Causer, J, Holmes, PS, Smith, NC and Williams, AM

Anxiety, Movement Kinematics, and Visual Attention in Elite-Level Performers

Article

Citation (please note it is advisable to refer to the publisher's version if you intend to cite from this work)

Causer, J, Holmes, PS, Smith, NC and Williams, AM (2011) Anxiety, Movement Kinematics, and Visual Attention in Elite-Level Performers. EMOTION, 11 (3). pp. 595-602. ISSN 1528-3542

Anxiety, Movement Kinematics, and Visual Attention in Elite-Level Performers

Joe Causer

Liverpool John Moores University

Paul S. Holmes and Nickolas C. Smith

Manchester Metropolitan University

A. Mark Williams

The University of Sydney

Liverpool John Moores University

Date of submission: February 6th, 2010

Date of re-submission: July 28th, 2010

Date of re-submission: November 2nd, 2010

Abstract

We tested the predictions of Attentional Control Theory (ACT) by examining the effect of anxiety on attention control and the subsequent influence on both performance effectiveness and performance efficiency within a perceptual-motor context. A sample (N = 16) of elite shotgun shooters was tested under counterbalanced low (practice) and high (competition) anxiety conditions. A head-mounted, corneal reflection system allowed point of gaze to be calculated in relation to the scene, while motion of the gun was evaluated using markers placed on the barrel which were captured by two stationary cameras and analyzed using optical tracking software. The quiet eye (QE) duration and onset were analyzed along with gun barrel displacement and variability; performance outcome scores (successful vs. unsuccessful) were also recorded. QE (Vickers, 1996) is defined as the final fixation or tracking gaze that is located on a specific location/object in the visual display for a minimum of 100ms. Longer QE durations have been linked to successful performance in previous research involving aiming tasks. Participants demonstrated shorter quiet eye durations, and less efficient gun motion, along with a decreased performance outcome (fewer successful trials) under high compared with low anxiety conditions. The data support the predictions of ACT with anxiety disrupting control processes such that goal-directed attention was compromised, leading to shorter QE durations which ultimately affects performance effectiveness.

Key Words: expertise; shotgun shooting; quiet eye; attentional control theory

Anxiety, Movement Kinematics, and Visual Attention in Elite-Level Performers

The effect of anxiety on both cognitive and motor performance has recently received significant research attention (e.g., see Eysenck, Derakshan, Santos, & Calvo, 2007; Wilson, Vine, & Wood, 2009). It is suggested that anxiety is an aversive emotional state that occurs as a result of threat (Eysenck & Calvo, 1992). Those individuals who are in an anxious state frequently worry about the threat to a current goal and attempt to develop strategies to reduce the effects of anxiety and ultimately complete the goal. In this paper, we explore the relationship between anxiety and performance in elite level athletes using the task of competitive shotgun shooting. We test the predictions of Attentional Control Theory (ACT) (Eysenck et al., 2007), and its predecessor Processing Efficiency Theory (PET) (Eysenck & Calvo, 1992), in an effort to examine how anxiety influences performance effectiveness (i.e., outcome) and efficiency (i.e., the amount of resources or effort needed to complete the task). These theories have previously not been examined in a task such as the one in the current study, therefore we attempt to extend understanding of the mechanisms involved in attentional control and the role of anxiety on performance using both outcome and process measures.

Eysenck and Calvo (1992) developed the PET as an explanatory account of the mechanisms through which anxiety influences performance. The PET predicts that cognitive anxiety, in the form of worry, has two main effects. First, worrisome thoughts consume the limited attentional resources of working memory which are, therefore, less available for concurrent task processing. Second, increased motivation can minimize the adverse effects of state anxiety by promoting enhanced effort and encouraging use of auxiliary processing resources and strategies. The main assumption of PET is that anxiety impairs processing efficiency more than performance effectiveness. However, the theory has been shown to have several limitations with certain assumptions lacking precision, explanatory power, or both (cf., Eysenck et al., 2007).

Eysenck et al. (2007) developed ACT in order to address the limitations of PET. The general assumption within ACT is that the effects of anxiety on attentional processes are of fundamental importance to an understanding of how anxiety affects performance. Corbetta and Shulman (2002) outlined two attentional systems; the goal-directed (top-down) system, which is influenced by expectation, knowledge, and current goals, and the stimulus driven (bottom-up) control system which responds maximally to salient or conspicuous stimuli. The ACT assumes that anxiety decreases the influence of the goal-directed attentional system and increases the influence of the stimulus-driven system. This process results in reduced attentional control and impairment of the inhibition and shifting functions. The inhibition function involves using attentional control in a restraining way to prevent attentional resources being allocated to task-irrelevant stimuli and response (Miyake et al., 2000; Friedman & Miyake, 2004) whereas, the shifting function was described as a positive way to shift the allocation of attention to remain on task-relevant stimuli (Ansari, Derakshan, & Richards, 2008).Eysenck et al. (2007) concluded that anxiety may not impair performance effectiveness when it leads to the use of compensatory strategies such as enhanced effort or increased use of processing resources. More specifically, the ACT predicts that anxiety reduces the ability to inhibit incorrect prepotent responses, increases susceptibility to distraction, impairs performance on secondary tasks in dual-task situations, and impairs task switching performance.

Traditionally, gaze characteristics have been employed as indicators of visual attention (e.g. Behan & Wilson, 2008; Nieuwenhuys, Pijpers, Oudejans, & Bakker, 2008; Wilson, Wood & Vine, 2009). An increase in anxiety has been reported to reduce the efficiency of gaze behavior in a multitude of perceptual-motor tasks (Janelle, 2002) as indexed by higher search rates, (Williams, Vickers, & Rodrigues, 2002), an inefficient use of the fovea (Williams & Elliott, 1999), and a shorter quiet eye (QE) duration (Behan & Wilson, 2008). The QE was defined by Vickers (1996) as the final fixation or tracking gaze that is located on a specific location or object in the visuo-motor workspace within 3° of visual angle for a minimum of 100ms. During this period, the performer is thought to set the final parameters of the movement to be executed and to engage in the cognitive programming required for successful aiming to a target (Williams, Singer, & Frehlich, 2002). Both earlier onset of this behavior and longer QE periods have been consistently reported in elite compared with sub-elite and successful compared to unsuccessful athletes in sports such as golf (Vickers, 2004), ice hockey (Panchuk & Vickers, 2006), rifle shooting (Janelle et al., 2000; Vickers & Williams, 2007), basketball (Harle & Vickers, 2001), and billiards (Williams et al., 2002a). There is evidence to suggest that anxiety-inducing situations are likely to reduce QE duration as a result of less efficient processing, leading to more fixations of shorter duration (cf., Williams & Elliott, 1999).

Vickers and Williams (2007) tested the gaze behaviors of elite biathlon shooters under high and low anxiety conditions after exercising at differing power output levels. Shooters who did not ‘choke’ under pressure employed a longer QE period during the high compared to low anxiety condition; those who demonstrated decrease in QE duration under anxiety showed corresponding performance decrements. The authors concluded that at high levels of anxiety visual attention is directed externally to critical task information and appears to protect athletes from ‘choking’. Behan and Wilson (2008) used a simulated archery task to examine the effects of state anxiety on visual attention. The QE durations were reduced and participants increased fixations peripheral to the target under conditions of elevated cognitive anxiety. Wilson et al.

(2009a) examined the influence of anxiety on visual attention in a basketball free throw task. Significant reductions in QE duration and free throw success rate as a result of increased anxiety were reported. These findings suggest that the control of visual attention is critical during high pressure situations, with longer QE durations enabling more accurate actions to be executed.

Although precise control of body segments is necessary to produce efficient and effective movement, particularly in fine motor tasks, few researchers have investigated the effect of anxiety on movement kinematics. Beuter and Duda (1985) examined changes in lower limb kinematics as a function of arousal in children performing a stepping task with increased arousal resulting in more variable movement patterns. Similar results were reported by Beuter et al. (1989), with stepping duration increasing as a result of greater arousal. Pijpers, Oudejans, and Bakker (2005) studied anxiety-induced changes in movement behavior in climbers. Participants showed longer climbing times, longer grasp durations, and slower movements when performing under high compared with low anxiety conditions. In terms of ACT, these results suggest that a decrease in processing efficiency was evident as anxiety increased. Nieuwenhuys et al. (2008) reported similar results, again in a climbing task, concluding that increased movement and climbing times reflected less efficient movement behavior.

In this paper, we examine the influence of anxiety on the QE period, gun barrel kinematics, and performance outcome using elite skeet shooters. Skeet is one of the three Olympic disciplines and the task requires shooters to track a moving target with the gun barrel before pulling the trigger. The ability to rapidly and reliably detect the target on release and to track the target accurately appears critical to successful performance (Abernethy & Neal, 1999). In skeet shooting, two towers (high and low) are situated on the left and right of the layout and targets are released horizontally across the shooter from either one or both of the trap houses simultaneously. The shooter has one shot per target to break the clays and shoots 25 targets from eight different positions per round.

Scientists investigating QE have consistently reported performance decrements as a result of shorter QE durations (Harle & Vickers, 2001; Janelle et al., 2000; Panchuk & Vickers, 2006; Williams et al., 2002a). Therefore, because ACT predicts that anxiety will affect processing efficiency more than performance effectiveness, we argue that performance outcome will significantly decrease under high compared with low anxiety conditions. In line with previous reports that have examined movement kinematics in skeet shooting, we assessed participants' movement efficiency by measuring gun barrel displacement, variability, peak velocity and movement times (Causer, Bennett, Holmes, Janelle, and Williams, 2010).We expected anxiety to have a negative effect on movement efficiency, as shown by increased movement variability and displacement (Beuter & Duda, 1985; Beuter et al., 1989; Pijpers et al., 2005; Nieuwenhuys et al., 2008). We expect earlier onset and longer duration of QE (cf. Causer et al., 2010; Vickers, 1996a; Williams et al., 2002), and less efficient movement kinematics (Causer et al., 2010) on successful compared to unsuccessful trials.

Method

Participants

A sample of 16 elite-level, skeet shooters (Kuwait National Squad) aged 24.5±4.4 years old and with 6.7±1.5 years of experience in shooting provided written informed consent prior to participation. All shooters had normal or corrected-to-normal visual acuity. Participants used their own personal shotguns and normal shooting attire. All participants were required to follow the rules of the discipline during data collection, as stipulated by the International Shooting Sport

Federation. Participants were free to withdraw from testing at any stage and approval for the study was gained via the local Ethics Committee of the lead author's institution.

Measures

The Mental Readiness Form-3 (MRF-3). The MRF-3 (Krane, 1994) was developed as an alternative to the Competitive State Anxiety Inventory-2 (CSAI-2; Martens, Burton, Vealey, Bump, & Smith, 1990) for use when the temporal constraints of a task do not allow the CSAI-2 form to be completed. The form comprises three items (somatic anxiety/cognitive anxiety/self-confidence) consisting of bipolar continuous scales (worried - not worried/tense - not tense/confident - not confident) separated by a line 10 cm long. For each of the three scales, participants are required to make a mark along the line that corresponds to how they feel at that specific time. Scores are obtained by measuring the position of the mark from the point of origin on the scale in millimeters. Validation work on the MRF-3 by Krane (1994) showed inter-correlations between its items and the intensity subscales of the CSAI-2 of 0.58 for cognitive anxiety, 0.59 for somatic anxiety, and 0.77 for self-confidence.

The Rating Scale for Mental Effort (RSME). This scale is one-dimensional and requires participants to rate the mental effort invested in task performance (Zijlstra, 1993). The scale is presented as a vertical axis with a range of 0 to 150 with three verbal anchors corresponding to 0 (not at all effortful), 75 (moderately effortful), and 150 (very effortful). Participants are asked to mark a point on the scale that indicates the effort invested in task performance. The scale has robust psychometric properties and has undergone extensive validation in a range of ergonomic settings (Zijlstra, 1993). The reliability of the scale across a range of laboratory (0.88) and real-life (0.78) settings has been shown to be acceptable and provides a valid and reliable measure of mental effort (e.g., see Veltman & Gaillard, 1996).

Visual search behaviors. The visual search behaviors employed by participants were recorded using a mobile eye system (Applied Science Laboratories; Waltham, MA, USA, Model ASL Mobile Eye II). The mobile eye system employs a method known as 'Dark Pupil Tracking' which uses the relationship between two eye features, the pupil, and a reflection from the cornea, to compute gaze within a scene. The mobile eye has an accuracy of 0.5° visual angle, resolution of 0.10° visual angle, and visual range of 50° horizontal and 40° vertical.

Gun barrel kinematics. Video data were collected to calculate the coordinates of the gun barrel in order to provide a more comprehensive understanding of the shooting action. Two Cannon XM2 Digital Video cameras (Cannon, Tokyo, Japan) sampling at 50Hz and with a shutter speed of 1/150 were employed. The cameras were positioned 4.0m in front of the shooting station at an angle of 50° relative to the centre of the range, one camera on the left side of the range and the other on the right, at a height of 0.9m. The cameras were connected to a central computer by two extended Firewire cables and the camera shutters were synchronized using a signal sent from the central computer. The cameras filmed simultaneously during each shooting trial. The shooting area was calibrated using a twelve point, three-dimensional frame (1.25x1.15x1.15m). The kinematic variables measures reported were, peak velocity (highest absolute velocity during shot two), movement time (from trigger pull on shot one to trigger pull on shot two), gun barrel displacement (change in gun barrel position, in space, from shot one to shot two), and variability (differences in gun barrel position, in space, at time of trigger pull on shot two, between trials), on shot two (from trigger pull on shot one until trigger pull on shot two), in the horizontal and vertical axes.

Procedure

Before collecting data from each participant, a 25mm diameter expanded polystyrene marker was attached to the underside of the gun barrel by a cable tie to enable the gun barrel to be digitized for kinematic analysis. The marker was not visible to shooters during their routine. The mobile eye system was then attached and calibrated using nine points in the environment at the same distance as the clay flight. The calibration was conducted while participants were in their 'normal' shooting stance. The video cameras were activated to record the movement and the outcome of each shot. The mobile eye system collected data for the entire duration of the test session, although accuracy of the calibration was checked periodically. An inter-trial interval of 60-seconds was employed. Participants completed the MRF-3 one minute before the first shot, after the fifth shot, and directly after the tenth shot. Scores for the RSME form were collected after every five shots, participants were asked to complete the form based on the mental effort experienced during the previous five shots.

Experimental task

The participants were then positioned on the skeet range at station 4 (see Figure 1). On the participants' call, two targets were released simultaneously, one from the high tower and one from the low tower. The participants were asked to always shoot the target from the high tower first. Participants each shot 15 pairs of targets from station 4.

Conditions

Participants were asked to shoot targets in two counterbalanced conditions, with half completing the low anxiety condition (practice round) first and the other half the high anxiety condition (competition round) initially. In the low anxiety condition, participants were asked to do their best and it was outlined that their performance scores would not be recorded and compared against other members of the squad. In the high anxiety condition, participants were informed that their score would be recorded for comparison to all other teammates in a competition scenario. The participants were asked to shoot as if they were in a competitive environment; they were also informed that there would be prize money for the top three shooters with US $1000 for first, $500 for second, and $200 for third place, respectively.

Data analysis

Due to the high frequency of success on the first target (96%), analysis of the second shot was deemed to be more relevant. An unsuccessful trial was defined as a hit on the first target with the second shot being missed; a successful trial was defined as hitting both the first and second targets. If a participant missed the first target, the trial was discarded from the analysis. After each trial, participants were asked to state whether the shot was a 'good' (the shot cluster hits the middle of the target and completely destroys the target) or 'bad' (the shot cluster clips the edge of the target chipping a small piece off the side) trial. For analysis, a random sample of the successful trials that were seen to be good shots, and unsuccessful trials that were seen to be bad shots were selected. A total of four successful and four unsuccessful trials were identified for each shooter for further analysis per experimental condition.

The visual search data were analyzed frame-by-frame using Gamebreaker (Sportstec, Camarillo, USA) software. The mean QE duration and onset were analyzed. The Onset of QE was defined as the time from the trigger pull on shot 1, until the gaze stabilizes on the second target, and the tracking gaze is initiated. The QE duration was measured as the continuous tracking gaze from onset of QE to trigger pull on shot 2 (measured as 1 frame (33ms) before the shot cluster is visible). The eye movements were logged manually from the video recordings and QE characteristics determined by frame counts. The objectivity of the eye movement data was established using intra-observer (98.1%) and inter-observer (97.3%) agreement methods. Altogether, just over 10% of the data were reanalyzed to provide these figures using the procedures recommended by Thomas, Nelson, and Silverman (2005).

For kinematic analysis, the video files were imported into the SIMI Motion 6 (SIMI Reality Motion Systems, Unterschleissheim, DE) analysis software. An average calibration error of 0.68% of screen size was found, SIMI software recommends an error range between 0 and 3% for accurate analysis. The gun barrel marker was manually tracked in both video recordings for five frames before the initiation of the movement (the first movement of the gun barrel after the targets were called) and the following five frames after the completion of the shot (trigger pull on shot two) were digitized.

A separate two-way repeated measures ANOVA was used to examine the effect of anxiety (low/high) and shot outcome (successful/unsuccessful) for each of the QE and kinematic variables respectively. A number of separate paired samples *t* test (low/high) was conducted to examine the anxiety variables (a mean score of the three measurements was used) and performance outcome data. Performance data were reported as the percentage of successful trials on the second target. The effect sizes were calculated using partial eta squared values (η_p^2) and Cohen's *d* as appropriate. The alpha level for significance was set at 0.05 using a Bonferroni adjustment to control for Type 1 errors. If the sphericity assumption was violated, the Huynh-Feldt correction was used.

Results

The Mental Readiness Form (MRF-3)

Participants recorded significantly higher cognitive anxiety scores in the high (M = 48.85±14.8) compared with the low anxiety condition (M = 39.96±14.4), t (15) = 6.204, $p < 0.05$, d = 0.61. Somatic anxiety scores were also significantly higher in the high (M = 47.31±12.8) compared with the low anxiety condition (M = 37.38±13.3), t (15) = 5.055, $p < 0.05$, d = 0.76. Participants reported feeling significantly less confident in the high (M = 43.98±18.2) than in the low anxiety condition (M = 35.21±15.4), t (15) = 4.624, $p < 0.05$, d = 0.52.

The Rating Scale for Mental Effort (RSME)

Participants reported significantly higher mental effort scores under high (M = 90.35±16.4) compared with low (M = 77.10±16.7) anxiety conditions, t (15) = 7.195, $p < 0.05$, d = 0.80.

Performance

Performance, as measured by the percentage of targets hit (successfully hitting both the first and second targets), was lower under high (M = 62.9±6.8%) compared with low (M = 74.6±8.2%) anxiety conditions, t (15) = 5.266, $p < 0.05$, d = 1.55.

Visual search behaviors

Quiet eye duration

There were significant main effects for anxiety, $F_{1, 15}$= 51.146, $p < 0.05$, $\eta_p^2 = 0.77$, and outcome, $F_{1, 15}$= 25.926, $p < 0.05$, $\eta_p^2 = 0.66$. In the high anxiety condition, shooters employed shorter QE durations (*M* = 362.9±34.1ms) when compared with the low anxiety condition (*M* = 403.0±40.4ms). Also, significantly longer QE durations were evident on successful (*M* = 417.3±29.1ms) compared to unsuccessful (*M* = 348.6±45.3ms) trials. The Anxiety x Outcome interaction was not significant, $F_{1, 15}$= 0.169, $p > 0.05$, $\eta_p^2 = 0.01$. The results are presented in Figure 2.

Onset of quiet eye

There were significant main effects for anxiety, $F_{1, 15} = 69.191$, $p < 0.05$, $\eta_p^2 = 0.82$, and outcome, $F_{1, 15} = 125.982$, $p < 0.05$, $\eta_p^2 = 0.89$. In the high anxiety condition, shooters employed a later onset of QE (*M* = 276.3±23.9ms) compared to the low anxiety condition (*M* = 252.9±27.1ms). An earlier QE onset was observed on successful (*M* = 245.3±18.9ms) compared to unsuccessful (*M* = 276.3±23.9ms) trials. The Anxiety x Outcome interaction was not significant ($F_{1, 15} = 0.652$, $p > 0.05$, $\eta_p^2 = 0.04$). The results are presented in Figure 3.

Gun barrel kinematics

Movement time (shot two)

There was a significant main effect for anxiety, $F_{1, 15} = 6.038$, $p < 0.05$, $\eta_p^2 = 0.29$. A shorter shot two movement time was evident under high (*M* = 1183.1±122.9ms) compared to low anxiety conditions (*M* = 1223.1±136.0ms). There were no significant main effects for outcome, $F_{1, 15}$ = 0.033, $p > 0.05$, $\eta_p^2 = 0.02$, and no significant interaction between anxiety and outcome, $F_{1, 15}$ = 0.050, $p > 0.05$, $\eta_p^2 = 0.03$.

Displacement of gun shot two (horizontal axis)

Significant main effects were noted for anxiety, $F_{1, 15} = 11.068$, $p < 0.05$, $\eta_p^2 = 0.43$, and outcome, $F_{1, 15} = 12.009$, $p < 0.05$, $\eta_p^2 = 0.45$. In the high anxiety condition, shooters employed a larger gun displacement ($M = 13.4 \pm 2.8$cm) compared to the low anxiety condition ($M = 9.6 \pm 2.6$cm). A smaller gun displacement was evident on successful ($M = 9.5 \pm 2.5$cm) compared to unsuccessful ($M = 13.5 \pm 2.9$cm) trials. The interaction between anxiety and outcome was not significant, $F_{1, 15} = 1.513$, $p > 0.05$, $\eta_p^2 = 0.09$. The results are presented in Table 1.

Displacement of gun shot two (vertical axis)

There were significant main effects for anxiety, $F_{1, 15} = 5.578$, $p < 0.05$, $\eta_p^2 = 0.27$. A larger gun displacement was employed under high ($M = 3.4 \pm 0.7$cm) compared to low ($M = 2.5 \pm 0.9$cm) anxiety conditions. There were no significant main effects for outcome, $F_{1, 15} = 0.0356$, $p > 0.05$, $\eta_p^2 = 0.02$, and no significant interaction between anxiety and outcome, $F_{1, 15} = 1.958$, $p > 0.05$, $\eta_p^2 = 0.12$.

Peak velocity for shot two

Significant main effects were observed for anxiety, $F_{1, 15} = 4.739$, $p < 0.05$, $\eta_p^2 = 0.24$, and outcome, $F_{1, 15} = 11.178$, $p < 0.05$, $\eta_p^2 = 0.43$. In the high anxiety condition, the shooters employed higher peak velocities ($M = 0.93 \pm 0.1$m/s) compared with the low anxiety condition ($M = 0.87 \pm 0.1$m/s). Significantly lower peak velocities were also observed on successful ($M = 0.85 \pm 0.11$m/s) compared to unsuccessful ($M = 0.96 \pm 0.1$m/s) trials. The interaction between anxiety and outcome was not significant, $F_{1, 15} = 3.411$, $p > 0.05$, $\eta_p^2 = 0.19$. The results are presented in Table 1.

Variability of gun barrel shot two (horizontal axis)

There was a significant main effect for anxiety, $F_{1,\ 15} = 6.644$, $p < 0.05$, $\eta_p^2 = 0.31$. A larger gun barrel variability was evident under high ($M = 5.97 \pm 1.2$cm) compared with low ($M = 3.43 \pm 0.8$cm) anxiety conditions. There was no significant main effect for outcome, $F_{1,\ 15} = 3.331$, $p > 0.05$, $\eta_p^2 = 0.18$, and no significant interaction between anxiety and outcome, $F_{1,\ 15} = 1.266$, $p > 0.05$, $\eta_p^2 = 0.08$.

Variability of gun barrel shot two (vertical axis)

There was no significant main effect for anxiety, $F_{1,\ 15} = 0.005$, $p > 0.05$, $\eta_p^2 = 0.00$. However, a significant main effect was evident for outcome, $F_{1,\ 15} = 19.494$, $p > 0.05$, $\eta_p^2 = 0.57$. A smaller gun barrel variability was employed on successful ($M = 1.20 \pm 0.3$cm) compared to unsuccessful ($M = 1.60 \pm 0.4$cm) trials. There was no Anxiety x Outcome interaction, $F_{1,\ 15} = 1.820$, $p > 0.05$, $\eta_p^2 = 0.11$. The results are presented in Table 1.

Discussion

We tested the predictions of ACT (Eysenck et al., 2007), and its precursor PET (Eysenck & Calvo, 1992), by examining how anxiety affected markers of attention control and ultimately performance efficiency and effectiveness. More specifically, we examined the effect of anxiety on gaze behavior, gun motion, and mental effort, as indicators of performance efficiency, and outcome scores, as a measure of performance effectiveness, in elite-level, clay target shooters *in situ* when under high and low anxiety conditions, respectively.

First, our attempt to create two distinct levels of anxiety by recording data under practice (low anxiety) and competition (high anxiety) conditions was successful. Participants reported higher levels of cognitive and somatic anxiety and lower levels of self-confidence in the high compared to the low anxiety condition. Although we acknowledge that the levels of anxiety reported during official events such as the Olympics may far exceed those reported in this study, it appears that our efforts to recreate such conditions using a pseudo competitive environment involving peer evaluation and meaningful amounts of prize money was at least moderately successful.

We recorded QE duration and onset to determine differences in gaze behaviors across the two anxiety conditions. An earlier onset and longer duration of QE have previously distinguished both elite from sub-elite shooters and successful from unsuccessful trials in rifle (Janelle et al., 2000; Vickers & Williams, 2007) and shotgun shooting (Causer et al., 2010). Our findings supported these earlier studies, with the elite shooters employing a significantly shorter QE duration during the high anxiety condition (competition) compared to the control condition (practice). In relation to ACT (Eysenck et al., 2007), the shorter QE durations reported under high anxiety may reflect a disruption to the attentional control processes employed by participants. A longer QE duration provides shooters with an extended time period both for motor programming (goal directed control) and optimal arousal control which in turn could minimize the effects of erroneous environmental cues (stimulus driven control; Corbetta & Shulman, 2002).

Researchers examining visual search behaviors have consistently reported that experts employ fewer fixations of longer duration during performance on aiming tasks (cf. Mann, Williams, Ward & Janelle, 2007). These results suggest a level of information processing efficiency that permits more time spent on task relevant cues and less time in search of these cues. The behaviors have been reported to be affected by state anxiety, with a shift towards a more stimulus-driven control of attention (cf. Wilson et al., 2008). Similarly, a prolonged QE may demonstrated a similar efficiency of information processing where task-salient cues are prioritized during the final fixation and cortical resources are likely reallocated away from analytical processing and irrelevant sensory cues and toward the visuo-spatially dominant perceptuo-motor processes that are critical for effective motor programming and execution. The decrease in QE duration reported in the current study appears to be detrimental to performance effectiveness, and in line with ACT, this may be indicative of reductions in goal-directed attention under anxiety.

Our findings support earlier reports where increases in anxiety have been shown to negatively affect QE characteristics. Behan and Wilson (2008), using a simulated archery task, and Wilson et al. (2009a), using a basketball free throw task, have reported similar results, with shorter QE durations evident under high compared with low anxiety conditions. The current study extends the work on ACT since data were collected using discrete and sensitive measures of both performance effectiveness and efficiency, while combining a detailed analysis of both gaze and kinematic variables. Our efforts to test *in situ* allowed previous laboratory based data to be corroborated and the predictions of ACT to be tested under more authentic performance conditions. The measurement of both gaze and kinematic variables demonstrates a more comprehensive examination of the effects of anxiety on performance and process measures.

A longer QE duration and earlier onset of QE were reported on successful compared to unsuccessful trials. Similar findings have been previously reported in a number of tasks including basketball (Vickers, 1996) and billiards (Williams et al., 2002a). Moreover, Causer et al. (2010) reported comparable findings in skeet, trap, and double trap shooting with significantly longer relative QE durations evident on successful compared to unsuccessful trials.

According to PET and ACT, the effect of anxiety will be more pronounced on processing efficiency compared to performance effectiveness. However, in studies investigating the effects of anxiety on QE characteristics there have been consistent results indicating a decrement in performance as a result of a reduction in QE duration (Behan & Wilson, 2008; Wilson et al., 2009a; Vickers & Williams, 2007). In the current study, a significant difference in performance outcome was observed across the two anxiety conditions with reduced performance scores being evident in the high anxiety condition. Therefore, it is apparent that, under the high anxiety condition, the shooters were unable to employ effective compensatory processes to avoid a performance decrement, despite increasing mental effort from the high (M = 90.35$\pm$16.4) to the low (M = 77.10$\pm$16.7) anxiety condition. This finding suggests that processing resources in the central executive were not available to allow effective balancing of the two attentional control systems, and therefore the role of the shifting and inhibition functions was diminished. The inability of the participants to maintain performance in the high anxiety condition may be due to the overall task demands placed on participants during the task. The participants have to process both the first target and then the second target to complete the task successfully. The ACT predicts that adverse effects of anxiety on performance become greater as overall task demands on the central executive increase. The perceived increased demands on the central executive in the current task may limit the ability of compensatory mechanisms to maintain performance effectiveness in the high anxiety condition.

In conjunction with the decline in performance effectiveness, a reduction in performance efficiency seems apparent in the high anxiety compared to the low anxiety condition. For example, the RSME scores reported above, alongside changes in gun barrel kinematics imply a significant reduction in performance efficiency. In the competition round, the increase in anxiety resulted in significantly more gun barrel variation in the horizontal axis. An increase in gun barrel variability was also evident in the vertical axis on unsuccessful compared to successful trials. More variable gun motion leads to a less consistent movement pattern which is likely to directly affect performance outcome. Beuter and Duda (1985) reported similar results when examining changes in the lower limb kinematics of children as a function of arousal using a stepping task; increased arousal resulted in more variable movement patterns.

There were also differences in gun barrel displacement as a function of increases in anxiety. Shooters demonstrated larger gun barrel displacement in both the horizontal and vertical axis under high compared with low anxiety conditions. Larger peak velocities were also evident as anxiety increased in the competition round. The smaller gun displacement along with the lower peak velocities in the low anxiety condition enables a more efficient gun motion with no periods of high acceleration and therefore a more stable shot. A shorter movement time was also demonstrated in the high anxiety condition; this effect would coincide with the decreased QE duration, which reflects a reduction in processing efficiency and most likely contributing to the detriment in processing effectiveness. Similar, shorter movement times were reported under increased anxiety by police officers in a handgun task (Nieuwenhuys & Oudejans, 2010). The importance of a stable gun motion has been seen in both pistol (Mason, Cowan, & Gonczol, 1990) and rifle shooting (Mononen, Viitasalo, Era, & Konttinen, 2003). Beuter et al. (1989) reported similar results in a stepping task where duration increased as a result of increased arousal implying a reduction in efficiency. Moreover, Nieuwenhuys et al. (2008) reported comparable results in a climbing task, concluding that movement behavior became less efficient due to increased movements and climbing times under a high anxiety condition. Other kinematic differences include smaller gun barrel displacements on successful compared to unsuccessful trials (cf., Causer et al., 2010).

The current findings have practical and theoretical implications. The theoretical assumptions of ACT were tested in a unique, dynamic, real world setting using elite-level performers. We identified the effect of anxiety using sensitive and discrete indicators of both performance effectiveness and efficiency, with a particular emphasis on how these effects manifest themselves as changes in visual and motor behaviors. The results provide greater understanding of the influences of anxiety on attentional control *in situ*, allowing the performance of these tasks to be improved via the development of suitable intervention programs. Contemporary research is attempting to investigate the effect of training under increased levels of anxiety in an attempt to mediate the adverse effects suffered in real life situations (Oudejans, 2008). A similar approach, to implement training interventions, could be utilized in other domains such as the military and in medicine in order to help combat the potential negative effects of anxiety on attentional control and subsequently, on performance.

In sum, in this paper we tested the predictions of ACT to ascertain the effect of anxiety on performance effectiveness and efficiency. We reported changes in performance effectiveness (as determined by a decrease in shooting accuracy) and efficiency (as inferred from the reductions in QE durations, more variable and less efficient gun motions, and an increase in mental effort invested on the task) under high compared with low anxiety conditions. Findings provide support for the predictions of ACT with increases in anxiety leading to reductions in goal-directed attention, as indexed by QE. Reductions in QE have been seen to have a detrimental impact on performance accuracy in a plethora of tasks and clearly play a vital role in performance outcome under anxiety. Our data provide support for ACT based on data gathered *in situ* in a meaningful competitive context with implications for theory and practice across domains.

References

Abernethy, B., & Neal, R.J. (1999). Visual characteristics of clay target shooters. *Journal of Science & Medicine in Sport, 2,* 1-19.

Ansari, T.L., Derakshan, N., & Richards, A. (2008). Effects of anxiety on task-switching: Evidence from the mixed antisaccade task. *Cognitive, Affective, & Behavioral Neuroscience, 8,* 229–238.

Behan, M., & Wilson, M. (2008). State anxiety and visual attention: The role of the quiet eye period in aiming to a far target. *Journal of Sports Sciences*, *26*, 207-215.

Beuter, A., & Duda, J.L. (1985). Analysis of the arousal/motor performance in children using movement kinematics. *Journal of Sport Psychology*, *7,* 229-243.

Beuter, A., Duda, J.L., & Widule, C.J. (1989). The effect of arousal on joint kinematics and kinetics in children. *Research Quarterly for Exercise and Sport*, *60*, 109-116.

Causer, J., Bennett, S.J., Holmes, P.S. Janelle, C.M., & Williams, A.M. (2010). Quiet eye duration and gun motion elite shotgun shooting. *Medicine & Science in Sports & Exercise. 42*, 1599-1608.

Corbetta, M., & Shulman, G.L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience*: *3*, 215-229

Eysenck, M.W., & Calvo, M.G. (1992). Anxiety and performance: The Processing Efficiency Theory. *Cognition & Emotion*, *6*, 409-434.

Eysenck, M.W., Derakshan, N., Santos, R., & Calvo, M.G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion*, *7*, 336-353.

Friedman, N.P., & Miyake, A. (2004). The relations among inhibition and interference control functions: A latent-variable analysis. *Journal of Experimental Psychology: General*, *133*, 101–135.

Harle, S.K., & Vickers, J.N. (2001). Training quiet eye improves accuracy in the basketball free throw. *The Sport Psychologist*, *15*, 289-305.

Janelle, C.M. (2002). Anxiety, arousal and visual attention: A mechanistic account of performance variability. *Journal of Sports Sciences*, *20*, 237-251.

Janelle, C.M., Hillman, C.H., Apparies, R.J., Murray, N.P., Meili, L., Fallon, E.A., & Hatfield, B.D. (2000). Expertise differences in cortical activation and gaze behavior during rifle shooting. *Journal of Sport & Exercise Psychology*, *22*, 167-182.

Krane, V. (1994). The Mental Readiness Form as a measure of competitive state anxiety. *The Sport Psychologist*, *8*, 89-202.

Mann, D.T.Y., Williams, A.M., Ward, P., Janelle, C.M. (2007). Perceptual-cognitive expertise in sport: A meta analysis. *Journal of Sport & Exercise Psychology, 29*, 457-478.

Martens, R., Burton, D., Vealey, R.S., Bump, L.A., & Smith, D.E. (1990). Development and validation of the Competitive State Anxiety Inventory-2. In R. Martens, R.S. Vealey, & D. Burton, *Competitive anxiety in sport* (pp. 117-190). Champaign, IL: Human Kinetics.

Mason, B.R., Cowan, L.F., & Gonczol, T. (1990). Factors affecting accuracy in pistol shooting. *Excel, 6*, 2-6.

Miyake, A., Friedman, N.P. Emerson, M.J. Witzki, A.H. Howerter, A., & Wagner, T.D. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive Psychology*, *41*, 49-100.

Mononen, K., Viitasalo, J.T., Era, P. & Konttinen, N. (2003) Optoelectronic measures in the analysis of running target shooting. *Scandinavian Journal of Medicine & Science in Sports*, *13*, 200-207.

Nieuwenhuys, A., & Oudejans, R. R. D. (2010). Effects of anxiety on handgun shooting behavior of police officers: A pilot study. *Anxiety, Stress & Coping*, *23*, 225-233.

Nieuwenhuys, A., Pijpers, J.R., Oudejans, R.D., & Bakker, F.C. (2008). The influence of anxiety on visual attention in climbing. *Journal of Sport & Exercise Psychology*, *30*, 171-185.

Oudejans, R.R.D. (2008). Training under pressure improves handgun shooting performance of police officers. *Ergonomics*, *51*, 261-273.

Panchuk, D., & Vickers, J.N. (2006). Gaze behaviors of goaltenders under spatial-temporal constraints. *Human Movement Science*, *25*, 733-752.

Pijpers, J.R., Oudejans, R.R.D., & Bakker, F.C. (2005). Anxiety-induced changes in movement behavior during the execution of a complex whole-body task. *The Quarterly Journal of Experimental Psychology*, *58A*, 421–445.

Thomas, J.R., Nelson, J.K., & Silverman, S.J. (2005). Research methods in physical activity. Champaign, IL: Human Kinetics.

Veltman, J.A., & Gaillard, A.W.K. (1996). Physiological indices of workload in a simulated flight task. *Biological Psychology*, *42*, 323-342.

Vickers, J.N. (1996). Visual control while aiming at a far target. *Journal of Experimental Psychology*: *Human Perception & Performance*, *22*, 342-354.

Vickers, J.N. (2004). The quiet eye: It’s difference between a good putter and a poor one. *Golf Digest*, *January*, 96-101.

Vickers, J.N., & Williams, A.M. (2007). Performing under pressure: The effects of physiological arousal, cognitive anxiety, and gaze control in biathlon. *Journal of Motor Behavior*, *39*, 381–394.

Williams, A. M., & Elliott, D. (1999). Anxiety, expertise, and visual search strategy in karate. *Journal of Sport & Exercise Psychology*, *21*, 362-375.

Williams, A.M., Singer, R.A., & Frehlich, S. (2002a) Quiet eye duration, expertise, and task complexity in a near and far aiming task. *Journal of Motor Behaviour*, *34*, 197–207.

Williams, A. M., Vickers, J. N., & Rodrigues, S. T. (2002b). The effects of anxiety on visual search, movement kinematics, and performance in table tennis: A test of Eysenck and Calvo's processing efficiency theory. *Journal of Sport & Exercise Psychology*, *24,* 438-455.

Wilson, M., Vine, S.J., & Wood, G. (2009a). The influence of anxiety on visual attentional control in basketball free throw shooting. *Journal of Sport & Exercise Psychology*, *31*, 152-168.

Wilson, M., Wood, G., & Vine, S.J. (2009b). Anxiety, attentional control, and performance impairment in penalty kicks. *Journal of Sport & Exercise Psychology, 31*, 761-775.

Zijlstra, F.R.H. (1993). Efficiency in work behavior: A design approach for modern tools. Delft: Delft University Press.

Author Note

Joe Causer is with the Research Institute for Sport and Exercise Sciences, Liverpool John Moores University.

Paul S. Holmes and Nickolas C. Smith are with the Institute for Performance Research, Manchester Metropolitan University.

A. Mark Williams is with the Discipline of Exercise and Sports Science, The University of Sydney and the Research Institute for Sport and Exercise Sciences, Liverpool John Moores University.

This study was funded by UK Sport/British Shooting.

We thank John Leighton-Dyson and the Kuwait Shooting Federation for their support in the study, providing facilities and participants.

Correspondence concerning this article should be addressed to Professor A. Mark Williams, Faculty of Health Sciences, Cumberland Campus, The University of Sydney, East Street Lidcombe, NSW, Australia, 2141. Tel - +61 2 9351 9067, Fax - +61 2 9351 9204, Email – mark.williams@usyd.edu.au.

Table 1

Mean and standard deviations for kinematic variables on successful and unsuccessful trials in low anxiety and high anxiety conditions on shot two.

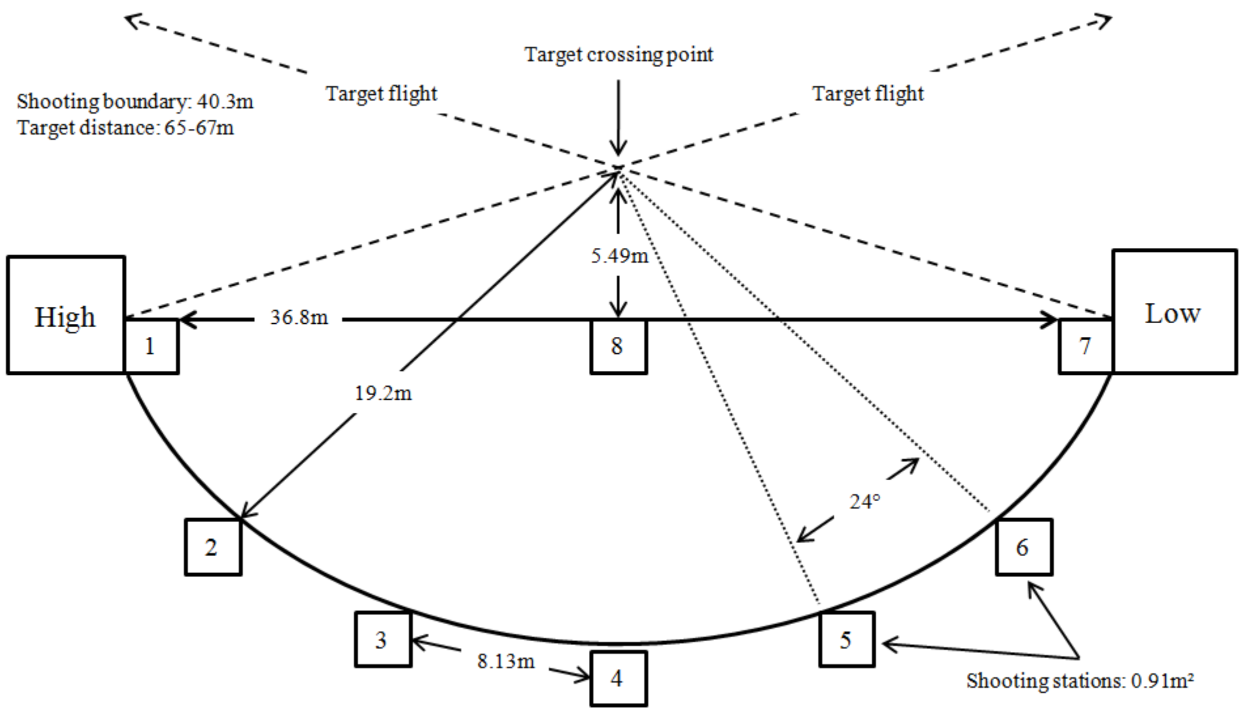
	Low anxiety		**High anxiety**	
	Successful	*Unsuccessful*	*Successful*	*Unsuccessful*
X variability (cm)	3.35±0.8	3.51±0.7	5.31±1.0	6.64±1.3
Z variability (cm)	1.11±0.3	1.70±0.5	1.29±0.3	1.50±0.3
Peak velocity (m/s)	0.79±0.1	0.95±0.1	0.90±0.1	0.96±0.1
X displacement (cm)	7.3±2.4	11.8±2.5	11.8±2.5	15.1±3.0
Z displacement (cm)	2.4±0.6	2.6±0.8	3.1±0.8	3.7±0.9
Movement time (ms)	1227.5±135.1	1218.8±141.2	1183.8±131.2	1182.5±118.2

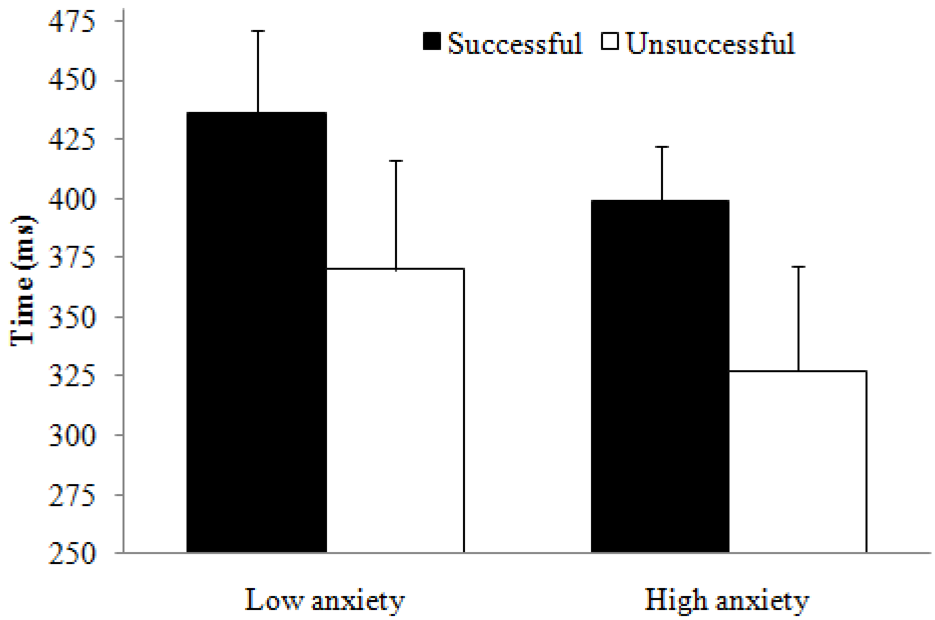
Figure Captions

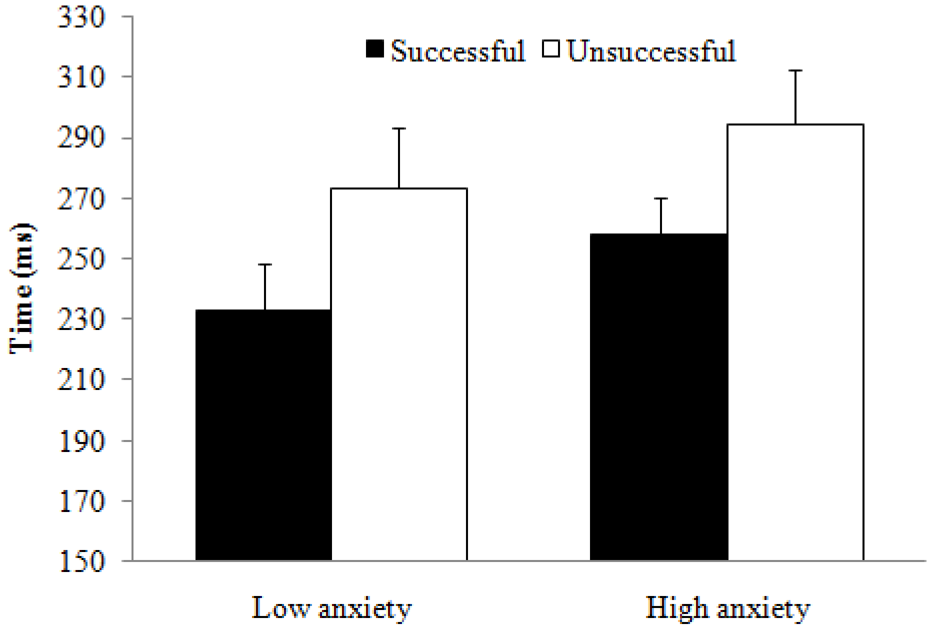
Figure 1. A schematic showing the layout of an Olympic skeet range.

Figure 2. The mean QE duration (ms) and standard deviations on successful and unsuccessful trials in low and high anxiety conditions.

Figure 3. The mean QE onset (ms) and standard deviations on successful and unsuccessful trials in low and high anxiety conditions.


Target crossing point
Target flight
Target flight
Shooting boundary: 40.3m
Target distance: 65-67m
5.49m
High
Low
36.8m
1
8
7
19.2m
24°
2
6
3
5
8.13m
4
Shooting stations: 0.91m²


Successful
Unsuccessful
Time (ms)
475
450
425
400
375
350
325
300
275
250
Low anxiety
High anxiety


330
310
290
270
250
230
210
190
170
150
Time (ms)
Successful
Unsuccessful
Low anxiety
High anxiety