



A Multidisciplinary Investigation of the Effects of Competitive State Anxiety on Serve Kinematics in Table Tennis

by

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Displays of anxiety in table tennis were assessed through subjective (a self-report questionnaire), physiological (heart-rate variability) and kinematic variables. Using a within-group crossover design, 9 university-level table tennis players completed a series of serves under low- and high-anxiety conditions. Anxiety manipulation was achieved through the introduction of a national standard table tennis player, known to the participants, to receive serves in the high-anxiety condition, whilst serves were received by no opponent in the low-anxiety condition. Automated motion capture systems consisting of high-speed 3D motion cameras and analytical software (QUALISYS) determined the subject's movement kinematics: bat face angle (degrees) and serve routine duration (s). Self-reported state anxiety (MRF-Likert) and heart rate measurements were collected to examine changes between conditions. Contrary to the hypothesis, bat face angles did not change significantly between anxiety conditions ($F(1,8) = 2.791, p = 0.133$) and movement times were faster in the high-anxiety condition. In light of these findings, research into other facets of movement behaviour must be analysed to gain further understanding of the effects of anxiety on performance, which remain unclear.

Key words: sports psychology, anxiety, athlete, racquet sports.

Introduction

One of the major tasks that athletes face in sport is dealing with pressure. Occasionally sport contests are decided by which team or player can cope better under pressure-inducing circumstances. Pressure is composed of "any factor or combination of factors that increases the importance of performing well on a particular occasion" (Baumeister, 1984). The acute inability to execute well-practised skills under pressure, otherwise known as choking (Baumeister and Showers, 1986), occurs frequently across all levels of competition, with anxiety understood to be a mediating factor (Kremer et al., 2012). Therefore, it is in the best interest of coaches and athletes to

understand the effects of anxiety on performance. Such effects have been examined extensively by sports researchers, coaches and performers (Krane, 1992). Numerous anxiety studies have evaluated changes to psychological, physiological and behavioural stress responses after the introduction of an experimental stimulus or anxiety inducer (Cooke et al., 2010; Pijpers et al., 2005; Tanaka and Sekiya, 2010). Understanding of how certain stressors can affect performance in sport could assist the development of effective strategies to perform optimally under pressure.

Psychological stress responses in sport have been shown to arise in the presence of four

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major pressure variables: audience presence, competition, performance-contingent rewards and punishments and ego-relevance of the task. Therefore, both state cognitive anxiety and state somatic anxiety tend to increase in the build-up to a competition (Martens et al., 1990). State cognitive anxiety relates to the acute fear of failure and negative thoughts which can result in the loss of self-confidence and concentration, whereas somatic states relate to the perception of any physiological symptoms of anxiety such as increased heart rates and blood pressure (Martens et al., 1990). Studies that have examined physiological changes have reported elevated heart rates (Wilson et al., 2007) and blood cortisol levels (Salvador et al., 2003) in driving and martial arts, respectively. In the motor driving study, the average heart rate of the drivers increased by 27.9 beats per minute from racing against the clock to racing an opponent.

Behavioural changes under pressure have been examined extensively over the past two decades. Research on this relationship lends primarily to two attentional theories that provide explanations for decrements in motor performance under pressure (Beilock and Carr, 2001). Firstly, distraction theories postulate that some stimuli (e.g. state anxiety) deter attention from task-relevant information towards task-irrelevant cues which leads to a decline in performance effectiveness (Wine, 1971). In other words, external distractions reduce the attentional capacity to perform a task, therefore, performance worsens. Secondly, self-focus theories propose that pressure induces self-awareness, leading to greater conscious control over the execution of a skill through explicit, step-by-step instruction (Baumeister, 1984; Masters, 1992). This process of recall is thought to 'deautomise' the execution of a well-rehearsed skill execution (Deikman, 1969). Furthermore, self-focus theories indicate that skills can regress to earlier stages of motor control, in the situation when the development of the skill has not been completed, under states of inward attention.

Numerous studies have tested attentional theories by testing subjects under different anxiety conditions (Beilock et al., 2010, 2011; Cooke et al., 2010; Pijpers et al., 2005; Tanaka and Sekiya, 2010; Williams et al., 2002). Within a sports setting, researchers have looked for any

differences in movement behaviour or performance when a pressure stimulus is added. One study compared arm kinematics in table tennis players to test PET using low and high working memory and anxiety conditions (Williams et al., 2002). In the low working memory (LWM) task, participants were required to return a simple serve towards one of three targets on the servers' side. In the high working memory (HWM) task, the players had to maintain a complex shot strategy that varied from trial to trial. Anxiety manipulation was achieved through a competitive ranking system in addition to a financial incentive of \$200 to the highest ranked player. Changes in gaze behaviour and poorer accuracy in the HWM task supported PET; however, there were no significant changes in the kinematic variables assessed (i.e. mean ball velocity, movement time, arm velocity at contact and peak arm velocity) between the conditions. The authors did not provide a possible explanation for their results; however, their experiment was based on a small sample size because kinematic measures were taken only in the first trial of each condition. This method was the first to assess movement behaviour under pressure using three-dimensional kinematic analysis. The use of three-dimensional analyses of sports movement has been well-supported, primarily, because it can measure rotational and translational movements which occur frequently in sport (Tanaka and Sekiya, 2010).

Self-focus theories provide an alternative explanation for changes in motor performance under pressure; Deikman (1969) noted that reinvesting actions with attention could lead to 'deautomisation' indicated by a regression to earlier stages of motor control (Masters and Maxwell, 2008). Reinvestment theory posits that anxiety influences the inward focus of attention under situations of high pressure. This inward attention disrupts the well-learned performance processes that usually run automatically, but instead become governed by conscious awareness (Beilock et al., 2004). Baumeister and Showers (1986) described this as a 'paradoxical performance effect' because despite deliberate efforts to improve task efficacy, reinvestment tended to elicit the reverse effect, i.e. of poorer performance.

Numerous researchers have tested self-

focus theories of suboptimal performance in proceduralised, complex sensorimotor tasks such as golf putting (Cooke et al., 2010, 2011), climbing (Pijpers et al., 2005) and soccer dribbling (Beilock et al., 2002) in tandem with reinvestment theory. Beilock and colleagues (2001, 2002) conducted a series of golf putting experiments to test explicit monitoring (conscious processing) theories of choking in novices and experts. Subscribing to the view that well-trained skills become proceduralised, expert players reported more detailed, explicit accounts compared to novices when asked to list the steps involved in putting. A continuation of this research found that skilled putters were less accurate when their attention was directed towards conscious control of the swing arm compared to when a task-irrelevant task (calling "tone" whenever a tone was played aloud) ran concurrently with the putting task (Beilock et al., 2002). Although these studies provide support for the reinvestment theory on a cognitive basis, the mechanistic determinants for decreased performance were not investigated. In light of this limitation, research into the manifestations of anxiety should implement a multidisciplinary approach (Beilock and Carr, 2001; Cooke et al., 2010).

Pijpers et al. (2005) assessed the impact of anxiety in novice climbers through physiological, subjective and kinematic measures. Two anxiety conditions were created using two identical climbing traverses at different heights from the ground. The physiological anxiety of the subjects increased when they climbed the higher wall as shown by elevated heart rates. Self-report scores of anxiety were taken using an anxiety thermometer and higher levels of anxiety were reported on the higher traverse. Furthermore, the movement behaviour analysis showed longer grasping of the holds and more explorative movements on the high traverse which contributed to slower climbing times (poorer performance). Slower movements in the high anxiety condition compared to the low anxiety condition conformed to the notion that anxiety could cause performance to revert from smooth execution to less fluent movements that mirrored that of a novice learner (Beilock and Carr, 2001).

In another multidisciplinary study, Cooke and colleagues (2010) conducted a mediation analysis of the psychological, physiological and

kinematic responses to pressure in golf putting to gain a causal understanding of the effects of anxiety on performance. This study showed that changes in movement kinematics partially mediated poorer putting performance (measured by the number of successful putts and mean radial error) under pressure. Lateral club head acceleration increased in the pressure conditions, implying that the club was swung out of line. However, a putter face angle (which accounts for 83% of ball direction (Pelz, 2000)) was not measured. Also, attributing the change in movement behaviour to conscious processing is questionable, considering that novice golfers completed the tasks, therefore, the scope for explicit monitoring would have been limited. The study was repeated (Cooke et al., 2011) with expert golfers and contrary to the novice golfers, more putts were made in the medium and high pressure conditions. The mediation analysis also conflicted with the Cooke et al.'s previous study, as changes in movement kinematics did not mediate poor putting accuracy under pressure.

In golfing terms, the 'yips' largely resembles the choking phenomenon experienced in other sports, but its definition specifically refers to the involuntary and uncontrollable jerking of the hand or wrist (Marquardt, 2009). Altered club kinematics, namely the face angle at impact, was shown to impair putting performance in golfers predisposed with the yips (Marquardt, 2009; Klampfl et al., 2013). Marquardt (2009) also found that downswing duration was slower in the putts by participants that were affected (by yips) compared to unaffected individuals; and anxious players demonstrated greater variability in time to impact. This result supports the findings of slower whole-body movement execution under anxiety in Pijpers et al.' (2005) climbing experiments. Tanaka and Sekiya's (2010) three-dimensional kinematic analysis of novice golfers indicated that when putting in the pressure condition, angular displacement of rotational movements and movement times decreased. However, the acceleration of movement during the swing was faster, suggesting that pressure may have caused more cautious, yet jerky movements in the participants. The finding that movement variability was associated with poorer putting performance during the pressure condition also supports the conscious processing hypothesis.

Accordingly, this study investigated the effects of anxiety on the movement kinematics in a sensorimotor task (a table tennis serve) to add to our current understanding of the underlying mechanisms that govern the anxiety-performance relationship. As with golf putting, table tennis serves require coordination of the playing hand and wrist in order to produce the desired bat angle at impact as this largely influences both the amount and type of spin on the ball. The study measured bat kinematics following two pressure tests. Based on previous findings, it was expected that the bat angle would change between the conditions. It was also predicted that slower serve routine duration and increased variability of time to ball impact would appear in the high anxiety condition.

Material and Methods

Participants

A purposive sample of 9 male university-level table tennis players (mean age 23.4 ± 5.9 years) took part in the study. The participants had a minimum of 2 years playing experience and were currently playing competitive table tennis in the local divisions. Informed consent was given by all participants and ethical approval was granted by the relevant institutional ethics committee (Institute for Sport, Exercise and Health Sciences, University of Edinburgh, Scotland, UK).

Experimental design

A within-group crossover design was used and the participants were randomly assigned to low and high anxiety conditions. Figure 1 shows a schematic representation of the experimental design for both anxiety conditions. Prior to testing, the participants were asked to select a serve which they would be able to repeat throughout the experiment in both low and high anxiety conditions. In the low anxiety condition, participants were asked to play five identical serves unopposed. For the high anxiety condition, a nationally ranked player, known to the participants, was introduced to the table and the participants were instructed to serve five times and proceed to play the point against the opposite player. The independent variables were low and high anxiety. The dependent variables measured were a bat face angle (degrees), serve routine duration (s), heart rate (bpm) and MRF-Likert

scores (cognitive and somatic scores).

Instruments/Measures

Self-report anxiety

The Mental Readiness Form-Likert (MRF-Likert; Krane, 1994) was implemented to measure state anxiety on 3 bipolar scales corresponding to cognitive anxiety, somatic anxiety and self-confidence. Respondents completed the questionnaire by circling a number that accurately reflected how they felt on an 11-point Likert-type scale. Good concurrent validity was reported between the MRF-Likert items and Competitive State Anxiety Inventory-2 (CSAI-2) subscales ($r = 0.74$; $p < 0.01$; Krane, 1994).

Heart rate

The heart rate was monitored using a Polar Team 2 system (Polar Team2 System, Kempele, Finland) consisting of a heart rate transmitter fixed around the subjects' torso. HR samples were collected over a twenty second period from the first reading, during which time the participants completed the MRF-L.

Movement kinematics

An array of nine infrared high speed cameras (frame rate 200 Hz) combined with QUALISYS Motion Capture Software was used to determine the bat 3D kinematics and service routine duration for the participants. Following standard system calibration procedures, three 12 mm reflective markers were attached to the edge of the subject's own table tennis bats. The movements of the markers were detected by QUALISYS Motion Capture Software and then Visual 3D software was used to determine the bat face angle (in three axes: X, Y and Z) at ball contact. Figure 2 depicts the global and local coordinate systems. Serve routine duration (s) was measured by frame analysis of the serve; each serve routine was standardised to represent the first movement of the bat to ball impact. Time accuracy, limited to the frame rate of the QUALISYS cameras, remained within 1/200 s.

Table tennis materials

Participants completed all serving tasks on an official ITTF approved (Victor Barna) table tennis table using their own bat and 40 mm Butterfly Match balls, which were covered in retro-reflective tape for detection by the cameras. The 'anxiety-inducing' player used in the high-anxiety condition (HAC) was instructed to wear sponsored national table tennis uniform when

facing the participants.

Procedures

Upon arrival, subjects were briefed on either the low-anxiety condition (LAC) or the HAC. Thus, the participants were informed that they would perform five identical serves of their choice to either no opponent (LAC) or a national team member (HAC) where the competitive point would be played. After this brief introduction, markers were placed on the participants' bat.

Then subjects performed a standardized warm-up as before competition (with no presence of the experienced player), which consisted of basic forehand and backhand rallies. **In addition to familiarising themselves** with the experimental conditions, the warm-up was also aimed at replicating a match situation. Following the warm-up, a heart rate monitor was attached and participants proceeded to the serving task in either the HAC or LAC. In the LAC, participants completed the MRF-L and were recorded playing five identical serves received by no opponent. The anxiety-inducer (AI) used in the HAC was instructed to try to win each point against serves from the participants. In the HAC, the AI was introduced to the participant who then completed the MRF-L. This was followed by five serves which were received by the AI and points were competed until the ball was out of play. Participants were given five minutes to rest and lower their heart rates between the following conditions.

Statistical analysis

Physiological arousal (heart rate data) was tested using a one-tailed paired *t* test. Self-reported anxiety scores (cognitive and somatic anxiety types; MRF-L) were analysed using a 2 × 2 repeated measures ANOVA (anxiety type vs condition). Mean bat face angles, given in 3 axes (X, Y and Z), were tested using a 3 × 2 repeated measure ANOVA (axis vs condition). Serve duration variability was assessed by comparing the standard deviations of the serves using a one-tailed paired *t* test. Effect sizes of within-subject effects were calculated as an estimation of the meaningfulness of the difference between means and standard deviations in conjunction with Cohen's (1988) levels. The data from the cognitive MRF-L scores in the LAC failed to comply with one normality assumption as statistical significance from the Shapiro-Wilk test of

normality was not reached ($p = 0.009$). This was also the case for bat angles in the Y-axis under the high anxiety condition ($p = 0.043$).

Results

Manipulation check

Self-reported state anxiety

Since the present study focused on the effects of state anxiety on kinematic behaviour, item 3 scores assessing self-confidence were removed from the analysis. ANOVA results revealed significant main effects for test conditions ($F(1,8) = 13.913$, $p = 0.006$, $\gamma = 0.8$), indicating that anxiety manipulation was successful on a subjective basis. There was also a significant main effect for the anxiety type (cognitive or somatic anxiety; $F(1,8) = 6.897$, $p = 0.030$, $\gamma = 0.7$). The MRF-L ratings for cognitive and somatic anxiety are presented in Figure 3. Statistical analyses show that both the test conditions and anxiety types correspond to large and medium effect sizes, respectively (Cohen, 1988).

The mean heart rate (bpm) was significantly higher in the HAC ($M = 132.22 \pm 45.66$ bpm) compared to the LAC ($M = 106.78 \pm 38.10$ bpm), $t(8) = 3.637$, $p = 0.004$, $\gamma = 0.6$. An increased heart rate in the HAC signifies that anxiety manipulation was successful on a physiological basis. Mean heart rates between anxiety conditions are shown in Figure 4.

Kinematic measures

Bat face angle at ball impact

Table 1 displays descriptive statistics of the movement kinematics. ANOVA results showed that the bat face angle (deg) did not change significantly between anxiety conditions ($F(1,8) = 2.791$, $p = 0.133$, $\gamma = 0.5$). There was no interaction effect found between condition and axis of measured angles (x, y or z; $F(1,8) = 2.352$, $p = 0.127$, $\gamma = 0.5$). The bat face angles at impact in the x, y and z axes of two anxiety conditions for one participant are presented in Figure 5.

Serve routine duration

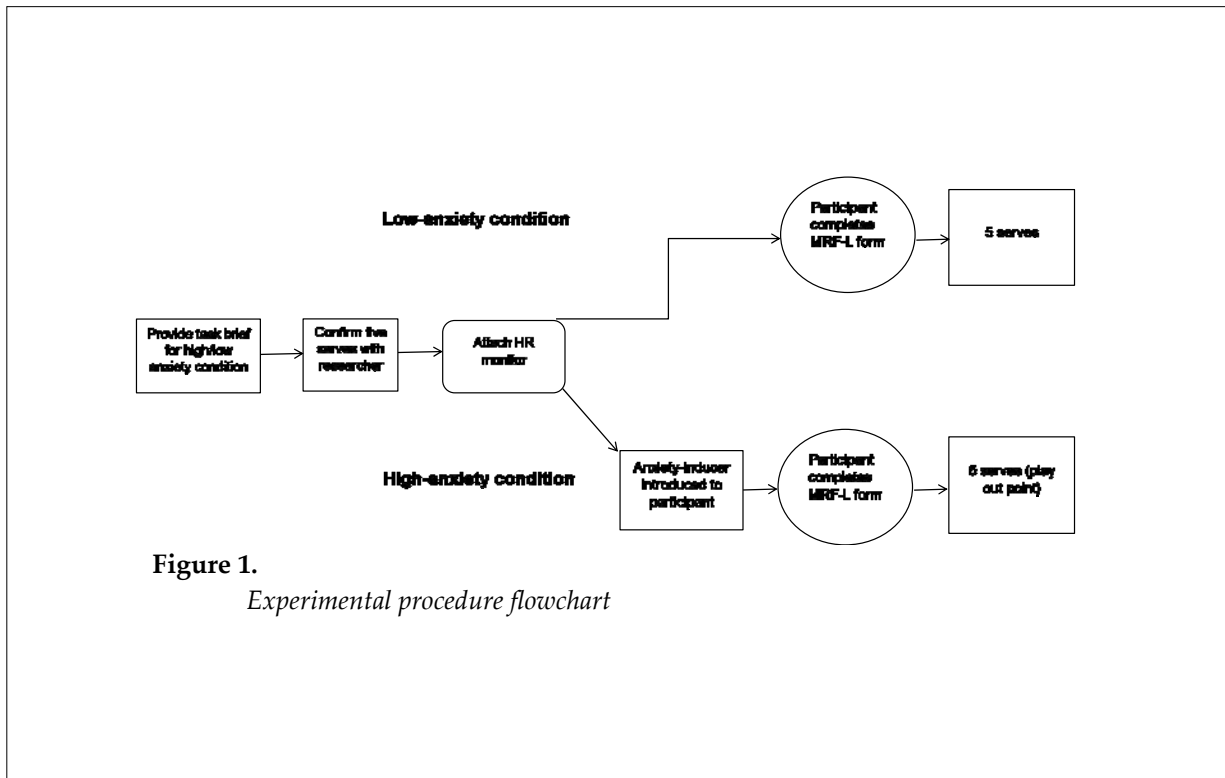
Due to a technical error, one serve in the low anxiety condition was removed from the data analysis. Mean service duration (Table 1) was significantly longer ($t(8) = 2.345$, $p = 0.05$, $\gamma = 0.4$) in the LAC ($M = 0.768 \pm 0.214$ s) compared to the HAC ($M = 0.699 \pm 0.159$ s). Trial to trial variability between anxiety conditions was greater in the

LAC ($M = 0.102 \pm 0.073$ s) compared to the HAC ($M = 0.066 \pm 0.050$ s), although the t test revealed

no significant difference between the two conditions ($t(8) = 1.445, p = 0.186, \gamma = 0.5$).

Table 1
Descriptive statistics of movement kinematics

Subject	A	B	C	D	E	F	G	H	I
Mean bat angle at impact (x-axis)									
LAC	-98.14	45.95	-85.98	13.34	-13.91	4.72	-39.05	76.09	-20.17
HAC	-93.99	45.79	-41.34	12.17	-08.95	5.55	-17.00	71.75	-26.42
Mean bat angle at impact (y-axis)									
LAC	-65.73	55.98	-48.25	-16.90	-34.54	-11.18	-31.07	56.60	-28.95
HAC	-60.87	58.18	-38.17	-14.98	-26.42	-14.42	-32.95	54.09	-28.59
Mean bat angle at impact (z-axis)									
LAC	-133.75	-27.46	-134.29	-12.00	-31.28	-47.97	-68.78	-42.54	-57.26
HAC	-119.78	-17.35	-68.90	-07.47	-25.28	-53.44	-58.90	-36.64	-58.07
Serve routine duration (s)									
LAC									
Mean	0.758	0.891	0.757	0.659	0.437	1.089	0.880	0.596	0.864
SD	0.147	0.265	0.097	0.028	0.091	0.096	0.040	0.034	0.115
HAC									
Mean	0.693	0.617	0.756	0.632	0.419	0.951	0.777	0.649	0.796
SD	0.082	0.078	0.121	0.037	0.045	0.162	0.017	.029	0.021



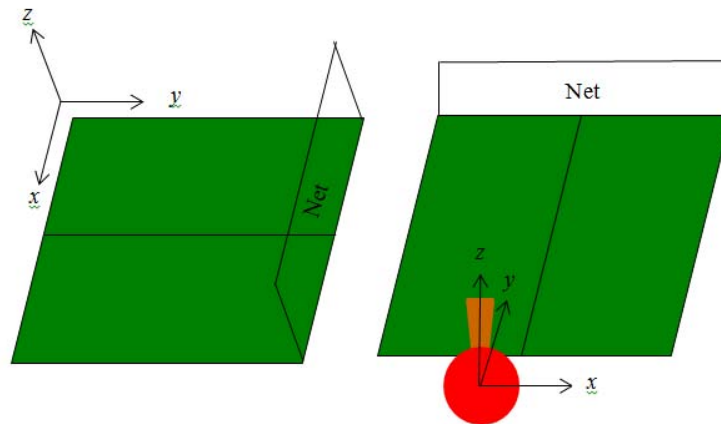


Figure 2a.
Global co-ordinate system (on the participants' side of the table)

Figure 2b.
Local co-ordinate system (on the participants' side of the table)

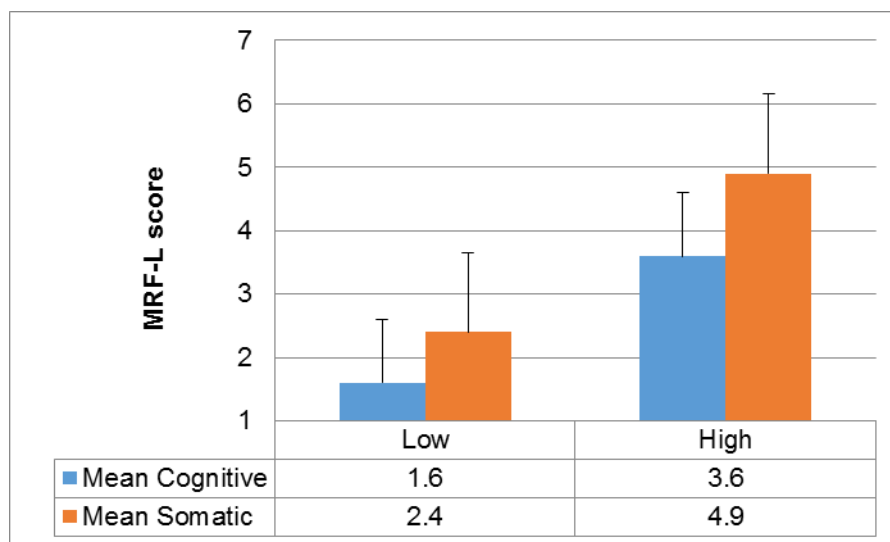


Figure 3.
MRF-Likert mean scores in LAC/HAC. Physiological anxiety (heart rate)

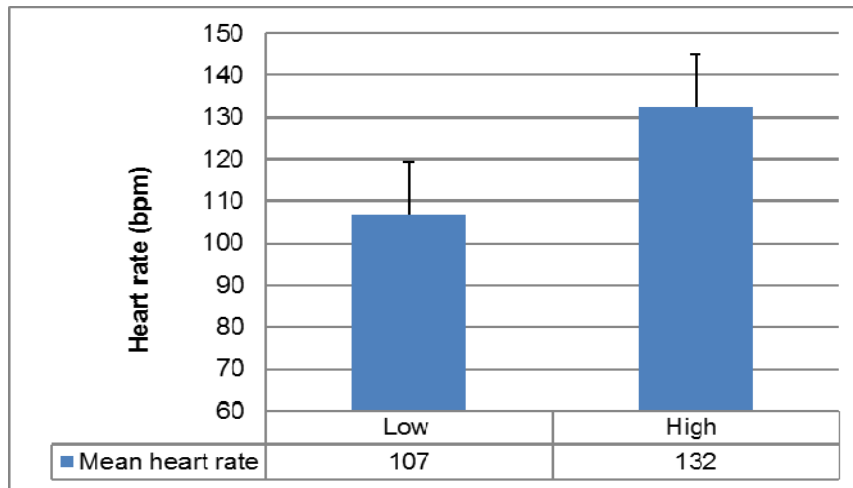


Figure 4.
Mean heart rate in LAC/HAC

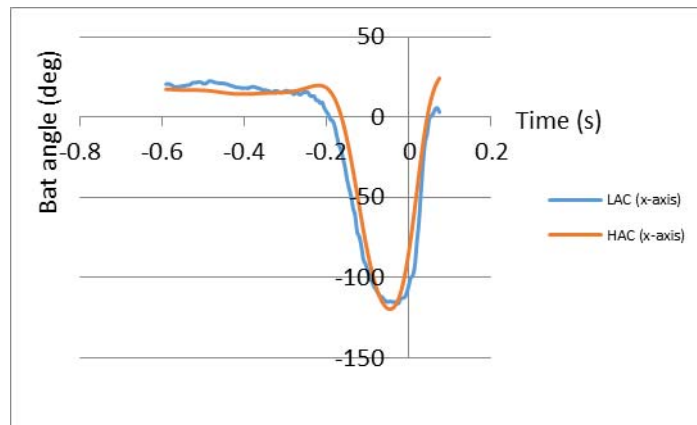


Figure 5a.
Subject A bat angles (x-axis) in low and high anxiety conditions.
Ball impact when $t = 0$

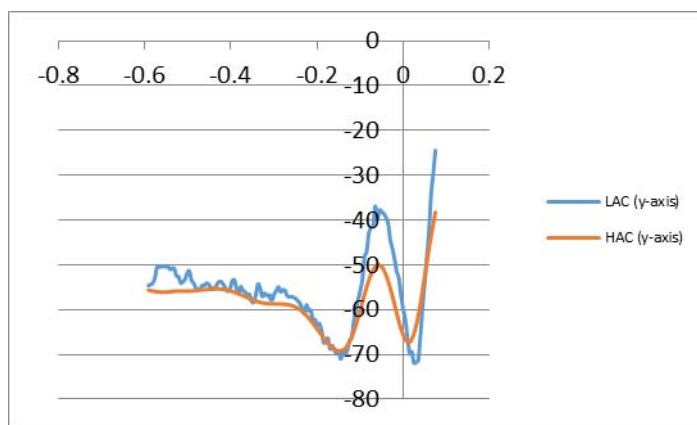


Figure 5b.
Subject A bat angles (y-axis) in low and high anxiety conditions.
Ball impact when $t = 0$

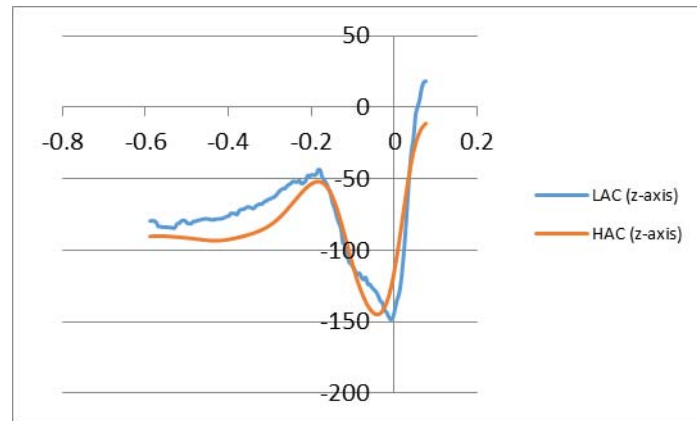


Figure 5c.

*Subject A bat angles (z-axis) in low and high anxiety conditions.
Ball impact when $t = 0$*

Discussion

An explanation for the changes in performance under pressure has eluded researchers over the last two decades. The purpose of this study was to examine the anxiety-related movement behaviours within a sporting setting to develop a mechanistic understanding of the anxiety-performance relationship using psychological, physiological and kinematic variables.

Manipulation check

Self-report anxiety

The results from the MRF-L show that anxiety manipulation was successful on a subjective level. Cognitive and somatic subscales of anxiety were significantly higher in the HAC. From a cognitive aspect, this finding supports Wilson et al.'s (2007) research on golfers who had either low or high trait anxiety. Regardless of trait anxiety, participants reported greater levels of cognitive anxiety in the high pressure condition where anxiety was raised through ego-threatening instructions and a cash prize. Participants in the present study reported greater effects of somatic anxiety when completing the MRF-L. Somatic anxiety is most likely to peak at the onset of a competition (Martens et al., 1990), whereas cognitive anxiety is more likely to be experienced during the performance where greater attentional focus to the task is present. As subjects completed the MRF-L just prior to the experimental task, higher levels of somatic anxiety were not a surprising result. The present

study provides further support for the use of the MRF-L as an expedient alternative to the CSAI-2 (Martens et al., 1990).

Heart rate

It was predicted that participants would experience increased physiological arousal under competitive pressure. The heart rate was significantly higher in the HAC as expected, providing further support for the success of anxiety manipulation. Higher heart rates under high anxiety conditions had also been reported in climbing (Pijpers et al., 2005) and golf putting (Beilock and Carr, 2002; Cooke et al., 2010). Mean heart rate values of 174 ± 8 bpm were reported in table tennis players during competition (Docherty, 1982), what corresponds to the values in the present study.

Kinematic measures

Bat face angle

Contrary to the hypothesis, bat angles at ball impact did not change between high and low anxiety conditions as shown by the traces in Figure 5. In three axes, the participant's bats followed a similar pattern and the face angles were consistent throughout the service motions. These results conflict with changes in movement kinematics found in golf putting anxiety (Cooke et al., 2010; Marquardt, 2009; Maxwell et al., 2003). However Mullen and Hardy's (2000) two-dimensional kinematic analysis showed no changes in club and arm movements under pressure. In a high working memory table tennis task, Williams et al. (2002) reported changes in

visual search behaviours, but not movement kinematics. Perhaps the increased variability of the face angles in golf compared to table tennis could relate to the contrasting distance between the hand(s) and the contact point on the putter or the bat.

Movement kinematics

Movement kinematics in table tennis were compared between implicit and explicit learners under conditions that required either concurrently low-complexity or concurrently high-complexity decisions (Masters and Maxwell, 2008). Implicit learners showed no movement changes between the low and high complexity tasks compared to explicit learners who demonstrated greater trial-to-trial variability and slower movements in the complex decision-making task. The authors concluded that implicitly learned skills stabilised cognitive motor control in conditions where a complex decision and motor action must be executed simultaneously. The experimental task in the present study was void of any decision-making during the serves, as they were pre-determined and repeated in all trials; given the playing experience of the participants, it could be assumed their serves had become implicitly learned and were repeatable in the high anxiety condition, resulting in no change in the bat angle. Future movement behaviour research into table tennis should therefore focus on open, rather than closed motor performances where there is a decisional component that may disrupt the cognitive processes (e.g. target accuracy during a point). Further analysis of other kinematic variables that were not measured in the present study such as bat angular velocity, the ball path and bat accelerations may also provide important insight into any movement-related changes under pressure.

Serve routine duration

It was expected that changes in movement timing, reflected by slower serve routines and greater trial-to-trial variability would be present in the high anxiety condition. Unexpectedly, participants' serve routines were slower and more variable in the low anxiety condition. Low variations in serve duration may reflect the procedural nature of table tennis serves in the participants and that anxiety simply did not affect the movement of the bat during serves. It could also be considered that in the low pressure

situation, the players simply took more time to complete the serve routine knowing that there was no point to be played. The results are comparable to Williams et al.'s (2002) table tennis study testing PET, which reported faster movement times in the high anxiety condition of a high working memory task compared to the low anxiety condition. Nieuwenhuys and Oudejans (2010) found that police officers' movements with a gun were faster when they were opposed by a threatening opponent. This finding supports the results of the present study as movement times reduced significantly in the HAC when participants were faced with an opponent with much greater expertise in the sport and could therefore be deemed as threatening.

Study limitations

One of the major limitations of the present study is the absence of an outcome measure for the participant's serves. This is primarily due to the practical adjustments made to assess bat kinematics exactly at the point of impact. The only feasible method to do this was to cover the ball in retroreflective tape for detection by the infrared cameras. Ecological validity was negatively impacted as the tape dramatically changed the playing characteristics of the ball and it was deemed that subsequent ball trajectories and velocities would not provide comparable results with other research; however, the bat kinematics at ball impact (i.e. bat angle) would not change significantly. Future research should incorporate an outcome measure such as target accuracy (Williams et al., 2002) to gain an understanding of the facilitative or debilitating effects of anxiety on performance effectiveness.

Eysenck and Calvo (1992) proposed that conscious attempts to change performance only occurred if there was a reasonable chance of success. The introduction of a nationally ranked player to face the relatively incompetent players in the present study may have ensued lack of effort in the high anxiety condition. Mediating factors of choking such as the presence of audience, performance-contingent rewards or threats to ego could be used in future studies to create a more realistic competitive environment. To develop a causal understanding of such mediating factors, researchers should consider a mediation analysis, as conducted by Cooke et al. (2010, 2011).

Lastly, some of the reported data failed to reach normality assumptions and this reduces the validity of the current findings. This could be attributable to the small sample used. An extension of this research should consider increasing the sample by including novice players to compare the movement behaviours between skilled and non-skilled task execution under stress condition. Beilock et al. (2004) and Cooke et al. (2010, 2011) reported opposite findings in putting movement times and movement kinematics, respectively.

Conclusions

The underlying mechanisms of the performance-anxiety relationship still remain

inconclusive in the scientific literature. This study proposed that anxiety, induced through the introduction of an expert table tennis player, would induce anxiety in the intermediate participants and this would elicit a change in bat kinematics and movement times. Although anxiety manipulation was successful on a physiological and self-reported basis, no changes in bat kinematics were found between high and low levels of anxiety. Future research should strive to analyse other kinematic aspects of table tennis performance within a realistic competitive environment to gain a wider understanding of the manifestations of anxiety in movement behaviour.

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