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State anxiety and visual attention: The role of the quiet eye period in aiming to a far target

MICHAEL BEHAN[1] & MARK WILSON[2]

[1]*Department of Exercise and Sport Science, Manchester Metropolitan University, Manchester, and* [2]*Sport and Health Sciences, University of Exeter, Exeter, UK*

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Abstract

In this study, we examined how individuals controlled their gaze behaviour during execution of a far aiming task and whether the functional relationship between perception and action was disrupted by increased anxiety. Twenty participants were trained on a simulated archery task, using a joystick to aim and shoot arrows at the target, and then competed in two counterbalanced experimental conditions designed to manipulate the anxiety they experienced. The specific gaze behaviour measured was the duration of the quiet eye period. As predicted, accuracy was affected by the duration of the quiet eye period, with longer quiet eye periods being associated with better performance. The manipulation of anxiety resulted in reductions in the duration of quiet eye. Our results show that the quiet eye period is sensitive to increases in anxiety and may be a useful index of the efficiency of visual orientation in aiming tasks.

Keywords: *Gaze behaviour, eye–hand coordination, processing efficiency, pressure*

Introduction

In competitive sports in which precise aiming movements are an integral component of performance, attending to and processing visual information are key determinants of successful motor execution (Williams, Singer, & Frehlich, 2002a). For this reason, research examining the mechanisms by which individuals integrate eye and hand movements is important to our understanding of the visuomotor control systems that govern the production of goal-directed movements (Starkes, Helsen, & Elliott, 2002). To date, researchers have demonstrated the functional coupling of the gaze behaviour and motor action of visually based aiming tasks (Helsen, Starkes, Elliott, & Ricker, 2000; Rodrigues, Vickers, & Williams, 2002). Moreover, it is evident that the temporal and spatial aspects of this relationship vary according to the aiming requirements of the task (Vickers, Rodrigues, & Edworthy, 2000). As most sports involve a component of aiming, investigation of optimal visuomotor strategies underlying accurate performance in aiming tasks is fundamental to the development of effective training programmes (Harle & Vickers, 2001; Oudejans, Koedijker, Bleijendaal, & Bakker, 2005).

Recently, researchers have examined the visual search behaviour adopted by performers during sport skills that require aiming to a far target (e.g. basketball, darts, rifle-shooting). Expertise differences in gaze control during successful and unsuccessful performance in both self-paced (e.g. Janelle *et al.*, 2000; Vickers *et al.*, 2000) and externally paced aiming tasks (Land & McLeod, 2000; Vickers & Adolphe, 1997) have been demonstrated. A consistent finding emanating from this research is that skilled and accurate performance is characterized by a specific visuomotor strategy, which has been termed the "quiet eye period" (Vickers, 1996). In this regard, longer quiet eye periods have been found to be characteristic of both expertise and accuracy of visually guided aiming performance (e.g. Janelle *et al.*, 2000; Vickers *et al.*, 2000; Williams *et al.*, 2002a).

Quiet eye can be defined as the final fixation or tracking gaze directed to a single location or object in the visuomotor workspace within 3° of visual angle (or less) for a minimum of 100 ms. The quiet eye has

Correspondence: M. Wilson, Sport and Health Sciences, St. Luke's Campus, University of Exeter, Heavitree Road, Exeter EX1 2LU, UK.
E-mail: mark.wilson@ex.ac.uk

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an onset that occurs before the final movement in the motor task and an offset that occurs when the fixation or tracking deviates off the target by more than 3° of visual angle for more than 100 ms (e.g. Rodrigues *et al.*, 2002; Vickers *et al.*, 2000). Seminal work in this area was conducted by Vickers (1996), who argued, based on the theoretical propositions of Posner and Raichle (1991), that the quiet eye period reflects the organization of visual attention control parameters of the movement (e.g. direction, force). More specifically, longer quiet eye periods improve performance by permitting individuals to extend the duration of cognitive programming required for accurate aiming movements (Janelle *et al.*, 2000).

It is evident that maintaining a tightly coupled relationship between the orientation of visual attention and the motor components of the task is important for performance. However, in addition to processing critical visual information, the ability to self-regulate emotional states associated with competition is integral to successful coordination and execution of self-paced aiming movements (Williams *et al.*, 2002a). Although several emotions have received attention, it is the influence of anxiety on performance that continues to be one of the main research interests for sport psychologists (see Hanin, 2000).

Anxiety has typically been viewed as an emotion characterized by negative affect that impairs motor performance, and in extreme cases can lead to "choking", or acute performance decrements under circumstances of heightened incentive for good performance (Baumeister, 1984). Anxiety is postulated to occur as a result of threat and is related to the subjective evaluation of a situation with regards to one's self-esteem (Schwenkmezger & Steffgen, 1989). Influences of anxiety on performance are assumed to relate to alterations in attentional mechanisms, where task-relevant information might be ignored and task-irrelevant information attended to (e.g. Eysenck & Calvo, 1992; Sarason, 1988).

Despite research examining the anxiety–performance relationship, only recently have researchers systematically investigated the attentional mechanisms underlying performance variability when performers are anxious (Janelle, 2002). Advances in eye movement registration systems have allowed researchers to examine gaze behaviour in tasks requiring visually guided movement. The gaze control system comprises mechanisms concerned with the acquisition of visually presented information, making it an excellent reflector of aspects of information processing, including attention (Sirevaag & Stern, 2000). Although the extent to which gaze behaviour represents the amount of cognitive processing has been questioned (e.g. Posner & Raichle, 1991; Viviani, 1990), recent research suggests that it is difficult to shift the point of gaze without shifting attention (Shinoda, Hayhoe, & Shrivastava, 2001). The attention shifts that precede saccadic eye movements are associated with their preparation and involve some of the same neuronal "machinery" (Corbetta *et al.*, 1998; Culham *et al.*, 1998).

Although limited in amount, recent research has demonstrated that when anxious, performers tend to exhibit less efficient visual search behaviours (e.g. Murray & Janelle, 2003; Williams & Elliott, 1999; Williams, Vickers, & Rodrigues, 2002b). Reduced efficiency is evidenced by the fact that anxious performers have higher search rates, characterized by more foveal fixations of shorter duration. The higher search rates employed as a function of anxiety represent an increase in attempts to extract information via the fovea and, consequently, a decline in efficiency (Williams *et al.*, 2002b).

Research examining the anxiety-attentional effects associated specifically with the efficiency of visual orientation (as indexed by quiet eye) has been less forthcoming. Janelle (2002) has suggested that the quiet eye period may be considered as being indicative of the "efficiency of visual orientation" (p. 243) and sensitive to manipulations of threat. Similar to search rate, where shorter duration fixations are less efficient and more indicative of novice behaviour, less efficient visual orientation is characterized by shorter quiet eye periods. Under stressful conditions, therefore, optimal quiet eye periods are likely to be reduced, as performers adopt a less efficient strategy, more representative of poorer performance.

Although research has demonstrated that quiet eye is altered as a function of temporal pressure (Rodrigues *et al.*, 2002; Williams *et al.*, 2002a) and task complexity (Williams *et al.*, 2002a), only Vickers and Williams (in press) have examined differences in the quiet eye period induced by elevated anxiety. These authors found that elite biathletes who increased their quiet eye duration during high pressure competition, as opposed to low pressure practice, were insulated from choking as physiological arousal increased to maximum (Vickers, 2007; Vickers & Williams, in press).

The main aim of the present study was to examine how individual control their gaze to acquire critical visual information for accurate performance on a computer simulated archery task. In line with previous research (e.g. Janelle *et al.*, 2000; Vickers *et al.*, 2000), longer periods of quiet eye were expected to be evident during the alignment phase of accurate, as opposed to inaccurate, shots to the target. A secondary aim was to explore whether the quiet eye period varies as a function of elevated anxiety. In line with the predictions of Janelle (2002), shorter, and therefore less efficient, quiet eye periods were predicted to occur in the high threat as opposed to low threat condition.

Methods

Participants

Twenty university students (mean age 26.4 years, $s = 5.5$) volunteered to take part. They had little or preferably no experience of video games (less than twice per week) in the previous 6 months (see Green & Bavelier, 2003). After the general nature of the study had been explained to them, the participants provided written informed consent before taking part. All participants had normal, uncorrected vision and local ethics committee approval was obtained before testing took place.

Apparatus

The archery task was undertaken in a purpose-built computer simulator consisting of an Applied Science Laboratories (ASL, Waltham, MA) 5000 P pan tilt eye-tracking device, a 42-inch plasma screen, a seat with fitted neck collar to maintain head stability (positioned to ensure that each participant was seated 110 cm from the plasma screen), a joystick (Logitech Extreme 3D Pro, UK), and the Athens 2004 PC software (Eidos Interactive, London, UK). The researchers and analysis hardware were situated in an adjacent room separated from the participant by a one-way mirror.

Experimental task

The 70-m individual target archery event from the Athens 2004 pc game was used for the study. Participants sat in front of the screen with the joystick attached to a stand to their right-hand side so that it would not obstruct their vision of the screen. They used the joystick to manoeuvre a "sight" that indicated where they were aiming and pressed a trigger to shoot the arrow. The performer initiated each shot sequence by pressing the trigger, which gave them a view of the target over the shoulder of the simulated archer. After a 4-s delay, the sight appeared and the target started shrinking as though moving away from the performer. The shot could be made at any time within a period of 60 s. Figure 1 provides an illustration of the display showing the location of the target at the start of the shot period (A) and after 15 s (B).

The target consisted of ten concentric rings, with the centre ring scoring 10 points. The scores for the remaining nine rings reduced by one point per ring as the distance from the centre increased. The practice level in arcade mode was used (only the individual competing on the range) so that the varying performance of other competitors would not influence the emotional state of the participant. In line with the structure for competitive target archery regulated by the International Archery Federation (FITA), each trial consisted of a set of 12 shots taken to the target.

Data acquisition

Line of vision (gaze) was recorded at 60 Hz using the ASL eye movement system, mounted at the base of the plasma screen. The ASL system measures the position of two components of the eye – the pupil and the corneal reflection – giving an accurate index of eye-line of gaze. The image recorded by the eye camera contains horizontal and vertical axes signifying the centre position of the pupil and corneal reflection, calibrated to an accuracy of $\pm 1^\circ$ and precision of 0.5° of visual angle (see white crosshair on Figure 1). Gaze coordinates were captured from the ASL control box (com port) and converted into two analog signals representing vertical (Y) and horizontal (X) components of gaze position. These analog signals were digitized at 200 Hz using a CED 1401 analog-to-digital converter (Cambridge Electronic Design) and analysed using Spike 2 software (Cambridge Electronic Design). The signals were therefore safely over-sampled to ensure no loss of signal content.

The joystick could potentially be moved through $\pm 25^\circ$ in the horizontal and vertical planes, which allowed full control of the sight over the display area. The trigger press to release the arrow was presented on the Spike 2 trace as a square wave output rising to 5 V and sampled at 200 Hz. The onset of the square wave was then converted offline to a trigger point using a rising voltage algorithm (Spike 2).

Procedure

The participants attended the laboratory individually, and after being informed that the purpose of the study was to investigate the accuracy of visual aiming under different conditions, written consent was obtained. The measures and test protocol adopted were then explained and the eye measurement device was adjusted and calibrated for use with each individual. Calibration consisted of each participant looking in sequence at nine reference points (top left, centre and right: midway down left, centre and right: bottom left, centre and right). At each target the amount of infra-red light flooding the eye and the retinal and corneal reflections were adjusted so as to

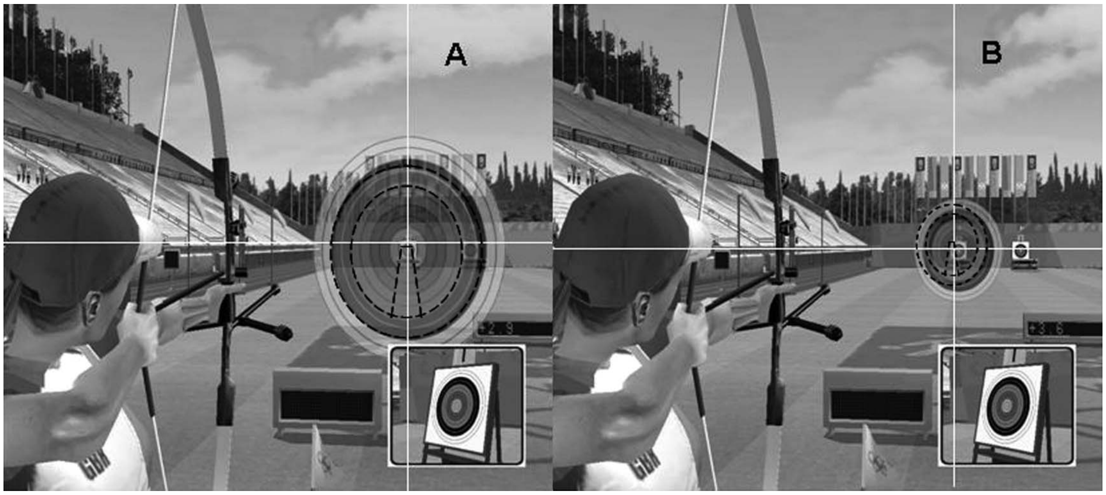

Figure 1. A screen grab of the archery environment showing the target and the sight used by the performers to line up the shot (shown here with dashed lines for clarity). Although the entire target shrinks over time (compare A and B), the centre ring remains in the same location on the screen. The white crosshairs show the gaze of the performer, which is overlaid on the video footage from the ASL scene camera.

obtain stable crosshairs superimposed onto the image of the participant's eye.

Following calibration, each participant fixated on the target for 30 s so that the coordinates of the target could be ascertained (see Measures section below). The participants then completed a series of practice trials (mean 9.6, $s = 2.04$), each consisting of 12 shots, until their performance scores had stabilized above a criterion of 90 points per trial. This criterion level of performance was derived from results of pilot testing which revealed that this was a score indicative of skilled performance. The participants needed to score consistently over 7 for each shot if they were to maintain a score of 90 for 12 shots. Previous research testing effects of anxiety on gaze behaviour and novel task performance have also required participants to attain a criterion level of performance to minimize learning effects during the testing phase (e.g. Wilson, Chattington, Marple-Horvat & Smith 2007).

After the training session, participants completed two test sessions. With the exception of the content of the evaluative instructions, the procedure for both test sessions was identical. The participants were exposed to the appropriate instructional set, and then provided a self-report of their pre-performance anxiety levels by completing the Competitive State Anxiety Inventory-2 (CSAI – 2) before undertaking the 12 competition shots for that session. The participants were then given a 10-min break, and the protocol was repeated for the final test session. The exposure to the pressure manipulation was counterbalanced across test sessions. Following the final test session, individuals were thanked and debriefed about the true objectives of the study.

For each test session, gaze direction was checked against landmarks in the scene between shots to ensure that the initial calibration was still valid. Re-calibration occurred if this was not the case. This occurred infrequently because of the lack of head movement afforded by the neck collar.

Experimental conditions

Each participant was tested under two counterbalanced conditions: a low pressure and a high pressure condition. In the low pressure condition, participants were informed that their performance scores would not be used for comparison with others, and that the purpose of the session was simply to collect some reference data using the visual search equipment. The high pressure instructional set informed participants that they had been assigned to a team, to which membership held some degree of significance (e.g. same course or group of friends), and that each team was to take part in a competition with prize money of £40.00. However, the prize money would be offered only to the highest scoring member of the highest scoring team (see Hardy, Beattie, & Woodman, 2007). Therefore, poor individual performance would decrease the team's average, reducing the likelihood of any individual within that team winning the money. Moreover, participants were made aware that, after the study, the league table of final rankings would be circulated to all participants. In addition, an ego-threatening instructional set was used in which participants were informed that the test provides a reliable indication of hand – eye coordination, where a poor performance represents low level in coordinating aiming movements (see Murray & Janelle, 2003).

Measures

Competitive state anxiety. The Competitive State Anxiety Inventory-2 (Martens, Burton, Vealey, Bump, & Smith, 1990) provided the main measure of state anxiety immediately before performance in each of the test sessions. The CSAI – 2 is a sport-specific, self-report inventory designed to assess pre-competitive cognitive and somatic anxiety and self-confidence, with the inventory consisting of 27 items, 9 for each of the three subscales. The 27 items are measured on a 4-point Likert scale ranging from 1 ("not at all") to 4 ("very much so"). Despite recent criticism based on conceptual and psychometric grounds (Lane, Sewell, Terry, Bartram, & Nesti, 1999), the CSAI – 2 has been used extensively by researchers as a reliable measure of pre-competitive state anxiety experienced by sport performers (Woodman & Hardy, 2001). In terms of validity of the CSAI – 2, Martens *et al.* (1990) demonstrated internal consistency for the three subscales, with Cronbach's alpha coefficients ranging from 0.79 to 0.90. As the purpose of the current study was to examine the effect of cognitive anxiety on the efficiency of visual attention, only the cognitive anxiety subscale of the CSAI – 2 was used.

Quiet eye period. Quiet eye duration was operationalized in an identical manner to Janelle and colleagues' (2000) study of rifle shooting, owing to the similarity of the tasks. Both studies required performers to aim at a distant target and squeeze a trigger to initiate the shot. Quiet eye duration was the performer's last acquisition of target information before the final movement, and therefore was calculated as the duration between the onset of the last fixation to the target (i.e. the centre ring) and the initiation of movement time (i.e. trigger pull to release the arrow). Instead of using frame-by-frame analyses of video footage, the coordinates of the centre ring were calibrated for each participant in the Spike 2 operating system.

The initial shot (see Procedures), where participants fixated on the 10-point centre ring without shooting an arrow, was used to ascertain a mean value for the horizontal and vertical position of the target, in degrees. These coordinates were then compared with the horizontal and vertical eye movement signals during the alignment phase of each shot. As with previous research, tolerance for the final target fixation was classified as $\leq 3^\circ$ of visual angle for a period ≥ 100 ms before the trigger press to release the arrow. Figure 2 provides an example of how the quiet eye period was calculated for one shot, from a Spike 2 data file for participant RE. The quiet eye period was calculated as the time between vertical cursor 2 and trigger 2, in Spike 2.

Data processing

Before analysing the gaze behaviour data, each testing epoch was assessed for ocular artefacts

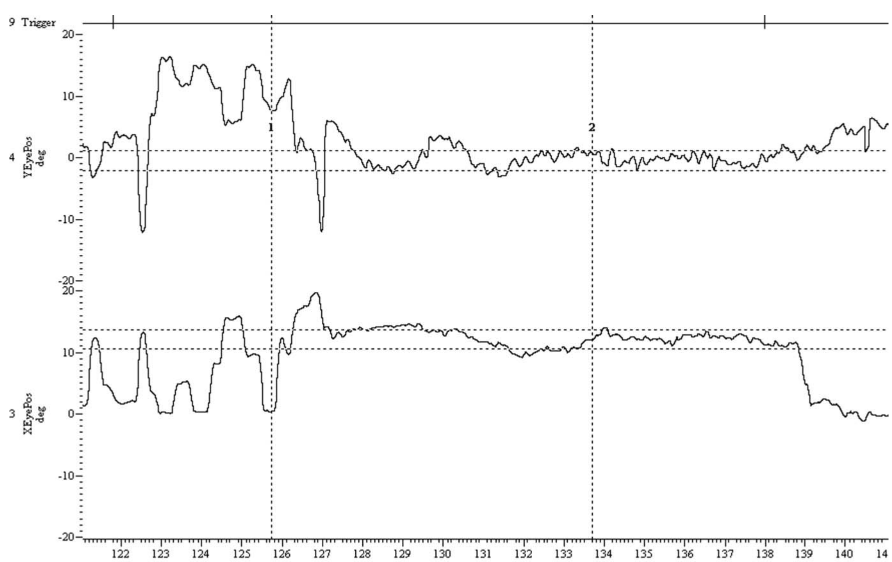

Figure 2. A screen grab of 20 s of a Spike 2 data file showing one shot. The top trace (Trigger) shows the two trigger pulls: the first to initiate the shot sequence and the second to shoot the arrow. The second trace shows the vertical (Y) gaze component during the period, with horizontal cursors set to define the target zone (with 3° tolerance). The third trace shows the horizontal (X) gaze component with similar target location boundaries. Vertical cursor 1 demonstrates the time when the "sight" becomes visible and the performer is in control of aiming. Vertical cursor 2 shows the start of the last fixation to the target zone before the trigger pull (i.e. within the 3° tolerance).

resulting from eye blinks. Although these were infrequent, they were subsequently removed by linear interpolation in Spike 2 (following Wilson, Smith, Chattington, Ford & Marple-Horvat, 2006). As shot lengths varied between participants, a normalization procedure was applied to calculate the duration of the quiet eye period relative to the initiation of the final movement. For every trial, the onset of the alignment phase (i.e. when the sight appears; cursor 1 in Figure 2) was transformed to 0% and the onset of the final movement (trigger pull to release arrow) to 100% (cf. Rodrigues *et al.*, 2002).

For the purpose of examining the relationship between the duration of quiet eye and performance accuracy, all hits (50; score = 10) from the high pressure session, an equal number of randomly selected hits from the low pressure session, and an equal number of randomly selected misses (50; score ≤ 9) from each test session were analysed. The distinction between accurate and inaccurate shots was derived from that used in previous research examining gaze control in far aiming tasks (e.g. Janelle *et al.*, 2000; Vickers *et al.*, 2000). A hit was recorded for shots where the arrow landed in the centre ring of the target and a miss was recorded for shots where the arrow landed in any other area of the target.

Statistical analysis

Paired samples *t*-tests were conducted to analyse differences in pre-competitive state anxiety scores between the high and low pressure sessions. The quiet eye duration data were analysed using a mixed design 2 (accuracy) × 2 (pressure manipulation) analysis of variance (ANOVA). The accuracy variable was a grouping factor and the pressure manipulation variable a repeated-measures factor. Effect sizes (*d*) for main effects were calculated as outlined by Cohen (1992), using control condition standard deviation for repeated-measure effects and pooled standard deviation for independent group effects. Statistical significance was set at $P = 0.05$ for all analyses.

Results

Cognitive anxiety (CSAI-2 – Cognitive scale)

A paired samples *t*-test indicated that participants reported significantly higher cognitive anxiety in the high pressure condition (mean 19.4, $s = 5.61$) than in the low pressure condition (mean 13.8, $s = 4.27$). This significant difference ($t_{19} = -5.21$, $P < 0.001$, $d = 1.31$), coupled with a large effect size, provided support for the effectiveness of the pressure manipulation.

Gaze behaviour: Quiet eye duration

The ANOVA on the data obtained for the duration of the quiet eye period revealed a significant main effect for pressure ($F_{1,98} = 18.28$, $P < 0.001$, $d = 0.53$). This finding illustrates that the duration of the quiet eye period was significantly shorter in the high pressure condition (mean 50.4%, $s = 21.17$) than in the low pressure condition (mean 61.9%, $s = 21.72$). In addition, the main effect for accuracy was significant ($F_{1,98} = 18.24$, $P < 0.001$, $d = 0.62$), with longer quiet eye periods evident in the alignment phase of the movement before accurate shots (mean 62.8%, $s = 26.26$) than inaccurate shots (mean 49.6%, $s = 14.49$). The pressure × accuracy interaction was not statistically significant ($F_{1,98} = 0.34$, $P > 0.05$). The quiet eye duration data for high and low pressure sessions are presented in Figure 3.

Discussion

The main aim of this study was to examine the visuomotor control strategy underlying the acquisition of critical visual information for accurate execution of aiming movements to a far target. For this purpose, gaze behaviours were recorded and then used to calculate the duration of the quiet eye period for accurate and inaccurate shots taken to a simulated archery target. A secondary aim was to examine whether the temporal control of this final target fixation relative to shot execution was disrupted under increased anxiety.

Accuracy

The gaze behaviour data showed that longer periods of quiet eye were evident during the alignment phase of accurate shots than inaccurate shots. The quiet eye duration for accurate shots was 63% of the

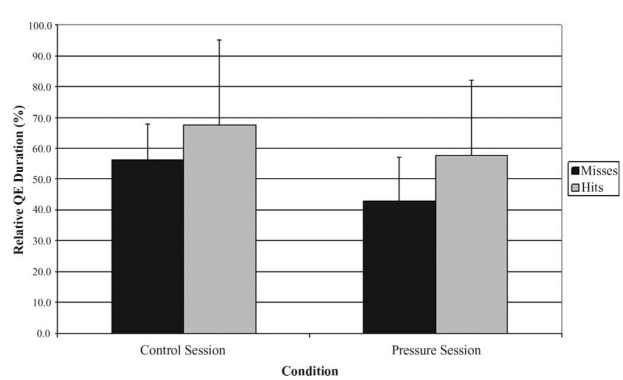

Figure 3. Gaze behaviour as indexed by relative quiet eye (QE) duration (%) across conditions for accurate (grey bars) and inaccurate (black bars) shots.

alignment phase of the movement, whereas quiet eye durations of 50% were typically observed during inaccurate shots. The results therefore corroborate findings from previous research that examined the difference in quiet eye duration between accurate and less accurate shots to a target (e.g. Janelle *et al.*, 2000; Vickers, 1996; Vickers *et al.*, 2000; Williams *et al.*, 2002a). In this way, the current study answered the call from researchers (e.g. Janelle, 2002) who have asked for the findings of the limited research examining visual orientation variables to be replicated.

The results indicate that an optimal duration of quiet eye is likely to exist for accurate performance in self-paced aiming tasks. The duration of optimum quiet eye has been shown to depend on the specific demands of the task adopted, with more difficult tasks requiring longer quiet eye periods (Williams *et al.*, 2002a). Although the quiet eye data in the current study were presented in relation to the total time of the alignment phase, it is evident from Figure 2 that the quiet eye durations were of similar magnitude to those of Janelle and colleagues' (2000) study of rifle shooters. Quiet eye periods in both these studies ranged from 5 to 15 s, whereas in basketball free throw shooting (Vickers, 1996) and billiards (Williams *et al.*, 2002a) quiet eye durations were in the order of half a second.

Although longer quiet eye durations also seem to be indicative of superior performance, it is naïve to assume a "longer is better" (Janelle *et al.*, 2000, p. 179) approach can be applied to quiet eye periods. There are practical limits to the length of the quiet eye period in most aiming tasks, such as postural and attentional fatigue. Future research could therefore attempt to understand more about how performers self-select quiet eye durations and how performance might be influenced by shortening and extending this critical period.

Effects of anxiety

Coupled with the changes observed as a function of accuracy, gaze behaviour was also altered as a result of the pressure manipulation, with reductions in the duration of quiet eye evident under high anxiety. More specifically, during the low pressure session performers exhibited final target fixations for 62% of the alignment phase of the movement, whereas in the high pressure session this fixation duration was reduced to 50%. Under conditions of elevated cognitive anxiety, optimal visual orientation, as indexed by quiet eye duration, was altered. The quiet eye durations for misses were similar to those for the high anxiety condition, suggesting that the alteration in visual orientation, caused by increased anxiety, may have led to poorer performance.

Previous research using eye-tracking equipment (e.g. Murray & Janelle, 2003; Williams & Elliott, 1999; Williams *et al.*, 2002b) has shown that the efficiency of visual search behaviour (e.g. search rate) is reduced when performers are anxious. However, to date, only Vickers and Williams (in press) have examined the effects of anxiety on the efficiency of visual orientation in aiming tasks. As a reduction in duration of quiet eye results in poorer performance, the organization of visual attention parameters under pressure may therefore be ineffective (Janelle, 2002).

This latter finding therefore offers direct support for theories that discuss attentional mechanisms underlying anxiety reactivity (e.g. processing efficiency theory; Eysenck & Calvo, 1992). Processing efficiency theory purports that when anxious, the efficiency by which information is processed decreases, potentially resulting in performance decrements (Janelle, 2002). The predictions of processing efficiency theory have recently been tested using various measures of efficiency, including visual search indices (Murray & Janelle, 2003; Williams *et al.*, 2002b), event-related potentials (Murray & Janelle, 2007), heart rate variability (Wilson, Smith, & Holmes, 2007), and movement efficiency indices (Wilson *et al.*, 2006). Future research should therefore adopt quiet eye measures of efficiency to test the predictions of processing efficiency theory, with regards the impact of anxiety on efficiency and performance in aiming tasks.

There are two main limitations in the current study, related to the ecological validity of the task and the operational definition of the quiet eye period. It is evident that the simulated archery task is far removed from the real archery environment. The application of the findings from the task to archery performance can therefore be questioned. However, the research has *general* applications to any task where hand – eye coordination is required for accurate performance in stressful environments. Furthermore, there is precedent for researchers using video games to investigate gaze measures when performers are anxious (e.g. Murray & Janelle, 2003; Wilson *et al.*, 2006). Also, Savelsbergh and colleagues (Savelsbergh, Williams, van der Kamp, & Ward, 2002) examined the anticipatory skills of football goalkeepers by measuring eye movements using head-mounted eye-tracking equipment and a joystick to measure the direction of first movement.

The second limitation concerns the definition of quiet eye offset as occurring on the trigger pull. Most research examining the quiet eye period has continued to examine quiet eye duration beyond the initiation of the final motor action (e.g. Rodrigues *et al.*, 2002; Vickers, 1996; Vickers *et al.*, 2000). By examining the duration of quiet eye relevant to this unrestricted end point, it is possible to examine the *timing*, as well as the *duration*, of the quiet eye period. Recent research has demonstrated that the timing of quiet eye may be more important than the duration for some tasks (e.g. Ferraz de Oliveira, Oudejans, & Beek, 2006; Rodrigues *et al.*, 2002). However, in the current study, as with the study of Janelle *et al.* (2000), the trigger pull signified the end of the aiming period, where all potential information had been gained. In basketball and darts throwing, for example, the initiation of arm extension, (i.e. the initiation of final movement) occurs during the aiming period. Maintaining quiet eye in such tasks is therefore potentially beneficial.

Implications

Janelle (2002) has previously suggested that attentional expertise is one of the most critical psychological skills to perform effectively in sports. Recent research (e.g. Williams, Ward, Smeeton, & Allen, 2004) has examined the efficacy of general perceptual–cognitive skills training in improving overall sports performance. There are therefore important practical considerations to be taken from the current study, and others measuring quiet eye, with regards to the training of sport skills. Vickers and colleagues (Adolphe, Vickers, & Laplante, 1997; Harle & Vickers, 2001) have demonstrated that quiet eye training may be an effective intervention in improving performance in both self-paced and externally paced tasks. For example, Harle and Vickers (2001) found that quiet eye training improved the performance of female university basketball players in both a laboratory environment and during match-play.

The current findings would suggest that such training programmes may also be a useful intervention to enhance attentional capabilities in stressful environments. By maintaining an effective visual orientation, the negative effects of anxiety on performance can be alleviated. However, before attempting to develop pre-performance routines incorporating quiet eye control components, more research is required to test the influence of anxiety on quiet eye duration and subsequent aiming performance in more ecologically valid environments.

From a research perspective, it would also be interesting to examine how the coordination of eye and hand movements, required to accurately align the sight on the target, may be affected by increased anxiety. In a related study examining the gaze control of international pistol shooters, Ripoll and colleagues (Ripoll, Pain, Guezennec, Verdy, & Philip, 1985) demonstrated that skilled performance in pistol shooting consisted of an initial alignment phase followed by a final adjustment phase. These authors concluded that "the final adjustment requires very precise coordination of eye and arm with the target as a visual reference point" (p. 100). There is obviously the potential for anxiety to upset this precise coordination, as performers acquire visual information for error correction in the latter stages of the alignment phase.

Conclusions

In conclusion, the findings from the current study support those of other researchers, suggesting that there is an ideal organization of visual attention in far aiming tasks. This effect was evidenced by significantly longer quiet eye durations for accurate as opposed to inaccurate shots. The results also revealed that the duration of quiet eye was reduced when performers were anxious, supporting Janelle's (2002) proposal that quiet eye reflects the efficiency of visual orientation. Quiet eye training may therefore be a useful intervention, either on its own or as part of a pre-performance routine, to enhance attentional capabilities in stressful environments.

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