 2002); Panchuk & Vickers, 2009). In the current study we occluded the availability of visual information before the initiation of, and during the execution of a putt. Based on previous findings (Oudejans et al., 2002; Vine et al., 2013) we predicted that occluding late visual information (online control) would be more disruptive to performance than occluding early (pre-planning) vision. In order to extend the work of Oudejans and colleagues, we also captured eye movement data to examine the extent to which the QE (in addition to performance) changed when visual information was occluded.

Furthermore, we collected kinematic movement data in order to understand how the occlusion conditions influenced the movements produced. The extent to which vision is utilised during movement production can be inferred from discrete corrections to the movement trajectory (Lawrence, Khan, Buckolz & Oldham, 2006) and may reflect the motor control processes at play. Furthermore, research has identified differences in the acceleration profiles of the golf putter club head between expert and novice golfers (Delay, Nougier, Orliaguet, and Coello, 1997); as a result of the influence of anxiety (Cooke, Kavussanu, McIntyre & Ring, 2010); and for shots of varying difficulty and length (Sim & Kim, 2010). As such, we predicted that occlusion conditions would have differential effects on club head kinematics.

Method

Participants

Twenty seven golfers (Mean age = 24.53, *SD* = 8.57) with an average handicap of 5.8 (*Range* = +2 to -16; *SD* = 5.01) participated in the experiment. Participants volunteered to take part and all provided written consent. Local ethics committee approval was obtained prior to testing.

Apparatus

Putts were taken from 10 feet (3.05m), directed to a regular hole (10.80cm diameter) on an indoor artificial putting green. All participants used a standard length (90 cm) steel-shafted blade style putter (Sedona 2, Ping, Phoenix, AZ) and standard-size (4.27cm diameter) white golf balls. A Liquid Crystal (LC) SmartGlass panel (28 x 19cm) (SmartGlass International; London), mounted on a wooden box, was used to occlude the view of the ball during different phases of the putting action (see Figure 1). The LC SmartGlass is switched on (clear) and off (opaque) when an electrical current is passed through the glass. An infrared sender was fitted to the putter head, and an infra-red reflector was mounted on the wooden box behind the position of the ball. As the infra-red signal was broken, the screen would change states from clear to opaque or vice versa, depending on the experimental condition.

Design

Participants took six putts (cf. Cooke et al., 2010; Moore, Vine, Wilson & Freeman, 2012b[1]) in each of three, counterbalanced, occlusion conditions: no occlusion, early occlusion and late occlusion. For all trials participants had to look directly through the LC SmartGlass and position their putter behind the ball before initiating their own pre-shot routine. In the no occlusion (control) condition, the screen remained clear throughout the entire preparation and execution phases of the putts. In the early vision condition, the screen was clear during the preparation phase, however, on the initiation of the backswing (when the laser signal was broken) the screen became opaque and remained opaque throughout the execution of the putt. In the late vision condition, the screen was made opaque once the putter was positioned behind the ball (i.e. during the preparation phase). On initiation of the backswing, the screen became clear, and remained clear until the putt had been executed.

***** FIGURE 1 NEAR HERE*****

Procedure

On attending the single testing session, participants read an information sheet, gave their written informed consent, and performed twenty familiarization putts from 10 feet. They then had the instructions related to their first counterbalanced condition explained and completed their six experimental putts. After each condition participants were given a two minute rest period while the next condition was explained. This procedure was repeated for all three conditions. Finally, participants were thanked, debriefed and given the opportunity to discuss their performance with the experimenter.

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[1] Six putts were used as a compromise between obtaining a meaningful average, and preventing participants from learning to adjust their head and body position to overcome the visual constraints imposed by the occlusion glass. We acknowledge that such an approach increases the influence of extreme values on the average.

Measures

QE duration. An Applied Science Laboratories (ASL; Bedford, MA, USA) Mobile Eye Tracker incorporated with a laptop (Lenovo R500 ThinkPad) installed with Eyevision (ASL) recording software was used to measure and record momentary gaze (at 30 Hz). 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) was recorded for offline analysis. The laptop and recording devices were placed on a desk behind the participant to minimise distraction.

The QE duration was operationally defined as the final fixation towards the ball prior to the initiation of the backswing (Vickers, 2007). A fixation was defined as a gaze maintained on an object within 1° of visual angle for a minimum of 100 ms. QE onset occurred before the backswing and QE offset occurred when the gaze deviated off the fixated object by 1° or more, for greater than 100 ms (Vine, Moore & Wilson, 2011). Gaze data was analyzed using Quiet Eye Solutions software (www.QuietEyeSolutions.com). This software allows for frame-by-frame coding of both the motor action (recorded from the Mobile Eye's scene camera at 30 Hz) and the gaze of the performer, and automatically calculates QE duration. During the analysis of the eye tracking data, prior to the ball being occluded the experimenters marked the location of the ball behind the occluded screen. This enabled coding of fixations to the ball's location even when the ball was not visible, and the calculation of a QE period during phases of the putting action when the ball was occluded.

10% of the data from the eye tracker were selected at random, and coded by a second analyst. A total of 102 trials were coded by the first analyst, and so one shot from 10 different participants were selected to give a representative sample. Interrater reliability was assessed using the inter-observer agreement method (Thomas & Nelson, 2001). This analysis revealed a satisfactory level of agreement at 96.6% (cf. Moore et al., 2012a).

Performance. Mean radial error (the average distance the ball finished from the hole in cm) was recorded as measure of putting performance (Cooke et al., 2010, 2011; Moore et al., 2012a; Vine et al., 2011). Measurements were taken from the centre of the ball to the centre of the hole, and putts that were holed were recorded as zero. A Logitech Web Cam was mounted directly above the hole, which enabled the experimenter to take a picture of where ball finished (via remote control) for offline analysis of error using 'Scoreputt' software (see Neumann & Thomas, 2008).

Putting kinematics. A tri-axial accelerometer (LIS3L06AL, ST Microelectronics, Geneva, Switzerland) was used to compute acceleration of the putter clubhead in X (lateral), Y (vertical), and Z (back-and-forth) axes (cf. Cooke et al., 2010, 2011. The signals were conditioned by a bespoke buffer amplifier with a frequency response of 15 Hz. Both the accelerometer and amplifier were mounted in a 39 mm X 20 mm X 15 mm plastic housing secured to the rear of the clubhead. A microphone (B5 Condenser, Behringer, Germany) connected to a mixing desk (Eurorack UB802, Behringer, Germany) was used to detect the putter–ball contact on each trial. These signals were digitized at 2500 Hz.

A computer program (written in Spike, Cambridge Electronic Design, UK) determined club-head acceleration for each putt from the onset of the fore-swing phase of the putting stroke until the point of putter–ball contact. An experimenter (blinded to condition) initially determined the initiation of the forewing phase. The values from all trials were averaged to provide a mean value (cf. Cooke et al., 2010; Moore et al., 2012b).

Statistical Analyses

Mean values from the six putts taken were computed and subjected to a series of repeated measures one-way Analysis of Variance (ANOVA). Significant differences were followed up with Least Significant Difference (LSD) corrected pair-wise comparisons. Effect sizes were calculated using partial eta squared (η_p^2) for omnibus comparisons.[2]

Results

QE Duration

There were no significant differences in QE duration across conditions, $F(2,36) = 0.73$, $p = .491$ (Figure 2).

Performance: Mean Radial Error

There were significant differences in radial error across conditions, $F(2,52) = 4.22$, $p = .020$, $\eta_p^2 = .14$[3]. Pairwise comparisons revealed that while the control and late vision conditions were similar to one another ($p = .774$), the early vision condition performance was significantly worse than both the control ($p = .011$) and late ($p = .039$) conditions respectively (Figure 3).

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[2] Due to technical errors and calibration issues with the eye tracker and club-head accelerometer, data were lost for some participants. As such these participants were not included in the analysis of QE duration (n = 10) and club head acceleration (n = 5; see degrees of freedom in ANOVA).

[3] The percentage of putts holed was also analyzed. While these data were in the same direction as the mean radial error, these differences did not reach significance [$F(2,52) = 2.13$, $p = .130$, $\eta_p^2 = .08$].

****** FIGURE 2 NEAR HERE******

Putting Kinematics

Kinematic analyses revealed significant condition differences for X-axis acceleration, *F*(2,48) = 4.56, *p* = .015, $\eta_p^2 = .16$; and Y-axis acceleration, *F*(2,48) = 3.44, *p* = .040, $\eta_p^2 = .13$, but not Z-axis acceleration, *F*(2,48) = 2.00, *p* = .146. Pairwise comparisons revealed that X-axis acceleration for the early vision condition was reduced in comparison to both the late vision and control conditions (*p*s = .004 and .026 respectively). The late vision and control conditions were similar (*p* = .731). Y-axis acceleration for the early vision condition was greater than the control condition (*p* = .013), but there were no differences between the late vision and both the early and control conditions (*p*s = .442 and .101 respectively). The full kinematic variable results are presented in Table 1.

Discussion

The aim of this study was to improve our understanding of the importance of the timing of the QE during the golf putt, by manipulating the availability of visual information, using an occlusion paradigm. Experienced golfers were asked to perform putts in three different conditions that manipulated the visual information available. Based on the findings of Oudejans et al. (2002) and Vine et al. (2013), we predicted that occluding late visual information (online control) would be more disruptive to performance than occluding early (pre-planning) vision. As predicted, we found no effect on performance (in comparison to a ‘full vision’ control condition) when early visual information was occluded, and only late visual information was available (late vision condition). However performance suffered when late visual information was occluded and only early visual information was available, (early vision condition).

These findings corroborate those of Oudejans et al. (2002) and Vine et al. (2013) who have provided previous support for the importance of the use of late visual information for far aiming skills.

The capturing of eye data during the occlusion of different phases of movement is an important addition to the body of literature and a manipulation check that has not been possible in previous studies (see Oudejans et al., 2002; De Oliveria, Oudejans & Beek, 2006). Interestingly, there were no differences in QE across the conditions that can easily explain the performance effect observed (Figure 2). Indeed, across all three occlusion conditions the performers displayed QE durations similar to those demonstrated by other experienced performers in normal putting from this same distance (e.g., Vine, Moore & Wilson, 2011). When visual information was occluded participants continued to use a strategy of keeping their eye steady on the ball's location (even though it was not visible).

Taking into consideration the QE findings there are two possible explanations for why performance was maintained in the late visual condition, but disrupted in the early vision condition. The first is that the early proportion of the QE that occurs before movement serves no functional purpose, however, this seems unlikely given the strength of the evidence relating an early and long QE to superior performance (e.g., Klostermann, Kredel & Hossner, 2013; Vickers, 1996; Williams et al,. 2002). An alternative explanation is that the proportion of the QE period that occurs before movement is not involved in active visual processing of the environment, but rather is reflective of the processing of visual information obtained during the pre-shot routine into putting control parameters (Vickers, 1996). The visual routine (fixating the hole and the line to the hole) leading up to their final (albeit occluded) gaze on the ball may have provided them with all the pre-programming information they needed to plan the putt, despite not seeing the ball prior to the initiation of the putting stroke. This early proportion of the QE therefore reflects the steadying of the eye, in order to focus attention (see Smith and Schenk, 2012) and internally programme the putter movement.

The late proportion of the QE (during movement) serves a different function. In the early vision condition when late visual information was occluded, performance suffered despite the eye remaining steady. Occluding the view of the ball significantly reduced performance accuracy, suggesting that the late proportion of the QE that occurs during movement relates to visual processing of the environment. Here it seems that visual information is being actively extracted and processed, likely to aid the control of the putter head and to ensure good putter-ball contact (Craig, Delay, Grealy & Lee, 2000). The visual processing of the target (ball) is preferred as late as possible with reference to the end of the movement (contact between putter and ball; Oudejans et al., 2002).

The kinematic data appear to provide some support for the importance of maintaining active visual control during the stroke itself. X-axis acceleration increased for both the control and the late vision conditions, in comparison to the early vision condition, perhaps reflecting online adjustments under the control of vision. Previous research has revealed that adjustment to the position of the putter head during the back and fore-swing can help to ensure a square putter face at contact (Pelz, 2000) which is related to improved putting performance (see Karlsen et al., 2008). While increased variability in putter head kinematics has been associated with poorer performance (see Bartlet, Wheat & Robins, 2007) research also suggests that some ‘functional variability’ is a characteristic of expert and accurate performance. Functional variability allows for the emergence of a movement which is tailored towards the end goal (striking the ball), and without this variability performers could not adapt to incorrect positioning at any stage of the action (Langdown, Bridge & Li, 2008). For example, Sim & Kim (2010) showed that the directional variability of the putter head during the swing increases with the length of the putt, and this increase in variability is greater for expert (more accurate) golfers, compared to novices.

There are caveats to our interpretation of the important role of late visual information in guiding putter-ball contact that should be discussed. Anecdotal evidence from participants raised the issue of reinvestment (Masters & Maxwell, 2008) or explicit monitoring (Beilock & Carr, 2001) in the early occlusion condition. With vision removed, a number of participants reported that they were more aware of the way in which they were controlling the putter to make the stroke, as this kinaesthetic information was all that was available. As experienced performers, any contingency that raises awareness of the mechanics of the stroke is likely to be detrimental to performance (Beilock & Gray, 2012). Unfortunately, we were unable to explore these mechanisms further, as our kinematic data were equivocal in reflecting increases in conscious control (Poolton, Maxwell, Masters, & Raab, 2006).

Second, there is also some evidence that the backswing of the putter might still be considered as pre-programming and that only the downswing should be considered as being truly online control (Craig et al., 2000). Future research should seek to extend the current study by including two additional conditions that would allow vision to be manipulated at the end of the backswing, as well as the start of the backswing. Providing vision in either the backswing or the downswing of the putting stroke would enable the relative role of the QE in assisting with pre-programming and online control of visually guided movement to be further explored. It is a limitation of the current study that we were unable to explore these issues due to the limited degree of software control we had with the liquid crystal display.

Theoretical implications

This ‘later is better’ interpretation of the QE that is provided by the data in the current study, fits more comfortably within a perceptual-cognitive expertise framework than a ‘longer is better’ interpretation. The fact that experts need longer processing time than novices to achieve better performance has always been difficult to rationalize, when compared with an expert’s ability to anticipate more quickly with less information than novices (e.g., Mann et al., 2007). While the current findings do not relate specifically to expertise, they do suggest that successful performance is likely to be underpinned by a steady QE fixation that is prioritized at a critical moment, and that this fixation might reflect different purposes (internal programming or active visual processing). This interpretation does not negate previous findings that have shown that experts had longer QE durations than novices, but it does call into question which part was critical and where the specific differences in QE were; early (before the movement) or late (as the movement unfolds). Experts may still have longer QE durations than novices just by keeping a steady fixation throughout the movement, whereas novices will attenuate their QE if their gaze is flitting around in a less efficient and effective manner (see Behan & Wilson, 2008; Wilson, Vine & Wood, 2009).

In conclusion, the aim of current study was to directly manipulate the availability of visual information during the QE period using an occlusion paradigm with experienced golfers. Our results supported the findings of Oudejans et al. (2002) and Vine et al. (2013) that QE provides online control function to help performance.

The late proportion of the QE that occurs during the movement may reflect online control of the movement. This phase of the action requires visual guidance, and so visual feedback is used to adjust and control movement online. Gaze may be stabilised for longer than this critical period in order to internally plan movement, or as part of a pre-performance routine, but, a growing body of evidence (e.g., Klostermann et al., 2013; Oudejans et al., 2012; Vine et al., 2013), points to a critical role for late processing of visual information. Future studies should seek to further elucidate the relative roles of pre-programming and online control in explaining the QE-visuomotor performance relationship, and also examine the individual proportions of the QE (before and after initiation of movement) that may account for performance variability.

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Tables:

Table 1: Mean (SD) putter kinematic variables for control, early vision and late vision conditions.

	Control	**Early**	**Late**
X-axis acceleration (m.s^{-2})	0.51 (0.22)	0.41 (0.21)	0.52 (0.24)
Y-axis acceleration (m.s^{-2})	1.04 (0.20)	1.09 (0.18)	1.06 (1.78)
Z-axis acceleration (m.s^{-2})	4.07 (1.17)	3.96 (1.08)	3.90 (1.22)

Figure Captions:

Figure 1: A diagram of the experimental set up showing key elements of the occlusion method: a) Infra-red reflector; b) Liquid Crystal SmartGlass; c) Infrared sender.

Figure 2: Mean (SE) QE duration (a) and radial error (b) for control, early vision and late vision conditions.

Figure 3: Mean (SE) radial error (cm) for control, early vision and late vision conditions.