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Running head: Mental Fatigue and High-Intensity Exercise

**Mental fatigue negatively influences manual dexterity and anticipation timing but not repeated high-intensity exercise performance in trained adults**

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### ABSTRACT

This study examined the impact of a period of mental fatigue on manual dexterity, anticipation timing and repeated high intensity exercise performance. Using a randomised, repeated measures experimental design, eight physically trained adults (mean age =  $24.8 \pm 4.1$  years) undertook a 40 minute vigilance task to elicit mental fatigue or a control condition followed by four repeated Wingate anaerobic performance tests. Pre, post fatigue/control and post each Wingate test, manual dexterity (Seconds), coincidence anticipation (absolute error) were assessed. A series of 2 (condition) by 6 (time) ways repeated measures ANOVAs indicated a significant condition by time interactions for manual dexterity time ( $p = .021$ ) and absolute error ( $p = .028$ ). Manual dexterity and coincidence anticipation were significantly poorer post mental fatigue compared to control. There were no significant differences in mean power between conditions or across trials (all  $p > .05$ ).

Keywords: Perception-Action Coupling; Vigilance; Cycling

## Introduction

Prolonged mental exertion, also termed 'mental fatigue', has been previously demonstrated to negatively influence attention, action monitoring and cognitive control (Boksem, & Tops, 2008). More recently, researchers have suggested that bouts of 'mental fatigue' might impair subsequent physical performance, although research on this topic is scarce (Brownsberger, Edwards, Crowther, & Cottrell, 2013). Marcora, Staiano & Maning (2009) conducted one of the first experimental studies on the effect of prolonged mental exertion on whole body performance using a cycling endurance protocol. They reported a reduction in cycling time to exhaustion at 80% peak power output following 90minutes performance of a demanding cognitive task. However, in their study, Marcora et al. (2009) did not find any changes in cardiovascular, respiratory or metabolic responses to exercise between their mental fatigue and control conditions. Only a higher rating of perceived exertion during cycling when mentally fatigued could explain premature exhaustion in this condition. Recent work by Brownsberger et al. (2013) has used a similar approach to examine the effect of mental fatigue on the performance of self-selected exercise. They reported increased electroencephalogram (EEG) beta-band activation, increased feelings of fatigue and reduced power output during 10 minutes of self selected cycling at a rating of perceived exertion (RPE) of 11 and 15 following the mental fatigue condition compared to a neutral observation condition. Likewise, Dorris, Power and Kenefick (2012) evidenced that rowers completed significantly fewer press-ups following completion of a cognitive task and a group of rugby

and hockey players completed significantly fewer sit-up following completion of a similar cognitive task. Dorris et al. (2012) suggested that ego depletion may explain such decrements in physical performance following a demanding cognitive task.

In some ways these findings are not surprising given that psychobiological models of performance have proposed that exhaustion is not caused by muscle fatigue per se (Marcora & Staiano, 2010) but rather results from a conscious decisions to disengage from an endurance based exercise task. In motivated participants, this effort-based decision is taken when perception of effort is maximal and continuation of the endurance task seems impossible. Subsequent research by Pageaux et al. (2013) has attempted to address this issue by examining the effect of a 90 minute mental fatigue protocol on neuromuscular function of the knee extensors. They reported that time to exhaustion during submaximal isometric knee extension exercise was reduced in the mental fatigue condition but that there were no significant differences on maximal torque, voluntary activation level or peripheral parameters of neuromuscular activation. This is however contrary to work by Bray, Graham, Martin Ginis, & Hicks (2012) that reported a negative effect of a short (20min) mental fatigue protocol on maximal voluntary contractions of the hand flexor muscles. Pageaux, Marcora & Lepers (2013) concluded that the effect of mental fatigue on performance is mediated by higher perception of effort at a given workload rather than impaired neuromuscular function. They also suggested that the negative impact of mental fatigue may be limited to endurance performance and may not have a negative impact on performance of short maximal voluntary efforts such as jumping and sprinting.

Considering the protocol employed by Pageaux et al. (2013) it would seem difficult to extrapolate their findings to whole body activity such as jumping and sprint performance. Moreover, in practical terms it is rare that a single sprint or jump is performed in sport or daily activity.

Research investigating the effects of mental fatigue on subsequent physical performance is lacking and as there have been calls to investigate the effects of mental fatigue on performance in activity, rather than endurance based exercise (Brownsberger et al., 2013). Previously mentioned research by Marcora et al. (2009) has determined the effects of mental fatigue on high intensity cycling that was predominantly aerobic in nature whilst Pageaux et al. (2013) have suggested that the effects of mental fatigue on exercise performance might be limited to endurance performance following their study which used an isokinetic knee extensor strength task. However, the effect of mental fatigue on repeated, anaerobically based, intensity exercise performance and perceptual and motor skills has not yet been investigated. As intermittent anaerobic exercise combined with execution of perceptual and motor skills are a feature of many sports and activities (e.g., football, basketball) understanding if, or how, mental fatigue might influence these capabilities may be useful in planning training programmes and optimising athletic performance as well as experimentally testing the hypothetical link between mental fatigue and exercise. Therefore, the aim of this study was exploratory in nature and sought to examine the impact of a period of mental fatigue on manual dexterity, anticipation timing and repeated high intensity exercise performance.

## Methods

### *Participants*

Eight physically trained adults (7 males, 1 female, mean age =  $24.8 \pm 4.1$  years) volunteered to participate in the study following institutional ethics approval and informed consent. All participants had specific experience performing high intensity exercise and were free of any musculoskeletal pain or disorders. All participants competed in team games (rugby union, football, basketball) at University level and testing took place during the preparatory period of their periodized training cycle. They were currently participating in greater than 10 hours week programmed physical activity including strength and endurance based activities. They were not, however, cycle trained specifically.

### *Procedures*

A repeated measures design was employed whereby participants completed a familiarisation protocol where they were introduced to all the procedures and equipment to be employed in subsequent sessions. Height and body mass were also assessed in this session using a Seca stadiometre and weighing scales (Seca Instruments, Hamburg, Germany). Following this, participants undertook two experimental conditions; Mental fatigue (MF) vs. control (CON), completed in a randomised order and separated by 72hours. Prior to each condition, participants were instructed to refrain from consumption of alcohol, caffeine, and any other stimulants and avoid any

vigorous exercise in the 24h prior to each session. All testing was conducted between 9am-11am to avoid any effect of circadian variation and at least 90minutes post breakfast. Participants were also instructed to consume the same breakfast on both experimental trial days.

The two experimental trials required the participants to complete a 40 minute pre exercise routine of either 1) a continuous cognitive activity task designed to induce mental fatigue (MF) or 2) a passive neutral observation procedure (CON). Both protocols took place seated in a thermo-neutral, sound attenuated room. The MF protocol comprised 40-minutes completing concentration grids (Greenlees, Thelwell, & Holder, 2006; Harris & Harris, 1984) requiring sustained vigilance to induce a state of MF. The CON protocol comprised of viewing 40-minutes of a neutral video, identified as "World Class Trains – The Venice Simplon Orient Express" (Pegasus-Eagle Rock Entertainment, 2004) as adopted by a number of prior authors when examining this area (Marcora, Staiano & Manning, 2009; Pageaux et al., 2013; Brownsberger et al., 2013).

The exercise test consisted of four, 30 second Wingate Anaerobic Tests (WANT) each separated by a four minute rest period (Greer, McLean & Graham, 1998) completed on a Monark Peak cycle ergometer (Ergomedic 894E, Vansbro, Sweden). The cycle ergometer was calibrated on each morning of testing and prior to any testing being conducted. Participants cycled with no resistance until they reached their perceived maximum speed. At this time, the predetermined load (7.5% body mass) was dropped and the test continued at maximal effort for 30 seconds. The mean power output (MPO, Watts) was calculated during the WANT using Monark's anaerobic

testing software (Version 1.0). No verbal encouragement was provided during the trials. Recommended guidelines for the completion of Wingate anaerobic tests were followed (Winter, and MacLaren, 2009).

On completion of each of the bouts of high intensity exercise, heart rate (HR, Polar RS400, Polar Kuopio, Finland) was determined using heart rate telemetry and rating of overall (i.e., central) perceived exertion was assessed using the Borg 6-20 RPE scale (Borg, 1970). In the third minute of the inter-repetition rest interval a 0.5  $\mu$ L capillary blood sample was drawn from the fingertip from which blood lactate (BLac) was determined (Lactate Pro, Arkray Inc, Japan).

Prior to undertaking both the MF and CON protocols, immediately post each protocol and post each of the four bouts of high intensity exercise, participants undertook assessment of coincidence anticipation timing (CAT) and manual dexterity (MD). These tests were chosen in particular as both manual dexterity and coincidence anticipation timing are skills required for successful performance in open skill sports. There are also performed multiple times following intermittent bouts of high intensity exercise. Hence the protocol sought as best as possible to replicate such demands in the laboratory setting.

Manual dexterity was assessed using the Minnesota Manual Dexterity Turning Test (MMDT). In this test, participants are asked to pick up, turn over and place back down, 60 plastic discs into a frame in the fastest time possible using their dominant hand and in standing posture. This is a validated manual dexterity test recommended for use with older adults (Desrosiers et al., 1997;

Yancosek & Howell, 2009) and recommended guidelines for administration were followed (Desrosiers et al., 1997).

The Bassin anticipation timer (Model 35575, Lafayette, USA) was used to assess CAT performance in the present study. CAT refers to the ability to predict the arrival of a moving object at a particular point in space and coordinate a movement response with that arrival (Payne, 1986). As such it can be considered a test of perceptual-motor coupling requiring integration of sensory-cognitive procession and sensory-motor integration (Fleury & Bard, 1985). At all time points, participants undertook 10 trials at a stimulus speed of 5mph using a trigger press response with their dominant hand to intercept a moving light. The Bassin Anticipation Timer was set up vertically (i.e., placed towards/away) from the front of the participant with the target stimulus moving distally to proximally. Three sections of runway (2.24 m in total length) with the system's LED lights facing the participant were used and the target light was light #13. The sequentially lighted LED lamps illuminate in a linear pattern with movement occurring distally to proximally in front of the participant. For each trial, scores were recorded in seconds. Start and end speeds were five mph for all trials to represent medium stimulus speeds, as has been used in prior studies (Lobjois, Benguigui, & Bertch, 2006) using a random cue delay (minimum delay = one second, maximum delay = two seconds). Scores for each block of 10 trials were then summarised into a score for absolute error (the absolute value of each raw score disregarding whether the response was early or late) as a measure of timing accuracy. This is consistent with recognised protocols using coincidence timing (Sanders, 2011; Isaacs & Pohlman, 1991).

### *Statistical Analysis*

Data were analysed in a number of ways. Any changes in Mean power, RPE, heart rate and BLac were analysed using a series of two (condition) by four (time) ways repeated measures ANOVAs. However, data for both CAT and MD were non-normal (all the values are positive). To correct for skewness, the data set were log transformed as log transforming data in this way has been shown to overcome skewness in previous work (Winer, 1971; Lyons, Al-Nakeeb, & Nevill, 2008). Any differences in MD or CAT pre and post the MF or CON protocol were analysed using a series of two (condition) by six (time) ways repeated measures ANOVAs. Where significant differences were found, Bonferroni post-hoc pairwise comparisons were used to determine where the differences lay. Partial eta squared ( $\eta^2$ ) 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 and statistical significance was set, a priori, at  $p = 0.05$ . Data is reported as mean  $\pm$  SE.

### **Results**

Results indicated significant time main effects for RPE ( $p = .001$ , Partial  $\eta^2 = .825$ ), HR ( $p = .005$ , Partial  $\eta^2 = .505$ ), BLac ( $p = .0001$ ,  $P\eta^2 = .870$ ), and mean cycling power ( $p = .0001$ , Partial  $\eta^2 = .743$ ). There were no significant condition by time interactions of condition main effects for these variables (all

$p < .05$ ). Mean  $\pm$  SE and 95% Confidence Intervals for RPE, HR, BLac and Mean cycling power are presented in Table 1.

In regard to RPE, post-hoc analysis indicated that RPE following the first Wingate test repetition was significantly lower compared to RPE following the third ( $p = .014$ ) and fourth ( $p = .008$ ) repetition. Likewise, RPE following the second Wingate test repetition was significantly lower compared to RPE following the third ( $p = .001$ ) and fourth ( $p = .004$ ) repetition. HR data followed the same pattern with HR following the first Wingate test repetition was significantly lower compared to HR following the third ( $p = .04$ ) and fourth ( $p = .042$ ) repetition. Likewise, HR following the second Wingate test repetition was significantly lower compared to HR following the third ( $p = .006$ ) and fourth ( $p = .02$ ) repetition.

BLac values were significantly lower following the first repetition of the Wingate test compared to the second ( $p = .0001$ ), third ( $p = .001$ ) and fourth ( $p = .002$ ) repetitions. Mean cycling power was also significantly higher for the first Wingate test compared to the second ( $p = .009$ ), third ( $p = .02$ ) and fourth ( $p = .02$ ) Wingate test.

Results for MD revealed a significant condition by time interaction ( $p = .021$ , Partial  $\eta^2 = .306$ , See Figure 1). Post-Hoc analysis indicated that manual dexterity scores were significantly higher immediately post MF compared to immediately post Con ( $p = .03$ ) and following the first Wingate test in the MF condition compared to Con ( $p = .05$ ). Likewise, CAT scores were also significantly poorer immediately following MF and after each repeated Wingate test in the MF condition compared to the CON condition ( $p = .028$ , Partial  $\eta^2 = .328$ , See Figure 2).

## Discussion

This study sought to examine the impact of a period of mental fatigue on manual dexterity, anticipation timing and repeated high intensity exercise performance. This is the first study to date to examine the effect of mental fatigue on repeated high intensity exercise interspersed with tests of skilled performance. The results of the present study demonstrate that a 40-minute bout of continuous cognitive activity leading to mental fatigue did not significantly influence power output in repeated Wingate cycling exercise tests. Mental fatigue did however negatively affect manual dexterity and coincidence anticipation timing performance compared to a passive observation control condition.

These results are contrary to prior research by Marcora et al. (2009) and Brownsberger et al. (2013) that reported poorer physical performance following mental fatigue in time to exhaustion and self paced exercise tests respectively. Both authors suggested that a period of continuous cognitive activity prior to exercise leads to an up regulation of the perception of effort from afferent physiological information and negative associations to the sensation of mental fatigue prior to exercise (Brownsberger et al., 2013; Marcora et al., 2009). Supposedly, this leads to an altered perception of task difficulty in subsequent physical tasks resulting in poorer exercise performance. The results of the present study also disagree with research by Bray et al. (2012) that reported reductions in maximum force production in repeated maximal voluntary contraction of the hand flexor muscles.

However, the results of the present study do agree with recent findings by Pageaux et al. (2013) which documented no significant effect of a mental fatigue protocol on isokinetically determined maximal torque, voluntary activation level or peripheral parameters of neuromuscular activation during knee extension exercise.

To some extent the discrepancy between the results of the present study and prior research is not unexpected. This is because of the relatively scant research in this area and also because the present study employed an exercise task that differed in intensity and energetic demands compared to other research that has examined effects of mental fatigue on subsequent physical performance (Marcora et al., 2009; Brownsberger et al., 2013; Bray et al., 2012; Pageaux et al., 2013). To date few studies have examined the reciprocal association of cognitively effortful tasks after effects on exercise performance (Bray et al., 2012). As a consequence it is difficult to draw clear conclusions between the present study and prior research in this area. For example, the present study also employed a shorter mental fatigue protocol than had been used in prior work by Marcora et al., (2009) or Brownsberger et al. (2013). However, mental fatigue protocols of 22 minutes (Bray et al., 2012) have been shown to impair subsequent physical performance and protocols of 20 minutes (Faber et al., 2012) to impair cognition. Any dose-response type effect of mental fatigue on subsequent performance has therefore yet to be established. To date, no study has examined the effect of mental fatigue on high-intensity, anaerobically based, exercise performance. Such an exercise modality places a different bioenergetic demand on the human body compared to submaximal endurance exercise or isolated muscle performance

as have been studied in prior research on this area (Marcora et al., 2009; Brownsberger et al., 2013; Bray et al., 2012; Pageaux et al., 2013). Longer duration, submaximal exercise also results in increased plasma serotonin levels which can subsequently enhance motivation, mood and sensory perception (Davis, Alderson, and Welsh, 2000), reducing effects of central fatigue. However, this mechanism is not necessarily evident in the case of high-intensity, anaerobically based exercise (Parise et al., 2001) which is more likely to result in peripheral fatigue. This may therefore be an explanation for the discrepancy between the findings of the present study and prior work using predominantly aerobically based exercise. The protocol employed in the present study required participants to perform multiple high intensity cycling bouts against a fixed load interspersed with rest periods. By completing measures of manual dexterity and coincidence anticipation timing we also sought to develop work in the area as many sports involve both high intensity physical effort and skill related elements within the same phases or elements of game performance. In such a protocol, it may be less likely that the supposed altered perception of effort association with mental fatigue would be apparent as each exercise bout required the participant to exert maximum effort for a short period. Data relating to RPE, HR and Blac evidenced similar changes over repeated bouts in the MF and CON conditions in the present study, supporting the suggestion that the exercise protocol employed in the present study necessitated maximal effort. It is however important to note that the physiological (BLac) and perceptual (RPE) responses following the first repetition of the Wingate anaerobic cycling test as presented in Table 1, are lower than would be expected for a truly maximal

exercise test. Participants may therefore have potentially not attempted this first repetition as maximally as was possible.

However, the main novel contribution of the present study is that performance of manual dexterity and coincidence anticipation were negatively impacted by MF compared to control. No prior research appears to have examined the effect of mental fatigue on performance of these variables either in isolation or in conjunction with exercise performance. However, prior research has evidenced similar negative effects of mental fatigue on performance of related cognitive and perceptual skills including visual selective attention (Faber, Maurits, & Lorist, 2012), reaction time performance (Langner, Steinborn, Chatterjee, Sturm, & Willmes, 2009) and simulated driving performance (Fischer, Langner, Birbaumer, & Brocke, 2008).

The data presented in the current study, although mixed in relation to mental fatigue's effects on physical or perceptual and psychomotor performance, do align with the limited strength or ego depletion model proposed by Baumeister, Vohs, & Tice (2007). According to this model, self-regulating effort on one task can diminish effortful performance on subsequent tasks, provided both tasks require some form of emotional, cognitive or physical effort regulation. The ego depletion model has also been shown to be effective in explaining decreased physical performance following cognitive effort in both endurance and team games athletes (Dorris et al., 2012). Meta-analytical research by Hagger, Wood, Stiff, & Chatzisarantis (2010) has also evidenced that effort-induced resource depletion in one domain (e.g., emotion, cognition or behaviour) has strong, consistent performance-

deteriorating after effects on subsequent effortful tasks regardless of whether those tasks are in the same domain or dissimilar domains.

The results presented in the current study are important and may have implications in performance contexts that require maximal investment of effort. For example, manual labourers, competitive athletes and combat soldiers are often placed into cognitively demanding situations with subsequent performance of physical, perceptual or decision making tasks (Bray et al., 2012). Thus, although MF did not influence repeated high intensity exercise performance in the present study, the negative effect of MF on coincidence anticipation and manual dexterity following each exercise bout might imply that, where performance requires repeated high intensity physical effort combined with perceptual and psychomotor performance (e.g., in team games), overall performance would be diminished as a consequence of mental fatigue.

The present study does have some limitations. The manual dexterity and coincidence anticipation timing tasks used in the present study although valid laboratory measures of the constructs they purport to examine may not be directly transferable to tasks of daily life such as those used in sports performance or organisation settings. Although this limitation is applicable to all prior studies of this topic, future research would be useful which uses more domain specific performance tasks. For example, the effect of mental fatigue on subsequent team games performance could be examined using sport specific physical and skill protocols. Likewise, the number of participants used in the present study might be considered low. It is also worth considering, in practical terms, that recruitment of participants to studies involving periods of

prolonged mental vigilance is potentially difficult because of the nature of the fatigue task rather than a lack of available potential participants. However, given the trained nature of the participants employed, high participant burden in terms of time commitment needed to participate and the need for participants who could perform multiple bouts of high intensity exercise, larger participant numbers were not realistic given the exploratory nature of this study. The participant numbers in the current study are also commensurate with some prior studies of the same topic (Pageaux et al., 2013).

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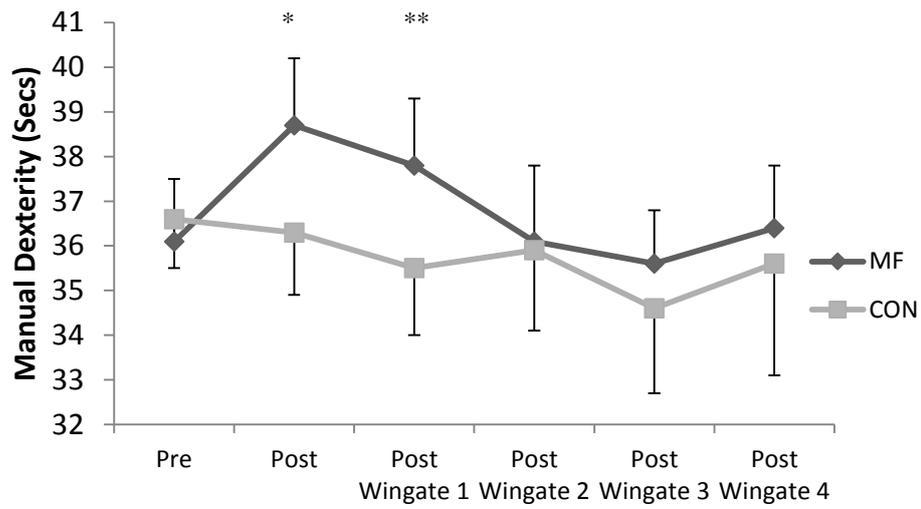


Figure 1. Mean  $\pm$  SE. of Minnesota Manual Dexterity Test scores (Secs) pre, immediately post and post 4 repeated Wingate tests in mental fatigue (MF) and control (Con) conditions. \* P = .03, \*\* P = .05.

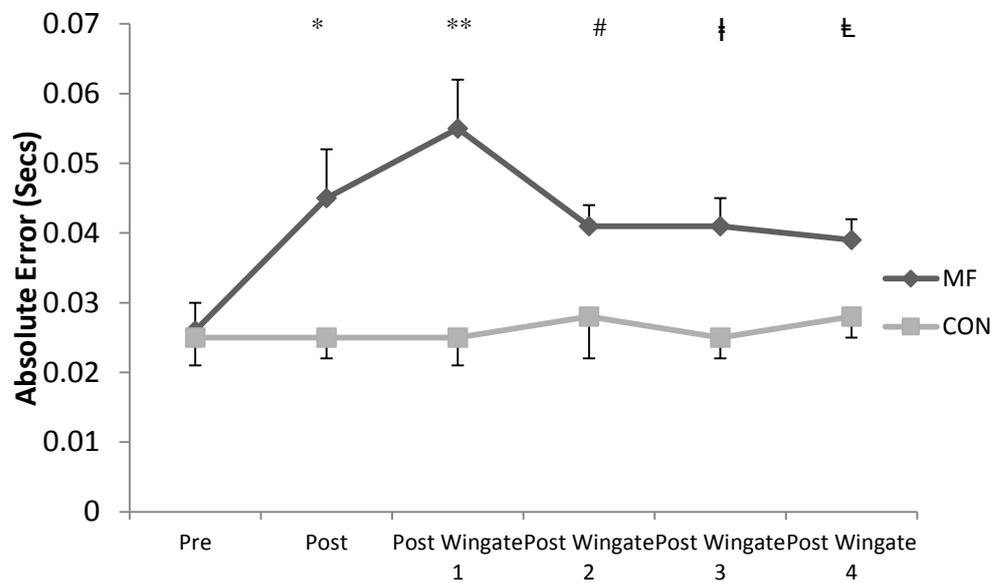


Figure 2. Mean  $\pm$  SE. of Absolute Error (SECS) pre, immediately post and post 4 repeated Wingate tests in mental fatigue (MF) and control (Con) conditions. \*  $P = .05$ , \*\*  $P = .021$ , #  $P = .012$ , †  $P = .002$ , £  $P = .04$ .