The Effects of Anxiety on Visual Search, Movement Kinematics, and Performance in Table Tennis: A Test of Eysenck and Calvo's Processing Efficiency Theory

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Processing efficiency theory predicts that anxiety reduces the processing capacity of working memory and has detrimental effects on performance. When tasks place little demand on working memory, the negative effects of anxiety can be avoided by increasing effort. Although performance efficiency decreases, there is no change in performance effectiveness. When tasks impose a heavy demand on working memory, however, anxiety leads to decrements in efficiency and effectiveness. These presumptions were tested using a modified table tennis task that placed low (LWM) and high (HWM) demands on working memory. Cognitive anxiety was manipulated through a competitive ranking structure and prize money. Participants' accuracy in hitting concentric circle targets in predetermined sequences was taken as a measure of performance effectiveness, while probe reaction time (PRT), perceived mental effort (RSME), visual search data, and arm kinematics were recorded as measures of efficiency. Anxiety had a negative effect on performance effectiveness in both LWM and HWM tasks. There was an increase in frequency of gaze and in PRT and RSME values in both tasks under high vs. low anxiety conditions, implying decrements in performance efficiency. However, participants spent more time tracking the ball in the HWM task and employed a shorter tau margin when anxious. Although anxiety impaired performance effectiveness and efficiency, decrements in efficiency were more pronounced in the HWM task than in the LWM task, providing support for processing efficiency theory.

Key Words: cognition, emotion, effectiveness

The relationship between anxiety and performance has attracted much interest in the research literature. Several theoretical explanations have been proposed ranging from unidimensional models of arousal-performance such as the inverted-
U hypothesis (Yerkes & Dodson, 1908) and drive theory (Hull, 1943; Spence & Spence, 1966), to multidimensional anxiety theory (Burton, 1988; Davidson & Schwartz, 1976; Martens, Burton, Vealey, Bump, & Smith, 1990), zones of optimal functioning (Hanin, 2000), and cusp catastrophe models (Fazey & Hardy, 1988; Hardy, 1990). While there are varying degrees of support for multidimensional and catastrophe perspectives on anxiety-performance (for recent reviews, see Hardy, Jones, & Gould, 1996; Jones, 1995a, 1995b; Woodman & Hardy, 2001), these models are somewhat descriptive and there have been few attempts to specify the mechanisms underlying the facilitative or debilitative effects of anxiety on performance.

Although there have been a few notable exceptions (e.g., Beuter & Duda, 1985; Weinberg & Hunt, 1976), most researchers have overemphasized the outcome measures of performance in anxiety research. Such measures may not be sensitive enough to determine the nature of the relationship between anxiety and performance (Jones, 1995a; Weinberg, 1990). A more complete understanding of the effects of anxiety on performance calls for the use of process oriented measures such as visual search behaviors or movement kinematics in conjunction with traditional outcome scores. For example, Williams and Elliott (1999) examined the effects of anxiety on visual search behaviors using simulated combat situations in karate. Experienced and inexperienced karate performers moved in response to life-size filmed sequences presented under conditions of low and high cognitive anxiety. Participants generally displayed scan paths that ascended and descended the centerline of their opponent's body with primary fixations on the head and chest region.

Anxiety had a significant effect on search strategy as highlighted by an increase in the number of fixations and in the areas fixated per trial. Similarly, the mean duration of fixation decreased concomitantly with increases in anxiety. The increase in search activity was more pronounced in inexperienced performers, with fixations moving from central (head/chest) to peripheral (arm/fist) regions. The respective authors suggested that these changes in search strategies with anxiety were due to peripheral narrowing (Easterbrook, 1959) and/or increased susceptibility to peripheral distracters or task irrelevant cues (Eysenck, 1992).

In a related study, Janelle, Singer, and Williams (1999) examined whether the changes in visual search behaviors observed under anxiety-producing circumstances were due to attentional narrowing or hypervigilance. They employed a simulated motor racing task in which participants had to navigate a track as quickly as possible while responding to relevant and irrelevant stimulus lights around the periphery. As anxiety increased, the time taken to detect relevant cues and to discriminate relevant from irrelevant cues increased, and there was a concomitant decrease in driving speed. Visual search behaviors became more variable, with an increase in the number of fixations directed toward the periphery. Anxious participants were more apt to be distracted by irrelevant peripheral cues and, in order to compensate for the detrimental effects of peripheral narrowing and hypervigilance, had an increased tendency to fixate peripheral cues using foveal vision to determine their relevance. Janelle and colleagues concluded that anxiety results in peripheral narrowing and increases the likelihood that participants focus on irrelevant (or distracting) cues versus relevant ones.

Surprisingly, few researchers have examined the effects of anxiety on movement kinematics (for exceptions, see Beuter & Duda, 1985; Beuter, Duda, & Widule,
1989). Beuter and Duda (1985) examined changes in lower limb kinematics as a function of arousal using a task that required children to step over a series of obstacles. As arousal increased, more variable movement patterns were observed particularly in distal joints such as the ankle. Similarly, Beuter et al. (1989) reported an increase in stepping duration as arousal increased, providing support for Adam and van Wieringen’s (1983, 1988) suggestion that anxiety affects timing more than it affects the spatial characteristics of movement. It appears that anxiety reduces the accuracy with which relevant information can be picked up, leading to changes in movement timing (cf. Bootsma, Bakker, van Snippenberg, & Tdloreg, 1992).

Also, recent theoretical advances have further highlighted the need to distinguish process from outcome measures of performance. In their processing-efficiency theory, Eysenck and Calvo (1992; Eysenck, 1992) distinguish between performance effectiveness, which refers to the quality of task performance, and processing efficiency, which refers to the product of performance effectiveness divided by effort. Effort is determined by the amount of processing resources invested in a task. The amount of processing resources allocated to a task may be determined by various secondary measures of performance. For example, they argued that a decrease in performance efficiency as a result of anxiety may manifest itself in higher levels of subjective effort, longer response times to reaction time probes, and changes in eye movement behavior and movement kinematics.

The central tenet of processing-efficiency theory is that anxiety reduces the processing and storage capacity of working memory. The essential features of a working-memory system are such that it is concerned with the active processing and temporary storage of information. Baddeley (1986, 1990) proposed that the working-memory system includes a central executive that is involved in active processing, an articulatory loop that is assumed to be responsible for the transient storage of verbal information, and a visuospatial sketchpad specializing in visual and/or spatial information. The central executive is assumed to be the most important component of the system since it is used in tasks that require planning and decision-making and which involve poorly mastered response sequences (Baddeley, 1986).

Another key assumption underlying the processing efficiency theory is that emotions such as worry and self-concern use up available processing resources and, consequently, reduce the resources available in working memory for the task at hand. The negative effects of anxiety on working memory can be avoided by allocating additional resources (effort) and/or initiating different processing activities (i.e., self-regulatory strategies), provided that the demands on working memory are not too great. If successful, such attempts would increase the capacity of available working memory, thereby maintaining performance effectiveness while also decreasing performance efficiency. To this end, cognitive anxiety may actually have facilitative effects on performance by motivating the performer to ensure that sufficient resources are available for the task (Hardy, 1997).

An increase in anxiety highlights the importance of the task to the individual who may subsequently invest more effort to ensure that performance does not fall below expectations (Woodman & Hardy, 2001). Eysenck (1982) argued that this increase in effort only occurs if participants feel they have a reasonable chance of success. An individual’s self-confidence and his or her tendency to view anxiety as either facilitative or debilitating may also have a bearing in this regard (Carver &
Scheier, 1988). In contrast, Eysenck and Calvo (1992) predict that when anxiety is high and the task imposes a heavy demand on working memory, the resources available are exceeded and this leads to decrements in both performance efficiency and effectiveness.

There have been few empirical attempts to examine the validity of Eysenck and Calvo’s theory in the domain of sport (Woodman & Hardy, 2001). This paucity of research is surprising, given that sport provides a rich environment for exploring the complex interactions between cognition, emotion, and action. An exception is a recent study by Murray and Janelle (in press) using the same motor racing task as adopted by Janelle et al. (1999). In addition to the central driving task, a cost/benefit paradigm (Posner, 1980) was employed in which participants were required to respond to peripheral cues that were valid, invalid, or neutral. Performance effectiveness was determined by the time taken to complete the race, whereas probe reaction time, visual search behaviors, and changes in cortical activation, as determined by evoked response potentials (the P3 amplitude was used to measure attentional resource allocation), were recorded as measures of performance efficiency.

No changes were reported in performance effectiveness as anxiety levels increased. However, marked changes in performance efficiency were observed under high compared with low anxiety, particularly in high trait-anxious individuals. Specifically, there was a reduction in reaction time and in P3 amplitude to the secondary probe, indicating an increase in attention in the primary driving task, and an increase in search rate as indicated by a decrease in mean fixation duration and an increase in the number of fixations. Although these measures suggest a significant decrease in efficiency, participants were able to maintain effectiveness, presumably by increasing the information processing resources available for the central task.

The current study tested assumptions arising from Eysenck and Calvo’s (1992) theory by asking participants to perform a modified table tennis task that placed either low or high demands on working memory under both low and high cognitive anxiety conditions. It was expected that high levels of anxiety would have a detrimental impact on efficiency in the low working-memory task, without necessarily affecting performance, whereas in the high working-memory task it was predicted that both efficiency and effectiveness would be affected. Participants’ accuracy at hitting table tennis balls toward concentric circle targets was taken as a measure of performance effectiveness, while probe reaction time, perceived mental effort, visual search behaviors, and arm kinematics were viewed as indicators of performance efficiency.

It was predicted that higher levels of subjective effort and longer probe reaction times would be indicative of increased cognitive activity and, consequently, a decrease in performance efficiency (Eysenck & Calvo, 1992). Similarly, and in keeping with previous research, anxiety was expected to have negative effects on visual search behavior, for example by increasing search activity (Williams & Elliott, 1999). Anxiety was also expected to disrupt the functional coupling between perception and action by reducing participants’ ability to pick up relevant optical information (Bootsma et al., 1992). For example, when anxious, participants may have difficulty picking up the impending time-to-contact between bat and ball. Lee (1976) demonstrated that humans are sensitive to the rate of dilation of the solid angle provided by an approaching object on the retina, and that this optic variable,
termed tau, could specify when the object will be at the observer's present location. The suggestion is that when tau reaches a critical value, a tau margin is specified which can be used to predict the moment to initiate a movement response. Bootsma and van Wieringen (1990) argued that the tau margin is useful in dynamic circumstances when compensatory variability between perceptual and motor systems allows performers to adjust temporal components of the movement.

**Methods**

**Participants**

Eight male and two female table tennis players ($M$ age = 28.9 yrs, $SD = 8.2$) provided informed consent prior to participating in the study. They had been playing recreational table tennis an average of 1.8 ($SD = 1.1$) times per week for 9.6 years ($SD = 6.4$). All had normal or corrected-to-normal visual acuity. The group recorded moderately high trait anxiety scores ($M = 19.9$; $SD = 3.1$), as determined by the Sport Competition Anxiety Test (Martens, 1977).

**Equipment**

**Eye Movement System.** An Applied Sciences Laboratories (ASL) 501 system was used to collect gaze data. This is a monocular, corneal reflection system that measures visual point-of-gaze with respect to helmet-mounted eye and scene cameras. The system works by detecting two features, the pupil and corneal reflection (determined by the reflection of an infrared light source from the surface of the cornea), in a video image of the eye. The relative position of these features is used to compute visual gaze with respect to the optics. A cursor, representing $2^\circ$ of visual angle with a 4.5-mm lens, indicates the location of gaze in a video image of the scene. The system collects data within a range of $40^\circ$ in the vertical field and $50^\circ$ in the horizontal plane. The accuracy of the system, the difference between true eye position and measured eye position, was $\pm 1^\circ$ visual angle. System precision, the amount of instrument noise in the eye position measure when the eye is perfectly stationary, was better than $.5^\circ$ in both horizontal and vertical directions. The helmet has a 10-meter cord attached to a control box fixed around the participant's waist, permitting near normal mobility.

**Vision-in-Action (VIA) System.** The Vision-in-Action system (see Vickers, 1996) integrates the image from the mobile eye tracker with an external camera that captures the participants' actions. A time code generator and two video mixers are used to integrate gaze, motor, and ocular behaviors. In the present study, the ASL 501 system was interfaced to an external video camera (Sony TRV82) and two digital video mixers (Videonics MX-1) to produce the frame of video data represented schematically in Figure 1. The three images were time-locked and collected at a sampling frequency of 60 Hz, one frame every 16.66 ms.

**Motion Analysis System.** Kinematic data were recorded via four high-speed video cameras set to 180 Hz and a computerized system (EVa). Participants were fitted with retro-reflective markers attached to the elbow (head of radius) and wrist (ulnar head) of the striking arm to allow the digital processing of marker recognition. The motion analysis system was calibrated before each data collection session. To calibrate the system, a metal cube with eight reflective markers was filmed
Figure 1 — A schematic showing (A) participant’s eye from which the pupil and corneal reflection centroids were recorded; (B) Scene camera image with visual point of gaze indicated by the white cursor; (C) Player’s physical actions and the concentric circle targets as recorded by an external camera.

using the four cameras. The EVA measured the same markers from each camera image and generated coefficients that showed the spatial relationship between the video images and “real” space occupied by the cube. These coefficients were used during the later 3-D reconstruction of the task. The table tennis ball (diameter 37.8 mm) was painted with a reflective liquid so that it could be detected clearly by the EVA system. The EVA provided 3-D position data for the striking arm and the ball’s flight path. Elbow and wrist position data were smoothed with a 4th-order Butterworth filter at 5 Hz, while ball position data were smoothed with the same filter at 30 Hz.

Experimental Tasks

Two tasks were designed to provide varying demands on working memory. The tasks involved varying degrees of active processing and transient storage of information and were likely to be dependent on the central executive and visuospatial sketchpad rather than on the articulatory loop component of working memory.

Low Working Memory (LWM) Task. This task required players to perform six consecutive shots per trial toward three concentric circle targets located on the opposite side of the table. The width of the table was divided equally into three sections, each containing a separate target (see Figure 1). Each target comprised five concentric circles. The outer circle had a diameter of 50 cm and each consecu-
tive circle was reduced by 10 cm such that the inner circle, or bull's eye, was 10 cm in diameter. The areas between each circle were worth a total of 10, 8, 6, 4, and 2 points, respectively, with the bull's eye worth the most points. Whenever the ball landed on the line dividing two concentric circles, the higher mark was awarded. No marks were awarded if the ball landed outside the outer circle but within the correct sector, whereas if the ball landed in one of the other sectors the trial was terminated.

Participants had to score as many points as possible, with a maximum of 60 points available per trial. The six shots were performed as part of a continuous drill sequence with a standardized feed performed by an experienced player. The server began each trial by feeding the ball to the participant using a backhand serve toward the middle of the central target area. The trial was terminated either when the participant had performed six consecutive shots or when the ball was out of play (e.g., hit the net or missed the table/correct sector). If the initial feed was not accurate or the rally ended prematurely because of an error by the server, the trial was repeated. On average, one trial was repeated per participant.

Five practice trials were followed by six experimental trials. Targets were placed on both sides of the table to facilitate consistency in the service provided to each player. Participants were required to play an accurate straight drive shot toward the target center in response to the server's preceding shot. For example, if the server played the ball toward the target located in the middle of the table, the participant had to return the ball toward the same target on the opposite side of the net. Similarly, a shot played to the target on the participant's right side was returned to the target on the server's left side, and so on. Only the server was allowed to change the direction of play. It was presumed that the demand on working memory was comparatively low in this task because participants did not have to employ a complex strategy in working memory; they merely had to return the ball to the target directly opposite.

*High Working Memory (HWM) Task.* In this task, players were required to maintain in working memory a complex shot strategy that was varied from one trial to the next. They were required to play a return shot either one or two sectors to the right or left of the server's feed. For example, if the server played the shot from the left target zone, the participant had to return the shot toward the target on the server's right in the "one sector to the left" condition, and to the center target in the "two sectors to the left" condition. In this sense the targets were viewed as being linked in a circular fashion such that one sector to left of the end sector would refer to the sector on the far right of the table. In the same scenario when performing in the "one or two sectors to the right" condition, participants had to return the ball either to the central target area (one sector) or to the target on the server's far right side (two sector). Five practice attempts were followed by six test trials. The requirements of the task were manipulated randomly from trial to trial such that participants had to rehearse and maintain the appropriate strategy in working memory as each rally sequence evolved. The targets and scoring scheme were the same as in the LWM task.

*Procedures*

A repeated-measures design was employed whereby all participants completed the LMW and HWM tasks under both LA and HA, respectively. To avoid
potential order effects, the presentation of task and anxiety conditions were counterbalanced across participants. Anxiety was manipulated through the use of a competitive ranking structure and prize money. In the LA condition, participants were informed that data were to be used merely for practice purposes and that they would not be assessed or compared to their peers. In the HA condition, participants were told their performance would be evaluated according to a ranking structure in which the highest ranked player would receive a $200 prize. Cognitive anxiety was measured prior to each condition using a modified version of the Competitive Sport Anxiety Inventory-2 (CSAI-2; Martens et al., 1990). The modified inventory included the directional scale developed by Jones and colleagues (Jones & Swain, 1992; Jones, Swain, & Hardy, 1993). This scale measures participants’ perceptions of anxiety, with regard to whether it is perceived to have facilitative or debilitative effects on subsequent performance, as well as its intensity.

After listening to the instructions, participants were fitted with the eye tracker helmet and joint center markers. The ASL 501 system was calibrated using a 9-point reference grid so that the recorded indication of fixation position corresponded to the participant’s visual gaze. Previous research (e.g., Williams, Davids, Burwitz, & Williams, 1994) has shown that the system requires only occasional recalibration and, consequently, a full calibration check was only undertaken prior to each experimental condition. However, participants were asked to fixate on a marker positioned in the center of the table immediately after each trial, which allowed for a rapid calibration check and minor corrections as appropriate. All participants reported that the helmet was comfortable and did not interfere with performance.

During each trial the players had to verbally respond by shouting “Yes” quickly and accurately to a randomly presented auditory reaction-time probe (PRT). The probe was triggered by the ball breaking a “bank” of infrared beams positioned vertically near the table tennis net. The participant’s verbal response was picked up on the soundtrack of the video camera used to record the VIA image. The time that elapsed from initiation of auditory probe to the participant’s verbal response was taken as a measure of reaction time. This measure was obtained from the VIA video soundtrack using Sound Forge 4.0d software (Sonic Foundry, Madison, WI). The software’s sampling rate was 44.4 KHz with a measurement error of ±1 ms. To avoid guessing, participants were randomly presented with one “catch” trial per condition in which the auditory probe was not presented. If participants responded to the catch trial, the trial was repeated and they were warned not to anticipate the presentation of the auditory stimuli.

At the completion of each condition, participants rated their effort on the task using a scale ranging from 0 to 150 (RSME; Zijlstra, 1993). The RSME has nine descriptive indicators along the axis (e.g., a value of 2 corresponds to “not effortful,” 58 to “rather effortful,” and 113 to “awfully effortful”). The scale provides a valid and reliable measure of mental effort (e.g., Veltman & Gaillard, 1996).

**Dependent Variables and Statistical Analysis**

*Cognitive Anxiety and Self-Confidence Intensity and Direction.* These measures were derived from the modified version of the CSAI-2. The possible range for intensity scores was 9 to 36, while the direction scores could vary from −27 to +27.
Performance Accuracy. Performance scores were recorded manually using frame-by-frame analysis of the VIA data.

Probe Reaction Time (PRT). This was the time (ms) from the presentation of the auditory probe to participant’s verbal response.

Rating of Mental Effort (RSME). This was the perceived mental effort for each participant across the four experimental conditions.

Visual Search Analysis. Three measures were obtained from the visual search data. Mean gaze duration (FD) was the average duration of gaze per trial for each participant across conditions. As in previous research (e.g., Vickers, 1996), a fixation was defined as a condition in which the eye remained fixated on an area for a period equal to or greater than 3 video frames (99.99 ms). The frequency of gaze was the mean number of times per trial that the participant’s gaze moved from one location to another. The location of gaze referred to those areas of the visual field to which the gaze was directed during the task. The following areas were identified for coding purposes: fixations on the server (bat, arm, wrist, trunk, and shoulder regions); ball tracking (all fixations on the ball during its flight); and the target. A new fixation was defined when the cursor moved more than 1° from the initial fixation point, whereas an error margin of 3° was used for ball tracking. These values were based on precedents in the literature (Bahill & LaRitz, 1984; Ripoll & Fleurance, 1988; Vickers, 1996), as well as guidelines for parafoveal tracking (Carpenter, 1988).

A further category labeled “other” was used for data that did not fall into one of the above classifications. This latter category primarily included those instances where the eye was farther than 3° away from the ball during flight. The mean time per trial that participants focused their gaze on each of these four locations was determined using frame-by-frame video analysis. In order to reduce the time-consuming nature of the analysis and to collect data when the calibration was likely to be most accurate, the values for each visual search measure represent mean scores based on each participant’s first three shots per trial.

Intertester reliability measures were obtained for each visual search measure as well as for the performance scores using intraclass correlation techniques and the calculation of limits of agreement (Atkinson & Nevill, 1998). Intraclass correlation coefficients ranged from 0.88 to 0.96, while 95% limits of agreement were achieved for each measure reported.

Kinematic Analysis. The following measures were obtained from the motion analysis system. Mean ball velocity (MBV) was recorded as the displacement of the ball during the final 500 ms prior to contact divided by the same duration. This measure was used to check on the consistency of the service. Movement time (MT) was defined as the time elapsed between initiation of the forward phase of arm movement (defined as the moment wrist velocity reached 0.3 m s⁻¹) until bat/ball contact. The initial position (IP) of the wrist relative to the leading edge of the table at the initiation of the stroke (the moment wrist velocity reached 0.3 m s⁻¹) was also recorded. Arm velocity at contact (AVC) was measured as the angular velocity between the arm (elbow-wrist segment) and the X-axis of transmitter coordinate system at the moment of ball/bat contact. Peak arm velocity (PAV) was the highest wrist velocity during the final 500 ms of ball flight. Finally, the tau
margin at the initiation of movement (TAUip) was calculated as the quotient of the distance between the eye of the player and the ball and its rate of change (cf. Bootsma & van Wieringen, 1990).

These kinematic variables were calculated for each condition using the first shot in each trial. Since each trial began with a feed to the central target area, this provided some standardization in comparing across trials and conditions. Because of difficulties with calibration and the loss of joint center markers on certain trials, complete data sets were only obtained for 6 of the 10 participants.

Cognitive anxiety and self-confidence intensity and direction scores were analyzed using separate one-way repeated-measures ANOVA for each variable. The fixation location data were analyzed using a factorial ANOVA in which anxiety (LA vs. HA), task (LWM vs. HWM), and location (fixations on server, ball tracking, fixations on the target, and “other”) were within-participant factors. The remaining process (PRT, RSME, FD, number of fixations, MT, IP, TAUip, AVC, and PAV) and outcome measures (performance accuracy) were analyzed using separate factorial ANOVAs in which anxiety (LA vs. HA) and task (LWM vs. HWM) were within-participant variables. The MBV data were also analyzed using a factorial ANOVA. Newman Keuls tests were used to follow up significant effects where appropriate. The alpha level for significance was set at \( p < .05 \).

Results

Anxiety Manipulation

Participants recorded higher cognitive anxiety intensity scores under the HA (\( M = 18.2, SD = 2.6 \)) compared with the LA (\( M = 10.9, SD = 3.1 \)) condition, \( F(1, 9) = 16.71, \omega^2 = .61, p < .05 \). These anxiety intensity scores were also perceived to be less facilitative under HA (\( M = +7.0, SD = 7.5 \)) compared with LA (\( M = +11.6, SD = 6.6 \)), \( F(1, 9) = 18.96, \omega^2 = .64, p < .01 \). A corresponding decrease was observed in self-confidence intensity scores under the HA (\( M = 22.8, SD = 5.4 \)) compared with the LA (\( M = 27.4, SD = 4.7 \)) condition, \( F(1, 9) = 7.53, \omega^2 = .40, p < .05 \). Moreover, self-confidence was perceived to be less facilitative when participants were more anxious (\( M = +9.0; SD = 6.6 \)), rather than less (\( M = +11.6; SD = 7.5 \)) anxious, \( F(1, 9) = 12.57, \omega^2 = .54, p < .01 \).

Performance Accuracy

The ANOVA indicated significant main effects for anxiety, \( F(1, 9) = 12.09, \omega^2 = .53, p < .01 \), and task, \( F(1, 9) = 9.63, \omega^2 = .46, p < .05 \). Participants recorded higher performance scores on the LWM task compared with the HWM task, and under the LA versus the HA condition. The data are presented in Table 1.

Probe Reaction Time (PRT)

Significant main effects were observed for anxiety, \( F(1, 9) = 6.19, \omega^2 = .34, p < .05 \), and task, \( F(1, 9) = 5.81, \omega^2 = .64, p < .05 \), while the Anxiety \times Task interaction approached significance, \( F(1, 9) = 3.40, \omega^2 = .20, p = .09 \). Participants had longer PRT values on the HWM task compared with the LWM task, and under the HA compared with the LA condition (see Table 1).
Table 1  Mean Values per Trial for LWM and HWM Tasks Across the Two Anxiety Conditions

<table>
<thead>
<tr>
<th></th>
<th>LA_LWM</th>
<th>HA_LWM</th>
<th>LA_HWM</th>
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<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Performance</td>
<td></td>
<td></td>
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<tr>
<td>accuracy</td>
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<td>5.7</td>
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<tr>
<td>PRT (ms)</td>
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<td>106.5</td>
<td>729.9</td>
<td>92.4</td>
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<tr>
<td>RSME</td>
<td>47.3</td>
<td>27.0</td>
<td>58.9</td>
<td>31.3</td>
</tr>
</tbody>
</table>

Table 2  Mean No. of Alterations in Gaze* and Mean Gaze Duration per Trial for LWM and HWM Tasks Across the Two Anxiety Conditions

<table>
<thead>
<tr>
<th></th>
<th>LA_LWM</th>
<th>HA_LWM</th>
<th>LA_HWM</th>
<th>HA_HWM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Number of alterations in gaze</td>
<td>11.2</td>
<td>0.7</td>
<td>12.2</td>
<td>0.9</td>
</tr>
<tr>
<td>Gaze duration (ms)</td>
<td>354.8</td>
<td>52.6</td>
<td>351.8</td>
<td>19.3</td>
</tr>
</tbody>
</table>

*Note: Total of 6 shots.

Rating of Mental Effort (RSME)

The ANOVA showed significant main effects for anxiety, $F(1, 9) = 20.70$, $\omega^2 = .66$, $p < .01$, and task, $F(1, 9) = 13.73$, $\omega^2 = .56$, $p < .01$. Participants felt that they were devoting more mental effort under the HA condition and in the HWM task than under the LA condition and in the LWM task (see Table 1).

Visual Search Measures

Frequency of Gaze. The ANOVA showed a significant main effect for anxiety only, $F(1, 9) = 13.99$, $\omega^2 = .57$, $p < .01$. Participants altered their gaze more often under the HA condition than under the LA condition. The data are presented in Table 2.

Gaze Duration (FD). No significant main effects or interactions were observed for gaze duration across conditions, $p > .05$.

Location of Gaze. The ANOVA revealed significant main effects for location, $F(3, 21) = 32.31$, $\omega^2 = .76$, $p < .01$, and significant interactions for Task $\times$ Location, $F(3, 21) = 4.78$, $\omega^2 = .27$, $p < .05$, and Anxiety $\times$ Task $\times$ Location, $F(3,$
21) = 3.93, ω² = .23, p < .05. Follow-up analyses using the Newman Keuls procedure indicated that participants spent more time tracking the ball (M = 39.5%) compared with other areas regardless of task or anxiety condition, p < .01. Also, they spent more time allocating their gaze to “other” areas (M = 28.7%) rather than on the server (M = 16.6%) or target (M = 15.2%), p < .01. Participants oriented their gaze toward similar areas of the display under the HA versus the LA condition on the LWM task; however, less time was spent with gaze allocated to “other” areas (22.1 vs. 33.0%) and more time was spent tracking the ball (45.0 vs. 30.8%) under the HA versus the LA condition in the HWM task, p < .01. These findings are shown in Figure 2.

Kinematic Measures

No significant differences were observed for MBV, AVC, PAV, or IP across task or anxiety conditions, p > .05 (see Table 3). The ANOVA showed a significant Task × Anxiety interaction for TAUIp, F(1, 5) = 6.53, ω² = .48, p < .05. Newman Keuls analysis revealed that participants employed shorter tau margins when anxious in the HWM (M = 248.8 ms) compared with the LWM (M = 312.1 ms) task. The ANOVA showed a significant task main effect for MT, F(1, 5) = 7.11, ω² = .50, p < .05. Shorter movement times were observed in the LWM (M = 246.9 ms) compared with the HWM (M = 281.4 ms) task.

Discussion

The aim in this study was to test specific predictions arising from Eysenck and Calvo’s (1992) processing efficiency theory. Specifically, the theory proposes that when a task does not place heavy demands on working memory, there should be no decrement in performance as anxiety increases. Performers should be able to compensate for the potentially negative effects of anxiety by allocating additional
Table 3  Means and Standard Deviations Across Conditions

<table>
<thead>
<tr>
<th></th>
<th>LA_LWM</th>
<th></th>
<th>HA_LWM</th>
<th></th>
<th>LA_HWM</th>
<th></th>
<th>HA_HWM</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M  SD</td>
<td>M  SD</td>
<td>M  SD</td>
<td>M  SD</td>
<td>M  SD</td>
<td>M  SD</td>
<td>M  SD</td>
<td>M  SD</td>
</tr>
<tr>
<td>Mean ball velocity</td>
<td>3.4 0.2</td>
<td>3.3 0.3</td>
<td>3.2 0.3</td>
<td>3.3 0.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Movement time (ms)</td>
<td>240.9 40.1</td>
<td>252.9 80.8</td>
<td>307.1 72.1</td>
<td>255.7 71.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initiation point (cms)</td>
<td>-26.8 6.4</td>
<td>-29.0 10.4</td>
<td>-32.4 11.2</td>
<td>-29.4 9.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tau-margin at init. (ms)</td>
<td>227.9 60.8</td>
<td>262.7 79.9</td>
<td>312.1 60.8</td>
<td>248.8 83.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avg velocity at contact (ms⁻¹)</td>
<td>1.5 0.3</td>
<td>1.6 0.2</td>
<td>1.5 0.3</td>
<td>1.5 0.2</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Peak arm velocity</td>
<td>1.6 0.3</td>
<td>1.7 0.2</td>
<td>1.7 0.3</td>
<td>1.6 0.3</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

resources and/or by adopting more effective processing strategies. Processing efficiency will decrease, but there should be no change in performance outcome or effectiveness. Alternatively, when the task places a heavier demand on working memory, high levels of anxiety are predicted to have negative effects on both processing efficiency and performance effectiveness. The combined demands of dealing with the task along with the high levels of anxiety would exceed the resources available to perform the task. We attempted to address these issues by using a novel task that placed varying demands on working memory in an ecologically valid setting involving high and low levels of competitive anxiety.

As expected, higher performance scores were observed in the LWM compared with the HWM task. Moreover, participants recorded higher PRT and RSME values in the HWM task. Taken together, these findings provide some degree of validity for the task manipulation employed in this study. The HWM task was more difficult, required greater attention and mental effort, and, by implication, placed higher demands on working memory than did the LWM task.

The manipulation of anxiety through the use of a competitive and evaluative setting was moderately successful in creating two distinct levels of cognitive anxiety intensity. A corresponding decrease in self-confidence intensity was observed across both conditions. Also, participants reported that they perceived their levels of anxiety and self-confidence to be less facilitative in the HA than in the LA condition. Although the values reported are comparable to previous attempts to manipulate anxiety under laboratory conditions (e.g., Janelle et al., 1999; Williams & Elliott, 1999), the anxiety experienced by participants was perhaps less than the levels expected in real-life competitive settings. The difficulties of manipulating anxiety in the laboratory are further highlighted (cf. Jones, 1995b).
Eysenck and Calvo’s predictions were only partially supported by the current study. Contrary to expectations, high levels of anxiety had a negative effect on performance efficiency and effectiveness in both the LWM and HWM tasks. There was a reduction in mean performance score (9.5 vs. 12.6) and an increase in resources allocated to the task, as determined by the increase in PRT (776.1 vs. 692.5 ms) and RSME (77.8 vs. 66.9) values, under HA compared with LA conditions. Also, changes were observed in visual search behavior, with participants altering their gaze more frequently (12.2 vs. 11.2) in the HA than in the LA condition. This latter finding provides support for the few other studies that have examined the effects of anxiety on visual search behavior (e.g., Janelle et al., 1999; Murray & Janelle, in press; Williams & Elliott, 1999). The assumption is that anxiety results in peripheral narrowing or hypervigilance and increased susceptibility to task irrelevant information, thereby increasing search rate.

Although a search strategy involving more fixations of shorter duration may not always be detrimental to performance (see Williams et al., 1994), research suggests that movement related information (e.g., ball tracking, visual monitoring of effectors) is processed more effectively via peripheral rather than foveal vision (see Goodale & Milner, 1992; Milner & Goodale, 1995). This latter suggestion implies that the higher search rates employed as a function of anxiety in the current study represent an increase in information extraction via the fovea and, consequently, a decline in performance efficiency.

The reduction in mean performance score as a result of anxiety in the LWM task was somewhat unexpected. The initial prediction was that performance effectiveness would be maintained as anxiety increased in the LWM condition, provided that participants allocated additional resources or used different strategies. It may well be that even though participants became more anxious, they did not markedly increase their mental effort or alter their performance strategy in the task. Participants recorded comparable PRT and RSME values and oriented their gazepath and movements in a similar manner under both LA and HA in the LWM task. According to Eysenck (1982), participants may decide not to invest more effort on the task if they perceive a low probability of success. However, in the present study the participants reported reasonably high levels of self-confidence regardless of the anxiety condition. An alternative explanation may be that the current task imposed a heavier demand on working memory than expected and, as a consequence, the findings from the LWM task mirrored more closely than expected those of the HWM task. Regardless, the interaction between cognitive anxiety, self-confidence, and effort would appear to be a fruitful avenue for future research (cf. Woodman & Hardy, 2001).

The negative effect of anxiety on performance effectiveness in the HWM task was predicted (cf. Murray & Janelle, in press). It was expected that this change would be accompanied by a reduction in performance efficiency. Some tentative support for this hypothesis was provided by the trend toward more pronounced changes in PRT under high anxiety in the HWM task compared with the LWM task. Moreover, as predicted, reduced tau margins were reported under high anxiety in the HWM compared with the LWM task. The reduction and increased variation in tau margins at the initiation of movement suggests that anxiety had a more marked effect on perceptual rather than motor components of performance. Anxiety disrupts the functional coupling between perception and action by reducing one’s ability to pick up relevant optical information (cf. Bootsma et al., 1992).
In support of the latter suggestion, more marked changes in gaze behaviors were apparent in the HWM than in the LWM task. As participants became more anxious, they spent less time fixating on “other” areas of the display (22.1 vs. 33.0%) and more time tracking the ball using the fovea (45.1 vs. 30.8%). These changes in gaze behavior as a function of anxiety suggest that participants employed a different strategy as they became more anxious. The “other” category included fixations in the general vicinity of the ball’s flight path, but outside the 3° visual angle bandwidth used as a measure of ball tracking. The tendency was for participants to maintain focus either somewhere along the ball’s flight path or to fixate in advance the expected area of bat(ball contact).

Previous research has indicated that skilled players may prefer to track a ball in the periphery using the image/retina rather than the eye/head system (Gregory, 1968; Haywood, 1984). In the former approach the participant positions the eye centrally relative to the action, for example around the bat(ball contact region, so that the ball “washes” across the retina. The information required to guide the action is extracted from the ball’s flight path using the parafovea and periphery rather than purely via the fovea. In the latter approach, the performer attempts to maintain pursuit tracking of the ball using a combination of eye and head movements. Although research has not clearly demonstrated the superiority of either system for performance of interceptive tasks (see Ripoll, 1991; Singer, Williams, Frehlich, et al., 1998), it is presumed that their relative effectiveness is determined by ball velocity and dynamic visual acuity (Sanderson, 1981).

Previous research has shown that as performers become anxious, the ability to process information via peripheral vision decreases and one’s susceptibility to distraction by irrelevant cues increases (see Janelle et al., 1999; Williams & Elliott, 1999). It is possible that the ability to track the ball using the image/retina system may decrease with anxiety, resulting in a more significant role for the eye/head system and longer mean gaze duration on the ball. The changes in gaze behavior observed in the HWM task as participants become anxious may therefore be symptomatic of a decrease in performance efficiency. An alternative interpretation may be that anxious participants increase their efforts to track the ball foveally, perceiving that this strategy would improve performance in the task. In this instance, the increase in time spent viewing the ball would be more indicative of a change in the focus of attention rather than peripheral narrowing effects.

In sum, various predictions arising from Eysenck and Calvo’s (1992) processing efficiency theory were tested using novel tasks in a naturalistic performance setting. Two tasks, which differed in their relative demand on working-memory resources, were performed under conditions of low and high anxiety, respectively. It was expected that under high anxiety, performance effectiveness would be maintained in the low working-memory task, at the expense of a decrease in performance efficiency, while in the high working-memory task both efficiency and effectiveness would decline. These predictions were not fully supported by the present findings. Although some evidence was presented to suggest that the decrement in performance efficiency with anxiety was greater in the high compared to the low working-memory task, performance efficiency and effectiveness were reduced in both tasks, highlighting the negative effects of anxiety on performance. Further research is required to determine the complex interactions between anxiety, effort, and performance using ecologically valid sports tasks.
References


Yerkes, R.M., & Dodson, J.D. (1908). The relation of strength and stimulus to rapidity of habit formation. *Journal of Comparative and Neurological Psychology*, 18, 459-482.


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