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Kayaking performance is altered in mentally fatigued young elite athletes

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Abstract

The present study aimed to assess the impact of 60 min of a cognitive demanding task inducing mental fatigue (Stroop) on kayaking performance in young elite athletes. The second objective was to elucidate the effect of mental fatigue on performance in a population of young under-17 elite athletes of national. Thirteen under-17 elite kayakers completed 60 min of an incongruent Stroop color-word test, or the equivalent time in a control condition in a cross-over study design. Afterwards, participants completed a 2000 m kayaking time trial in which power output, stroke rate and time at the end of 400, 800, 1200, 1600 and 2000 m were recorded. Physiological and perceptual measures of heart rate (HR), blood lactate and rating of perceived exertion (RPE) were collected during the time trial. Psychological questionnaires were used to assess fatigue and mental demand of the Stroop. Subjective ratings of mental fatigue following the Stroop were almost certainly higher. Results of the time trial suggested that mental fatigue almost certainly impaired power output, stroke rate and time (552± 30 s) compared to the control (521± 36 s) condition. Yet, during the time trial RPE was almost certainly higher in the mental fatigue condition, while HR was reported to be possibly lower. Blood lactate resulted almost certainly lower in the mental fatigue state at completion of the time trial (10.3±1.5 vs 12.2±1.6 mmol$\cdot$L^{-1}). In conclusion, mental fatigue has an almost certain negative impact on 2000-m kayaking performance in young elite athletes.

Key words: cognition, perception, RPE, endurance performance, mental fatigue.

Introduction

In the past decade in the sport world, it has drastically increased the attention and the interest for cognitive processes relating to sport performance [1]. The brain has begun to play such a central role as ultimate challenge in the sport domain that it has pushed exercise scientists to expand and combine their knowledge with other areas of expertise such as neurophysiology [1].

Particular attention have been given to the role that mental fatigue has on subsequent physical performance [2]. Defined as a psychobiological state caused by prolonged periods of demanding cognitive activity [3], mental fatigue has been proved to produce a deleterious effect on several types of physical exercises [2]. Endurance performance [3-5] as well as intermittent running and repeated sprint ability [6] studies have revealed the negative impact that previously induced mental fatigue has on physical exercise. Instead, mental fatigue does not seems to alter anaerobic and maximal power/force performance [7].

Despite the significant detrimental impact that mental fatigue can have on the physical domain, it is still debated and often overlooked its importance in the sport context and more in particular in the elite world. This may be due to the fact that previous research involved mainly sedentary or well-trained participants [2, 8]. Very few studies have used elite or experienced athletes as participants. Martin et al [7] was the first to investigate if elite athletes would be affected differently by mental fatigue compared to amateurs in a cycling time trial. In that study it has been revealed that elite cyclists were more resilient and resist more to mental fatigue compared to amateur ones when the cognitive stimulus inducing mental fatigue was 30 min long [7]. It was hypothesized that elite athletes are characterized by a higher inhibitory control that might be both genetically in origin and/or developed during many years of sport practice.

It is not clear whether young elite athletes behave similarly and possess the same attitude. However, very recently it has been questioned whether a given cognitive task (of a certain duration) is sufficient to induce significant mental fatigue [8]. Therefore, very little is known on the effect of mental fatigue on particular population such as elite athletes. Furthermore research conducted so far has mainly focused on cycling, running, swimming and football performance, while other sports (both team and individual), characterized by an endurance component, still lack of evidence upon the detrimental effect that mental fatigue can have on specific performance.

The amount of controlled studies testing the effects of mental fatigue on performance is still scarce and even reviews and meta-analysis carried out thus far cannot clearly show the net detrimental effect of mental fatigue [8]. Therefore, more research and even replication studies seem to be necessary to increase the knowledge in this field.

Kayak is a sport characterised by exceptional demands on upper body performance and the importance of the aerobic and anaerobic system is very well known [9, 10]. In fact, several studies suggest that Olympic kayak paddlers not only need a high aerobic power, but the anaerobic contribution is also very important for successful performance [11, 12]. Many studies have been conducted identifying the physical demand of this sport [9, 13], however no studies have been previously conducted on the effect of mental fatigue on this particular sport where a combination of aerobic/anaerobic capacity and upper/lower limbs actions are involved.

The main aim of this study was to test the hypothesis that 60 min of a highly demanding cognitive task inducing mental fatigue produces a reduction in a simulated 2000 m kayaking performance test in young elite athletes.

Moreover, the second aim of this study was to determine if mental fatigue would affect performance in a population of young under-17 elite athletes of national level. As pointed out in Martin et al.'s study [7], elite athletes were immune to 30 min of a mentally demanding cognitive task probably due to the amount of physical and cognitive training they were exposed during many years. In the present study we investigated if the assumption proposed by Martin at al.[7] are still valid even in young under 17 athletes.

Methods

Participants

Thirteen elite kayakers from the under -17 national team (16.4±0.8, years, 60.7±7.0 kg, 172.5±7.2 cm, ~5 training sessions per week, an average of 5 years of kayaking experience) signed an informed consent form describing the study protocol and possible discomfort which was approved by the Institutional Review Board of the department where the study was conducted according to the Declaration of Helsinki for the Human Rights. Given the age of participants a parent or the responsible of the parental authority for each participant also signed the informed consent. All participants received written instructions describing study procedures but were naive to its true aims and hypotheses. At the end of the final visit, participants were debriefed and asked not to discuss the real aims of the study with other participants.

Experimental Protocol

A randomised crossover design was used for the present study. The order of the experimental treatment (mental fatigue/control or control/mental fatigue) was allocated in random order based on balanced permutations generated by a web-based computer program (www.randomization.com). Participants were required to visit the laboratory on 3 occasions, in a period no longer than 2 weeks between the first and last visit. Testing during visits 2 and 3 (experimental visits) was completed at the same time of the day. The first visit acted as familiarization in which participants became familiar with the Stroop task and all the psychological, perceptual and physiological measures. During visits 2 and 3, participants completed the baseline mood and motivation questionnaire, followed by either the Stroop task or the control task. Afterwards they filled in the subjective workload and again the mood questionnaires. Participants were then moved to the kayak ergometer where they completed a standardized warm-up and a 2000 m time trial.

Prior to visits 2 and 3, participants were instructed to drink 35 ml of water per kilogram of body weight, sleep for at least 7 h, refrain from the consumption of alcohol, and avoid any vigorous exercise the day before visiting the laboratory. Participants were also instructed to avoid any caffeine and mentally demanding tasks for at least 3 h before testing. The day of visit 2, participants were asked to record the time and content of the meals consumed before testing, and to keep them consistent the day of visit 3. At the beginning of visits 2 and 3, participants were asked to complete a checklist to ascertain that they had complied with the instructions given to them. Participants were also asked to declare if they had taken any medication/drug or had an acute illness, injury, or infection on the day.

Experimental treatment

In the mental fatigue condition participants completed a 60-min modified incongruent version of the Stroop colour-word task. Participants performed this cognitive task at a computer, whilst sitting comfortably in a quiet, dimly lit room. This Stroop task consists of four words (yellow, blue, green, red) serially presented on the computer screen, displayed until the participant responded, followed by a 1.5 s rest interval. Participants were instructed to press one of four coloured buttons on the keyboard (yellow, blue, green, red), with the correct response being the button corresponding to the ink colour (either yellow, blue, green, red) of the word presented on the screen. For example, if the word blue appeared in yellow ink, the yellow button had to be pressed. If, however, the ink colour was red, the button to be pressed was the button linked to the written word, not the ink colour (e.g. if the word blue appears in red, the button blue was to be pressed). If the ink colour was blue, green or yellow, then the correct button pressed matched the ink colour. The word presented and its ink colour was randomly selected by the computer. Twenty practice attempts were allowed to ensure the participant fully understood the instructions. The Stroop task was also performed for 5 min during familiarization in visit 1. Participants were instructed to respond as quickly and accurately as possible. Visual feedback was given after each word in the form of correct or incorrect response, reaction time, and accuracy so far.

Control

The control condition consisted of watching a neutral documentary on cars and trains performed under the same conditions as the Stroop task. Participants were instructed to sit quietly in front of the computer screen for 60min.

Familiarization Test and Time Trial

During the first visit, participants underwent a familiarization exercise test. The exercise test was completed on a kayak ergometer (Speed Stroke Gym, Kayak-Pro, USA). Participants completed the time trial during each of the other 2 visits to the laboratory. A standardised warm-up was completed by all participants prior to each time trial using the same ergometer utilized for the familiarization visit. The time trial was then completed on the same ergometer. All the ergometers were fitted to replicate the same participants' positions. Participants were instructed to complete 2000 m as fast as possible. A fan was placed behind the timer at a standardized position and turned on at the end of the warm-up and was on during all time trial, and water was provided ad libitum. During visits 2 and 3, a researcher who was blind to the experimental treatment received by the participants provided verbal encouragement throughout the test. This researcher was consistent within participants. Another researcher recorded power output, stroke rate and time at the end of 400, 800, 1200, 1600 and 2000 m of the time trial.

Physiological and Perceptual Measures

Capillary blood samples were collected at rest, at completion of warm-up and time trial during visits 2 and 3. Samples were analysed immediately for blood lactate concentration using a portable blood lactate analyser (Lactate Pro, Arkray, Japan). During visits 2 and 3, heart rate was recorded at the end of the warm-up, and during the final 15 s of the 400, 800, 1200, 1600 and 2000 m of the time trial using a heart rate monitor fitted with a chest strap (Polar Team 2 and Polar T34 non-coded heart-rate transmitter, Polar, Finland). Rating of perceived exertion (RPE) was measured using the Borg 6–20 scale [14]. During visit 1, RPE was introduced to participants using standard procedures and anchoring [14]. During visits 2 and 3, RPE was measured at the end of the warm-up, and during the final 15 s of the 400, 800, 1200, 1600 and 2000 m of the time trial. At the appropriate time point, participants were asked to point on a large Borg 6–20 scale the number corresponding to their perception of effort defined as “the conscious sensation of how hard, heavy, and strenuous exercise is”.

Psychological Measures

Subjective workload

The National Aeronautics and Space Administration Task Load Index (NASA-TLX) [15] was used to assess subjective workload of the cognitive tasks. The NASA-TLX is composed of six subscales: mental demand (How much mental and perceptual activity was required?), physical demand (How much physical activity was required?), temporal demand (How much time pressure did you feel due to the rate or pace at which the task occurred?), performance (How successful do you think you were in accomplishing the goals of the task set by the experimenter?), effort (How hard did you have to work to accomplish your level of performance?) and frustration (How irritating or annoying did you perceive the task?). Participants were asked to score each of the items on a scale divided into 20 equal intervals anchored by the bipolar descriptors high and low. This score was multiplied by 5, resulting in a final score between 0 and 100 for each of the subscales. Regarding the subscale of success, the value on the sheet was then inverted as mention in the instructions of the NASA-TLX [15].

Mood

The Brunel Mood Scale (BRUMS) developed by Terry et al. [16] was used to assess changes in mood from the beginning to the completion of the cognitive tasks of visits 2 and 3. This questionnaire, which is based on the Profile of Mood States, contains 24 items (e.g., angry, uncertain, miserable, tired, nervous, energetic) divided into six respective subscales: anger, confusion, depression, fatigue, tension, and vigor. The items are answered on a 5-point Likert scale (0 = not at all, 1 = a little, 2 = moderately, 3 = quite a bit, 4 = extremely), and each subscale, with four relevant items, can achieve a raw score in the range of 0 to 16.

Motivation

Motivation related to the time trial was measured using the success motivation and intrinsic motivation scales developed and validated by Matthews et al. [17]. Each scale consists of 7 items (e.g., “I want to succeed on the task” and “I am concerned about not doing as well as I can”) scored on a 5-point Likert scale (0 = not at all, 1 = a little bit, 2 = somewhat, 3 = very much, 4 = extremely). Therefore, total scores for these motivation scales range between 0 and 28.

Statistical Analysis

Data are presented as mean ± SD unless otherwise stated. The effects of mental fatigue on performance, physiological, biomechanical and perceptual responses to exercise were tested using the magnitude-based inference (MBI) approach [18] by means of definite spreadsheets [19]. The effect statistic was the difference between the two conditions (mental fatigue condition minus control condition).Chances that the true effect (90% confidence limits) was harmful, trivial or beneficial were quantitatively estimated and then discussed using qualitative descriptors (<1%, almost certainly not; 1-5%, very unlikely; 5-25%, unlikely; 25-75%, possibly; 75-95%, likely; 95-99%, very likely; >99%, almost certainly). When an effect could be both positive and negative (that is with its confidence limits overlapping the thresholds for substantiveness more than 5% in both directions) was considered unclear. A smallest worthwhile (important) change for an outcome measure has to be defined a priori when the MBI approach is used; the smallest important change for time trial performance was set at 1% while a smallest standardized change was assumed to be 0.20 [20] for the other dependent variables (e.g. heart rate, RPE, etc.). The standardized difference in means (the mean difference divided by the between–subject standard deviation) was used as measure of effect size (ES) [21]. Threshold values of 0.20, 0.60, 1.20, 2.0 and 4.0 were considered as small, moderate, large, very large and extremely large respectively.

Results

Performance and biomechanical measurements

Kayaking performance (Fig 1) was almost certainly worsened after the mental fatigue task (552 ± 30 s) compared to control (521 ± 36 s) with a mean increase in time to complete the 2000 m time trial by 5.7% (ES = - 1.03 ± 0.25).

The effect of mental fatigue determined almost certainly lower power outputs at all the 400 m fractions (with moderate and large effect sizes) (Fig 6 a); only at the end of the 2000 m time trial there was a very likely lower power output in the mental fatigue condition (ES = -0.53 ± 0.24). Similarly stroke rate was very likely negatively affected during the 200 m time trial under mental fatigue (effect sizes from moderate to large) (Fig 6 b).

Psychological measurements

Apart from the possibly and likely higher state of tension (ES = -0.30 ± 0.42) and confusion (ES = 0.44 ± 0.48) respectively and the possibly lower state of anger (ES = 0.39 ± 0.47) prior to commencing the baseline stroop test during the experimental condition (Mental Fatigue), all the other items of mood resulted similar between the two conditions (Fig 2 - Pre). On the contrary, almost certainly and very likely higher state of confusion (ES = 0.97 ± 0.44), anger (ES = 0.86 ± 0.55), depression (ES = 0.85 ± 0.63) and fatigue (ES = 1.01 ± 0.49), accompanied with a very likely lower state of vigor (ES = -0.89 ± 0.65), were observed in the BRUMS completed after the mental fatiguing task (Fig 2 - Post). The experimental treatment affected the subjective workload (Fig 3) (effect statistics from possibly to almost certainly) resulting higher compared to the control condition with effect sizes for the single items ranging from moderate (physical demand, ES = 0.58 ± 0.51) to very large (mental demand, ES = 1.89 ± 0.45). A trivial effect statistic for intrinsic (experimental 21.9 ± 2.5 a.u, control 21.8 ± 2.5 a.u., ES = 0.06 ± 0.30) and success (experimental 15.3 ± 4.9 a.u, control 15.5 ± 4.5 a.u., ES = -0.04 ± 0.30) motivations was seen.

Physiological and perceptual measurements

Blood Lactate concentration (Fig 4) was possibly higher (ES = 0.15 ± 0.20) at baseline during the experimental condition but resulted almost certainly lower (ES = - 1.09 ± 0.36) during the same condition at the end of the 2000 m time trial compared to control. A likely lower heart rate (Fig 5 a) with moderate effect sizes (ranging from -0.28 ± 0.25 to -0.44 ± 0.30) was recorded every 400 m during the experimental condition; heart rate at 2000 m was possibly lower with a moderate ES (-0.29 ± 0.25) during mental fatigue. On the contrary, RPE (Fig 5 b) was from possibly to almost certainly higher (with moderate effect sizes) every 400 m when the participants were under mental fatigue but at the end of the time trial where a possibly lower perception of effort was recorded (ES = -0.33 ± 0.44).

Discussion

The main aim of this study was to determine if mental fatigue, induced by 60 min Stroop task would affect performance on 2000 m kayaking time trial in young elite athletes. The outcome confirms our hypothesis that mental fatigue produced a detrimental effect on kayaking performance as we have observed in time, power output and stroke rate during the time trial. As stated in a recent review and meta-analysis [22] a possible random error could explain the negative effects of cognitive tasks prior to physical performance in several studies published up to now. For this reason, our study, using a modern contemporary statistical approach [18], showed a strong negative effect of mental fatigue on kayak endurance performance and contributes to the enrichment of the knowledge upon the relation between mental fatigue and physical performance.

Psychological markers of mental fatigue

Participants showed the same level of motivation during the two conditions; this finding excludes any potential effect of this important component on performance, physiological and all the other psychological variables. Given the high level of athletes involved, we managed to keep similar high level of motivation through encouragement and in particular by underlining that performance would be compared with the ones from the others team mates [23].

Mood assessed before the experimental and control treatment was nearly identical except for few items. In particular, tension and confusion seemed marginally higher the day of the experimental treatment compared to control while anger evidenced an opposite tendency on the same day. Although the chances for these differences were low (with small to moderate effect sizes), it can be hypothesized that they could be attributed to the uncertainty and concern for the completion of the experimental task. Indeed, participants, due to the previous familiarization, were aware of the characteristics of the task and the relatively long time to spend for its accomplishment. On the other way, results of the BRUMS after the experimental task were those typical of a state of mental fatigue and consistent with previous literature [4, 5]. Higher states of confusion, tension, depression, fatigue and a lower vigor were evident signs of mental fatigue induced by the performance of a highly demanding cognitive task such as 60 minutes of the stroop color task. Furthermore, the NASA TLX questionnaire showed a nearly identical perceived physical demand on the two occasions but with all the other cognitive items higher during the experimental condition. Altogether, from a psychological point of view, the experimental task effectively induced mental fatigue in the participants.

Prior studies where the effect of mental fatigue on physical performance were investigated showed similar results to the present study for what concerns the psychological questionnaires [4, 5].

Effect of mental fatigue on time trial performance and pacing

As described above, mental fatigue was successfully induced in the participants the day of the experimental treatment and this led to a decrease in performance by almost 6%. Previous research on the effect of mental fatigue on 3000 m running time trial [24] showed a decrease in performance around 2%. Similarly, other authors, showed that 5000 m running performance was decreased by about 5% after a response inhibition task [5]. In addition, a further study in which swimming was used as exercise modality reported the detrimental effect by 1.2% of mental fatigue on performance [25]. Although different kind of exercises (running and swimming versus kayaking), these seem to be the only studies where the effects of mental fatigue on whole body time trial performance were investigated.

It deserves to be highlighted that in the present study, compared to that of MacMahon et al. [24] and Penna et al. [25], there was a higher detrimental effect of mental fatigue despite a shorter duration of the mental fatigue task preceding the physical exercise (60 min Stroop color task versus 90 minutes AX CPT). There may be two reasons for this difference. Firstly, although the Stroop task and the AX CPT task share similarities in terms of the cognitive functions they target in the brain, they used different paradigms which suggest they may produce different effects in the brain [26]. So it can be speculated that 60 min of Stroop, well known for its strong inhibitory component [26] may induce similar amount of mental fatigue as using 90 min of AX CPT Task. Furthermore, it cannot be excluded that 30 min of Stroop task prior to swimming performance [25] were not enough to cause high levels of mental fatigue.

However, another relevant difference is the younger age of the participants of the present study (around 16 compared to 25 years old). This might suggest that young athletes are more mentally fatigable than adults. It can be speculated that young individuals are less trained to tolerate cognitive tasks compared to adults; this is because adults received a larger bulk of cognitive stimuli during their lifespan [27].

Pacing strategy was similar in the two conditions and was a parabolic-shaped pacing; this means that mental fatigue did not affect strategy used by athletes to pace themselves during the time trial. An additional reason why elite kayakers showed unaffected pacing strategy may be due to the fact that they are used to this type of exercise.

Those results are in line with the one from MacMahon [24]and Pageaux [5]. When the kayakers underwent the time trial in the mental fatigue condition were constantly exercising at a lower power output (Fig 6). Due to the characteristics of the kayaking and the ergometer used to simulate the 2000 m time trial, it was possible to detect that the lower power output entailed by the mental fatigue condition was caused by a lower stroke rate. It seems that mental fatigue influences negatively, at least in kayaking, the frequency of the actions. Those results are in line with a previous study [28] showing that a combination of physical and cognitive fatigue affected cadence during a cycling time to exhaustion test.

Stroke rate is a paramount component of kayaking performance and it has to be kept as high as possible during the competition to keep a constant speed on the boat [29]. However, higher stroke rate demands significantly higher power output from muscles [29]. Therefore, if the stroke rate is impaired, subsequently also performance will be affected.

As previous studies on mental fatigue and physical performance have not measured pacing components such as stride and frequency in running or gear-changing and cadence in cycling, this is the first study, to the best of our knowledge, measuring the effect of mental fatigue on pacing components during a time trial performance.

Effect of mental fatigue on physiological responses to exercise and RPE

As expected heart rate and RPE increased over time during the time trial and this is consistent with previous research [4, 5, 24, 25] but, differently to previous studies, in the present study a lower heart rate was encountered in the presence of mental fatigue. Considering the lower power output, it is evident that the physiological response was lower in the mental fatigue condition compared to the control. Moreover, blood lactate provided a similar trend across each visit and between the two groups in line with previous studies [3], showing that, at exhaustion, it was almost certainly higher in the control condition, most likely because of the higher power output produced.

However this was not sufficient to reduce RPE: perception of effort is in large part dependent by the central motor command [30] and therefore we should have expected a lower RPE but this was not the case. The main reason is that mental fatigue altered perception of effort as suggested in previous studies both during time trial and time to exhaustion [3-5]. The large effect of mental fatigue on perception of effort seen in the present study is suggested by the higher RPE in the mental fatigue condition.

The mechanism underpinning this finding has to be ascribed to the areas of the brain involved during the cognitive task (namely the Stroop color task performed prior to exercising) and the physical task (the 2000 m kayaking performance). As described in previous works [3-5, 7], both types of tasks requires high level of effort and such effort (either physical or cognitive) seems to share similar brain areas in terms of activation and neurotransmitters modulation. Anterior cingulate cortex (ACC), motor cortex and supplementary motor area (SMA) seem to be heavily involved in generating perception of effort [3]. Thus, previously activation of those areas using 60 minutes of cognitive task is likely to produce alterations in those areas. It is therefore evident that this sort of "deficiency" has an effect on the successive activation of this area during the physical task. The result is a detrimental effect on the perception of effort (RPE) during the physical task, that is a higher RPE for the same power output when a time to exhaustion is performed [3] or a lower power output for the same RPE in time trials performance [5].

In the present study the huge effect of mental fatigue caused by the cognitive task yielded an even worse and unexpected outcome: an even higher RPE with a lower power output during the experimental condition. In practical terms, as locomotor muscle fatigue *"per se"* decreases physical performance [31], performing a cognitive task is a kind of fatiguing exercise for the brain that decreases physical performance. These two outcomes are both mediated by a higher perception of effort.

As suggested in previous study and confirmed by the results in the present study, RPE seems to ultimately mediate the outcome of performance. According to the psychobiological model proposed by Marcora and colleagues [3, 31-33] exercise performance in time trial tests is determined by five factors:

1. Potential motivation, defined as the maximum effort an individual would be willing to exert in a physical task [34].
2. The Perception of Effort, defined as the conscious sensation of how hard, heavy, and strenuous exercise is [32].
3. The subject's memory of the effort perceived during previous exercises of different intensities and durations.
4. The subject's knowledge of the total time trial time/distance to cover, which refers to the awareness of the time, speed or power needed to complete the task and to plan the suitable strategy to complete the task in the shortest time.
5. The subject's awareness of the elapsed time/distance remaining, which refers to the feedback given on the time/distance remaining to complete the task.

If we consider that in the present study, motivation did not change across the visits. Given that factors 3, 4 and 5 related to previous knowledge and experience in the specific performance test did not impact performance through pacing as our elite young athletes have had multiple years of experience and practice in performing this specific test. Perception of effort resulted to be the only parameter that ultimately affected performance in the current study.

Mental fatigue and elite athletes

Results in the current study showed that mental fatigue affected time trial performance in elite young athletes. Previously, only one study has been published which compared effect of mental fatigue on both elite athletes vs amateur cyclists [7]. In that study mental fatigue induced by 30 min of Stroop task did not affect cycling performance in elite cyclists while, instead, impaired the performance in amateur ones. Our results are contradictory to those ones by Martin et al.[7]. A possible explanations could be that cyclists in the study by Martin and colleagues [7] were exposed to only 30 min of Stroop test instead of 60 min as we did in our study. So it may be argued that 30 min of a cognitive demanding task may be enough to induce mental fatigue and produce a negative effect of performance in amateurs, while for elite athletes is probably not sufficient. It can be speculated that if cyclists in Martin`s study [7] would be exposed to 60 min of Stroop task, that could have probably produced a detrimental effect in the time trial performance as we saw in our current study. In support of this theory, it is interesting to point out that in the study by Pageaux et al. [5] the effect of 30 min of Stroop task entailed a decrease of 5% in performance in amateur runners, while in the current present study elite athletes needed to undertake 60 min of Stroop task to produce a similar detrimental effect on the performance (about 6 %).

As speculated my Martin and colleagues [7], elite athletes may be more resilient to mental fatigue due to high intensity and volumes of training they are exposed over years or practice, due to a more self-regulated types of life (training routines, diet and so on) and genetic factors.

Conclusion

This investigation proved that 60 min of cognitive demanding task inducing mental fatigue affected kayaking performance in elite young athletes. This study is the first of its kind to use kayaking as measure of sport performance and it may be beneficial for all scientists and coaches interested in the cognitive aspect of kayak related to performance. Moreover, the present study is the first to show that mental fatigue might affect in a peculiar way also biomechanical parameters related to performance such as stroke rate as previously studies has never put attention on it. Lastly, this research is the first one using a young sample (under 16) of elite athletes to test the effect that mental fatigue has on their kayaking performance.

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Conflicts of interest The authors declare none conflicts of interest

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Figures captions

Figure. 1 Effect of mental fatigue on 2000 m kayak performance. The black circles represent the mean values while the white circles the individual values. Data are presented as mean ± SD. The diamond (on the right hand side of the graph) represents the mean difference between the two conditions with the 90% confidence limits. #### almost certainly negative effect of mental fatigue on performance.

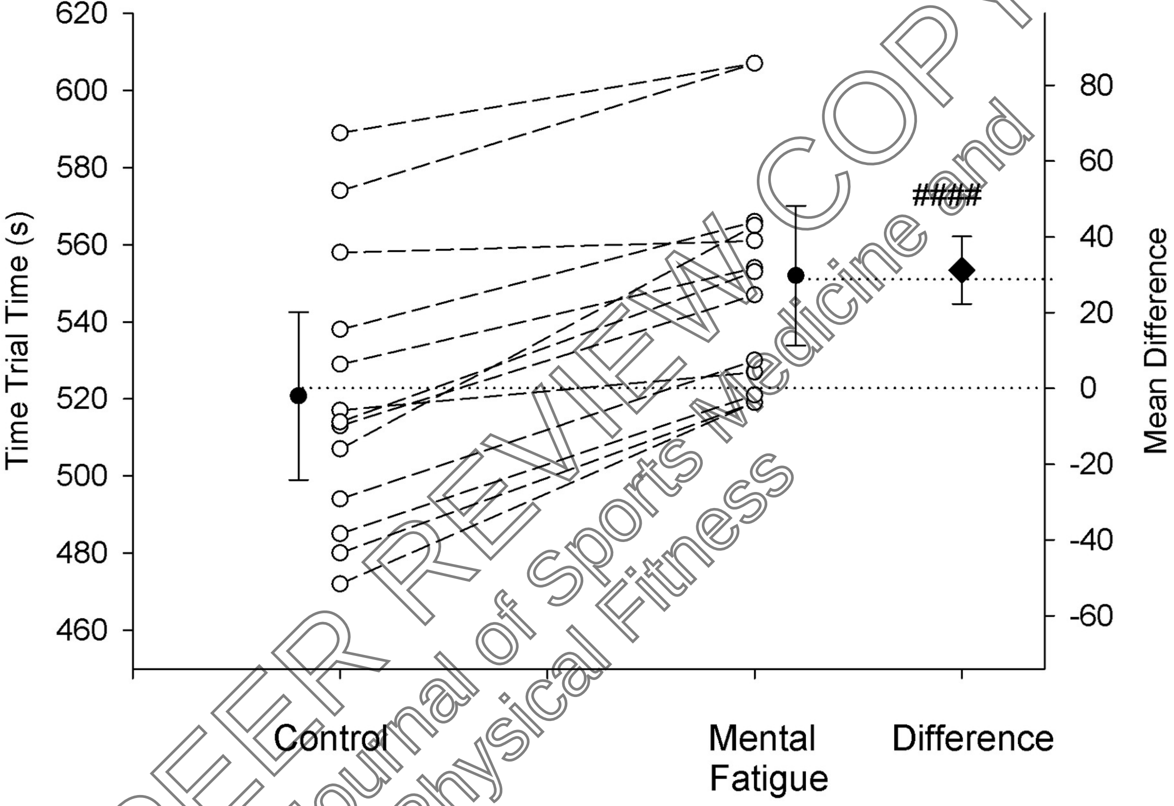
Figure. 2 The profile of mood state. The profile of mood state before (BRUMS Pre) and after (BRUMS Post) either the experimental intervention consisting in 60 minutes of Stroop color task (Mental Fatigue) or the control condition consisting in watching 60 minutes of an emotionally neutral video (Control). Qualitative chances that the true value of the statistic is practically negative or positive: # possibly, ## likely, ### very likely, #### almost certainly. When the chances are trivial or unclear no descriptor is highlighted on the comparison present in the graph.

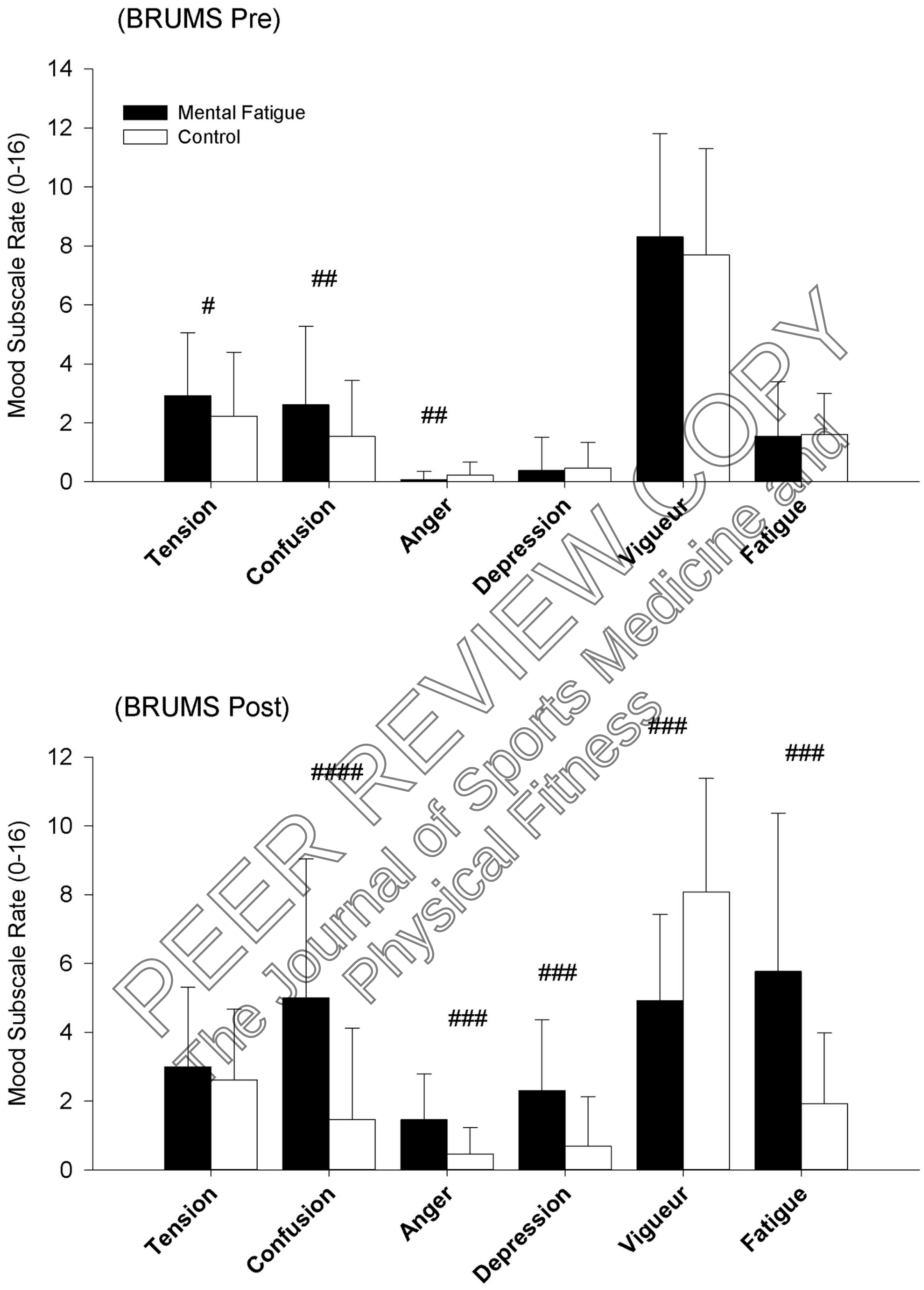
Figure. 3 The NASA-TLX questionnaire. The effect of mental fatigue on the subjective workload assessed after the 2000m kayak performance in both conditions (Mental Fatigue and Control). Qualitative chances that the true value of the statistic is practically negative or positive: # possibly, ## likely, ### very likely, #### almost certainly. When the chances are trivial or unclear no descriptor is highlighted on the comparison present in the graph.

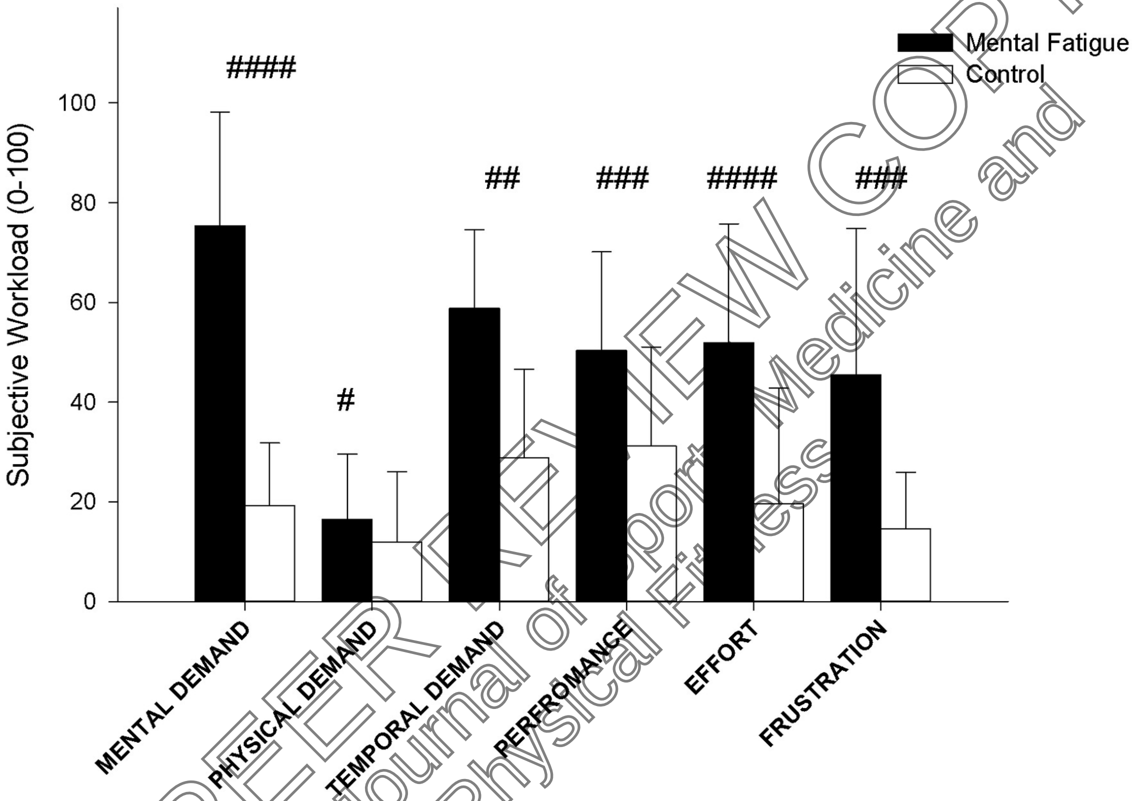
Figure. 4 Blood Lactate concentration. Comparison of the blood lactate concentration between the experimental (Mental Fatigue) and control condition. Qualitative chances that the true value of the statistic is practically negative or positive: # possibly, ## likely, ### very likely, #### almost certainly. When the chances are trivial or unclear no descriptor is highlighted on the comparison present in the graph.

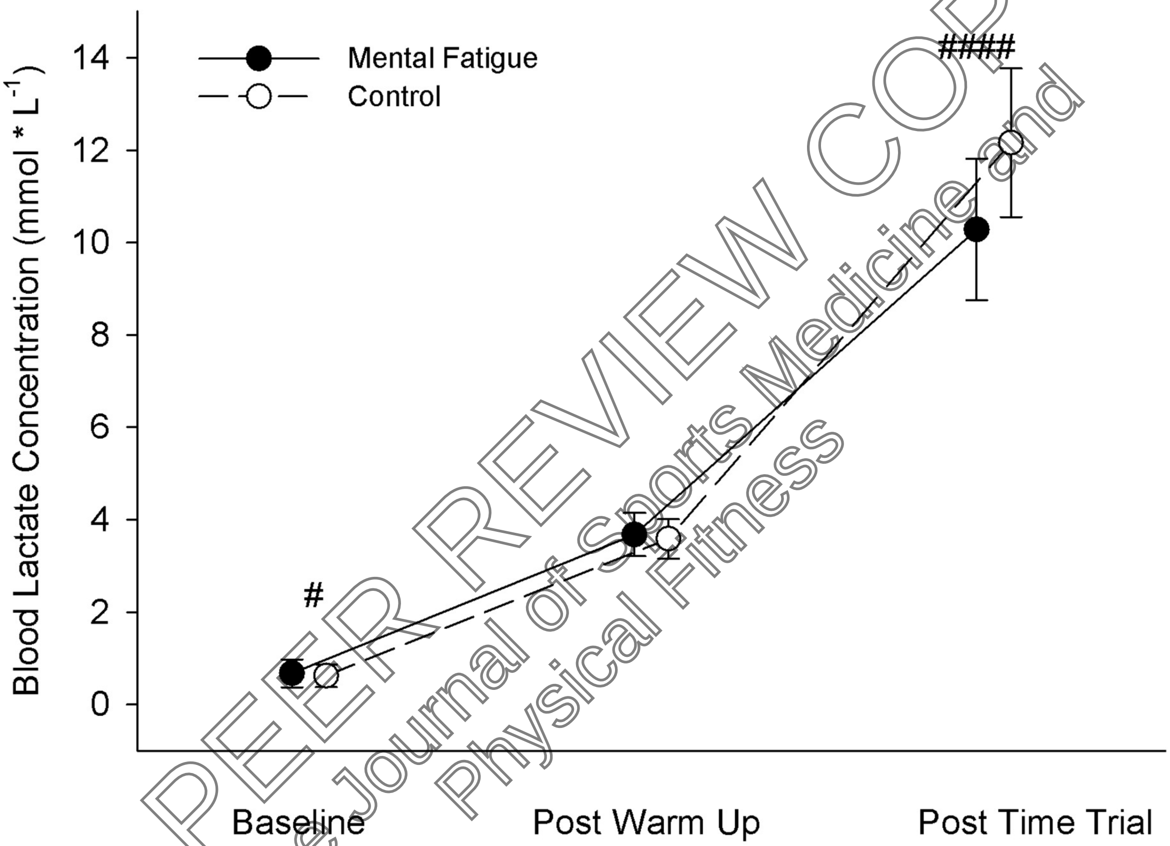
Figure. 5 Heart rate and RPE during time trial. The effect of mental fatigue on heart rate (panel a) and perception of effort (panel b) assessed every 400m during the 2000m kayak performance. Qualitative chances that the true value of the statistic is practically negative or positive: # possibly, ## likely, ### very likely, #### almost certainly. When the chances are trivial or unclear no descriptor is highlighted on the comparison present in the graph.

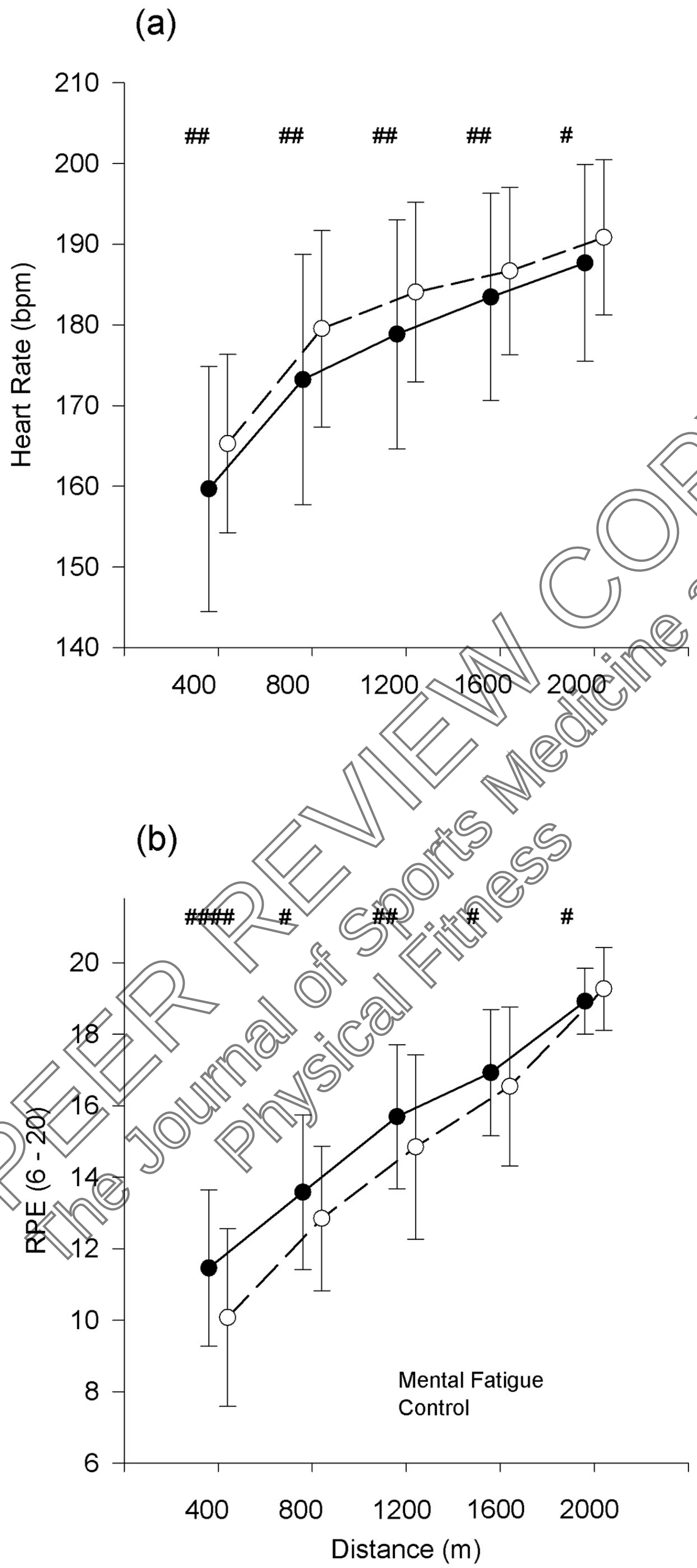
Figure. 6 Biomechanical parameters during time trial. The effect of mental fatigue on power output (panel a) and stroke rate (panel b) assessed every 400m during the 2000m kayak performance. Qualitative chances that the true value of the statistic is practically negative or positive: # possibly, ## likely, ### very likely, #### almost certainly. When the chances are trivial or unclear no descriptor is highlighted on the comparison present in the graph.

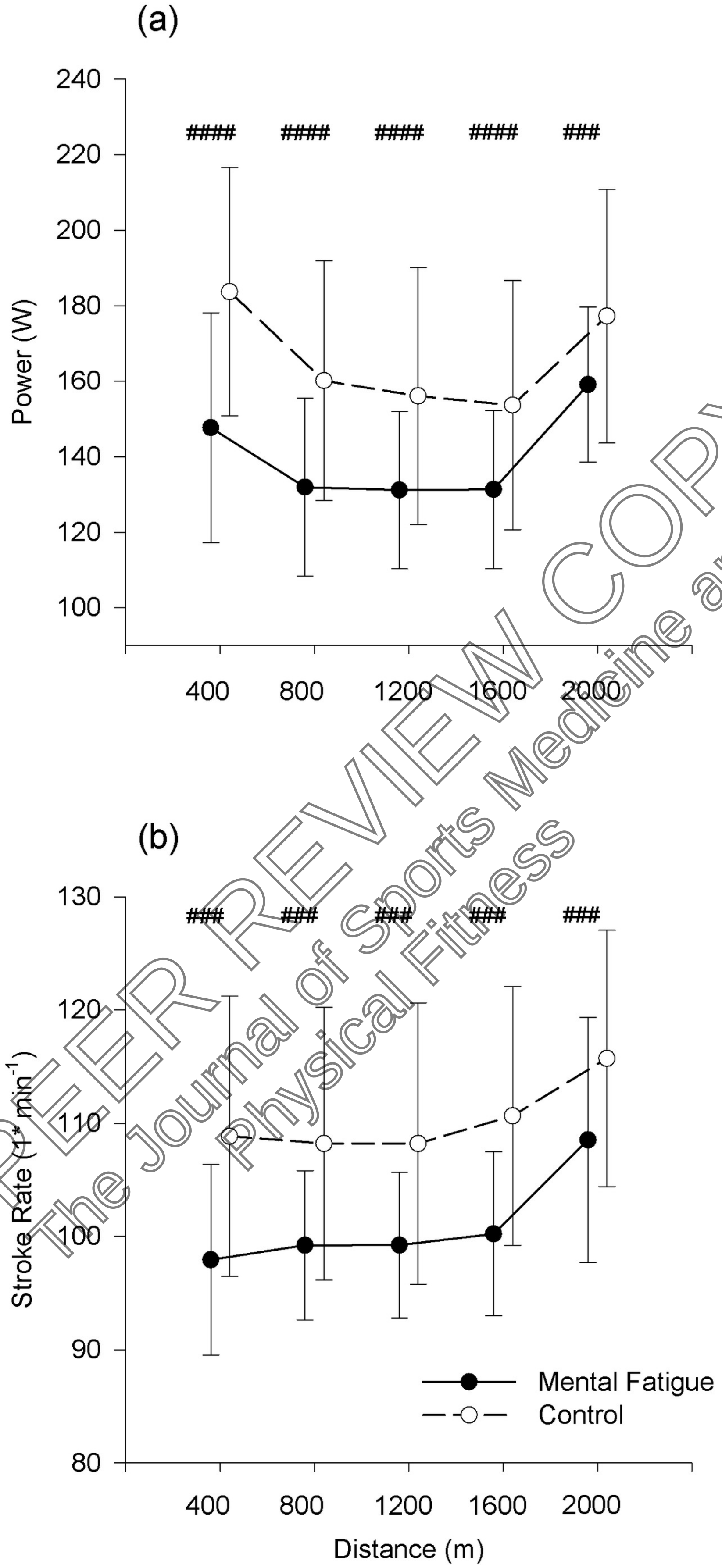

620
600
580
560
540
520
500
480
460
Time Trial Time (s)
####
80
60
40
20
0
-20
-40
-60
Mean Difference
Control
Mental Fatigue
Difference


(BRUMS Pre)
Mood Subscale Rate (0-16)
0
2
4
6
8
10
12
14
Mental Fatigue
Control
#
##
##
Tension
Confusion
Anger
Depression
Vigueur
Fatigue
(BRUMS Post)
Mood Subscale Rate (0-16)
0
2
4
6
8
10
12
####
###
###
###
###
Tension
Confusion
Anger
Depression
Vigueur
Fatigue


Mental Fatigue
Control
Subjective Workload (0-100)
0
20
40
60
80
100
####
#
##
###
####
###
MENTAL DEMAND
PHYSICAL DEMAND
TEMPORAL DEMAND
PERFROMANCE
EFFORT
FRUSTRATION


Blood Lactate Concentration (mmol * L^{-1})
0
2
4
6
8
10
12
14
Mental Fatigue
Control
#
####
Baseline
Post Warm Up
Post Time Trial


(a)
Heart Rate (bpm)
210
200
190
180
170
160
150
140
#
400
800
1200
1600
2000
(b)
RPE (6 - 20)
20
18
16
14
12
10
8
6
#
Mental Fatigue
Control
400
800
1200
1600
2000
Distance (m)


(a)
Power (W)
240
220
200
180
160
140
120
100
####
####
####
####
###
400
800
1200
1600
2000
(b)
Stroke Rate (1* min-1)
130
120
110
100
90
80
###
###
###
###
###
400
800
1200
1600
2000
Distance (m)
Mental Fatigue
Control