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ABSTRACT

Purpose. The quiet eye (QE) is a characteristic of highly skilled perceptual and motor performance that has been shown to be sensitive to increases in anxiety. The present study is the first to examine changes in the QE at the precise point of performance failure under heightened anxiety. QE durations were compared for the first, penultimate (next to last), and final (missed) putts taken in a pressurized 'shootout' task. To probe the effects of anxiety more specifically, differences in the component of the QE that occurred before (QE-pre), during (QE-online), and after (QE-dwell) putter movement were examined. **Methods**. Fifty expert golfers (average handicap of 3.6) performed putts under pressure until they missed ('shootout'). Gaze was recorded throughout with an ASL Mobile Eye Tracker. Total QE, pre-programming QE (the proportion of QE that occurred prior to backswing; QE-pre), online control QE (the proportion of QE that occurred during the putting stroke; QE-online), and QE dwell (the proportion of QE that occurred after putter-ball contact; QE-dwell), were calculated for the first, penultimate, and final putts. **Results**. Total QE duration was significantly shorter for the final (missed) putt compared to the first and penultimate (successful) putts. Although QE-pre duration was similar across the three putts, the components of the QE occurring during (QE-online) and after (QE-dwell) putter movement were significantly shorter on the missed putt. **Conclusion**. Performance failure under pressure appears to be due to disruptions in attentional control once movement has been initiated. These findings support the predictions of attentional control theory (ACT) and suggest that the QE may have an online control function, providing visual sensory information as the movement unfolds.

Keywords: quiet eye; attentional control theory; anxiety; visuomotor control.

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In order to produce accurate goal-directed movements, the motor system requires accurate and timely visual information about targets critical to task completion [14]. Models of visuomotor control suggest that the gathering of such information is under the control of top-down attention (see Land, [14] for a review). One objective measure of visual attentional control that has been the subject of recent research attention is the Quiet Eye (QE; [25]) - defined as the final fixation towards a relevant target prior to the initiation of a critical movement [26]. The finding that experts demonstrate earlier and longer QE durations than novices is one of the most robust in the perceptual-cognitive expertise literature (see [17] for a meta-analysis and review).

However, even experts can 'miss' and the QE has been shown to be sensitive to such intra-individual variations in performance - with successful attempts having longer QE durations than unsuccessful attempts [17]. The *choke* is one particular classification of 'miss' that has been the topic of much recent research in sport psychology (see [11] for a review). Choking is defined as, "a critical deterioration in skill execution leading to substandard performance that is caused by an elevation in anxiety levels under perceived pressure at a time when successful outcome is normally attainable by the athlete" ([18], p. 343). Interference to optimal attentional processing has been implicated as central to the choking experience [8]. A number of recent studies have revealed anxiety-induced disruptions in attention - as indexed by shortened QE durations - in a range of far aiming tasks including simulated archery [1]; shotgun shooting [2]; dart throwing [20]; basketball free-throw shooting [30, 35]; golf putting [20, 28, 29]; and soccer penalty shooting [37].

These studies discussed the impairment of optimal attentional control (QE) in relation to the predictions of attentional control theory (ACT; [7]). Specifically, ACT suggests that anxiety causes an increase in the sensitivity and influence of the stimulus-driven (bottom-up) attentional system at the expense of the goal-directed (top-down) attentional system. According to ACT, anxiety impairs processing efficiency by reducing attentional control and making it difficult for

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the goal-directed attentional system to override the stimulus-driven attentional system [7]. In far aiming tasks, this impairment due to increased anxiety has been reflected in attenuated QE durations (less effective goal-directed attentional control), presumably because of an inability to inhibit distracting thoughts related to the consequences of poor performance (see [34, 19] for reviews).

The current study seeks to overcome two potential limitations in research using the QE to examine the processes underpinning choking in sport. First, much of the experimental research examining choking adopts blocked pressure conditions, with mean values calculated to represent the entire pressure condition (see [38, 39] for notable exceptions). While such an approach ensures good internal control and measurement reliability, it is inconsistent with real world sporting competition where pressure-induced failure is typically a one-off event. The current study therefore adopts a novel approach that allows differences in attentional control to be examined at the point of performance failure, in a pressurized task where every shot counts.

Second, in an attempt to establish *why* longer QE durations support improved motor accuracy, researchers have tended to limit themselves to a motor pre-programming explanation [12, 16, 32]. Vickers' seminal study in basketball free-throw shooting suggested that experts initiated an early QE to the target to set the parameters of the shot, and then suppressed visual information during the execution phase, in order to protect these parameters [26]. In effect, Vickers' early conceptualization of the QE phenomenon (the location suppression hypothesis; LSH) suggested that using online control was a less expert strategy, prone to disruption from visual distraction [26]. While the location suppression element of the theory has received little attention in the literature (see [32] for an exception), the emphasis on a pre-programming role for the QE has remained. For example, Mann and colleagues [16] concurrently examined the Bereitschaftspotential (BP), a pre-motor readiness potential, and QE among a population of experienced golfers, as they made putts from twelve feet. Their results revealed that the QE and

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BP were closely associated, supporting their contention that the QE served an important preparatory motor programming function.

While the work of Mann and colleagues has several strengths, the definition of QE used in the study is contradictory to other research. Specifically, Mann et al. [16] only considered the duration of the QE that occurs up until the initiation of movement, whereas previous research has shown that the QE of experienced golfers is steady on the ball prior to the stroke, throughout the stroke, and often beyond putter-ball contact [25, 27, 33]. QE dwell, the proportion of the QE that occurs after contact with the ball, is more likely related to online control rather than motor preparation [27]. Vickers proposes that an overt gaze shift away from the ball at around the point of contact is preceded by a covert attentional shift that occurs approximately 100-300 ms before contact. This shift in attention is potentially disrupting and can lead to poor contact between putter and ball [27, 29]. With evidence supporting the importance of accurate gaze control during (and after) the putt [25], it is unlikely that the QE in golf putting reflects only the pre-programming of movements to be run in an open loop (predictive) fashion (cf. [22, 23]).

Indeed, a number of unrelated lines of research appear to support the importance of online control during the performance of far aiming tasks. First, research examining kinematic profiles in golf putting suggests that the putting action is continually adjusted on the basis of visual information (Tau) during movement execution (e.g. [4, 6]). Second, research by Oudejans and colleagues in basketball has suggested that performers may prefer to use late visual information to guide movement - a form of online control - rather than early predictive information (e.g., [22]). Finally, recent research by Lawrence and colleagues [15], has demonstrated that increased state anxiety disrupts online - as opposed to offline - control processes responsible for the visual regulation of limb movements in target-directed aiming. Such impairments in online control resulted in subsequent decrements in task performance [15].

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The aim of the current study was therefore to (1) examine if reductions in the QE duration of expert golfers might explain misses in a 'shootout' golf putting task under incentives for good performance. We predicted that QE duration would be significantly reduced on the final (missed) putt compared to the penultimate (the last successful attempt before the miss) and first (successful) putts in the task, irrespective of how many putts were taken. We also explored the extent to which (2) pressure might influence either the early (pre-programming) or late (online control and dwell) components of the QE duration. We predicted that the reduction in the overall QE for the final (missed) putt will be due primarily to a reduction in the proportion that occurred after movement had been initiated (online control); thus suggesting that choking is related to inferior attentional control during the latter phases of the putting stroke.

Methods

Participants

Fifty right-handed expert golfers (Mean age = 29.34 years, *SD* = 14.00) with single figure handicaps; average handicap of 3.6 (Range = +2 to -9; *SD* = 2.81), volunteered to participate in the study. Written information about the study was provided and written consent was gained from all participants. Local ethics committee approval was obtained prior to the start of testing.

Apparatus

Participants putted from 5 feet (1.52 m) to a regulation hole (10.80 cm diameter) on an artificial putting green, using standard size (4.27 cm diameter) white golf balls and their own putter. 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) indicating the location of gaze in a video image of the scene

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(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 minimize distraction.

Measures

Anxiety. Cognitive state anxiety was measured at three time points (baseline, pre-shootout, and post-shootout) using the Mental Readiness Form 3 (MRF-3; [13]) to assess the effectiveness of the pressure manipulation (see Procedure below). The MRF-3 has three, bipolar, 11-point Likert scales that are anchored between not worried - worried for the cognitive anxiety scale; not tense - tense for the somatic anxiety scale; and not confident - confident for the self-confidence scale. As with other research examining the influence of worry on expert golfers' putting performance, the cognitive anxiety subscale was of particular interest (e.g., [35, 29]).

Movement phase durations. The durations of the phases of the putting action (preparation, backswing, and foreswing) were calculated using Quiet Eye Solutions software (Quiet Eye Solutions Inc., Calgary, CA). The preparation phase represented the time from the placement of the putter behind the ball, until the initiation of the backswing. The backswing phase began with the first backwards movement of the clubhead and finished as the clubhead changed direction at the top of the backswing. The foreswing phase began with the first forward movement of the clubhead and finished when the clubhead contacted the ball [27].

Quiet eye duration (QED). The QE was operationally defined for golf putting as the final fixation (within 1° of visual angel for a minimum of 100ms) towards the ball prior to the initiation of the backswing [25, 27]. Onset of the QE was defined as the initiation of the final fixation that occurred prior to the start of the backswing, and was marked by the first frame in which the performer directed their gaze towards the ball. Offset of the QE occurred when the gaze deviated from the ball location by 1° of visual angle for more than 3 frames (100 ms; see

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[27]). The values assigned to the onset and offset of the QE reflect the time elapsed (in ms) from the start of the preparation phase of the movement. The components of the QE were calculated using Quiet Eye Solutions vision-in-action software (Quiet Eye Solutions Inc., Calgary, CA). 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. In order to test our specific hypotheses we defined the QE in a novel manner; in terms of the proportion that occurs before (pre-programming), during (online control), and after (dwell) the initiation of the critical movement (the start of the backswing).

Pre-programming duration (QE-pre). The pre-programming phase of the QE was defined as the component of the QE starting at QE onset and ending with the initiation of the backswing. As such, this duration reflects the proportion of the QE that may be responsible for the pre-programming of the ensuing putting stroke.

Online control duration (QE-online). The online control phase of the QE was defined as the component of the QE starting with the initiation of the backswing and finishing when the putter contacted the ball, or when gaze deviated from the ball by 1˚ of visual angle for more than 3 frames. As such, this duration reflects the proportion of the QE that may be largely responsible for the online control of the putting stroke.

Dwell duration (QE-dwell). The dwell phase of the QE was defined as the component of the QE that started when the putter contacted the ball, and ended when the gaze deviated from the same location on the green by 1˚ of visual angle for more than 3 frames [27]. If the QE offset occurred before ball-putter contact than dwell was recorded as zero.

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Procedure

Participants attended individually and after reading an information sheet provided written informed consent. An ASL mobile eye tracker was fitted on the participant and calibrated using five golf balls positioned at their feet. Participants were asked to adopt a stance as though they were about to putt, and instructed to hold their gaze steady on the centre of each of the five balls in turn. Participants were given the chance to 'warm up' and familiarize themselves with the putting green by taking a series of twenty putts from a distance of 10 feet. Following these putts a baseline measure of anxiety was collected using the MRF-3. Participants were then asked to take part in a 'shootout' putting task, which involved holing as many balls as possible from five feet without missing. This is a popular task used by golfers to practice their short putting under pressure [24]; it emphasizes the importance of every single putt and is therefore a useful task for examining processes underpinning performance failure. The number of consecutive successful putts achieved by the participants ranged from 3-237 (mean = 23.06, *SD* = 35.04). If participants missed the first or second putt they were given the opportunity to take part again (after a short break), although his only happened on three occasions.

In order to incentivize the participants and increase the levels of pressure experienced, a £50 cash prize was made available to the person who made the most consecutive putts. Furthermore, participants received ego-threatening feedback about their 20 practice putts. An experimenter informed them that their performance on the 20 practice putts would put them in the bottom 30% of participants that had already taken part [29]. Finally, participants were told that their scores would be shared with all participants who had taken part in the study via a published leader board [29]. Participants subsequently completed the MRF-3 before beginning their 'shootout' putts. Once a putt was missed, participants filled out the MRF-3 for a third time. MRF-3 scores taken at the beginning and end of the 'shootout' were averaged to give an aggregate level of anxiety experienced throughout the 'shootout', which was later compared with

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their baseline measure given after the familiarization putts. Finally, participants were thanked, debriefed, and offered the opportunity to discuss their gaze and performance data with the experimenter.

Data Analysis

The various QE and movement phase durations were calculated for the first, penultimate, and final (missed) putts and subjected to one-way repeated measures ANOVA. Greenhouse-Geisser corrections were applied if sphericity assumptions were violated. Significant differences were followed up with Bonferroni corrected pairwise comparisons. A paired samples *t*-test was performed on the self-report anxiety data (baseline vs. average during 'shootout'). Effect sizes were calculated using partial eta squared (η_p^2) for omnibus comparisons and Cohen *d* for simple comparisons.

Results

Cognitive Anxiety

A paired samples *t*-test revealed that participants reported significantly higher cognitive anxiety; $t(49) = 9.91$, $p < .001$, $d = 1.63$, during the 'shootout' (mean = 5.5, $SD = 2.65$) compared to the baseline (mean = 2.13, $SD = 1.49$) condition.

Movement Phase Durations

ANOVA revealed a significant main effect for preparation phase duration; $F(2,98) = 5.12$, $p = .008$, $\eta_p^2 = .10$. Post hoc comparisons revealed that preparation was significantly longer for first putts compared to penultimate putts ($p = .015$). There were no significant differences between final putts and both first ($p = .352$) and penultimate ($p = .143$) putts. There were no significant differences in backswing phase duration; $F(2,98) = 2.70$, $p = .072$, $\eta_p^2 = .05$, and

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foreswing phase duration; $F(2,98) = 1.94$, $p = .150$ $\eta_p^2 = .04$ across the three putts. Movement phase data are presented in Table 1.

QE Durations

ANOVA yielded a significant main effect for overall QED; $F(2,98) = 14.71$, $p < .001$, $\eta_p^2 = .23$. Post hoc comparisons revealed that the total QED was significantly shorter for final putts when compared to first and penultimate putts (ps < .001). There was no significant difference in QED between first and penultimate putts ($p = .477$).

There were no significant differences in QE-pre across the three putts; $F(2,98) = 1.12$, $p = .330$. Participants took similar lengths of time (~1000 ms) between fixating the ball and initiating their putting strokes on first, penultimate, and final putts.

However, there was a significant main effect for QE-online; $F(2,98) = 10.33$, $p < .001$, $\eta_p^2 = .17$. Post hoc comparisons revealed that the component of the QE occurring during the putting stroke was significantly shorter for final putts compared to first ($p = .008$) and penultimate putts ($p < .001$). There was no significant difference in QE-online between first and penultimate putts ($p = .274$).

Finally, there was a significant main effect for QE-dwell; $F(2,98) = 12.65$, $p < .001$, $\eta_p^2 = .21$. Post hoc comparisons revealed that the duration of a stable fixation on the ball location after contact was significantly shorter for final putts when compared to first and penultimate putts (ps < .001). There was no significant difference in QE-dwell between first and penultimate putts ($p = .405$). QE data are presented in Figure 1.

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Discussion

The QE has been shown to underpin the accurate performance of visuomotor skills in a number of different sports (see [27] for a review). Studies indicating that the QE is susceptible to disruption under conditions of heightened anxiety caused by performance pressure have examined changes in mean values, derived from blocks of multiple trials (see [28] for a review). Such an approach may not only dilute the effects of pressure, but may also fail to consider the individual 'variability' in QE duration that may occur when a shot is missed. As such, the first aim of this study was to adopt a novel approach that allowed changes in QE duration to be examined at the precise point of performance failure, in a pressurized task where every shot counted (a 'shootout'). Fifty expert golfers with single figure handicaps were recruited to take part, reflecting a larger and more elite sample than has been previously adopted in research examining the QE in golf putting [16, 25, 33].

QE Duration

In order to ensure that participants were incentivized and that the conditions of the 'shootout' task simulated those of sporting competition, a pressure manipulation was used. Participant's responses to the MRF-3 questionnaire supported the effectiveness of the manipulation; anxiety levels were significantly higher during the 'shootout' than at baseline. The reported anxiety levels are similar to those found in other laboratory environments (e.g., [30, 31, 36]); however, we acknowledge that they are unlikely to be as high as those encountered in real competition. Furthermore, as mobile eye-trackers are not permitted to be worn in real competition, we believe that the novel approach and pressure manipulation used in the present study may represent a 'best attempt' at understanding failure at the exact point of pressure.

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For the successful first and penultimate putts QE durations were 2284 ms and 2205 ms, respectively (Figure 1). These durations are of similar magnitude to previous research examining successful putts for expert golfers' [25, 29, 33]. However, the final (missed) putt was accompanied by a QE (1601 ms) that was significantly shorter than both the first and penultimate putts (Figure 1). This duration is below the optimal threshold of 2 seconds proposed for successful golf putting performance and so it is unsurprising that this duration was associated with unsuccessful performance [25, 28, 33]. While this finding supports previous research that has shown that the average QE across a block of multiple 'pressure' shots is attenuated (e.g., [1, 2, 36]), this is the first study to highlight a reduction in QE at the specific point of performance failure. It appears that the 'choke' was associated with a lapse in visual attentional control (reduced QE duration), which may have led to poor accuracy. Interestingly, as the penultimate putt did not have a reduced duration, this lapse in visual attention is unlikely to have been due to attentional and/or postural fatigue experienced as a result of performing multiple putts. Moreover, the number of successful putts that each participant achieved before missing varied considerably (mean = 23; range = 3-237 putts), again suggesting that fatigue was unlikely to be the major factor. These findings support the predictions of ACT [7] and likely reflect the impairment of attentional control in terms of the mechanisms highlighted by Eysenck and colleagues [7]. Anxiety, resulting from competitive pressure, increased the influence of the stimulus-driven attentional system, at the expense of the goal-directed attentional system, leading to a shortening of the QE [2, 36].

Pre-Programming vs. Online Control

One of the limitations of previous research examining *how* longer QE durations benefit accuracy is the focus on only a cognitive *pre*-programming explanation [15, 24]. Vickers (1992) originally identified that the duration of the fixation made *during* the putting action differentiated

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high and low handicap golfers [25]. This finding suggests that the QE in golf putting likely serves an online control function as well as a pre-programming function. The second aim of this study was therefore to divide the QE into early (pre-programming) and late (online control and dwell) components, to determine which might be most critical to accuracy and most susceptible to breakdown under pressure. While there were no changes in the proportion of the QE responsible for the pre-programming of movement (QE-pre; ~1000 ms) across all three putts, there were significant reductions in measures related to online control (QE-online and QE-dwell) for the final (missed) putt (Figure 1). QE-online dropped from over 800 ms to 560 ms in the final putt and QE-dwell dropped from approximately 400 ms to less than 100 ms. The act of planning an eye movement to a new location has been shown to be coupled with an obligatory shift of covert attention to that location before the eyes have even begun to move [8, 9]. As such, participants' attention had likely moved from the ball before contact was made, disrupting the contact between the putter and ball [30].

Importantly, these changes in QE-online and QE-dwell could not be explained by changes in the durations of the movement phases of the putt (Table 1). Indeed, the only significant difference in movement was that preparation time was longer for the first putt than both the penultimate and final putts. This is perhaps not surprising and may reflect a process of getting comfortable over the first putt in the shootout. It may also reflect additional, generic parameter setting for the task which is not required once the task becomes more practiced and well learned. It is noticeable that these preparation differences are most likely due to physical adjustments because there were no differences in pre-programming QE durations (QE-pre; Figure 1).

The results therefore support our first hypothesis that maintaining a long QE duration is critical for performing an aiming task under pressure. These findings are consistent with previous research that has demonstrated that choking under pressure is related to shorter QE durations [34]. Our second hypothesis was also supported, as increased anxiety impaired online control

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rather than pre-programming - the missed putt had a shorter QE duration than the other putts because it was attenuated, rather than having started later. The findings support models of motor control that point to the importance of online visual information for regulating control of movements (e.g., [6, 22]); the predictions of ACT [7]; and recent evidence revealing that anxiety disrupts online, rather than offline, control of goal-directed aiming [14].

There are also implications for researchers using the QE as an objective measure of attentional control in far aiming tasks (under pressure). First, there has been inconsistency in the operational definition of the QE and this might hamper attempts to further our understanding of its role in supporting superior performance. Second, the relative role of the QE in supporting pre-planning and/or online control might be task-dependent, and is likely to be influenced by the relative duration of the unfolding critical movement; the period over which online control may occur. Third, the role of the QE may be different in underpinning proficient performance versus performance under pressure. While there has been consistent support for early QE *onset* differences between experts and novices [17], findings from the few studies examining the impact of increased anxiety on QE in aiming tasks have suggested that pressure disrupts the *offset* of the QE more than the onset [28]. These somewhat conflicting findings suggest that performance degradation due to increased anxiety (i.e., choking) may be due to subtly different QE mechanisms than differences in performance proficiency. Novices may not *initiate* their QE fixation early enough to successfully pre-programme the movement response to the same degree as an expert, but trained performers who choke, fail to *maintain* their QE fixation and hence disrupt subsequent online control. From an applied perspective, the findings further support the efficacy of QE training regimes aimed at facilitating better performance under pressure for expert performers (e.g., [3, 29]). Such interventions should focus on an early QE onset to optimize performance improvements [3] and focus on maintaining the QE throughout the entire movement phase as a way of protecting elite performers from the negative influence of anxiety

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on attentional control [29].

While the results from the current study are novel and potentially interesting, they should be considered with caution because of the limitations inherent in the research design. First, anxiety and performance were not measured to the same level of sensitivity as the QE measures. Anxiety was not measured for every putt, which would have been possible had objective or continuous measures of arousal (e.g., heart rate) been taken, and we did not take a measure of performance error (the distance the ball finished from the hole in cm) on the final (missed) putt. Second, the present study did not assess movement kinematics of the putting stroke and we were therefore unable to examine measures of movement variability during early and late phases of the putt, which might have provided more information on the degree to which online and offline control was impaired [15].

Third, an important consideration for research examining the visual attention (gaze) of participants is the degree to which visual overt attention is representative of covert attention. Recent neuroscience research suggests that a shift in gaze invariably predicts a shift in attention [5] and that it is difficult to shift the point of gaze without shifting attention [9]. However, it is possible that covert attention could shift (e.g., inwardly) while overt attention, as measured by QE, remains fixed. Future research should consider adopting direct cortical measures of attentional control in order to assess potential dissociations in the orientation of overt and covert attention [28].

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Conclusions

To conclude, the results demonstrate that a disruption in visual attentional control (reduced QE duration) occurs at the precise point of performance failure during a pressurized golf putting task. In separately assessing differences in the proportion of the QE that occurs before, during, and after the execution of the skill, the findings of the current study support Vickers' seminal work in golf putting [27], but perhaps call into question the importance of a pre-programming role for the QE. Specifically, the results demonstrate that pressure has a greater impact on visual attention during the execution of the movement than it does during the preparation of this movement. The results highlight the need for future research to consider the task specific nature of the role of QE in supporting the pre-programming and online control of goal-directed movement under stressful conditions.

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Figure Captions

Figure 1. Mean (± s.e.m.) duration of the pre-programming (QE-pre), online control (QE-online), and dwell (QE-dwell) components of the overall quiet eye duration (QED; sum of the three sub-phases) for the first, penultimate, and final putts of the shootout.

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Figure 1

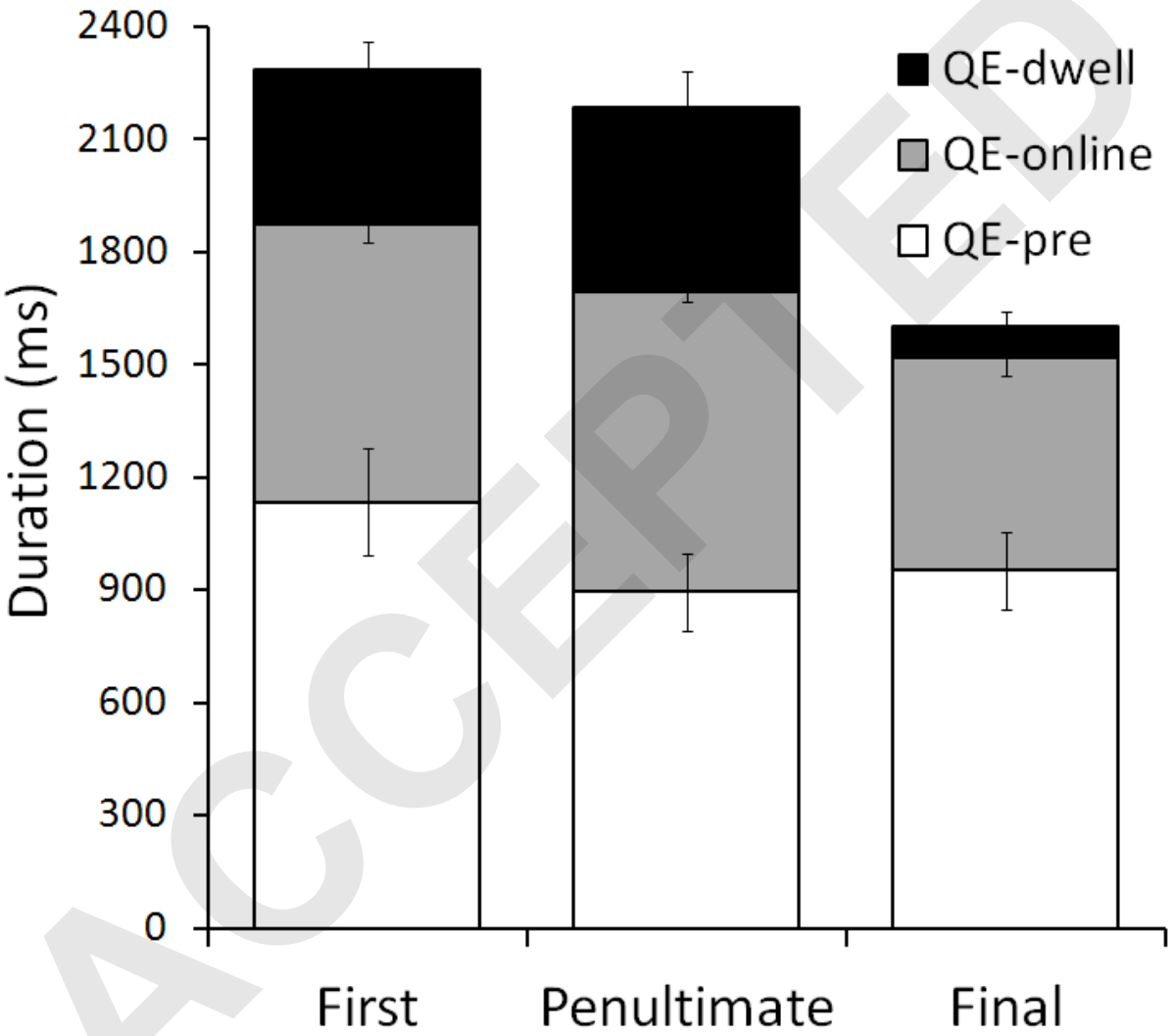

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Table 1. Mean (SD) duration (ms) of the preparation, backswing, and foreswing phases of the first, penultimate, and final putts of the 'shootout' task.

	First	**Penultimate**	**Final**
Preparation phase	2401.57 (1589.67)	1836.08 (1080.62)	2059.52 (1183.97)
Backswing phase	556.32 (159.33)	511.68 (148.65)	530.98 (119.34)
Foreswing phase	339.02 (71.98)	328.06 (70.90)	315.06 (70.05)

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