The effect badminton specific exercise on badminton serve performance in competition and practice climates

Michael J. Duncan, Cheryl K.Y. Chan, Neil D. Clarke, Martin Cox and Mike Smith

Coventry University, UK

Address for correspondence: Michael J. Duncan, School of Life Sciences, Coventry University, James Starley Building, Priory Street, Coventry, UK, CV 5HB. E-mail: michael.duncan@coventry.ac.uk

ABSTRACT

This study examined the effects of changes in physiological and psychological arousal on badminton short and long serve performance in competitive and practice climates. Twenty competitive badminton players (10 males, 10 females) volunteered to participate in the study following ethics approval. After familiarisation, Badminton short serve performance was measured at rest, mid-way through and at the end of a badminton specific exercise protocol in 2 conditions; competition vs practice. Ratings of cognitive and somatic anxiety were assessed at three time points, prior to badminton short serve performance using the Mental Readiness Form 3 (MRF3). Heart Rate (HR) and Rating of Perceived Exertion (RPE) were assessed during the exercise protocol. Results indicated better short serve performance was evident in practice compared to competition ($P = 0.034$). There was a non-significant trend for long serve performance towards better performance in practice compared to competition ($P = 0.066$). RPE values were significantly higher in the competition condition compared to practice ($P = 0.007$). Cognitive anxiety intensity was significantly lower post exercise in the practice condition compared to competition ($P = 0.001$). Cognitive anxiety direction showed greater debilitation post exercise in the competition condition compared to practice ($P = 0.01$). Somatic anxiety intensity increased from pre, to mid to post exercise ($P= 0.001$) irrespective of condition. This study suggests that badminton serve performance is negatively affected when physiological arousal, via badminton specific exercise, and cognitive anxiety, via perceived competition, are high.

INTRODUCTION

It has been suggested that exercise intensity acts as a physiological (Audiffren, 2009; Duncan, Smith, & Lyons, 2012), cognitive (McMorris, Sproule, Turner, & Hale, 2011) and psychomotor (Lyons, Al-Nakeeb, & Nevill, 2008) stressor leading to an inverted-U relationship between exercise intensity and associated performance. Research by Duncan et al. (2016) built on this suggestion and reported that cognitive performance was significantly poorer when exercise intensity was high (90% heart rate reserve) in a laboratory based competitive situation compared to a practice situation. The authors concluded that cognitive performance is most debilitated when physiological arousal is high (via exercise intensity) and cognitive anxiety is high (via competition state), supporting the proposal of the catastrophe model (Fazey, and Hardy, 1988). Examining the effect of physical exercise on cognitive and perceptual-motor function is now new and has been well studied from the beginning of the 20th Century (Brisswalter, Collardeau, & Rene, 2002; McMorris, et al., 2015). However, the findings of experimental research in this area have been contradictory. One of the reasons for this has been timing of performance task administration in comparison to the exercise bout undertaken. Brisswalter, et al. (2002) suggested that when the performance task is undertaken during exercise, rather than afterwards, consistent results are shown demonstrating declines in task performance with increasing exercise intensity. Similar criticisms could be levelled at those studies that have tested the aforementioned catastrophe model where measures of anxiety have been taken pre-event using a time to event paradigm (Hardy, Beattie, & Woodman, 2007; Hardy, Parfitt, & Pates, 1994; Krane, Joyce, & Rafeld, 1994).

A more representative way to examine the effects of changes in physiological arousal and cognitive anxiety on performance is to measure in situ as it acknowledges that physiological arousal and cognitive anxiety are dynamic and influence each other. Additionally, in many sports situations, visual, cognitive and motor performance is undertaken in conditions where cognitive anxiety is higher (via competition) and physiological arousal is higher (via exercise intensity) and both act at the same time that performance is required. Indeed, Pinder, Davids, Renshaw, & Araújo (2011) have suggested that ecological representative designs may be better placed to train athletes as a means to enhance action fidelity (Araújo, Davids, & Passos, 2007). In basic terms, there is a need for scientists to replicate the demands of performance when examining the effect of any intervention on performance variables. In such situations, the use of competitive situations as simulated competition settings has been shown to impact on cardiovascular reactivity and motor skill performance differently to practice (Turner, Jones, Sheffield, & Cross, 2012; Turner, Jones, Sheffield, Barker, & Coffee, 2014). There is however a need to better understand how competition influences skilled performance in circumstances where there is relevant physiological load as, within many sport and exercise domains, skilled performance is not undertaken in the absence of physiological load. For example, successful performance in racquet sports, such as badminton, requires players to accelerate, decelerate, change direction, move quickly and maintain balance, (Girard & Millet, 2008) whilst at the same time performers must also repeatedly demonstrate skilled performance via optimum stroke production (Girard & Millet, 2008). Consequently, such situations provide a useful vehicle to investigate how combined physiological and psychological load may impact skilled performance. The badminton serve has also been used by multiple studies to assess skilled performance which can be controlled and assessed in between bouts of exercise that mimic the physiological load experienced during game play (Clarke, and Duncan, 2016; Jeon, Kim, Ali, & Choi, 2014; Tzetzis, and Votsis, 2006). In order to enhance understanding in the field this study examined the effects of changes in physiological and psychological arousal on badminton long and short serve performance in competitive and practice climates.

METHODS

Participants

Following institutional ethics approval and informed consent, 20 physically competitive badminton players (10 males, 10 females) participated in this study. Mean ± s of age was 19.4 ± 1.7, and 20.0 ± 2 years for males and females respectively. Mean ± s of years spent training for badminton specifically and time spent per week in badminton specific training was 7.0 ± 2.8 years and 7.5 ± 3.6 years and 4.9 ± 2.9 hours and 3.5 ± 2.8 hours for males and females respectively. A priori power calculations indicated a sample of 20 participants was needed with an effect size of 0.25 and alpha level of 0.05 at 80% power. Participants were excluded if they had a musculoskeletal or cardiovascular contraindication to exercise, were taking any medication that could impact on mood/affect or were not currently playing competitive badminton at BUCS (British University) standard or above. All participants in the current study were currently engaged in national level University badminton competition and playing in League 1/2 of the British University sport system, equivalent to competitive club standard in the United Kingdom.

Design

This study employed a within-participants, counter-balanced design whereby participants engaged in a familiarisation session and two experimental conditions. Experimental conditions were counterbalanced and performed at the same time of day with participants in a well-rested and well hydrated state. All participants were asked to refrain from vigorous exercise and maintain normal dietary patterns in the 48 hours prior to testing and were asked not to consume caffeine for 24 hours before testing. During the first visit, participants completed a familiarization session where the monitoring procedures, badminton specific protocol and badminton short serve tests to be used in the subsequent experimental trials were explained to participants.

Experimental Trials

On completion of the baseline session, participants then undertook two badminton specific exercise trials presented in a counterbalanced order. One trial comprised a perceived competitive situation and the other trial a perceived practice situation. In both trials participants completed measures of badminton short serve skill performance and ratings of cognitive anxiety and somatic anxiety at rest and immediately on completion of the badminton specific exercise protocol.

Practice and Competition Conditions

The creation of a practice or competitive performance climate was employed to manipulate cognitive anxiety across the trials. This was achieved using standardised instructions lasting approximately 1-minute before the start of each experimental trial. This methodology has been used in prior research as a stressor to elicit increases in cognitive anxiety (Duncan, et al., 2016; Turner, et al., 2012; Barker, Jones, & Greenlees, 2010; Hardy, Parfitt, & Pates, 1994). The statements comprised of demand appraisals which informed participants that their badminton short serve test scores indicated the level of their badminton ability. In the case of competitive trials, the participants were told their scores would be compared to all other participants and publically posted in ranking order, and that they would need to try very hard to perform well. Participants were then asked to sit for five minutes before the trial began. This was considered as the high cognitive anxiety trial, in line with prior research (Barker, et al., 2010). In the practice trial participants were informed that their scores would only be used to examine the consistency of their own performance and would not be used further and that the other (competitive) trials were considered as more important. This was considered as the low cognitive anxiety trial, in line with prior research (Barker, et al., 2010).

Badminton Specific Exercise Protocol

In both experimental trials participants undertook the badminton specific exercise protocol, replicating the time of a badminton match, developed by Bottoms et al. (2012). The protocol comprises a series of circuits with each circuit involving 1 min of intense ghosting to allocated targets on the badminton court (2 in the forecourt, 2 mid court, 2 rear court) with directions given by the investigator, an adapted agility course followed by 3 min of active recovery (walking at 5.0 $km \cdot h^{-1}$) (See Appendix I). In the current study, to allow for mid-point analysis of badminton short serve performance 6 circuits were performed by each participant in each condition.

Performance Measures

Badminton Performance

All participants in the present study completed tests of badminton short and long serve accuracy as a measure of skilled performance. The Edwards et al. (2005) badminton service test, consisting of 10 short and 10 long serves towards a target (50 x 50cm) positioned in the far left corner behind the net was employed, with the number of successful hits being recorded and used as a measure of service performance, as has been used in prior studies (Clarke and Duncan, 2016, Bottoms et al., 2012).

Heart Rate, Rating of Perceived Exertion and Blood Lactate

Prior to the inducement of competition and practice climates participants were fitted with a Polar RS400 heart rate monitor (Polar OY, Kuopio, Finland) and were asked to sit for three minutes, at which point baseline heart rate (HR) was determined. Standardised instructions were then read to each participant to induce competitive or practice states. HR was then taken five minutes post instructions. The Borg 6-20 rating of perceived exertion (RPE) scale was also used as a measure of exercise exertion during experimental trials (Borg, 1970). HR was monitored throughout each experimental trial and was recorded at 6 points during the protocol (at the end of each circuit of the protocol). RPE scores were also assessed at the same points. Blood lactate (mmol/l) was also determined 3 minutes after completion of the badminton specific exercise trials via a capillary blood sample taken from the fingertip (Lactate Pro, Arkray Inc, Japan).

Cognitive Anxiety and Somatic Anxiety

Cognitive anxiety and somatic anxiety were measured at rest, mid-point and on completion of the badminton specific exercise protocol by using a moderated version of the Mental Readiness Form 3 (MRF-3) (Krane, 1994). In all cases the measures were taken immediately prior to execution of the badminton short serve tests. The original MRF-3 has two, bipolar; 11-point Likert scales that are anchored between *worried-not worried* for the cognitive anxiety scale, *tense-not tense* for the somatic anxiety scale which is a shorter and more expedient alternative to the 27 questions of the Competitive State Anxiety Inventory-2 (CSAI-2) (Martins, Burton, Vealey, Bump, & Smith, 1990). Correlations between the original MRF-3 and the CSAI-2 subscales of .76 for cognitive anxiety, .69 and for somatic anxiety have been reported (Krane, 1994). Consequently, The current study, included a directional scale to the original MRF-3 similar to that of the CSAI-2 congruent with research suggesting the directional scale is the most important scale when reporting athlete's perceptions of whether cognitive and somatic symptoms are facilitative or debilitative to performance (Jones, and Hanton, 1996). Each participant was asked to rate the perceived intensity of their cognitive and somatic anxiety and whether these symptoms were either facilitative or debilitative to subsequent performance. The scale ranged from -3 (very debilitative) to +3 (very facilitative), with the midpoint of 0 representing 'unimportant'. Internal reliability coefficients of this scale were reported by Jones and Swain (Jones, and Swain, 1992) as 0.83 for cognitive anxiety and 0.72 for somatic anxiety.

Cortisol

A saliva sample (minimum 0.5 ml, passive drool) were provided for each condition prior to standardised instructions being read to participants and then post exercise. This process was employed so post exercise saliva collection corresponded to 35 min post-delivery of competition/practice instructions. This time window has been suggested as optimal for determining any change in cortisol as a consequence of behavioural intervention (VanBruggen, Hackney, McMurray, & Ondrak, 2011), due to the delayed cortisol response in saliva compared to blood (Umeda, Hiramatsu, Iwaoka, Shimada, Miura, & Sato, 1981). This procedure was used to examine the effect of the condition (practice vs. competition) on the 'stress' response. Collected saliva samples were transferred into cryo-freeze tubes and stored at –80°C for later analysis. Cortisol levels were measured using an expanded range high sensitivity enzyme immunoassay kit (Salimetrics, State College, PA, USA). All saliva specimens were assayed in duplicate and coefficients of variation for within-between assay determinations of 10% or less were required (Hackney, and Viru, 2008).

Statistical Analysis

Results are expressed as mean and standard deviation (s). Any changes in badminton short serve performance, long serve performance, cognitive anxiety intensity and direction and somatic anxiety intensity and direction were examined using a 3(pre, mid, post) x 2 (practice vs. competition) X 2 (gender) ways repeated measures analysis of variance (ANOVA). Although MRF data is non-parametric in nature there is no non-parametric equivalent to examine any differences in repeated measures data across time and, at the same time, between different conditions. MRF data was also near normal in terms of distribution and parametric statistics have been previously shown to be robust when analysing MRF data in prior studies (e.g., Wilson, Wood, & Vine, 2009; Vine, Moore, & Wilson, 2011). Recognising this, a series of Freidman's ANOVAs were also conducted to verify the findings from the 3 X 2 ways repeated measures ANOVA. HR reactivity was assessed using a paired samples t-test with the change in HR pre to post instructions in practice and competition conditions as the dependant variables. Any changes in HR and RPE during the exercise were examined using a 2 (practice vs. competition) X 6 (time point) X 2 (gender) ways repeated measures ANOVA. Where significant differences were found, Bonferroni post-hoc pairwise comparisons were used to determine where the differences lay. Backwards elimination to achieve a parsimonious solution was employed in all analysis. Partial eta squared ($P\eta^2$) was also used as a measure of effect size. As blood lactate values were only assessed post exercise in each trial, a paired samples t-test was used to examine any differences in post-exercise blood lactate concentration between conditions. The Statistical Package for Social Sciences (SPSS, Version 20, Chicago, Il, USA) was used for all analysis and statistical significance was set, a priori, at $p < 0.05$.

RESULTS

In all cases gender was not significant as a between subjects factor (all $P>0.05$) and is therefore not reported further.

Badminton Performance

For short serve performance there were no significant higher order interactions and no main effect due to time (pre, mid, post), (all $P>0.05$). There was a significant condition main effect ($P = 0.034$, $P\eta^2 = 0.226$) where better short serve performance was evident in practice compared to competition (See Figure 1). For long serve performance there were no significant higher order interactions and no main effect due to time (pre, mid, post), (all $P>0.05$). The main effect was also not significant but did show a trend towards an effect ($P = 0.066$, $P\eta^2 = 0.176$) where better long serve performance was evident in practice compared to competition (See Figure 2).

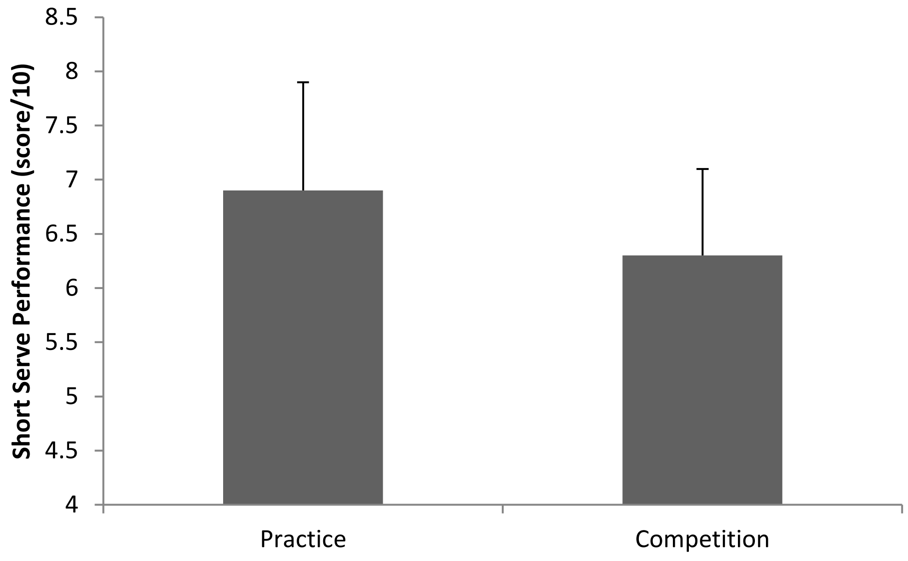


Figure 1. Mean ± SD of badminton short serve performance in practice and competition conditions

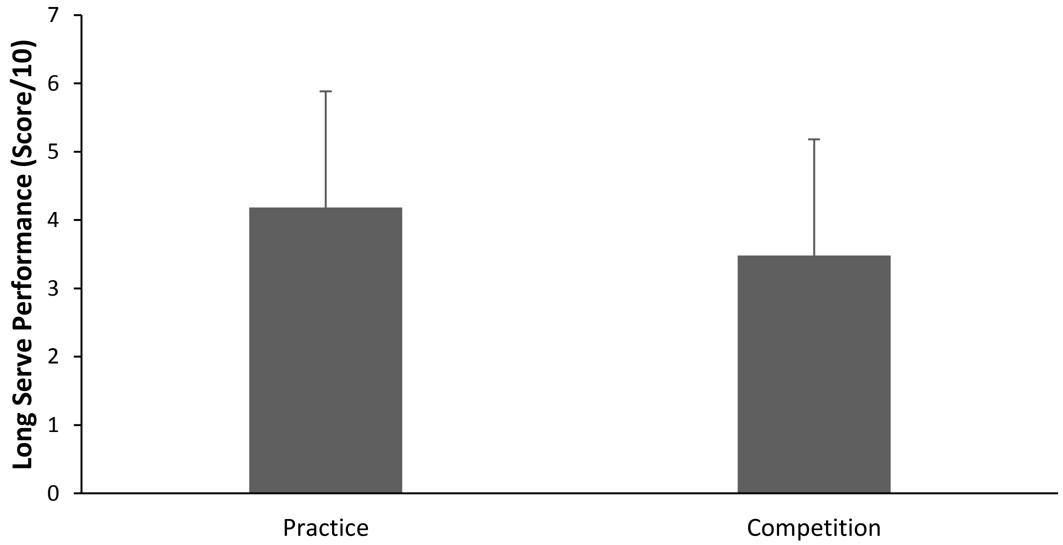


Figure 2. Mean ± SD of badminton long serve performance in practice and competition conditions

Heart Rate, Rating of Perceived Exertion and Blood Lactate

A significantly greater change in HR values pre to post standardised instructions in the competitive condition compared to the practice condition was observed ($P = 0.0001$). Mean ± SD of HR change was 3.7 ± 2.2bpm in the practice condition compared to 12.8 ± 6.5bpm. HR during the exercise protocol was not different between competition or practice conditions and there was no condition X time interaction ($P>0.05$). There was however a main effect for time, where HR rose significantly with each circuit in the badminton specific exercise protocol ($P = 0.0001$, $P\eta^2 = 0.451$, See Figure 3). For RPE, there were no higher order interactions ($P>0.05$) but there were main effects for time ($P = 0.0001$, $P\eta^2 = 0.642$) and condition ($P = 0.007$, $P\eta^2 = 0.336$). RPE values increased with each circuit in the badminton specific protocol (See Figure 4) and RPE values were significantly higher in the competition condition compared to practice; 14.5 ± 1.6 in practice vs. 15.7 ± 1.7 in competition. There was no significant differences in post exercise blood lactate values between conditions ($P >0.05$). Mean ± SD of post exercise blood lactate values were 10.8 ± 2.4 and 11.1 ± 2.0 mmol/L in practice and competition conditions respectively. There was also a significant condition X pre-post interaction for salivary cortisol ($P = 0.005$, $P\eta^2 = 0.399$) with post-hoc analysis indicating significant increases in salivary cortisol pre instructions and post exercise in the competition condition ($P = 0.039$) and no significant difference in cortisol concentrations pre instructions to post exercise in the practice conditions ($P = 0.139$). Mean ± SD of salivary cortisol was 0.558 ± 0.15 µg/dL and 0.632 ± 0.15 µg/dL pre instructions to post exercise in the competition condition and 0.562 ± .13 µg/dL and 0.512 ± 0.11 µg/dL pre instructions to post exercise in the practice condition.

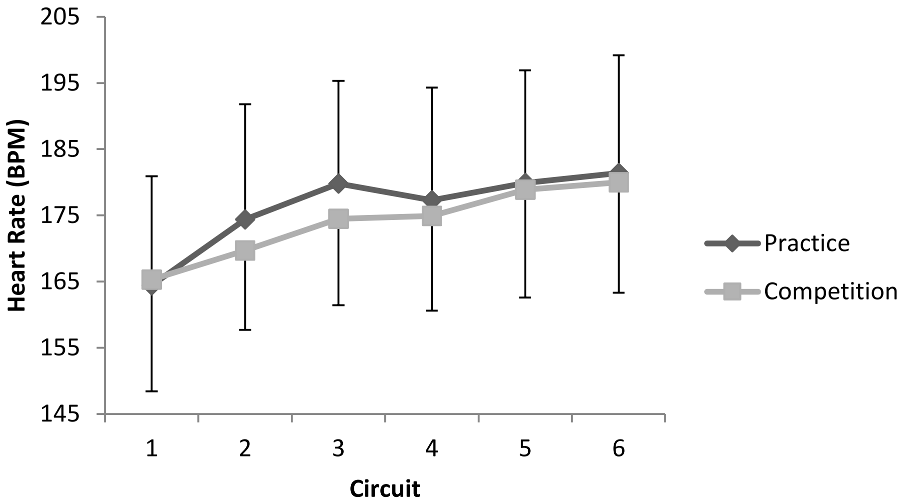


Figure 3. Mean ± SD of heart rate (BPM) across each circuit of the badminton specific exercise protocol in practice and competition conditions.

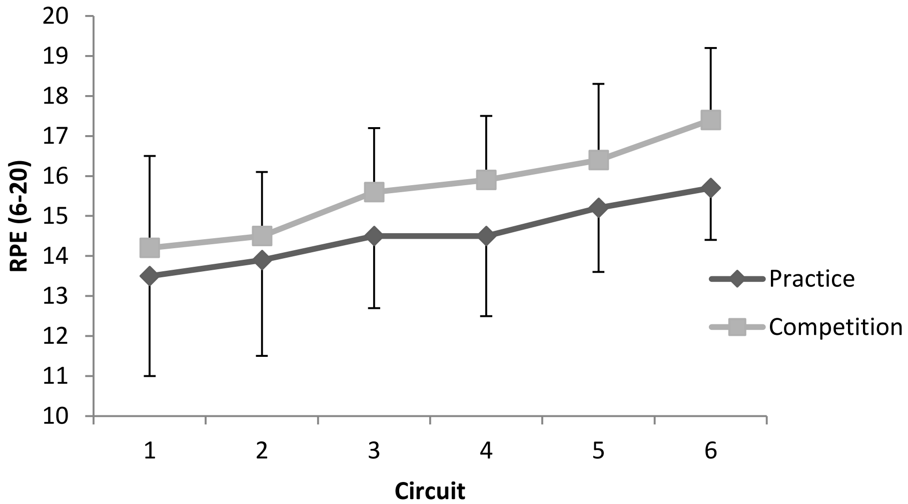
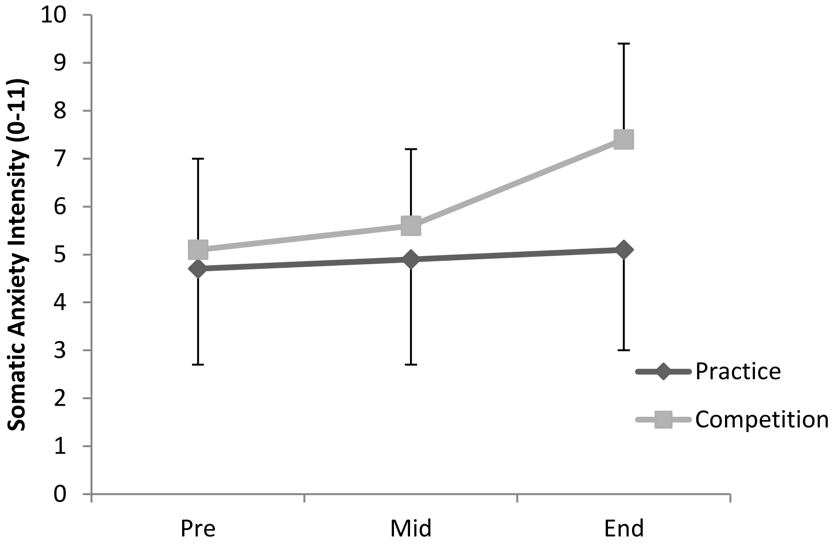


Figure 4. Mean ± SD of RPE (6-20) across each circuit of the badminton specific exercise protocol in practice and competition conditions.

Cognitive and Somatic Anxiety

Results from repeated measures ANOVA for cognitive anxiety intensity revealed a significant condition x time interaction (P = 0.001, $P\eta^2$ = 0.332, See Figure 5a). Bonferroni post hoc analysis indicated significantly lower cognitive anxiety pre exercise compared to post exercise (P = 0.001, mean diff = -2.350) and mid exercise compared to post exercise (P = 0.001, mean diff = -1.850). Cognitive anxiety was also significantly lower post exercise in the practice condition compared to competition (P = 0.001, mean diff = -2.3). There were no other significant differences for cognitive anxiety intensity (P>0.05). These results were verified using Friedman's ANOVAs where cognitive anxiety intensity increased (P = 0.001) in the competition but not the practice (P>0.05) condition. This pattern was replicated for cognitive anxiety direction where a significant condition x time interaction (P = 0.01, $P\eta^2$ = 0.216, See Figure 5b) was evident. Post hoc analysis indicated significantly greater debilitation post exercise compared to pre exercise (P = 0.009, mean diff = 1.2) and mid exercise (P = 0.003, mean diff = 1.2).There was also significantly greater debilitation post exercise in the competition condition compared to practice (P = 0.01, mean diff = 1.65). Again, using Friedman's ANOVA, cognitive anxiety direction became more debilitative from pre to mid to post exercise (P = 0.01) in the competition condition, whereas there was no significant difference in the practice condition (P>0.05).

a



b

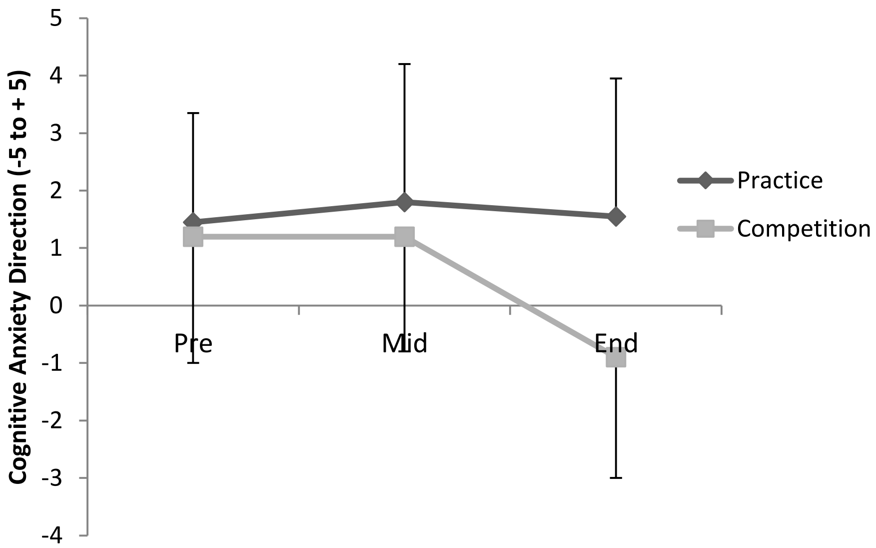


Figure 5. a: Mean ± SD of cognitive anxiety intensity pre, mid and post, practice and competition conditions and b: Mean ± s of cognitive anxiety direction pre, mid and post, practice and competition conditions.

For somatic anxiety intensity there was a significant main effect for time (P = 0.001, Pη^2 = 0.333) where somatic anxiety scores pre exercise were significantly lower than mid (P = 0.006) and post (P = 0.014) exercise, irrespective of condition. Mean ± SD of cognitive anxiety intensity was 4.8 ± 1.9, 6.5 ± 1.9 and 6.7 ± 2.0 pre, mid and post exercise respectively. There were no higher order interactions or main effect of condition for somatic anxiety intensity (all P>0.05). There were also no significant higher order interactions or main effects for somatic anxiety direction (all P>0.05). Friedman's ANOVA supported these conclusions showing significantly higher somatic anxiety intensity scores over time in both the competition (P = 0.003) and practice (P = 0.004) conditions and no significant differences in somatic anxiety direction for the competition or practice conditions (P>0.05).

DISCUSSION

This study is novel in that it examines the effects of badminton specific exercise on badminton performance in non-laboratory competition and practice conditions. Prior research has tended to rely on pre-event measures of anxiety to predict 'in-task' performance (Hardy, Parfitt, & Pates, 1994; Jones, and Hanton, 1996; Edwards, and Hardy, 1996; Hardy, and Parfitt, 1991). However, the combination of 'in-game' badminton performance, physiological and psychological measures has not been previously investigated. As such, the in situ design employed in the present study extends previous research. The results of the present study show decreased badminton short serve performance, pre, during and post in the competition condition when compared to the practice condition. There was also a trend towards this effect for long serve performance. Although there were no differences in physiological (i.e., heart rate, blood lactate) parameters between the two conditions during exercise, there was elevated cortisol pre to post instructions in the competition condition, but not the practice condition, and the participants rated their perceived exertion as greater in the competitive condition. The results of the present study also identify greater change in heart rate pre to post standardised instructions in the competition condition. This is consistent with prior research examining the effect of standardised practice and competition instructions on cardiovascular parameters (Turner, et al., 2012; Turner, et al., 2014). Moreover, there were greater increases in cognitive anxiety intensity scores in the competition compared to practice condition as well as significantly higher debilitative cognitive anxiety direction scores. Collectively, this indicates that, at the end of the badminton specific exercise bout (i.e., when physiological arousal was at its highest), participants reported the greatest increase in cognitive anxiety, which was shown to be more debilitating to performance in the competition condition compared to practice. In terms of practical implications, the results of this study do align with suggestions made by Pinder, et al. (2011) in that competition conditions produced different responses to practice conditions. Thus, coaches and scientists would benefit from employing more representative learning designs in their research and practice in order to better optimise understanding of sports performance.

The multidimensional catastrophe model (Fazey, and Hardy, 1988) goes some way in providing an explanation for the confounding results in the present study in that the model predicts the ever changing relationship between physiological arousal and cognitive anxiety on task performance. In the current study, the increased physiological arousal (via badminton specific exercise) coupled with increased self-reported (and more debilitative) cognitive anxiety, in the competition condition, appears to have resulted in poorer short serve-performance. Despite this, the performance decrement reported in the present study may not necessarily be considered 'catastrophic'. The significant main effect for serve performance indicated less than a 1 point/serve decrease in short serve performance in the competition condition compared to practice.

Despite this, the Catastrophe model falls short of fully explaining what may have caused the changes we report. Lang's (Lang, 1979) bio-informational theory helps explain how the changes in perception (competition vs practice) affected badminton short serve performance. In the present study, perception of the stimulus (i.e. competition or practice) may have been more meaningful in the competitive condition as the participants were informed that their results would be publicly displayed and were recruited on the basis that they were competitive badminton players. Consequently, the threat of possible public evaluation may have evoked higher physiological and neurological responses, as evidenced by the increase in heart rate and reported debilitative directional cognitive anxiety, and the subsequent decrement in performance competitive condition. This is congruent with Bioinformational theory (Lang, 1979). Such a suggestion aligns with research examining changes in various facets of performance in competitive and practice climates (Duncan, et al., 2016; Turner, et al., 2012; Turner et al., 2014). We suggest that as competition (and possible subsequent public evaluation/humiliation) is more meaningful to the participant than practice, it evokes higher cognitive anxiety and physiological arousal responses (BP, HR) which results in overall greater performance task error. It is also important to recognise individual variation to the simulated competition and practice conditions in the present study. Within the competition condition 13 participants showed a decrement in short serve performance and 4 showed improved performance from pre to end of the exercise protocol. Conversely, in the practice condition, 7 participants showed decreased service performance and 10 improved performances from pre to end of the exercise protocol. Understanding the individual factors and the interlinking environmental constraints that may predispose an individual to perform better or worse in competitive situations is a key direction for future research on this topic.

The present study has some limitations. It is not possible to blind treatment condition as participants have to be explicitly informed which trials are competition and practice trials. Only state anxiety was assessed in the present study whereas assessment of trait anxiety may also have benefitted the current study. Processing efficiency theory (Eysenck, and Calvo, 1992) predicts that state anxiety experienced by a performer is determined interactively by trait anxiety and the perceived threat in the performance setting. Future researchers should therefore consider the inclusion of both state and trait measures of anxiety in their designs. Furthermore, to achieve an accurate account regarding the effects of changes in physiological arousal and skilled performance on ‘in-situ’ performance a bioinformational perspective must be incorporated in future research.

REFERENCES

Araújo, D., Davids, K., Passos, P. (2007). Ecological validity, representative design, and correspondence between experimental task constraints and behavioural setting: Comment on Rogers, Kadar, and Costall (2005). *Ecological Psychology*, 19, 69-78.

Audiffren, M. (2009). Acute exercise and physiological functions: a cognitive-energetics approach. In: McMorris, T., & Tomporowski, P.D. (Eds). Exercise and cognitive function. John Wiley & Sons. Hoboken NJ., p. 3-39.

Barker, J.B., Jones, M.V., Greenlees, I. (2010). Assessing the immediate and maintained effects of hypnosis on self-efficacy and soccer wall-volley performance. *Journal of Sport & Exercise Psychology*, 32, 243–252.

Borg, G. (1970). Perceived exertion as an indicator of somatic stress. *Scandinavian Journal of Rehabilitation Medicine*, 2, 92-98.

Bottoms, L., Sinclair, J., Taylor, K., Polman, R. & Fewtrell, D. (2012). The effects of carbohydrate ingestion on the badminton serve after fatiguing exercise, *Journal of Sports Sciences*, *30*, 285-293.

Brisswalter, J., Collardeau, M., René, A. (2002). Effects of acute physical exercise characteristics on cognitive performance. *Sports Medicine,* 32, 555-566.

Clarke, N. D., & Duncan, M. J. (2016). Effect of carbohydrate and caffeine ingestion on badminton performance. *International Journal of Sports Physiology and Performance*, 11, 108-115.

Duncan, M., Smith, M., Lyons, M. (2012). The effect of exercise intensity on coincidence anticipation performance at different stimulus speeds. *European Journal of Sport Science*, 13, 559-66.

Duncan, M. J., Smith, M., Bryant, E., Eyre, E., Cook, K., Hankey, J., Tallis, J., Clarke, N., Jones, M. V. (2016). Effects of increasing and decreasing physiological arousal on anticipation timing performance during competition and practice. *European Journal of Sport Science*, 16, 27-35.

Edwards, T., & Hardy, L. (1996). The interactive effects of intensity and direction of cognitive and somatic anxiety, and self-confidence upon performance. *Journal of Sport & Exercise Psychology*, 18, 296-312.

Edwards, B. J., Lindsay, K., & Waterhouse, J. (2005). Effect of time of day on the accuracy and consistency of the badminton serve. *Ergonomics*, *15*, 1488-1498.

Eysenck, M. W., Calvo, M. (1992). Anxiety and performance: The processing efficiency theory. *Cognition and Emotion*, 6, 409-434.

Fazey, J. A., Hardy, L. (1988). *The inverted-U hypothesis: A catastrophe for sport psychology*. British Association of Sports Sciences Monograph no. 1. Leeds: The National Coaching Foundation.

Girard, O., & Millet, G. P. (2008). Neuromuscular fatigue in racquet sports. *Neurologic Clinics*, *26*, 181-194.

Hackney, A. C., Viru, A. (2008). Research methodology: issues with endocrinological measurements in exercise science and sport medicine. *Journal of Athletic Training,* 43, 631–639.

Hardy, L., Beattie, S**.,** Woodman, T. (2007). Anxiety induced performance catastrophes: investigating effort required as an asymmetry factor. *British Journal of Psychology*, *98, 15-31*.

Hardy, L. & Parfitt, G. (1991). A catastrophe model of anxiety and performance. *British Journal of Psychology*, 82, 163-178.

Hardy, L., Parfitt, G., Pates, J. (1994). Performance catastrophes in sport: A test of the hysteresis hypothesis. *Journal of Sports Science*, 4, 327-334.

Jeon, H., Kim, J., Ali, A., Choi, S. (2014) Noise distraction and mental practice in closed and open motor skills. *Perceptual and Motor Skills*, 119, 156-168.

Jones, G., Hanton, S. (1996). Interpretation of Competitive Anxiety Symptoms and Goal Attainment Expectancies *Journal of Sport and Exercise Psychology,* 18, 144-157.

Jones, G., Swain, A. B. J. (1992). Intensity and direction dimensions of competitive state anxiety and relationships with competitiveness. *Perceptual and Motor Skills*, 74, 467–472.

Krane, V. (1994). The Mental Readiness Form as a Measure of Competitive State Anxiety. *Sport Psychologist,* 8, 189-202.

Krane, V., Joyce, D., & Rafeld, J. (1994). Competitive anxiety, situation criticality, and softball performance. *The Sport Psychologist*, 8, 58-72.

Lang, P. J. (1979). A bio-informational theory of emotional imagery. *Psychophysiology,* 16, 495-512.

Lyons, M., Al-Nakeeb, Y., Nevill, A. (2008). The effect of moderate and high intensity fatigue on coincidence anticipation in expert and novice Gaelic games players. *European Journal of Sport Sci*ence, 8, 205-216.

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., Vealey, D., Burton D. (Eds). Competitive anxiety in sport. Human Kinetics, Champaign, IL. p. 117-118.

McMorris, T., Hale, B. J., Corbet, J., Robertson, K., Hodson, C. I. (2015). Does acute exercise affect the performance of whole body, psychomotor skills in an inverted-U fashion? A meta-analytic investigation. *Physiolgy and Behaviour,* 141, 180-189.

McMorris, T., Sproule, J., Turner, A., Hale, B. J. (2011). Acute, intermediate intensity exercise, and speed and accuracy in working memory tasks: A meta-analytical comparison of effects. *Physiology and Behav*ior, 102, 421-428.

Pinder, R. A., Davids, K., Renshaw, I., Araújo, D. (2011). Representative learning design and functionality of research and practice in sport. *Journal of Sport and Exercise Psychology*, 33, 146-155.

Turner, M., Jones, M. V., Sheffield, D. C., Cross, S. L. (2012). Cardiovascular indices of challenge and threat states predict competitive performance. *International Journal of Psychophysiology*, 86, 48-57.

Turner, M. J., Jones, M. V., Sheffield, D., Barker, J. B., Coffee, P. (2014). Manipulating cardiovascular indices of challenge and threat using resource appraisals. *International Journal of Psychophysiology*, 94, 9-18.

Tzetzis, G., Votsis, E. (2006). Three feedback methods in acquisition and retention of badminton skills. *Perceptual and Motor Skills*, 102, 275-284.

Umeda, R., Hiramatsu, R., Iwaoka, T., Shimada, T., Miura, F., Sato, T. (1981). Use of saliva for monitoring unbound free cortisol levels in serum. Clinica Chimica Acta, 110, 245–253.

VanBruggen, M. D., Hackney, A. C., McMurray, R. G., Ondrak, K. S. (2011). The relationship between serum and salivary cortisol levels in response to different intensities of exercise. International Journal of Sports Physiology and Performance, 6, 396-407.

Vine, S. J., Moore, L., Wilson, M. R. (2011). Quiet eye training facilitates competitive putting in elite golfers. Frontiers in Psychology, 2, 1-9.

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

Appendix I

Badminton Specific Exercise Protocol: example