The influence of cycling intensity upon cognitive response during inferred practice and competition conditions

Duncan, M. J., Clarke, N. D., Cox, M., Smith, M.

Original citation & hyperlink:

Duncan, MJ, Clarke, ND, Cox, M & Smith, M 2016, 'The influence of cycling intensity upon cognitive response during inferred practice and competition conditions' Journal of Sports Sciences, vol (in press). DOI: 10.1080/02640414.2016.1240877
https://dx.doi.org/10.1080/02640414.2016.1240877

DOI 10.1080/02640414.2016.1240877
ISSN 0264-0414
ESSN 1466-447X

Publisher: Taylor & Francis

This is an Accepted Manuscript of an article published by Taylor & Francis in Journal of Sports Sciences on 8 Oct 2016 available online: http://www.tandfonline.com/10.1080/02640414.2016.1240877

The influence of cycling intensity upon cognitive response during inferred practice and competition conditions

Michael J. Duncan, 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

Running Head: Competition vs. Practice

ABSTRACT

In many sport and exercise situations cognitive performance is required under conditions of high physiological load and high cognitive anxiety. However, few studies have assessed all these components in-situ. The current study sought to address this issue. Fourteen adults (9 males, 5 females) completed 2 incremental exercise trials (perceived competition or perceived practice) in a counterbalanced order. Cognitive performance, via a test of visual discrimination, RPE, heart rate (HR), blood lactate (Bla), and anxiety scores, were recorded at rest, 70% $\dot{V}O_{2max}$ and 90% $\dot{V}O_{2max}$. Visual discrimination response times were faster at rest compared to 70% ($P = 0.001$) and 90% $\dot{V}O_{2max}$ ($P = 0.002$) and at 70% compared to 90% $\dot{V}O_{2max}$ ($P = 0.04$) in the competitive condition. HR post instructions ($P = 0.0001$), at 70% ($P = 0.001$) and 90% $\dot{V}O_{2max}$ ($P = 0.0001$) was significantly higher in competition compared to practice. RPE was higher in the competitive condition compared to the practice condition ($P = 0.023$). Cognitive anxiety intensity was significantly higher in the competitive condition, at 70 and 90% $\dot{V}O_{2max}$ ($P = 0.001$). This study suggests that cognitive performance is more negatively affected when physiological arousal and cognitive anxiety are at their highest. Coaches and athletes should be mindful of such effects and seek to develop skills to offset such responses or to structure training to better represent competition.

Keywords: Visual Discrimination; Cognitive Anxiety; Performance;
Catastrophe Model; Bioinformational Theory

INTRODUCTION

The effect of changes in arousal and anxiety on sport performance continue to be of interest to sport and exercise scientists with studies evidencing performance decrements on a variety of sports related skills as a consequence of increased arousal and anxiety (Mullen, et al., 2005; Wilson, Smith, & Holmes, 2007; Wilson, Wood, & Vine, 2009). There has been particular emphasis on the effect of anxiety on visuomotor performance in the literature due to the importance of integrated visual and motor performance in many sports (See Janelle, 2002 and Wilson, 2008 for reviews). For example, Wilson, et al. (2009) examined penalty kick performance and gaze behaviour in high and low anxiety conditions, elicited via pre-experiment instructions. Wilson, et al. (2009) reported that participants made faster visual fixations and fixated for a longer period of time when anxiety was higher, resulting in poorer penalty kick performance, compared to when anxiety was lower. More recently, Duncan, et al. (2016) reported poorer visual anticipation tracking performance when physiological arousal was high (elicited via treadmill running) and cognitive anxiety was also high (elicited by pre-task instructions). Duncan et al. (2016) suggested such findings were supportive of the cusp catastrophe model (Hardy, & Parfitt, 1991).

The cusp catastrophe model is based on the tenet that cognitive and physiological components that interact with each other during performance (Hardy, & Parfitt, 1991). Specifically, when cognitive anxiety is low, the relationship between physiological arousal and performance should follow an inverted-U. Several researchers who have tested the catastrophe model propose that it is an accurate predictor of how changes in physiological arousal, cognitive anxiety and somatic anxiety can affect performance (Edwards & Hardy, 1996; Hardy, Beattie, & Woodman, 2007; Hardy & Parfitt, 1991; Hardy, Parfitt, & Pates, 1994; Krane, Joyce, & Rafeld, 1994). Despite this, there are limitations to a number of these studies (Edwards & Hardy, 1996; Hardy & Parfitt, 1991; Hardy, Parfitt, & Pates, 1994) in that a time to event paradigm was used. Specifically, cognitive and somatic anxiety was measured by self-report (i.e. Competitive State Anxiety Inventory-2 (CSAI-2), Marten, Burton, Vealey, Bump, & Smith, 1990) prior to the performance as Hardy & Parfitt, (1991) suggest "to manipulate cognitive anxiety independently of physiological arousal" (p.168). This is the case in a recent study by Mabweazara, Leach, & Andrews (2016) who administered the CSAI-2 one hour before a 50m swimming event and claimed that "somatic anxiety partially dominated cognitive anxiety and became the significant predictor of swimming performance." This is a bold claim from the authors to suggest that a measure taken 1hr before performance is in some way an accurate predictor of in-event performance. Further work by Krane, Joyce, & Rafeld (1994) used the Mental Readiness Form (MRF; Murphy, Greenspan, Jowdy, & Tammen, 1989) at a softball tournament where participants were required to complete the MRF before entering the batter's box, which was as close to performance as possible (Krane, et al., 1994). Although such a procedure is understandable in terms of managing data collection it artificially separates physiological arousal from cognitive anxiety. 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. It is important to acknowledge that, 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. The effect of increasing physiological arousal, via exercise intensity, on visual, cognitive and motor performance has been well studied (Davey, Thorpe, & Williams, 2002; Duncan, Smith, & Lyons, 2012; Lyons, Al-Nakeeb, & Nevill, 2008; McMorris, Hale, Corbet, Robertson, & Hodson, 2015), yet few studies have assessed physiological arousal, cognitive anxiety and skilled performance at the same time in conditions where cognitive anxiety is increased via simulated competition. Such a process is needed to better understand how performance can be optimised in competitive situations where visual motor performance is required at the same time as high level of physiological arousal. The aim of the present study was therefore to provide a more holistic examination of the effect of cognitive anxiety and increasing physiological arousal on visual discrimination performance. This will be achieved by using a psychophysiological approach, integrating measures of cardiovascular reactivity, effort perception, cognitive and somatic anxiety and by assessing these variables in-situ, thereby providing a stronger link between measures of physiological arousal, cardiovascular reactivity, cognitive anxiety and performance than previous studies have achieved. It is hypothesised that as a consequence of manipulating physiological arousal (via exercise intensity), cognitive performance will follow the predictions of Fazey and

Hardy’s (1988) catastrophe model in that’ cognitive performance will be worst when both physiological arousal (exercise intensity) and cognitive anxiety are at their highest when compared to resting values.

METHODS

Participants

Following institutional ethics approval and informed consent, 14 physically active adults (9 males, 5 females, mean age = 21 ± 2 years Mean ± S.D. of participants’ baseline $\dot{V}O_{2\ max}$ values was 47.9 ± 4.8 $ml \cdot kg^{-1} \cdot min^{-1}$ (range: 41.3-55.8 $ml \cdot kg^{-1} \cdot min^{-1}$) volunteered to participate in the study. Participants were recreational exercisers and reported being in good health. Inclusion criteria included being habitually engaged in recreational physical activity of more than three but less than 10 hours per week and not including formal competitive sports performance. Participants were excluded if they had a musculoskeletal or cardiovascular contraindication to exercise, were taking any medication that could impact on mood/affect, engaged in less than three or more than 10 hours physical activity per week or were engaged in competitive sports activity as part of their habitual physical activity.

Design

This study employed a within-participants, counter-balanced design whereby participants visited the laboratory on three occasions at the same time of day in a well-rested and well hydrated state. The first trial comprised familiarisation and an incremental exercise test to assess $\dot{V}O_{2max}$ in order to determine exercise intensities for use in the subsequent two experimental trials. 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.

An incremental exercise test was performed to determine $\dot{V}O_{2max}$ on a mechanically braked cycle ergometer (Monark Exercise AB, Sweden) to following previously published guidelines (Moseley & Jeukendrup, 2001). Expired air was collected via the Douglas bag technique during the final minute of each incremental exercise stage. Samples were analyzed for oxygen and carbon dioxide content (Servomex, Crowborough, England) and expired air volume (Harvard dry gas meter, Harvard Apparatus, Kent, England) with values for oxygen consumption ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) subsequently calculated. Heart rate (Polar Electro, Kempele, Finland) and rating of perceived exertion (RPE), using the Borg 6-20 RPE scale (Borg, 1970), was recorded during the final 15 seconds of each workload. Participants were judged to have reached $\dot{V}O_{2\,max}$ if they presented at least 3 of the following: a) a respiratory exchange ratio of greater than 1.1, b) a heart rate during the last stage of testing that was ± 10 beats of age predicted maximum heart rate, c) an RPE of 18 or greater, d) a plateau in VO_2 with an increase in workload, e) volitional fatigue. All participants met these criteria during their incremental exercise test.

Experimental Trials

At least 48 hours following completion of the baseline testing session, participants then undertook two incremental exercise trials presented in a counterbalanced order. These trials comprised one trial in a perceived competitive situation and another in a perceived competitive situation. In both cases participants completed performance measures at rest, at 70% $\dot{V}O_{2\,max}$ (Moderate intensity) and then 90% $\dot{V}O_{2\,max}$ (High Intensity). Key physiological (heart rate, rating of perceived exertion (RPE), and blood lactate) and psychological (cognitive and somatic state anxiety and self-confidence) relating to the predictions of the cusp catastrophe model were assessed in-situ alongside the primary outcome measure, cognitive performance, assessed using a test of visual discrimination. In this way we sought to address the limitations of prior research by assessing the physiological and psychological related to arousal and anxiety whilst participants were exercising and at the same time executing the test of visual discrimination.

An incremental cycling protocol was used to induce exercise arousal states. All trials began with a warm up at 35 Watts. Participants then cycled at a workload corresponding to 70% $\dot{V}O_{2\,max}$ until they reached steady state, at which point performance measures were taken whilst the participants continued to cycle. On completion of the performance trials at 70% $\dot{V}O_{2\,max}$, participants continued to cycle at a workload of 90% $\dot{V}O_{2\,max}$ whereby the above process was repeated. The total time to complete each experimental trial was similar and comprised approximately 18-20 minutes of cycling.

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 (Barker, Jones, & Greenlees, 2010; Duncan, et al., 2016; Hardy, Parfitt, & Pates, 1994; Turner, et al., 2012). The statements comprised of demand appraisals which informed participants that their Visual Discrimination test scores indicated a level of their cognitive ability. In the case of competitive trials, 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., 2015). 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., 2015).

Cognitive Performance

Participants in the present study completed a test of visual discrimination modelled on one developed by Pontifex, Hillman, & Polich (2009) and previously used by Moore, Romine, O'Connor, & Tomporowski, (2012) to assess cognitive performance. The test required participants to respond quickly and accurately to a 5.5 cm diameter circle that occurred on

12.5% of trials and not to respond to a 5.0 cm diameter non-target circle that occurred on 75% of trials, or a 2 cm distractor square that occurred on 12.5% of trials. The test consisted of 200 trials and required approximately four minutes to complete. Within the test, stimuli were presented for 300 ms with a 1000 ms inter-stimulus interval via open source experiment software (Mathôt, Schreij, & Theeuwes, 2012) at the centre of a computer monitor located on the treadmill in front of the participant. For each trial, participants were asked to press a trigger button, with their dominant hand, if the target stimulus was presented which enabled participants to complete the visual discrimination test during exercise. Visual discrimination test performance was assessed using two measures. An error rate was calculated, relating to instances where the stimulus was presented and the trigger not pressed or when the non-target stimulus was presented and the trigger was pressed. Response times (ms) were also calculated for target stimulus trials indicating the time taken to respond when the target stimulus was presented and the trigger pressed. Performance on the visual discrimination test was considered as the primary performance variable in the present study.

Physiological Measures

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 as was resting blood pressure (BP, mmHg), using automated sphygmomanometry (Bosu, Bosch and Sohn, Germany). Standardised instructions were then read to each participant to induce competitive or practice states. HR and BP were then taken five minutes post instructions. This process was used as a manipulation check for the standardised practice and competition instruction sets employed in the present study.

During each exercise trial, HR was monitored continuously throughout each experimental trial and was recorded once participants reached steady state at 70% $\dot{V}O_{2\ max}$ and then 90% $\dot{V}O_{2\ max}$. Blood lactate (mmol/l) was also determined at 70% $\dot{V}O_{2\ max}$ and at 90% $\dot{V}O_{2\ max}$ (after completion of the visual discrimination tests) via a capillary blood sample taken from the fingertip (Lactate Pro, Arkray Inc, Japan).

Psychological Measures

Cognitive and Somatic State anxiety were measured during performance at 70% $\dot{V}O_{2\ max}$ and 90% $\dot{V}O_{2\ max}$ by using the Mental Readiness Form 3 (MRF-3) (Krane, 1994). 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. The original MRF-3 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) and Krane’s validation work revealed correlations between the MRF-3 and the CSAI-2 subscales of .76 for cognitive anxiety and .69 for somatic anxiety (Krane, 1994).

Statistical Analysis

Results are expressed as mean and standard error (SE). Any changes in visual discrimination performance (error rate and response times) were examined using two, 3 (rest, 70% $\dot{V}O_{2\ max}$ and 90% $\dot{V}O_{2\ max}$) x 2 (practice vs. competition) ways repeated measures analysis of variance (ANOVA). ANOVAs. Any changes in systolic (SBP) and diastolic (DBP) blood pressure before and after standardised instructions in the practice and competitive conditions were analysed using a 2(pre to post) x 2 (practice vs. competition) ways repeated measures analysis of variance (ANOVA). HR data was examined using a 2 (practice vs. competition) X 4 (pre instructions, post instructions, 70% $\dot{V}O_{2\ max}$ and 90% $\dot{V}O_{2\ max}$) ways repeated measures ANOVA. Any changes in RPE, blood lactate and MRF scores for Cognitive and Somatic state anxiety whilst exercising at 70% $\dot{V}O_{2\ max}$ and then 90% $\dot{V}O_{2\ max}$ were examined using a series of 2 (70% $\dot{V}O_{2\ max}$ vs. 90% $\dot{V}O_{2\ max}$) x 2 (practice vs. competition) ways repeated measures ANOVAs. Finally, any changes in visual discrimination performance (error rate and response times) were examined using two, 3 (rest, 70% $\dot{V}O_{2\ max}$ and 90% $\dot{V}O_{2\ max}$) x 2 (practice vs. competition) ways repeated measures ANOVAs. 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. The Statistical Package for Social Sciences (SPSS, Version 20, Chicago, Il, USA) was used for all analysis.

RESULTS

Cognitive performance

In respect to error rate during the visual discrimination test, results indicated significant main effects for condition (practice vs competition) (P = 0.01, Pη^2 = 0.460) with error rate being higher in the competitive condition (2.5 ± .35%) compared to the practice condition (1.4 ± .32). Likewise, there was a significant main effect for time (P = 0.0001, Pη^2 = 0.528). Post-hoc analysis indicated significantly greater error during exercise at 70% $\dot{V}O_{2\ max}$ compared to rest (P = 0.017) and during exercise at 90% $\dot{V}O_{2\ max}$ compared to rest (P = 0.0001) but no significant difference between error rate during exercise at 70 and 90% $\dot{V}O_{2\ max}$ (P = 0.07). Mean ± SE of error rates were .93 ± .24% at rest, 2.0 ± .39% at 70% and 2.9 ± .42% at 90% $\dot{V}O_{2\ max}$ respectively.

For response time there was a significant condition X time interaction (P = 0.009, Pη^2 = 0.346, Figure 1). Post-hoc analysis indicated that response times were significantly greater at 90% $\dot{V}O_{2\ max}$ compared to 70% $\dot{V}O_{2\ max}$ in the practice condition (P = 0.032). Likewise, response times were significantly smaller at rest in the competitive condition compared to 70% $\dot{V}O_{2\ max}$ (P = 0.001) and 90% $\dot{V}O_{2\ max}$ (P = 0.002) and at 70% $\dot{V}O_{2\ max}$ compared to 90% $\dot{V}O_{2\ max}$ (P = 0.04) in the competitive condition. Response times were also significantly smaller at rest in practice compared to rest in the competitive condition (P = 0.004), at 70% $\dot{V}O2$ max in the practice compared to the competitive condition (P = 0.0001) and at 90% $\dot{V}O2$ max in the practice compared to the competitive condition (P = 0.0001).

Physiological Measures

For SBP, results indicated a significant pre to post X practice vs. competition interaction with a large effect size (P = 0.001, $P\eta^2 = 0.791$, Figure 2). Post-hoc analysis indicated no significant difference between SBP pre instructions in both the practice and competitive conditions (P>0.05). However, pre to post instructions there was a significant increase in SBP in both the practice (P = 0.05) and competition (P = 0.001) conditions with the magnitude of change in SBP being greater in the competitive condition (delta = 14.9 mmHg), compared to the practice condition (delta = 4.8 mmHg). For DBP, there were no significant main effects pre to post or between practice and competition conditions, nor was there a significant interaction between the two (all P>0.05).

In regard to HR, there was also a significant practice vs. competition X time interaction (P = 0.001, $P\eta^2 = 0.537$, Figure 3). Post hoc analysis indicated there was no significant difference in HR pre instructions between practice and competitive conditions or pre to post instructions in the practice condition (both P>0.05). HR significantly increased from post instructions to 70% $\dot{V}O_{2\ max}$ and then to 90% $\dot{V}O_{2\ max}$ in both the practice and competitive conditions (all P = 0.001). However, HR post instructions (P = 0.0001), at 70%

$\dot{V}O_{2\ max}$ (P = 0.001) and 90% $\dot{V}O_{2\ max}$ (P = 0.0001) was significantly higher in the competitive condition compared to the practice condition.

For blood lactate there was no significant practice vs. competition X 70% vs. 90% $\dot{V}O_{2\ max}$ interaction or main effect for condition (both P>0.05). There was a significant main effect for exercise intensity (P = 0.001 $P\eta^2$ = 0.863) whereby blood lactate (mmol/L) significantly increased from 70% (5.04 ± .457 mmol/L) to 90% $\dot{V}O_{2\ max}$ (8.114 ± .458 mmol/L).

Psychological Measures

Results from repeated measures ANOVA for cognitive anxiety intensity indicated a significant practice vs. competition X exercise intensity interaction (P = 0.003, $P\eta^2$ = 0.578, Figure 4). Post-hoc analysis revealed that cognitive anxiety intensity increased from 70 to 90% $\dot{V}O_{2\ max}$ in both the practice (P = 0.037) and competitive (P = 0.0001) conditions but the magnitude of change was greater in the competitive condition (delta = 3.1) compared to the practice conditions (delta = 1). Cognitive anxiety intensity was also significantly higher in the competitive condition, compared to practice, at both 70 and 90% $\dot{V}O_{2\ max}$ (P = 0.001 in both cases).

Significant main effects were found for somatic anxiety intensity (P = 0.001, $P\eta^2$ = 0.732) where somatic anxiety intensity increased from 70 to 90% $\dot{V}O_{2\ max}$ (4.8 ± .42 at 70% compared to 7.1 ± .45 at 90% $\dot{V}O_{2\ max}$). There were no significant main effects for condition or condition X exercise intensity interactions for either somatic anxiety intensity (P>0.05).

Results for RPE indicated significant main effects for condition (practice vs. competition), (P = 0.023 $P\eta^2 = 0.387$) and exercise intensity (70% vs. 90% $\dot{V}O_{2\ max}$), (P = 0.001 $P\eta^2 = .842$) whereby RPE was significantly higher in the competitive condition compared to the practice condition (Mean ± SE of RPE was 16.1 ± .392 and 14.1 ± .660 in competitive and practice conditions respectively) and was significantly higher at 90% $\dot{V}O_{2\ max}$ compared to 70% $\dot{V}O_{2\ max}$ (Mean ± SE of RPE was 13.6 ± .626 and 17.4 ± .323 at 70% and 90% $\dot{V}O_{2\ max}$ respectively).

DISCUSSION

This is the first study to examine the effects of 'in-situ' changes in moderate and heavy exercise intensities on cardiovascular parameters, cognitive and somatic anxiety, and cognitive performance in practice and competition situations. As such the findings of the present study extend previous research (Edwards, & Hardy, 1996; Hardy, et al., 1994; Jones, & Hanton, 1996; Hardy, & Parfitt, 1991) that measured 'pre-event' anxiety in relation to task performance. In particular, there was a more marked increase in cognitive anxiety when participants went from moderate to high intensity exercise in the competition condition compared to the practice condition. This was coupled with higher error rates and longer response times in the competitive condition compared to practice.

The acute changes in systolic blood pressure and heart rate in the competition condition compared to the practice condition are consistent with prior research examining the effect of standardised practice and competition instructions on cardiovascular parameters (Turner, et al., 2012; Turner, et al., 2014) and is supportive of conclusions drawn by Turner et al. (2014) that eliciting a competition climate, via standardised instructional sets, results in cardiovascular reactivity. The elevated post-instruction heart rate in the competitive condition persisted during exercise of moderate and high intensity in competition, compared to practice. While the perception of effort (via RPE) was greater in competition even though physiological strain, via blood lactate, was similar in competitive and practice conditions. The current study therefore addresses some of the limitations of prior research that has investigated the association between exercise intensity and performance using a multidimensional protocol (i.e. with a physical and cognitive component), but has attempted to align their findings with a unidimensional model such as inverted-U (Yerkes, and Dodson, 1908), subsequently failing to separate the independent and covarying elements of arousal (i.e. physiological and cognitive). From a practical perspective coaches and sports scientists need to consider physiological and cognitive factors relating to sports and exercise performance together as well as seeking to develop effective strategies that can be used to dampen cognitive anxiety in competitive conditions where they is a concurrent need for high physiological load.

The multidimensional catastrophe model (Fazey, & Hardy, 1988) goes some way in addressing the limitations of adopting a unidimensional approach in that the model predicts the relationship between physiological arousal and cognitive anxiety on performance. Specifically, the model predicts that huge increases in physiological arousal and cognitive anxiety will result in a catastrophic decrement in performance which appears to be the case in the current study. The results of the present study suggest that, when physiological arousal was at its highest (i.e. 90% exercise intensity) and cognitive anxiety was at its highest (via the competition conditions), cognitive performance was poorest. This would support the tenants of the catastrophe model.

Results from recent meta-analysis by McMorris, et al. (2015) provide a clearer explanation of changes in cognitive performance between practice and competition seen in the present study. McMorris, et al. (2015) reported that heavy exercise (>80%) disrupted the signal to 'noise' ratio by increasing concentrations of catecholamines in the brain which also lead to changes in perception (Arnsten, 2009; 2011). This may go some way to explaining the increase in reported cognitive anxiety from the practice to competition conditions, and the consequent decrement in cognitive performance in the present study. However, in the present study cognitive performance was poorer for both the moderate (70%) and high (90%) intensity competitive conditions when compared with the moderate and high practice conditions. Yet one would expect that cognitive performance would be worse in the high (90%) intensity practice condition when compared to the moderate (70%) competition condition, but this was not the case and further explanation is required.

In the present study, perception of the stimulus (i.e. competition or practice) may have been more meaningful in for competition as the participant was informed that their results would be publicly displayed. This is consistent with Lang's (1979) bio-informational theory. Consequently, the threat of possible public evaluation evoked higher physiological responses, as evidenced by the increase in systolic blood pressure, as well as the decrement in performance in the 70% and 90% exercise intensity competitive conditions. 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; 2014). One important point, related to the present study is that the perception of the event (i.e., practice or competition) has to be considered. Higher exercise intensity leads to increased brain catecholamine concentrations and subsequent synthesis and release of dopamine and norepinephrine which can modify perception (Arnsten, 2009; 2011). It is therefore possible that the perception of competition or practice prompts a different biochemical reaction (Goldman-Rakic, 1987) and not only impacts on cognitive performance but that this impact may differ depending on the intensity of exercise. Prior studies have examined the effects of simulated competition on visual-motor performance (Wilson et al., 2009; 2007) due to the importance of visual information in sports performance (Janelle, 2002). In the present study, visual discrimination performance was employed and is considered a test of visual-cognitive performance (Moore, et al., 2012). As such the current study demonstrates an effect of simulated competition on visual cognitive performance during exercise. While the competition condition may have been perceived as more meaningful, the poorer cognitive performance may have resulted because, in line with attentional control theory (Eysenck, Derakshan, Santos, & Calvo, 2007), higher cognitive anxiety increases the allocation of attentional resources to threat related stimuli (i.e. the perception of competition) (Eysenck, et al., 2007). This results in impaired processing efficiency via reduced attentional control. In the current study task demands required the maintenance of a set exercise intensity at the same time as performing a visual cognitive test requiring sustained attention. The higher cognitive anxiety reported in the competitive condition may have been the splitting factor resulting in a dual task trade off where cognitive performance was poorer due to reduced attentional resource and as there was a need to maintain set exercise intensity.

The change in self-reported cognitive anxiety scores of 3.1 and 1 in competition and practice conditions respectively should also be contextualised. These scores reflect a shift in responses on an 11 point Likert scale and reflect the self-reported cognitive anxiety of the participants. As with other studies that have employed self-reported measures of anxiety (Wilson, et al., 2009; Wilson et al., 2007; Duncan et al., 2016; Edwards & Hardy, 1996; Hardy & Parfitt, 1991; Hardy, Parfitt, & Pates, 1994), these scores reflect the individual's perception of their cognitive and /or somatic anxiety at the time of assessment. In real world terms the meaningfulness of such scores could be questioned. Likewise, the nature of the competition and practice conditions may not have been truly representative of actual sports competition. However, the results of the present study do have practical significance for sports performers, coaches and psychologists in that, this laboratory based study as they indicate this simulated practice vs competition dichotomy resulted in poorer performance and higher self-rated anxiety when exercise induced physiological arousal was high. Although speculative, it is likely that actual sports competition situations could elicit greater increases in cognitive and somatic state anxiety than demonstrated in this study. Therefore, developing strategies to reduce the effects of cognitive state anxiety, when cognitive performance is required, at high levels of exercise intensity (e.g., football, basketball) may be useful in optimising cognitive performance in sport competition. This could entail use of simulated competition instead of practice during training that could be employed to control cognitive anxiety in-situ during high intensity exercise.

The present study does however have some limitations. Allocation of treatment could not be completely blinded from participants as they were explicitly informed which trials were competition and practice trials. Only state anxiety was assessed in the present study, and as processing efficiency theory (Eysenck, & Calvo, 1992) predicts that state anxiety experienced by a performer is determined interactively by trait anxiety and the perceived threat, future researchers should consider the inclusion of state and trait measures of anxiety in their designs.

This study suggests that cognitive performance is negatively affected in perceived competition when physiological arousal and cognitive anxiety are high. This is potentially due to higher cognitive anxiety disrupting attentional resource allocation combined with the demands of maintaining exercise intensity resulting in poorer visual discrimination performance. Such effects are not seen in perceived practice settings. Coaches and athletes should be mindful of such effects and seek to develop skills to offset such responses or to structure training to better represent competition and familiarise performers with higher anxiety situations where cognitive performance is required alongside exercise performance.

Conflict of interests: None

REFERENCES

Arnsten, A. F. T. (2009). Stress signalling pathways that impair prefrontal cortex structure and function. *Nature Reviews Neuroscience*, 10, 410–422.

Arnsten, A. F. T. (2011). Catecholamine influences on dorsolateral prefrontal cortical networks. *Biological Psychiatry,* 69, e89–e99.

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.

Davey, P. R., Thorpe, R. D., Williams, C. (2002). Fatigue decreases skilled tennis performance. *Journal of Sports Sciences,* 20, 311-318.

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.

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

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

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.

Goldman-Rakic, P. S. (1987). *The nervous system, higher functions of the brain.* In: F. Plum (Ed). Handbook of Physiology, vol. V, American Physiological Society, Bethesda, pp. 373–417.

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, J. P. L., Parfitt, G. A. (1991). 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.

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

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

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

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.

Mabweazara, S. Z., Leach, L., Andrews, B. S. (2016). Predicting swimming performance using state anxiety. *South African Journal of Psychiatry*, e-pub ahead of print

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.

Mathôt, S., Schreij, D., Theeuwes, J. (2012). OpenSesame: An open-source, graphical experiment builder for the social sciences. *Behavioural Research Methods, 44*, 314-324.

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.

Moore, R. D., Romine, M. W., O'Connor, P. J., Tomporowski, P. D. (2012). The influence of exercise-induced fatigue on cognitive function. *Journal of Sports Science,* 30, 841-850.

Moseley, L., Jeukendrup, A. E. (2001). The reliability of cycling efficiency. *Medicine and Science in Sports and Exercise*, 33, 621-7.

Mullen, R., Hardy, L., & Tattersall, A. (2005). The effects of anxiety on motor performance: A test of the conscious processing hypothesis. *Journal of Sport and Exercise Psychology,* 27, 212–225.

Murphy, S., Greenspan, M., Jowdy, D., & Tammen, V. (1989, October). Development of a brief rating instrument of competitive anxiety: Comparison with the CSAI-2. Paper presented at the meeting of the Association for the Advancement of Applied Sport Psychology, Seattle, WA.

Pontifex, M. B., Hillman, C. H., Polich, J. (2009). Age, physical fitness and attention: P3a and P3b. *Psychophysiology*, 46, 379-387.

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.

Wilson, M. (2008). From processing efficiency to attentional control: A mechanistic account of the anxiety-performance relationship. *International Review of Sport and Exercise Psychology, 1,* 184–201.

Wilson, M., Smith, N. C., Holmes, P. S. (2007). The role of effort in influencing the effect of anxiety on performance: testing the conflicting predictions of processing efficiency theory and the conscious processing hypothesis. *British Journal of Psychology*. 98, 411-428.

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.

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