Context affects Quiet Eye duration and motor performance independent of cognitive effort

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Abstract

An extensive body of research exists which has investigated ‘Quiet Eye’ and performance in aiming tasks. However, little attention has been paid to whether the context in which tasks are executed affects Quiet Eye and, despite consistent behavioural effects, little is known about the mechanisms that underpin the phenomenon. In this study, 21 novice participants completed golf putts in three different contexts while pupil dilation, Quiet Eye duration, and putting accuracy were measured. Results showed putting was more accurate when putting to win compared to the control (no context) condition and Quiet Eye duration was longer when putting to win or tie a hole compared to the control condition. There was no effect of context on pupil dilation. Results suggest that, while the task was challenging, performance scenarios can be included in learning environments for novice golfers to enhance representativeness of practice without adding additional load to cognitive resources.

Key Words: perceptual-cognitive skill; expertise; gaze behaviour, motor control

Introduction

Over the past two decades, researchers have conducted numerous empirical investigations in to the visual control of movement in aiming tasks (Causer, Hayes, Hooper, & Bennett, 2017; Causer, Holmes, Smith, & Williams, 2011; Miles, Wood, Vine, Vickers, & Wilson, 2015; Vickers, Vandervies, Kohut, & Ryley, 2017; Vine & Wilson, 2011). A consistent finding is that the final visual fixation (lasting over 100ms; within one-degree of visual angle) prior to execution of an action is exhibited for longer by higher skilled participants. Longer final fixations are associated with more successful performance outcomes (Lebeau et al., 2016), commonly referred to in the literature as the 'Quiet Eye' (QE; Vickers, 1992; Vickers, 1996; Vickers & Williams, 2007). Research findings highlighting the performance benefits of QE have been consistently shown in sport (Lebeau et al., 2016), surgery (Causer et al., 2014; Harvey et al., 2014), and coordination disorders (Miles et al., 2015). Researchers have also developed interventions to increase QE duration and reported subsequent performance improvements (Causer, Holmes, & Williams, 2011; Panchuk et al., 2014; Vine et al., 2011; Vine & Wilson, 2011).

Researchers working in the field of perceptual-motor control have investigated how task constraints affect gaze behaviour, anxiety, and cognitive effort, to glean a broader understanding of the factors affecting performance. To this end, researchers have examined how QE is affected by factors such as physiological arousal (Vickers & Williams, 2007), the presence of opponents (Vickers et al., 2019), and in particular the manipulation of anxiety (Causer et al., 2014; Causer et al., 2011; Moore et al., 2012; Vine et al., 2013; Wood & Wilson, 2011). In an effort to manipulate anxiety, previous work has often used competition scenarios. For example, Causer et al. (2011) instructed skilled shotgun shooters to 'shoot as if they were in a competition' in an attempt to heighten anxiety and found an increase in self-reported anxiety as well as later QE onset and shorter QE duration alongside reduced shooting accuracy in this condition. From here on, we refer to such manipulations of situational variables as manipulations of ‘context’ where context is defined as referring to ‘the situation within which something exists or happens, and that can help explain it’ (Cambridge English Dictionary, 2020).

The manipulation of context has been of particular interest following recent reviews which have identified the need for researchers to further investigate its influence (see Cañal-Bruland & Mann, 2015; Loffing & Cañal-Bruland, 2017; Williams & Jackson, 2019). Such research has reported that the presence of contextual information (i.e., that which provides information about the situation and does not seek to alter anxiety) can improve anticipation accuracy in cricket (Runswick et al., 2019; Runswick et al., 2018) and tennis (Murphy et al., 2016). McRobert et al. (2011) reported that providing contextual information that did not focus on manipulating anxiety resulted in not only enhanced accuracy in a perceptual-cognitive anticipation task, but also led to a reduction in length of mean fixation duration which was suggested as being due to a reduction in the time required to process information. This suggests that the provision of contextual information which does not seek to manipulate anxiety may also affect the functional coupling between QE and action execution and may do so differently than reported in previous QE research that has focused on anxiety (Rodrigues et al., 2002).

Recent evidence that has specifically investigated whether anxiety and context operate through separate mechanisms has affirmed this assertion (Broadbent et al., 2019; Runswick et al., 2018). Runswick et al. (2018) conducted an experiment using an in-situ cricket batting task where context and anxiety were manipulated separately. Results showed that when performing in conditions where anxiety was manipulated there was a reduction in and batting performance and processing efficiency, inferred from an increase in visual fixations on irrelevant stimuli. In contrast, when contextual information was provided in the absence of the anxiety manipulations, bat-ball contact was negatively affected but through changes in the execution of motor responses without changes in processing efficiency. A similar study by Broadbent et al. (2019) sought to confirm these findings by having expert soccer players complete an anticipation task in high or low anxiety conditions with and without ‘contextual priors’ that detailed the opponents action tendencies. In conditions where anxiety was manipulated (through performance evaluation) performance was negatively affected and was underpinned by a decrease in processing efficiency measured through self-reported mental effort. However, context enhanced performance without affecting processing efficiency. Taken together, these findings reported by Runswick et al. (2018) and Broadbent et al. (2019) suggest that the provision of context and the manipulation of anxiety both affect aspects of perceptual-motor control, including gaze behaviour, cognitive load, and performance execution, but do so through separate mechanisms. There is then a need to consider how the provision of contextual information independent to any manipulation of anxiety affects QE and associated performance.

Despite consistent research findings concerning QE and motor performance, there remains some debate over the mechanisms that underpin the phenomenon. In their review, Gonzalez et al. (2017) highlighted a number of mechanisms that have been proposed to underpin the QE effect. Mechanisms included allocation of attention (Klostermann et al., 2014), motor programming (Mann et al., 2011) and response selection and online control (Causer et al., 2017). For example, Vine et al. (2017) used a temporal occlusion paradigm during a golf putting task to show that the latter portion of the QE period was critical when executing the putt, suggesting therefore that QE is not just a motor programming period but also has a role to play in online control. However, evidence has recently emerged which suggests that QE mechanisms may be linked to information processing and increased cognitive effort (Campbell et al., 2019; Klostermann et al., 2014). This suggests that the performance enhancing effects of longer QE periods are due to QE being a proxy for increases in allocation of cognitive resources devoted to the task at hand.

Pupil dilation has been used as a measure of cognitive effort, with larger task-invoked pupil dilation reported as being related to increased cognitive effort during harder cognitive tasks (Campbell et al., 2019; Moran et al., 2016; Robinson & Unsworth, 2019). While Vine et al., (2017) have shown the importance of information available late in the QE period in a golf-putting task, Campbell et al. (2019) found that participants' peak pupil dilation occurred at the onset of QE, consistent with the suggestion that this was the most cognitively demanding time in the task and that QE may be related to cognitive effort. Pupil dilation could, therefore, provide a useful window into the mechanistic underpinnings of QE, however Campbell et al's (2019) study represents one of the first to investigate the relationship between QE and pupil dilation and so there is a need to examine this further. Further, there has been no investigation into how experimental manipulations of context which alter the degree of cognitive challenge may affect this relationship. By understanding if context affects QE duration, cognitive effort, and perceptual-motor performance, it is possible to better understand the findings of previous work that has used context to manipulate anxiety. Such investigations can then inform the design training environments that are as representative as possible (Pinder et al., 2016) without overloading the cognitive resources of the learner (Runswick, et al., 2018; Van Merriënboer & Sweller, 2005).

In this study, we used a golf-putting task and manipulated the context under which participants putted to investigate how context affects QE duration and motor performance. Specifically, participants putted under conditions where they were instructed that a successful putt would either 'win the hole', would 'tie the hole' (traditionally referred to as a half), or to putt as if they were practising (i.e., absence of context). We recorded QE duration (ms) and putting accuracy (error score) to assess how context affected perceptual-motor control, motor performance and recorded pupil dilation (mm) as an indicator of cognitive effort. Based on the literature showing the effects of QE on performance (Lebeau et al., 2016; Mann et al., 2007) and effects of context on cognitive processes (McRobert et al., 2011b), we predicted that the presence of context would improve putting accuracy and this would be mediated by an increase in QE duration. On the basis of Campbell et al's (2019) proposals, we expected an increase in QE duration would also be accompanied by an increase in pupil dilation as a proxy of cognitive effort. However, Runswick et al. (2018a; b) reported that context had little effect on cognitive effort, which contrasts with the proposals of Campbell et al. (2019). Runswick et al's (2018a; 2018b) findings therefore would inform the hypothesis that the presence of context would affect QE duration and performance but with no change in pupil dilation. Given the relatively novel nature of this part of the study and the limited yet contrasting existing research findings, our aim here was to test these competing hypotheses.

Method

Participants

We conducted an a-priori power analysis using G*power (Faul et al., 2007). The calculation was based on the main effect size from Runswick et al. (2018) that represents the only previous study to investigate the effects of context on perceptual-cognitive-motor performance in a sports-based task. We used the within-factor effect size that displayed a significant effect of context on motor performance ($\eta p^2 = 0.46$). We set a moderate correlation ($r = 0.3$) and power at 0.95. The minimum sample size required was $n = 10$. Given the very large effect size in Runswick et al. (2018), and to account for potential dropout, we recruited 21 participants. The 21 participants (mean age 21.22 ± 1.89 years) who completed the study were all classed as novice golfers, defined as those with no experience playing golf. Due to the nature of the sample some participants may have had some limited exposure to putting during classes or playing 'crazy golf'. The research was conducted in accordance with the ethical guidelines of the lead institution and written informed consent was obtained from all participants at the outset.

Apparatus and task

The experimental task required participants to complete a golf putt without break from a distance of 243cm (8 ft). Testing was conducted using a hole on an indoor putting green in a laboratory. The golf club used was a ‘Series Tour’ golf putter, and the ball was a regulation golf ball (diameter = 43.67 mm, mass = 45.93). Gaze behaviour, QE duration and pupil diameter were recorded using a SensoMotoric Instruments (SMI) mobile eye tracker recording at 60hz. Pupillometry was recorded at a sampling frequency of 30 Hz from both the left and right eye. Putting accuracy was recorded using a standard digital video camera positioned above the hole.

Procedure

Participants were required to attend one testing session. Upon arrival at the laboratory, all participants provided written informed consent. Participants then put on the SMI eye-tracker, which was calibrated by the lead investigator using the 3–point calibration system with participants looking at golf balls on the ground from a putting stance to represent the viewing angle to be used during testing. Participants were informed that they would be asked to perform 18 golf putts, representing an 18-hole match and were instructed to perform the putt in the way they deemed most appropriate for the scenario they were given. Prior to each putt, the lead investigator provided the participant with contextual information. This consisted of participants being informed that the subsequent putt was to either win the hole, tie the hole, or the putt was simply a practice putt. The order of putts was counterbalanced across participants. As participants were all considered novice golfers, in ‘win’ and ‘tie’ scenarios the researcher also outlined the possible outcome of each putt to ensure the participant understood the context but did not direct them on how to behave. For example, "This putt is to win the hole. If you hole the putt you will win, if you miss you will have a second putt to tie (draw) the hole"; "This putt is to tie (draw) the hole. If you hole the putt you will tie (draw), if you miss the putt you will lose the hole"; "The hole is over and you are taking a practice putt".

Dependent Measures

Putting Accuracy

Putting accuracy was recorded as a measure of putting performance. Ten concentric circles surrounded the hole that progressively increased in radius from 10cm to 100cm at 10cm intervals. Error was scored out of 10 (putt finishes in the hole) with the score decreasing by 1 for every ring further from the hole. Any putt that finished outside the 100cm radius ring (the furthest ring from the hole) was scored as zero.

Quiet Eye Duration

Consistent with previous literature (e.g., Causer et al., 2017; Vickers, 2007), QE was defined as the initiation of the final fixation on the ball that occurred prior to the start of the backswing. QE duration was recorded using the eye tracker and defined as the length of the fixation (ms) starting from onset, the first frame when the final fixation on the ball began, to offset, when gaze deviated by more than 1 degree of visual angle from the ball for more than 100 ms (Vickers, 2007).

Pupillometry

Campbell et al., (2019) suggested that pupil dilation would peak at the onset of QE. However, in this study pupil dilation peaked after the onset of QE in 74% of all trials. We therefore recorded pupil dilation in three ways. Firstly, the pupil dilation (mm) at the onset of QE (Campbell et al., 2019). Secondly, the peak task–evoked pupillary response that occurred during the QE period, and finally the mean pupil dilation across the period of the QE. The dilation of the right eye was used for all analyses(Kahya et al., 2018; Moran et al., 2016;

Porter et al., 2007). Full QE and pupillometry data was available for 19 out of 21 participants due to technical issues with the eye tracker for the remaining two participants.

Data Analysis

Separate one-way repeated measures ANOVA were used to establish the effect of context (win vs tie vs practice conditions) on each dependent variable (putting accuracy, Quiet Eye duration and both mean and peak pupil dilation). Any violations of sphericity were corrected for by adjusting the degrees of freedom using the Greenhouse Geisser correction when epsilon was less than 0.75 and the Huynh-Feldt correction when greater than 0.75 (Girden, 1992). The alpha level (p) for statistical significance was set at 0.05. A Bonferroni adjustment was employed for multiple comparisons in order to lower the significance threshold and avoid Type I errors (McLaughlin & Sainani, 2014). Partial eta squared (ηp^2) was used as a measure of effect size for all ANOVA analyses and Cohen's d for post-hoc comparisons.

Results

Performance

Putting accuracy. There was a main effect of context on putting accuracy (F (2,40) = 3.696, $p < 0.034$, $\eta p^2 = 0.156$, Figure 1). Post hoc tests using Bonferroni correction revealed a higher performance score (more accurate putting) in the *Win* (4.92 ± 1.48) compared to *Practice* (3.93 ± 1.51) condition (p = 0.026, d = 0.66). There was no difference in putting accuracy between the *Tie* (4.23 ± 1.74) and *Practice* (p = 1.0, d = 0.18) or *Win* (p = 0.42, d = 0.43) conditions.

Quiet Eye Duration

There was a main effect of context on QE duration (F (1.520, 27.361) = 5.250, $p < 0.02$, $\eta p^2 = 0.226$, Figure 2). Post hoc tests using Bonferroni correction revealed shorter QE duration in the *Practice* (489.23 ± 453.19 ms), compared to *Tie* (752.82 ± 747.76 ms, p = .05, d = 0.43) and *Win* (704.80 ± 607.48 ms, p = .005, d = 0.40) conditions. There was no difference in QE duration between *Tie* and *Win* conditions (p = 1.0, d = 0.07).

Pupillometry

There was no main effect of context on pupil dilation at the onset of QE (Practice = 3.77 ± 0.80; Tie = 3.56 ± 0.84; Win = 3.67 ± 0.72; F (2, 36) = 2.299, p = 0.116, $\eta p^2 = 0.119$). There was also no main effect of context on mean pupil dilation (Practice = 3.81± 0.72; Tie = 3.71 ± 0.71; Win = 3.66 ± 0.66; F (2, 36) = 2.536, p = 0.093, $\eta p^2 = 0.123$). Finally, there was also no main effect of context on peak pupil dilation during the QE period (Practice = 3.94 ± 0.72; Tie = 3.88 ± 0.67; Win = 3.85 ± 0.62; F (2, 36) = 0.71, p = 0.45, $\eta p^2 = 0.04$).

Discussion

Our aim in this experiment was to investigate how manipulation of context affected visual motor control and motor performance. Participants completed a golf-putting task under manipulations of context or in the absence of context. We recorded Quiet Eye duration as a measure of visual motor control, putting accuracy as a measure of motor performance, and pupil dilation as an indicator of cognitive effort. We predicted that context would positively affect performance, and this would be mediated by changes in QE duration. If Campbell et al's (2019) proposals were accurate then we expected that an increased in QE duration would also be accompanied by an increased in pupil dilation as a proxy of cognitive effort. However, the contrasting findings of Runswick et al. (2018a; b) informed the competing hypothesis that context would affect QE duration and performance with no change in pupil dilation as an indicator of cognitive effort.

In line with our hypotheses, and consistent with findings from previous empirical investigations, there was a significant main effect of context on performance (Causer et al., 2011; McRobert et al., 2011b; Murphy et al., 2016). Participants putted more accurately when putts were in context 'to win' compared to practice putts (no context). These findings are partially consistent with those reported by Runswick et al. (2018) who found the presence of context affected performance in an interceptive perceptual-cognitive-motor task. However, whilst we observed an *improvement* in putting accuracy, Runswick et al. (2018) found the presence of context caused a *degradation* in quality of bat-ball contact. When the cricket batters in Runswick's study were exposed to context (in the form of fielder position and score line information) there was an enhanced likelihood of negative outcomes (i.e., they could lose their wicket, or the fielders could intercept their shots). In this study, however, the context of putting to win meant participants had two attempts to avoid losing the hole, meaning a potential increase in possible positive outcomes. Together, these findings suggest that the type of scenario presented, and task may mediate the effects of context on motor performance.

The main effect of context on performance (putting accuracy) was accompanied by a main effect of context on QE duration. However, QE durations reported here are shorter than reported elsewhere previously (e.g., Vine et al., 2011), which may be due to novice participants being used in this experiment whereas much previous research has employed skilled participants. Despite QE duration being comparatively short, both putting conditions where context was provided (i.e., putting 'to win' or 'tie') were characterised by significantly longer QE durations than when putting in the absence of context (i.e., the 'practice' condition), which was also the condition in which putting was least accurate. Although not in an aiming task, McRobert et al. (2011) previously reported changes in gaze behaviour during perceptual-cognitive tasks when provided with contextual information relative to when performing the same tasks without contextual information. In the study reported here, the link between an increase in QE duration and enhanced putting accuracy in the 'putt to win' condition is consistent with much of the literature concerning QE and motor performance, both within golf putting (see Campbell et al., 2019; Causer et al., 2017) and other tasks (see Lebeau et al., 2016). While previous research has shown that QE duration and subsequent motor performance was affected by anxiety manipulated through the addition of context (Causer et al., 2011), here we have specifically shown the context in which a task is performed- independent of anxiety- affects QE and performance outcomes. This suggests that to develop measures of optimum gaze applicable to real world settings, non-visual information such as contextual factors should be represented in experimental designs and practice environments.

To test recent suggestions that QE may be underpinned by cognitive mechanisms based on greater cognitive effort and information processing (Campbell et al., 2019; Klostermann et al., 2014), we collected pupillometry data in three ways during the QE period. The pupil dilations recorded were large compared to those reported in classical work involving participants completing seven digit memory tasks (see Beatty & Kahneman, 1966), suggesting the putting task was cognitively challenging for a novice. However, despite a significant increase in QE duration in the ‘putt to win’ and ‘putt to tie’ conditions compared to the control ‘practice’ condition, there was no effect of the additional context on onset, peak or mean pupil dilation despite concurrent changes in motor performance. This suggests that context manipulations affect perceptual-motor processes independent from changes in cognitive effort. Our findings therefore challenge the predictions of Campbell et al. (2019) who suggest QE may be mediated by changes in cognitive processes. These findings are, however, in line with those of Runswick et al. (2018a;b) and Broadbent et al. (2019) who reported that changes in context affect perceptual-motor processes independent of cognitive effort and anxiety.

The results have practical, theoretical and empirical implications. First, much of the current understanding around QE behaviour, while predicated on a strong base of scientific evidence derived from research studies that have manipulated numerous constraints on the task (e.g Causer et al., 2014; Causer et al., 2011; Moore et al., 2012; Vine et al., 2013; Wood & Wilson, 2011), has not considered contextual information which is present in performance environments independent of anxiety. It is important that researchers seek to ensure that factors present in performance environments are faithfully represented, as much as is possible, when designing experiments (Broadbent et al., 2015; Pinder et al., 2016; Stone et al., 2014). Second, the finding that context influenced perceptual-motor processes independent of cognitive effort suggests that not only should context be included in experimental design, but that it could be incorporated in learning environments without overloading the cognitive resources of even novice learners (c.f. Cognitive Load Theory; van Merriënboer & Sweller, 2005). We did not find evidence for the proposal that QE duration may be an indicator of enhanced information processing. Future research could also include more specific measures to investigate other proposed QE mechanisms alongside pupillometry that focus on cognitive approaches.

In this study, we employed a context manipulation in a golf-putting task to investigate the effects of context on QE duration, target aiming motor performance and cognitive effort. Findings showed that context led to an increase in QE duration and more accurate motor performance, yet these effects occurred without changes in pupil dilation; a proxy for cognitive effort. Findings suggest that QE may not be underpinned by cognitive processing and that context could be introduced into both the design of QE experiments and training environments using simple hypothetical manipulations.

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Figure Captions

Figure 1. Mean performance score per putt with individual participant data points for each context.

Figure 2. Mean Quiet Eye duration with individual participant data points for each context.

Figure 3. Mean and individual participant data points for each context for (A) Pupil dilation at QE onset (B) Peak pupil dilation during the QE period and (C) Mean pupil dilation during the QE period.