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Physical and mental fatigue reduce psychomotor vigilance in professional football players

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Abstract

PURPOSE: Professional football players experience both physical and mental fatigue. The main aims of this randomized crossover study were to investigate the effect of mental fatigue on repeated sprint ability (RSA), and the effects of both physical and mental fatigue on psychomotor vigilance. METHODS: Seventeen male professional football players performed 10 maximal 20-m shuttle sprints interspaced by incomplete recovery (RSA test). Running speed, heart rate (HR), brain oxygenation and rating of perceived exertion (RPE) were monitored during each sprint. The RSA test was preceded by either a 30-min Stroop task to induce mental fatigue (MF), or by watching a documentary for 30 min (CON) in a randomized counterbalanced order. Participants performed a psychomotor vigilance test (PVT) at baseline, after the cognitive task (MF or CON), and after the RSA test. RESULTS: HR and RPE significantly increased, while running speed and brain oxygenation significantly decreased over the repeated sprints ($p < 0.001$) with no significant differences between conditions. Response speed during the PVT significantly declined after the Stroop task but not after CON ($p = 0.001$). Response speed during the PVT declined after the RSA test in both conditions ($p < 0.001$) and remained lower in the MF condition compared to CON ($p = 0.012$). CONCLUSIONS: Mental fatigue does not reduce RSA. However, the results of this study suggest that physical and mental fatigue have negative and cumulative effects on psychomotor vigilance. Therefore, strategies to reduce both physical and mental fatigue should be implemented in professional football players.

Keywords: soccer, physical performance, cognitive performance, repeated sprint ability, brain oxygenation

Introduction

Professional football players experience a decline in various parameters of physical performance during the match [1]. Technical performance also declines as proved by a reduction in ball possession and, an increase in the number of unsuccessful passes [2]. A higher number of goals scored during the second half of the match is also abserved[3]. Understanding the mechanisms of this match-related fatigue is important if we want to reduce its impact and further improve football performance.

Playing football induces significant neuromuscular and metabolic alterations that reduce the player's ability to produce force, speed and power [1]. In addition to this physical fatigue, playing football induces significant mental fatigue especially during congested fixtures [4]. This is not surprising because the game requires football players to react quickly, make important decisions, remember and switch plays and strategies, and remain vigilant throughout the whole match. Psychological stressors outside the game itself (e.g. frequent travelling and education) can also induce mental fatigue [4].

Recent studies have experimentally investigated the effects of mental fatigue on different aspects of physical, technical, and cognitive performance in football players [5–8]. Smith and colleagues reported a decrease in football-specific measures of aerobic endurance capacity as well as passing and shooting ability [5]. These initial findings have been confirmed and expanded by other authors who reported impairments in dribbling accuracy, decision-making and peripheral visual perception in mentally fatigued football players [10,7,5]. We are not aware, however, of any experimental study investigating the effect of mental fatigue on repeated sprint ability (RSA). The ability to perform multiple sprints at high speed despite incomplete recovery is important in professional football [8]. Importantly, RSA is well known to induce metabolic perturbations within the muscle with concomitant reduction in cerebral deoxygenation [11]. The reduced brain oxygenation can impact areas such as the premotor cortex and motor cortex[12] which are relevant for cognitive tasks and descending motor commands. As previously observed, the reduced brain oxygenation is in part associated with reduced cognitive performance [13] and neural drive to the locomotor muscles (i.e., central fatigue) thus impairing physical performance [11,14].

The first aim of our study was to investigate the effect of mental fatigue on RSA in professional football players. Although performance during physical tests that require short and maximal efforts does not seem to be negatively affected by mental fatigue [15], we hypothesised that, due to multiple maximal efforts with incomplete recovery [16], performance in the RSA test may be lower in mentally fatigued professional football players. The second aim of our study was to investigate the isolated and joint effects of physical and mental fatigue on psychomotor vigilance, operationally defined as the ability to quickly react to random visual stimuli and sustain attention over time [17]. A reduction in psychomotor vigilance is a clear sign of mental fatigue and high-intensity exercise has been shown to slow reaction time and reduce brain oxygenation in young and fit adults [18,12,19]. Third, as the left dorsolateral prefrontal cortex (L-DLPFC) is relevant for effortful cognitive tasks requiring inhibitory control and a wide range of tasks requiring psychomotor vigilance [20], this study aimed to monitor the cerebral oxygenation of the L-DLPFC. Therefore, we hypothesised that both physical and mental fatigue reduce psychomotor vigilance in professional football players.

Methods

Volunteers

A group of 18 male professional football players were recruited from three different football teams: Gillingham FC, Cagliari Calcio S.p.a. and Team Ticino CH. Goalkeepers were excluded. One participant did not complete the experimental protocol due to personal reasons. The mean values ± SD of height, weight and age for the remaining 17 participants were: 171.5 ± 5.2 cm, 75.5 ± 1.8 kg, 26 ± 2 years, respectively. None of the volunteers had any history of cardiorespiratory disease, were injured or taking any medication. All volunteers trained regularly at the time of the study (6-8 h/w) and were in the middle of the competitive season. Players signed an informed consent form describing the potentials risks and study procedures. Albeit not blind to treatment allocation, participants were not aware of that the main purpose of the study was to investigate the negative effects of mental fatigue on RSA and psychomotor vigilance. This "partial blinding" was implemented to reduce the nocebo effect on their performance. All the experimental procedures were approved by the local ethical committee and were conformed to the Declaration of Helsinki.

Experimental protocol

This was a partially-blind, randomized crossover trial consisting of one preliminary session and two experimental sessions separated at least by 24 hours of recovery and completed within 14 days. Volunteers were asked to refrain from caffeine, alcohol, stimulants or depressants, and strenuous exercise for 24 hours prior to each experimental session. Volunteers performed each experimental session at the same time of the day at their training ground. The experimental protocol is illustrated in Fig 1.

The first visit served to familiarise volunteers with all the experimental procedures. Moreover, volunteers performed the Level 1 Yo-Yo intermittent recovery to assess their physical fitness.

During visits 2 and 3 each volunteer performed the RSA test in either an experimental (MF) or control (CON) condition according to a randomized and counterbalanced order. The RSA test consisted of 10 shuttle sprints of 40 m (20 + 20 m) at the maximal possible speed interspaced by 20 s of passive recovery. The RSA test was performed after 10 min of standard warm-up. Volunteers were instructed to sprint as fast as possible from the start and were verbally encouraged throughout each sprint to promote a maximal effort [16]. The main parameters obtained from the RSA test were RSA total time (RSA_{time}), Running speed and decrement score (S_{dec})The person providing verbal encouragement during the RSA test was blind to treatment allocation.

Treatment

The cognitive tasks were performed prior the RSA test in a quiet room under the supervision of the same researchers.

Mental Fatigue Condition (MF) - demanding cognitive task: mental fatigue was induced by using the paper version of the Stroop task for 30 min as in previous experiments [9].

Control Condition (CON) - non-demanding cognitive task: the control treatment consisted of volunteers watching a documentary about the history of Ferrari for 30 min.

Psychological and physiological measures during the RSA test

Global ratings of perceived exertion (RPE) were obtained during the recovery period between each sprint of the RSA test using the 15-point Borg RPE scale. Heart rate (HR) was continuously monitored during the RSA test by a HR monitor (Polar RS800CX, Polar Electro Oy, Kempele, Finland). A 20-µl sample from the finger was taken at Baseline and after the

RSA test (Post-RSA) and analysed for blood lactate concentration (B[La$^-$]) using a portable analyser (Lactate Pro, Arkray Inc., Kyoto, Japan). Oxygenation of the left prefrontal cortex (PFC) was measured via near infrared spectroscopy (NIRS) by means of a portable device (Portalite, Artinis, Zetten, Netherlands) emitting continuous wavelengths of 760-850-nm. The probe was placed on the left forehead Fp1/Fp3 according to the international electroencephalographic 10-20 EEG system. Sampling frequency was set at 10 Hz. To obtain baseline NIRS measures, data acquisition was performed for 4 min at rest with the volunteer sitting on a chair in a relaxed position. The probe position was marked used anatomical references for each volunteer to place it in the same position for each visit. Changes from baseline concentration for oxyhaemoglobin (ΔO_2Hb), deoxyhaemoglobin (ΔHHb), total haemoglobin ($\Delta tHb = O_2Hb + HHb$) were calculated. An age-dependent differential optical path length factor for cerebral cortex was used in the study. The same NIRS procedures were used during both cognitive tasks.

Other measures

The Fatigue and Vigour subscales of the Brunel Mood Scale (BRUMS) were measured at Baseline, after the cognitive tasks (Post-CT) and after the RSA test (Post-RSA) to quantify subjective fatigue. The National Aeronautics and Space Administration Task Load Index (NASA-TLX) was used to assess subjective workload at Post-CT and at Post-RSA. Motivation related to the RSA test was measured beforehand using the Success Motivation and Intrinsic Motivation scales of the Dundee Stress State Questionnaire.

The 3-min version of the PVT was performed at Baseline, Post-CT and Post-RSA. Visual stimuli were provided by a red light appearing on the display screen of the device (PVT-192, CWE, Inc, USA). Briefly, volunteers were asked to press the button as soon as the light appeared. The light appeared randomly every few seconds for 3 min. The PVT has been shown to be a valid and reliable tool for assessing psychomotor vigilance in various settings [17]. The PVT was performed in the same room used for the cognitive tasks.

Data analysis

Brain oxygenation data were averaged over the last minute during baseline measurement. During the cognitive tasks, the 30 min period was divided into 5 min blocks, and data were averaged for the last minute for each block. During the RSA test, data were averaged over the last 5 s for each sprint. Raw PVT data were inspected prior to analysis. Responses < 100 ms and above > 500 ms were excluded since the former is too fast to represent a conscious response (false start response), and the latter were considered as lapses. Response speed was calculated as the reciprocal of reaction time in milliseconds (RT) according to this formula: 1/RT*1000. Fatigue index during the RSA test was calculated by using the sprint decrement index (S_{dec}) according to this formula:

$$S^{dec}\,(\%) = \left\{\frac{(S^1 + S^2 + S^3 + \ldots S^{final})}{S^{best} \times \text{number of}^{\,sprints}} - 1\right\} \times 100$$

Statistical analysis

All data are presented as mean ± SD unless otherwise noted. Assumption for normal distribution was checked by using the Shapiro-Wilk test, whilst the assumption of sphericity of data was checked by using the Mauchly's test. The Greenhouse-Geisser correction was applied when violations to sphericity was found whilst a non-parametric alternative to the tests listed below was used if the assumption of normality was not met. A two-way 2 × 10 ANOVA for repeated measures was performed to test the effect of condition (MF vs CON) and time (defined as sprint number) on HR, RPE, running speed, ΔO_2Hb, ΔHHb, ΔtHb during the RSA test. A paired t-test was performed to test the effect of condition on B[La-] accumulation (Post-RSA minus Baseline), RSA_{time} and S_{dec}.

A two-way 2 × 3 ANOVA for repeated measures was performed to test the effect of condition (MF vs CON) and time (Baseline, Post-CT, and Post RSA) on response speed during the PVT, and for the Vigour and Fatigue scores. A paired t-test was performed to test the effect of condition on RSA_{time} and S_{dec}, subjective motivation related to the RSA test, and on subjective workload related to the cognitive tasks and RSA test. When a significant condition × time interaction or a main effect of time were found, the relevant pairwise comparisons were conducted using the Bonferroni method (post-hoc analysis). Alpha level was set at $p < 0.05$. Statistical analysis was performed by SPSS ~~26~~27.

Results

All volunteers completed the experiment without any adverse event. The average distance covered on the Level 1 Yo-Yo test was 2492 ± 708 m. This finding suggests that our sample is representative of professional football players in terms of physical fitness [21].

Subjective measures. The BRUMS questionnaire revealed a significant decrease in Vigour over time in both conditions ($p = 0.006$, $\eta^2_p = 0.291$), with no significant condition × time interaction ($p = 0.277$, $\eta^2_p = 0.082$). Post-hoc analysis revealed a significant lower Vigour both at Post-CT ($p = 0.017$, *d*~~η^2_p~~ = 0.808~~081~~) and Post-RSA ($p = 0.027$, *d*~~η^2_p~~ = 0.751~~212~~) compared to Baseline in both conditions. The Fatigue subscale demonstrated a significant main effect of time in both conditions ($p = 0.001$, $\eta^2_p = 0.582$) with no significant condition × time interaction ($p = 0.573$, $\eta^2_p = 0.028$). Post-hoc analysis revealed a significantly higher Fatigue Post-RSA compared to Baseline and Post-CT ($p = 0.006$, *d*~~η^2_p~~ = 1.570~~1.006~~) (Table 1).

No significant differences between conditions were found for intrinsic motivation (CON = 18.57 ± 4.99, MF = 18.00 ± 5.32; $p = 0.477$, *d*~~η^2_p~~ = 0.196~~1.823~~) and motivation to succeed in the RSA test (CON = 17.07 ± 5.40, MF = 16.88 ± 6.32; $p = 0.820$, *d*~~ηd^2_p~~ = 0.062~~3.445~~) between the two conditions.

Concerning the subjective workload during the cognitive tasks, no significant differences were found between MF and CON for Physical Demand ($p = 0.100$, *d*~~η^2_p~~ = 0.438~~13.566~~), Performance (p = 0.496, *d*~~η^2_p~~ = 0.175~~26.861~~) and Frustration ($p = 0.138$, *d*~~η^2_p~~ = 0.391~~ 34.337~~). On the contrary, Temporal Demand, Effort and Mental Demand were significantly higher for the Stroop task compared to watching the documentary ($p = 0.003$, *d*~~η^2_p~~ = 0.870~~23.343~~, $p = 0.044$, *d*~~η^2_p~~ = 0.548~~31.315~~ and $p = 0.007$, *d*~~η^2_p~~ = 0.778~~29.323~~ respectively). With regards to subjective workload during the RSA test, no significant differences between conditions were reported for Physical Demand ($p = 0.565$, *d*~~η^2_p~~ = 0.152~~15.337~~), Performance ($p = 0.664$, *d*~~η^2_p~~ = 0.115~~23.289~~), Effort ($p = 0.738$, *d*~~η^2_p~~ = 0.088~~11.37~~), Frustration ($p = 0.276$, *d*~~η^2_p~~ = 0.293~~19.352~~), Temporal Demand ($p = 0.583$, *d*~~η^2_p~~ = 0.150~~18.985~~) and Mental Demand (p = 0.576, *d*~~η^2_p~~ = 0.148~~18.014~~) (Table 2).

PVT. A condition × time interaction was found for response speed during the PVT ($p = 0.001$, η^2_p = 0.399~~964~~). Post-hoc analysis revealed no significant baseline difference between conditions (p = 0.626~~352~~, d_z = 0.129~~241~~). At Post-CT the response speed significantly declined compared to Baseline only in the MF condition (p = 0.~~007~~002, d_z = 0.979~~608~~) and was significantly lower compared to CON (p = 0.001, d_z = 1.016~~1.073~~). Post-RSA, the response speed declined further in both conditions (CON $p = 0.001$, *d*~~η^2_p~~ = 1.398~~0.748~~, MF $p = 0.003$, *d*

= 0.919) and remained lower in the MF condition compared to CON (p = 0.02312, d_z = 0.660722) (Fig 2).

RSA Test. RSA_{time} and S_{dec} did not differ between conditions (p = 0.245, d = 0.314 and p = 0.407, d = 0.221 respectively). RPE and HR significantly increased, while Running speed significantly decreased over time (all $p < 0.001$ and all $\eta^2_p > 0.681$) with no significant main effects of condition (p = 0.274, η^2_p = 0.085, p = 0.624, η^2_p = 0.018, and p = 0.286, η^2_p = 0.081 respectively) and no significant condition × time interactions (p = 0.826, η^2_p = 0.016, p = 0.197, η^2_p = 0.106, and p = 0.128, η^2_p = 0.115 respectively). There was no significant difference between conditions in B[La^-] accumulation (p = 0.963, d = 0.012) (Fig 2).

Brain oxygenation. ΔO_2Hb and ΔtHb during the cognitive task were significantly higher in the MF condition compared to CON (p = 0.045, η^2_p = 0.257, p = 0.032 and η^2_p = 0.287 respectively) while ΔHHb was significantly lower in the MF condition compared to CON (p = 0.031, η^2_p = 0.290) with no significant changes over time (p = 0.151, η^2_p = 0.236, p = 0.301, η^2_p = 0.081 and p = 0.260, η^2_p = 0.086 respectively) and no significant time × condition interaction (p = 0.668 and η^2_p = 0.024, and p = 0.848, η^2_p = 0.031 respectively). During the RSA test, ΔO_2Hb significantly decreased over time while ΔHHb, ΔtHb increased over time (all $p < 0.001$ and all $\eta^2_p > 0.305$) with no significant differences between conditions (p = 0.473, η^2_p = 0.048, p = 0.780, η^2_p = 0.007 and p = 0.893, η^2_p = 0.002 respectively) and no significant condition × time interaction (p = 0.889, η^2_p = 0.041, p = 0.780, η^2_p = 0.048 and p = 0.715, η^2_p = 0.065 respectively) (Fig 3).

Discussion

Contrary to our hypothesis, mental fatigue did not reduce RSA in professional football players. However, the results of this study suggest that mental fatigue and physical fatigue have negative and cumulative effects on psychomotor vigilance in this population.

Effect of mental fatigue on psychomotor vigilance

As expected, participants reported that the Stroop task was more effortful, and more mentally and temporally demanding than watching the documentary (control condition). In other words, the mental load associated with the Stroop task was higher than that of watching the documentary. The significant differences in brain oxygenation between the two tasks are in line with previous work 17 regarding the importance of the PFC activity for tasks like the Stroop that require inhibitory control. Despite no significant differences in the subjective measures of fatigue, a slower response speed during the PVT was found only after the Stroop task thus confirming the presence of mental fatigue and its negative effect of psychomotor vigilance [17]

Effect of mental fatigue on repeated sprint ability

RSA is important for professional football players and it is known to be affected by various factors such as energy supply, metabolite accumulation, reduced neural drive, and environmental factors [8,11]. One of the primary aims of the present study was to extend our understanding of the factors that affect RSA by testing the hypothesis that mental fatigue reduces it. However, we failed to find any significant effect of our experimental manipulation (30 min of a demanding and effortful cognitive task) on running speed during the subsequent RSA test. Additionally, mental fatigue did not affect brain oxygenation during the RSA test which may, in part explain, why RSA was not negatively affected by mental fatigue[12].

Our findings align with those of Smith and colleagues who found no significant effect of mental fatigue on peak running velocities during a 45 min intermittent running protocol in a group of team sport players including footballers[22]. However, in the same study, Smith and colleagues found that mental fatigue increased perception of effort and reduced low-intensity running performance thus further demonstrating the negative effect of mental fatigue on aerobic endurance capacity in team sport players [22]. Although the ability to sprint seems to remain intact in mentally fatigued football players, their reduced aerobic endurance capacity may impair players' ability to move in the right field position when a sprint is required.

Effect of physical fatigue and mental fatigue on psychomotor vigilance

To the best of our knowledge, this is the first study investigating the effects of both mental fatigue and physical fatigue on psychomotor vigilance in professional football players. During the RSA test there was a substantial decrease in running speed as well as an increase in perception of effort which are both indicative of significant physical fatigue [23]. During repeated sprint exercise, the decrease in power production has been associated with PCr degradation and accumulation of various metabolites most probably derived from anaerobic glycolysis and by a progressive reduction in neural drive to the locomotor muscles (i.e., central fatigue) [11]. Our study also showed that oxygenation of L-DLPFC declined progressively during the RSA test in this group of professional football players. Similar findings have been reported during intermittent high intensity cycling exercise in a group of health and fit adults [19]. As previously suggested the progressive reduction in brain oxygenation may in part contribute to central fatigue during repeated sprints with insufficient recovery [19,24].

Going back to the cognitive effects of physically fatiguing exercise, we found (in both conditions) a decline in response speed during the PVT performed after the RSA test. This novel finding is in line with the U-shape relationship between exercise intensity and cognitive performance, with low-to-moderate intensity exercise having a positive effect compared to resting conditions, whilst high-intensity exercise has a negative effect [25]. Given the important role played by the PFC in tasks like the Stroop that require inhibitory control [26], it is possible that the reduced oxygenation of the PFC observed after the RSA test may contribute to the reduction in response speed during the PVT.

An even more important finding is the observation that response speed during the PVT was further reduced compared to baseline when players performed the RSA test in a mentally fatigued state. In other words, the negative effects of physical and mental fatigue on psychomotor vigilance are cumulative. Given that the ability to sustain attention and react quickly to visual stimuli is important in football and many other sports [27], the cumulative effect of physical and mental fatigue on PVT performance observed in the present study is likely to be relevant to the technical and tactical performance of professional football players on the field and needs further investigations.

Study limitations

Our study has some technical limitations which should be considered when interpreting the results. In the "real world" context of official football matches, the physical and mental demands are likely to be significantly higher compared to those of this study. Congested fixtures, frequent travel and other psychological stressors associated with the life of a competitive footballer also contribute to physical and mental fatigue [4]. Therefore, both the physical and the mental fatigue experimentally induced in this study are likely to be less severe than those experienced by professional football players. Another limitation is that the PVT is not specifically designed for testing football players. Thus, the test might only partially capture the negative effects or indeed capture non relevant aspects of both physical and mental fatigue on the psychomotor vigilance of professional football players. With regards to the NIRS measurements, the probe was placed only over the left PFC and therefore we cannot provide a full picture of brain oxygenation. For example, previous research has shown that prolonged cognitive tasks may also activate deeper cortical areas, such as the anterior cingular cortex [26], which ~~cannot~~ could not be monitored ~~been accessed~~ by NIRS. Furthermore, we did not include NIRS data during the PVT tests conducted immediately following the RSA test. Previous research has demonstrated a sudden hyperaemic response following high intensity exercise with high variability between participants [28]. Therefore, a reliable comparison of brain oxygenation across each PVT test was not possible. Lastly, our conclusions about the effects of physical fatigue are based on comparing measurements taken before, during and immediately after the fatiguing physical task (i.e., the RSA test). This study design is commonly used in studies about the ~~neuromuscolar~~neuromuscular effects of physical fatigue [23]. Nevertheless, the inclusion of a resting control condition (which was not feasible in this occasion as it would have added one day of testing to the players burden) would have strengthened our conclusions about the negative effects of physical fatigue on psychomotor vigilance and brain oxygenation.

Conclusion

Our study provides evidence that physical and mental fatigue have negative and cumulative effects on psychomotor vigilance in professional football players whilst there was no evidence to support the hypothesised negative effect of mental fatigue on RSA. Together with the findings of previous experimental studies on the effects of physical and mental fatigue on the physical, technical and cognitive performance of football players, it is clear that both kinds of fatigue can have a negative impact on football performance [5,29].

Practical applications

Given the evidence provided here that both mental and physical fatigue can reduce the psychomotor vigilance of professional football players, the practical recommendation is to implement strategies to reduce both types of fatigue. A strategy directly suggested by the present study is to reduce as much as possible the cognitively demanding tasks (e.g., tactical rehearsal and emotion control) before a soccer match. Our results also provide further justification for the use of caffeine before and during a match in professional football players [30]. Indeed, caffeine is well known to improve physical performance and reduce the negative effects of mental fatigue in humans [31]. Further research is required to optimise the use of these strategies and develop new fatigue countermeasures for professional football players.

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Figure captions

Fig 1. Overall view of the experimental protocol.
Brain oxygenation was measured during the cognitive tasks and the repeated sprint ability (RSA) test. Additionally, during the RSA test, rating of perceived exertion and heart rate were measured. PVT stands for psychomotor vigilance task.

Fig 2. Physiological and perceptual responses during the repeated sprint ability (RSA) test and psychomotor vigilance (PVT) test.
Panel A shows time courses of running speed; Panel B shows time courses of heart rate (HR); Panel C shows time courses of rating of perceived exertion (RPE); Panel D shows the effect of cognitive tasks and RSA test on response speed during the PVT at baseline, after the cognitive tasks (Post-CT) and after RSA test (Post-RSA). Panel E shows blood lactate (B[La-]) accumulation. #Denotes significant condition x time interaction. *Denotes significant main effect of time. †Significantly different from CON condition. Data are presented as mean ± SD (n=17).

Fig 3. Brain oxygenation changes from resting baseline (BL) during the cognitive tasks and the repeated sprint ability (RSA) test.
Panel A, B and C show time courses of oxyhaemoglobin (ΔO_2Hb), deoxyhaemoglobin (ΔHHb) and total haemoglobin (ΔtHb) during the cognitive tasks. Panel D, E and F show time courses ΔO_2Hb, ΔHHb and ΔtHb during the repeated sprint ability (RSA) test. *Denotes significant main effect of time. †Denotes significant main effect of condition. Data are presented as mean ± SD (n=17).

Table 1. Subjective ratings of vigour and fatigue.

	Vigour		Fatigue	
	CON	**MF**	**CON**	**MF**
Baseline	8.~~88~~9 ± 3.0~~1~~	8.5~~0~~ ± 3.0~~3~~	4.75 ± 2.~~86~~9	5.~~56~~6 ± 2.94
Post-CT	6.~~69~~7 ±3.6~~3~~*	7.1~~3~~ ± 3.~~67~~7*	5.8~~1~~ ± 3.~~66~~7*	7.~~13~~2 ± 4.~~26~~3*
Post-RSA	6.75 ± 2.8~~2~~*	5.8~~1~~ ± 3.5~~1~~*	9.~~38~~4 ± 3.34*	9.75 ± 3.2~~1~~*

Subjective ratings of Vigour and Fatigue in mental fatigue (MF) and control (CON) condition measured trough the Brunel Mood Scale (BRUMS) questionnaire. Values are expressed as mean ± SD. *Significantly different compared to Baseline.

Table 2. Subjective ratings of workload.

	Mental Demand		Physical Demand		Temporal Demand		Performance		Effort		Frustration	
	CON	**MF**	**CON**	**MF**	**CON**	**MF**	**CON**	**MF**	**CON**	**MF**	**CON**	**MF**
Cognitive task	42.~~19~~2 ± 23.94	65.0~~0~~ ± 23.24*	0.6~~3~~ ± 2.50	6.~~56~~6 ± 13.0~~0~~	30.3~~1~~ ± 20.~~37~~4	50.6~~3~~ ± 18.4~~3~~*	50.3~~1~~ ± 22.3~~2~~	55.0~~0~~ ± 21.7~~6~~	25.3~~1~~ ± 22.4~~0~~	46.~~88~~9 ± 31.~~46~~5*	24.~~38~~4 ± 22.94	37.8~~1~~ ± 36.~~38~~4
RSA test	72.~~67~~7 ± 15.~~57~~6	70.94 ± 16.55	88.~~67~~7 ± 14.6~~0~~	85.0~~0~~ ± 16.4~~3~~	61.4~~3~~ ± 16.4~~2~~	60.6~~3~~ ± 20.4~~0~~	65.3~~3~~ ± 19.5~~0~~	67.5~~0~~ ± 19.8~~3~~	85.~~67~~7 ± 13.~~48~~5	86.~~88~~9 ± 16.9~~2~~	54.0~~0~~ ± 30.3~~1~~	61.~~56~~6 ± 30.54

Subjective ratings of Mental Demand, Physical Demand, Temporal Demand, Performance, Effort and Frustration in mental fatigue (MF) and control (CON) condition assessed trough the National Aeronautics and Space Administration Task Load Index (NASA-TLX) questionnaire. Values are expressed as mean ± SD. *Significantly different compared to CON.

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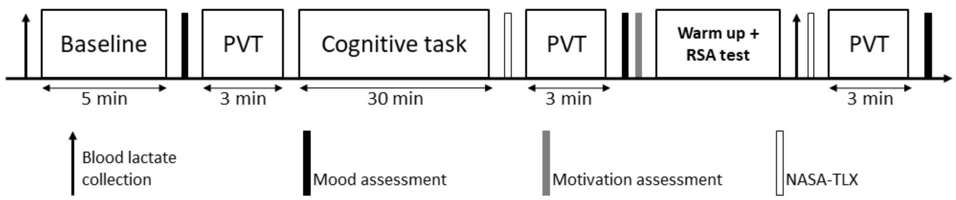

Figure 1

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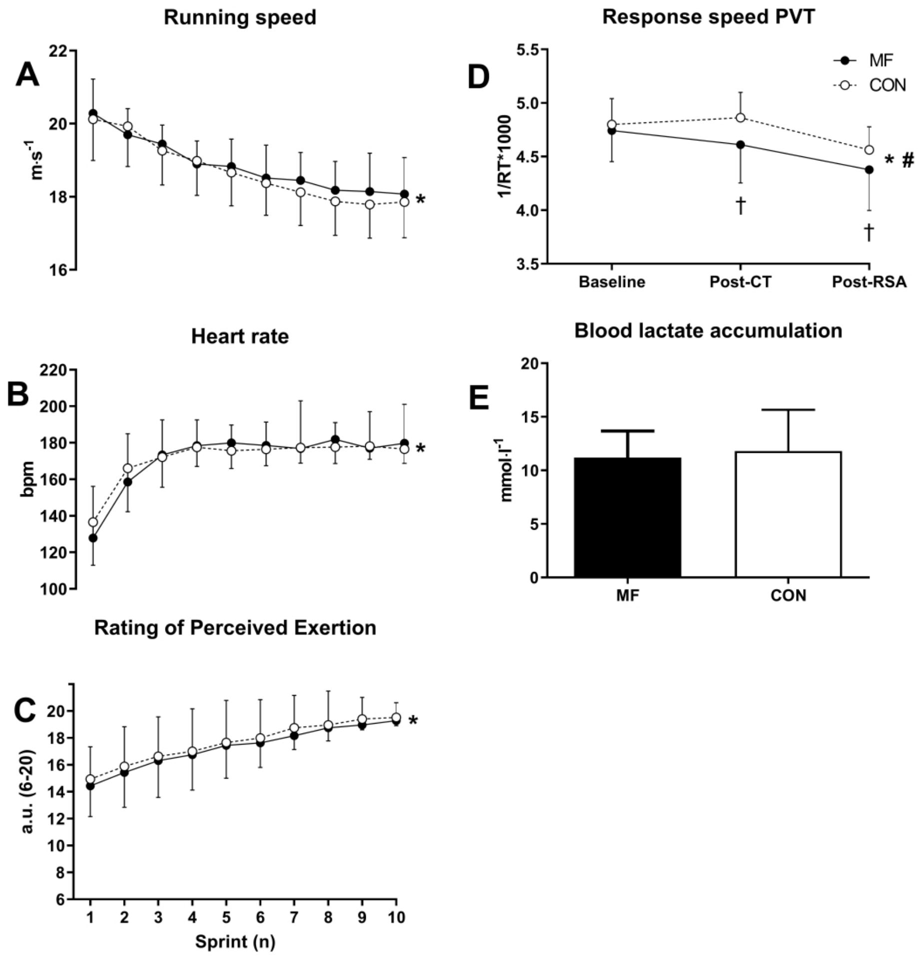

Figure 2

208x210mm (600 x 600 DPI)

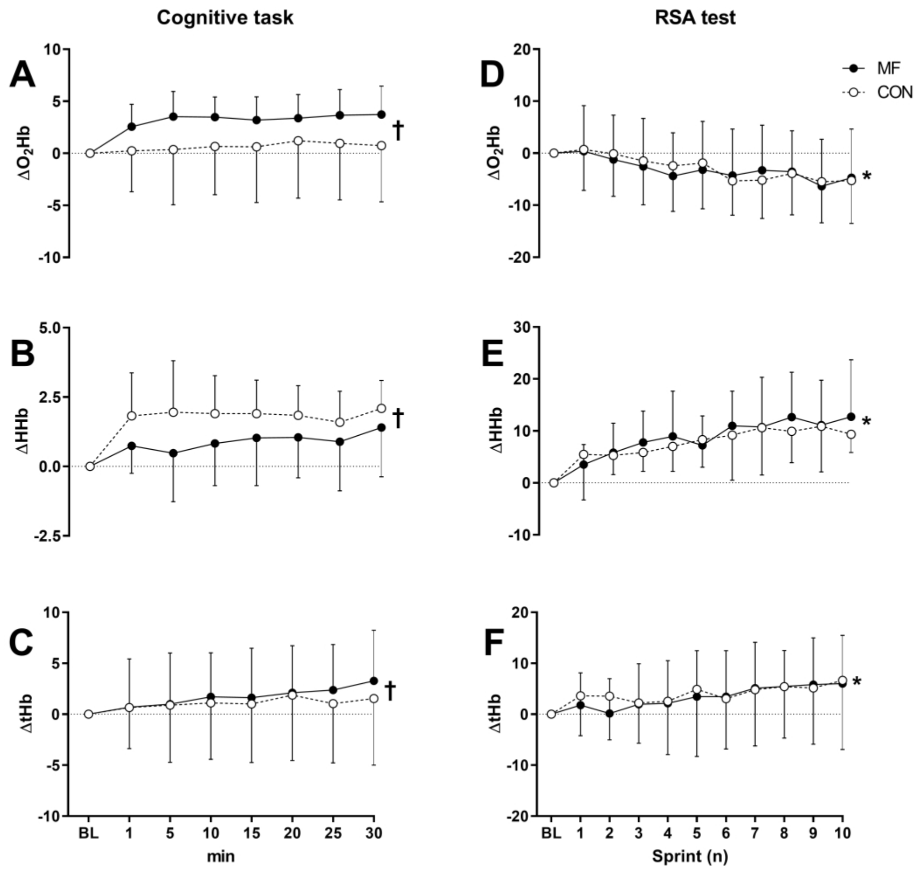

Figure 3

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