Does mental fatigue impair physical performance? A replication study

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Objective: to replicate the hypothesis that mental fatigue impairs physical performance.

Design: a pre-registered (https://osf.io/wqkap/), randomized, within-subject experiment.

Methods: 30 physically active sports people completed a time-to-exhaustion test (TTE) at 80% VO_2max in two separate sessions, after completing a mental fatigue task or watching a documentary for 90 min. We measured power output, heart rate, RPE and subjective mental fatigue state.

Results: Bayes factor analyses showed moderate-to-strong evidence for the null hypothesis (i.e., no evidence of reduced performance) for average time in TTE (BF_{+0} = 0.102) and anecdotal evidence for the null hypothesis in RPE (BF_{+0} = 0.345) and heart rate (BF_{+0} = 0.387), although the Bayes factor analyses revealed extreme evidence supporting the alternative hypothesis that the mental fatigue task was more mentally fatiguing than the control task, BF_{+0} = 116.69

Conclusions: our data seem to challenge the idea that mental fatigue has a negative influence on exercise performance. Although we did succeed at manipulating subjective fatigue, this did not impair physical performance. However, we cannot discard the possibility that mental fatigue may have a negative influence under different conditions, e.g., in the long term. Our replication study opens interesting avenues for future studies in this field with more rigorous methodological practices, such as a priori power calculation, data sharing or pre-registration.

Keywords

Cognitive fatigue ; endurance performance ; cognitive exertion ; exercice performance

Citation

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Introduction

Cognitive processes, such as inhibitory or cognitive control, are fundamental to achieve a high level of performance in sports (Vickers & Williams, 2017). Under this assumption, a sizable volume of literature has explored the theme of the potential negative influence of mental fatigue on subsequent exercise (Pageaux & Lepers, 2018). Mental fatigue is considered a complex psychobiological state induced by a prolonged period of demanding cognitive activity, which usually has a negative impact on cognitive function (Ishii, Tanaka, & Watanabe, 2014). In addition, mental fatigue affects several objective and subjective measures, such as lack of energy (Cutsem et al., 2017), altered brain activity (Wang et al., 2016) or decreased accuracy response in tasks (Boksem & Tops, 2008).

To address this issue, Marcora et al. (Marcora, Staiano, & Manning, 2009) asked participants to carry out a demanding cognitive task (experimental condition) or watch a documentary (control condition) for 90 minutes before a cycling time-to-exhaustion test at 80% of their peak power output. The AX-continuous performance task (AX-CPT) was chosen to induce mental fatigue because it requires sustained attention, working memory, response inhibition, and error monitoring (Wiemers & Redick, 2018). The results of the study showed that, in the mental fatigue condition, participants reached exhaustion sooner than in the control condition (Marcora et al., 2009). The starting hypothesis of the study was that mental fatigue increases rating of perceived exertion (RPE) during exercise, and consequently athletes would fatigue sooner or would select a lower self-selected exercise intensity (Cutsem et al., 2017; Pageaux, 2014). However, motivation and RPE were not influenced by the mental fatigue manipulation.

Marcora et al.'s (2009) report was the first of a series of studies looking at the negative influence of mental fatigue on exercise performance. However, the evidence for this relationship is inconclusive, as subsequent studies did not confirm that mental fatigue affected RPE, even when exercise performance did decrease (Martin et al., 2016; Penna et al., 2018). Furthermore, upon closer inspection of a recent review (Pageaux & Lepers, 2018), almost 50 percent of the studies showed no effects of mental fatigue on exercise performance itself. Likewise, most of these studies have relied on small samples (mean $N = 12$, with an 8-25 range), which renders them underpowered to detect small but non trivial effect sizes.

In sum, we believe that the extant evidence is inconclusive, at best, regarding the potential effect of mental fatigue (induced by a demanding cognitive task) on exercise performance and perceived exertion. Therefore, we consider pertinent to replicate Marcora et al.'s (2009) original study to investigate the reliability of their findings.

Methods

Design

The experiment followed a pre-registered protocol (https://osf.io/7hz3x), with a single-blind, counter-balanced, within-participant design. This study was approved by the University of Granada Ethics Committee (287/CEIH/2017). All experimental procedures complied with the Declaration of Helsinki. Before being recruited for the study, participants read and signed an informed consent. All data were entered in a case report form and subsequently in a computerized database. Participants were naïve to the aim of the study in order to avoid expectation effects. Once they completed their participation, they were debriefed with the purpose of the study.

Participants

We recruited participants from the Granada area population, in Spain. Experimental sessions took place in the Mind, Brain, Behaviour Research Centre, at the University of Granada. We recruited male and female recreational sports people involved in regular aerobic training (>6h/week), with ages between 18 and 44, free of any known disease, and not taking any medication with the exception of contraceptives. Exclusion criteria were the presence of symptomatic cardiomyopathy, metabolic disorders such as obesity (BMI >30) or diabetes, chronic obstructive pulmonary disease, epilepsy, therapy with b-blockers and medications that would alter cardiovascular function, hormonal therapy, smoking, and neurological disorders.

Sample size was determined by using sequential testing with one-sided Bayes factors. We planned to collect data from a minimum of 30 participants and then monitor the Bayes factor for the average time in the time-to-exhaustion test until it reached moderate evidence (BF > 6) in favor of either the alternative or the null hypothesis. The alternative hypothesis was that performance in the mental fatigue condition would be reduced relative to the control condition (i.e., MF < CON in time to exhaustion, and MF > CON in RPE), so the null hypothesis was the non-existence of a detrimental effect of the mental fatigue manipulation on exercise performance. We used a half-Cauchy prior with width 0.707 (the default width in JASP (JASP Team, 2019)). If none of these thresholds was reached, we planned to terminate data collection if the sample size reached 50 participants or if none of the previous criteria was met by July, 2019. A final sample of 30 (24 males, 6 females) participants with an age 23.5 ± 6.3 years, VO_2Max 41.88 ± 9.08 mil/min/kg, completed the study.

Apparatus and materials

We used a ViaSprint 150P cycle ergometer (Ergoline GmbH, Germany) to induce physical effort and to obtain power values, and a JAEGER Master Screen gas analyser (CareFusion GmbH, Germany) to provide a measure of gas exchange during the effort test. We used a V800 Polar monitor (Polar Electro, Finland) to monitor and record (through a Polar H7 sensor band attached to the participant's chest) the heart rate (HR) of the participants during the experiments. We used a PC and the E-Prime software (Psychology Software Tools, Pittsburgh, PA, USA) to control the stimulus presentation and response collection for the AX-CPT task. Moreover, we used the same PC screen to reproduce the documentary in the control condition.

Procedure

Screening visit

During the first visit, participants performed an incremental exercise test until exhaustion. The test begun with a load of 50W for 2 minutes and then the load incremented automatically in steps of 50 W every 2 minutes until volitional exhaustion (i.e., a pedal frequency of less than 60 rpm for more than 5 seconds despite strong verbal encouragement). We used the 80% of the peak power output in this session to establish the intensity of the time-to-exhaustion test. This value was determined by the last steep completed or the fraction of the remaining time to complete that steep.

Experimental session

After the familiarization visit, participants attended to the lab on two separate sessions to perform either the AX-CPT task or watch the documentaries before the cycling time-to-exhaustion test. Upon arrival, participants filled in the Brunel Mood Scale (BRUMS) to assess mood and a VAS (see subjective scales below). After that, they completed the treatment in a counterbalanced order. Once participants had completed the task, they filled in again the BRUMS, the VAS, together with a motivation questionnaire. Immediately afterwards, they were positioned on the cycle ergometer to start the time-to-exhaustion test approximately 15 minutes after the end of treatment. This constant-power cycling test can detect changes in endurance performance (Amann, Hopkins, & Marcora, 2008). The time-to exhaustion cycling test consisted of a 3-min warm-up at 40% of peak power output followed by a rectangular workload corresponding to 80% of peak power output achieved in the screening visit. The test finished when the pedal frequency was less than 60 RPM for more than 5 s despite standardized verbal encouragement. To increase participants' motivation, we offered a prize of 50€ for the best cycling performance after each treatment. The third visit was exactly the same except for the treatment, which was the opposite of the second visit.

Mental fatigue condition

In the mental fatigue condition, participants completed a 90 minutes long AX-CPT [8]. Participants seated in a room in front of a 21' PC screen, and sequences of letters were visually presented one at a time in a continuous fashion. They were instructed to press the right button on target trials and the left button otherwise. Target trials were defined as a cue-probe sequence in which the letter A appeared as the cue and the letter X appeared as the probe. The remaining letters of the alphabet served as invalid cues and nontarget probes, with the exception of the letters K and Y, which were excluded because of their similarity in appearance to the letter X. Letter sequences were presented in pseudorandom order, such that target (AX) trials occurred with 70% frequency and nontarget trials occurred with 30% frequency. Non-targets were divided evenly (10% each) among the following trial types: BX trials, in which an invalid cue (i.e., non-A) preceded the target; AY trials, in which a valid cue followed by a non-target probe (i.e., non-X); and BY trials, in which an invalid cue followed by a non-target probe. To increase task difficulty, two white distractor letters (which could be any letter but A, K, X, or Y) were presented between the cue and probe, which were both red. All letters were presented centrally, on a black background, for a duration of 300 ms in 24-point uppercase Courier font. Each letter was followed by a 1,200-ms interval, which gives a 4,500-ms delay between the presentation of cue and probe stimuli. Any missed or incorrect response elicited a bleep sound from two speakers as a prompt to increase speed and accuracy. To further increase engagement in the AX-CPT, a 50€ prize was given for the best performance. Feedback on performance was presented on the computer screen every 30 min as a percentage of the maximum possible score. Performance was scored automatically by the computer on the basis of correct responses and response times. Because a reduction in vigilance and working memory are well-established effects of mental fatigue, the proportion of correct responses to the AX trials during the first and last 15-min period of the AX-CPT was compared as manipulation check.

Control condition

In the control condition, participants watched two documentaries (approximately 45 minutes each), which were able to maintain a neutral mood, during 90 minutes in the same PC screen used for the AX-CPT. These two documentaries were the Spanish version of “World Class Trains—The Venice Simplon Orient Express” (Pegasus-Eagle Rock Entertainment, 2004) and “The History of Ferrari—The Definitive Story” (Boulevard Entertainment, 2006).

Subjective scales

Rating of perceived exertion (RPE): we asked participants to rate their perceived effort in the 6-20 RPE (Borg, 1982) scale after the time-to-exhaustion test and after reading a standardized written instruction (Pageaux, 2016).

BRUMS. We assessed participants’ mood before and after both treatments with The Brunel Mood Scale (BRUMS) developed by Terry et al. (Terry, Lane, & Fogarty, 2003). The questionnaire is based on Profile of Mood States, but it only 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, yields a raw score in the range of 0 to 16. We only considered the subscales of fatigue and vigor as the main items to assess the state of mental fatigue.

VAS. We used a visual analog scale (VAS) to check the task demands of mental fatigue and control condition to the following questions: 1) What is your activation level now?" 2) "What is your physical fatigue level now?" and 3) "What is your mental fatigue level now?" (Holgado et al., 2018)

Motivation. We assessed motivation before the time-to-exhaustion tests with the success motivation and intrinsic motivation scales developed and validated by Matthews et al. (Matthews, Campbell, & Falconer, 2001). 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). The final score of the questionnaire ranged between 0 and 28.

Statistical analysis

We calculated one-sided Bayes factors for paired-samples *t*-tests (mental fatigue vs control) using the open-source JASP statistical package (JASP Team, 2019). The alternative hypothesis was the existence of a reduced performance in the mental fatigue condition compared to the control condition (MF < CON in time to exhaustion, and MF > CON in RPE), so the null hypothesis was the non-existence of a detrimental effect of the mental fatigue manipulation on exercise performance. Additionally, we used a one-sided test for each pairwise comparison (e.g., mental fatigue condition would reduce motivation or increase the subjective mental fatigue state compared to control). As prior distribution of the population effect size (δ), we used a zero-truncated Cauchy distribution with 0.707 width. To ensure that this arbitrary choice did not affect the results, we conducted robustness checks with a wide range of alternative scaling factors (see supplemental materials).

The dependent variables for the time-to-exhaustion test were the average time completed by participants, the average heart rate and the session RPE.

Manipulation check

The psychological variables for the mental fatigue or control conditions were the BRUMS values for fatigue and vigor, the upcoming motivation to performance physical task and the VAS. These data scales were analyzed by (normalized) rating change: post-test rating minus pre-test rating divided by post-test ratting plus pre-test rating.

Results

Confirmatory analysis

AX-CPT task

The one-sided Bayes factor for the accuracy in the AX-CPT task between the first and the last 15 minutes of the task was BF_{+0} = 0.247, indicating that the observed data support the null hypothesis of no effect. According to the interpretation guidelines proposed by Jeffrey (Jeffreys, 1961), this represents moderate evidence for the null hypothesis that there is no decline in accuracy between the first and the last 15 minutes. The accuracy (percentage of correct responses) for both periods were: 0.953 (95% Credible Interval (CI) 0.932 - 0.975) and 0.95 (95% CI 0.934 - 0.966) for the first and last 15 minutes, respectively.

Subjective scales

The one-sided Bayes factor for the normalized VAS score for the question "1) What is your activation level now?" was BF_{+0} = 1.442, which represents anecdotal evidence in favor of the alternative hypothesis. The normalized VAS score for both conditions were: -0.17 (95%CI -0.271 - -0.068) IU and -0.296 (95%CI -0.43 - -0.179) IU, for the control and mental fatigue conditions, respectively.

The one-sided Bayes factor for the normalized VAS score for "What is your physical fatigue level now?" was BF_{+0} = 7.355, providing substantial support for the alternative hypothesis that fatigue increased after the task. The normalized VAS scores for both conditions were: -0.148 (95%CI -0.261 - -0.034) IU and -0.17 (95%CI -0.068 - 0.268) IU for the control and mental fatigue conditions, respectively.

The one-sided Bayes factor for the normalized VAS score for "What is your mental fatigue level now?" (Fig.1) was BF_{+0} = 116.69, which represents extreme evidence in favor of the alternative hypothesis, i.e., that the mental fatigue task was more mentally fatiguing than the control task. The normalized VAS score for both conditions were: 0.08 (95%CI -0.061 - 0.221) IU and 0.371 (95%CI 0.251 - 0.492) IU for the control and mental fatigue conditions, respectively.

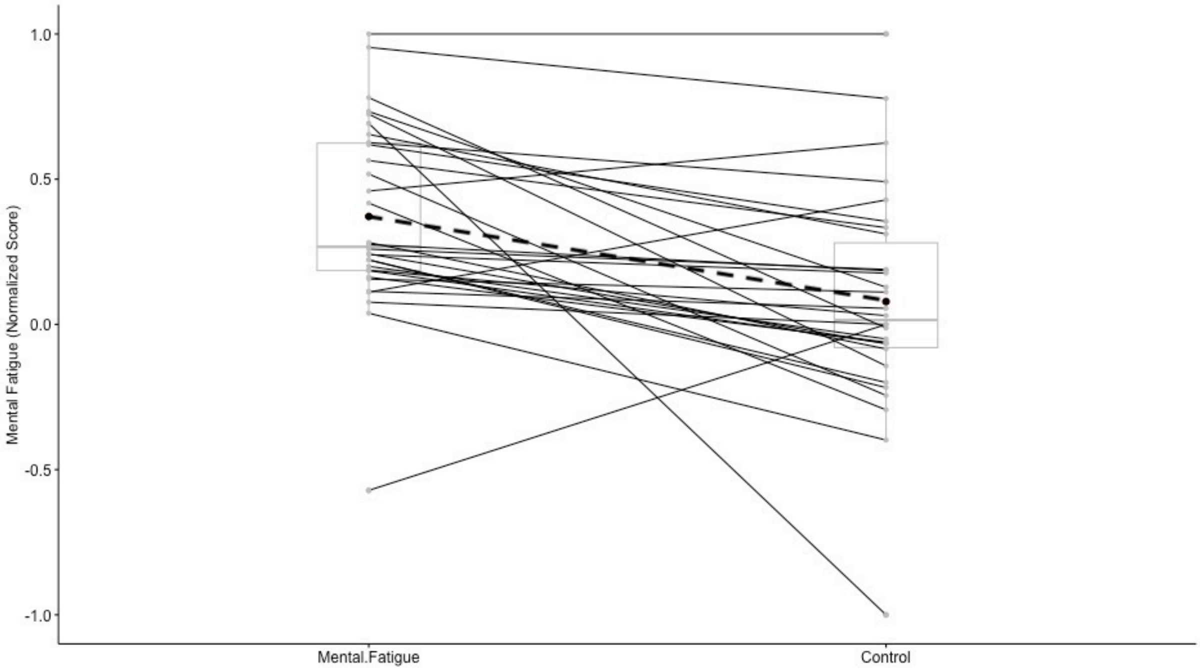

Fig 1. Normalized VAS score for each participant and condition for the question "What is your mental fatigue level now?". Dashed line represents the overall mean.

The one-sided Bayes factor for the BRUMS score of fatigue was BF_{+0} = 40.03, providing very strong evidence in favor of the alternative hypothesis. The normalized score for both conditions were: 0.106 (95%CI -0.058 - 0.270) IU and 0.442 (95%CI 0.312 - 0.572) IU for the control and mental fatigue conditions. Likewise, the one-sided Bayes factor for the BRUMS score of vigor was BF_{+0} = 3.267. This provides moderate evidence in support of the alternative hypothesis. The normalized score for both conditions were: -0.62 (95%CI -0.174 - 0.05) IU and -0.269 (95%CI -0.416 - -0.123) IU for the control and mental fatigue conditions, respectively.

Contrary to the initial hypothesis, the one-sided Bayes factor for the motivation score was BF_{+0} = 0.121, which provides moderate evidence in favour of the null hypothesis, i.e., mental fatigue did not have a detrimental effect on motivation. The scores for the two conditions were: 13.07 (95%CI 11.73 - 14.41) IU and 13.53 (95%CI 11.85 - 15.21) IU for the control and mental fatigue condition, respectively.

Performance

The one-sided Bayes factor for the time-to-exhaustion (Fig.2) measure was BF_{+0} = 0.102, indicating that the observed data moderately to strongly support the null hypothesis that mental fatigue did not have a detrimental effect on exercise performance. The average time completed for both conditions was: 765.5 (95%CI 577.2 - 953.8) and 705.4 (95%CI 542.8 - 868) seconds for the mental fatigue and control conditions, respectively (Fig. 2).

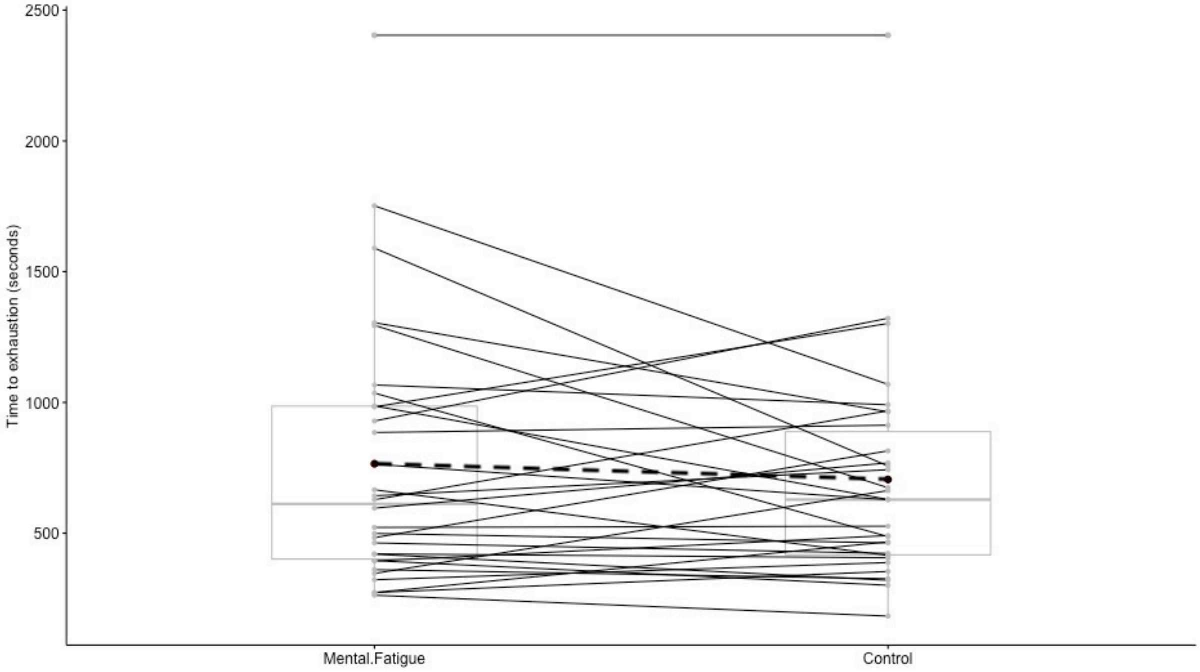

Fig 2. Time-to-exhaustion (seconds) for each participant and condition during the 80% cycling time-to-exhaustion test. Dashed line represents the overall mean.

The one-sided Bayes factor for the average heart rate during cycling time-to-exhaustion test was BF_{+0} = 0.387, indicating anecdotal evidence in favor of the null hypothesis that mental fatigue did not have a detrimental effect on the average heart rate. The heart rate for both conditions was: 161 (95%CI 159 - 165) bpm and 156 (95%CI 156 - 165) bpm for the control and mental fatigue conditions, respectively.

The one-sided Bayes factor for the average RPE (Fig.3) after the cycling time-to-exhaustion was BF_{+0} = 0.345, which indicates an anecdotal evidence in favor of the null hypothesis indicating the mental fatigue did not have a detrimental effect on RPE. The average RPE for both conditions was: 15.8 (95%CI 14.94 -16.66) IU and 15.93 (95%CI 15.08 - 16.79) IU for the control and mental fatigue conditions, respectively.

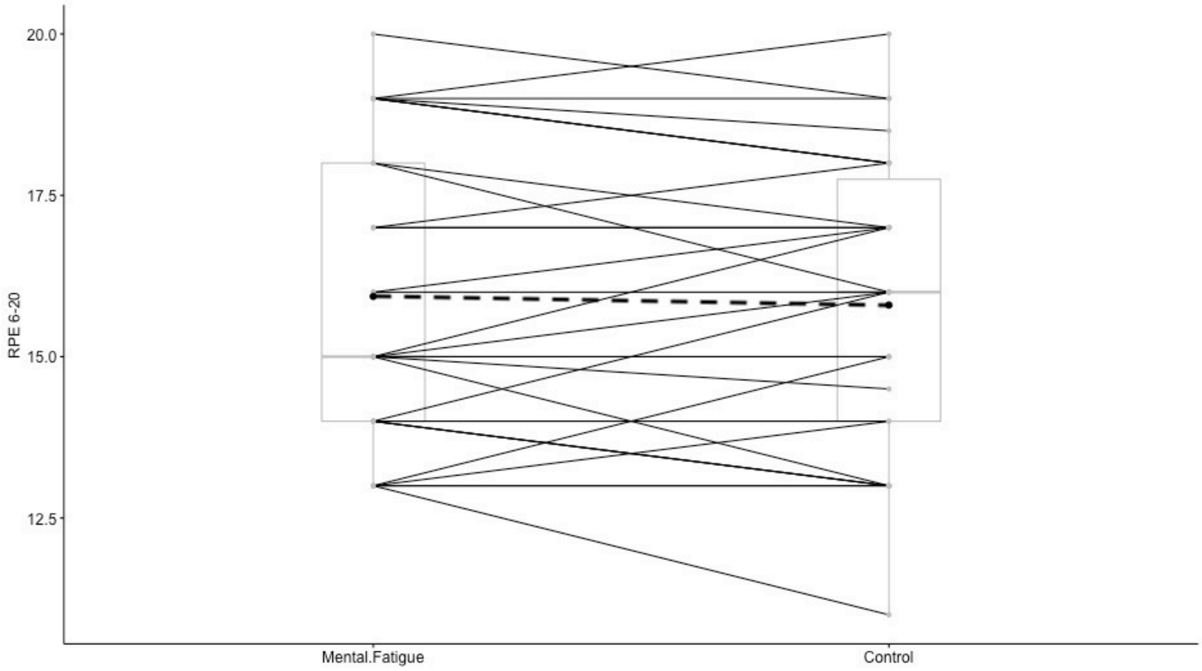

Fig 3. RPE for each participant and condition after the 80% cycling time-to-exhaustion test. Dashed line represents the overall mean.

Discussion

The purpose of this study was to replicate the effect of mental fatigue on physical performance in humans reported by Marcora et al. (Marcora et al., 2009). The results were straightforward: even if participants felt more mentally fatigued in the mental fatigue condition (AX-CPT session), we did not find evidence of an inferior physical performance in the mental fatigue condition. No evidence of increments in RPE and HR or reduction in motivation was found either. Our results are sharply in contrast with those of Marcora et al. (2009) and add to the growing number of studies failing to find any effects of mental fatigue on physical performance. As pointed out in the Introduction, a recent review (Pageaux & Lepers, 2018) showed that almost 50 percent of the studies found no effects of mental fatigue on variables related to exercise performance.

Our results cannot definitely discard the existence of a small mental fatigue effect on performance. As shown in robustness analyses, with sufficiently small prior widths, Bayes Factors fall in the anecdotal evidence range (i.e., the available evidence becomes insufficient to choose between the two hypotheses, as the alternative and the null hypotheses grow closer to each other). Beyond the discussion regarding the practical significance of such small effects, their detection would require sample sizes much larger to the ones used to date. Still, as far as we know, we have tested the largest sample number of participants in this literature and the results show no hint that mental fatigue influences physical performance, at least to the extent considered in previous studies. Actually, the visual difference between the two conditions was in the direction opposite to the one reported by Marcora et al., i.e., on average participants were exhausted later in the mental fatigue condition than in the control condition.

Although our data showed moderate evidence in favour of the hypothesis that mental fatigue does not have a negative influence on exercise performance, we cannot reject completely this hypothesis. A possible explanation for the lack of evidence for the alternative hypothesis in our study could be that an acute session is not effective enough to affect exercise performance and/or that the effects might depend on individual differences. Indeed, we cannot discard the possibility that mental fatigue induced over consecutive days might have a negative influence on performance, as the long-term effects of mental fatigue on exercise performance have not been studied yet (Russell, Jenkins, Smith, Halson, & Kelly, 2019). Moreover, given that almost half of the participants became exhausted sooner in the mental fatigue condition than in the control condition, the inter-individual variability might be an important factor to consider in this context.

In conclusion, our data seem to challenge the idea that mental fatigue has a negative influence on exercise performance. Our study, however, does not provide the definitive answer on whether mental fatigue might affect exercise performance under different conditions, but opens new avenues for future research on this topic that should consider factors like mental fatigue induced over consecutive days and individual differences. Finally, we propose that greater efforts, such as a priori power calculation, data sharing or pre-registration of studies are needed.

Compliance with ethical standards

Contributors: All authors have made substantial contributions to various elements of the study.

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Data availability

Data from the experiment can be found here: https://osf.io/wqkap/

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