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Human Kinetics
ORIGINAL INVESTIGATION

Mental Fatigue: The Cost of Cognitive Loading on Weight Lifting, Resistance Training, and Cycling Performance

Walter Staiano,[1,2] **Lluis Raimon Salazar Bonet,**[3] **Marco Romagnoli,**[1] **and Christopher Ring**[4]
[1]Department of Physical Education and Sport, University of Valencia, Valencia, Spain; [2]Department of Psychology, Biological and Cognitive Psychology, University of Southern Denmark, Odense, Denmark; [3]International University SEK, Quito, Ecuador; [4]School of Sport, Exercise & Rehabilitation Sciences, University of Birmingham, Birmingham, United Kingdom

Purpose: Mental fatigue (MF) can impair physical performance in sport. We tested the hypothesis that cognitive load alone, and intermixed with standard resistance training, would induce MF, increase rating of perceived exertion (RPE), alter perception of weight lifting and training, and impair cycling time-trial performance. ***Methods:*** This 2-part study employed a within-participant design. In part 1, after establishing leg-extension 1-repetition maximum (1RM), 16 participants lifted and briefly held weights at 20%, 40%, 60%, and 80% of 1RM. RPE and electromyography (EMG) were measured for each lift. During the testing sessions, participants completed cognitive tasks (MF condition) or watched neutral videos (control condition) for 90 minutes before lifting the weights. In part 2, they completed submaximal resistance training comprising 6 weight training exercises followed by a 20-minute cycling time trial. In the MF condition, they completed cognitive tasks before and between weight training exercises. In the control condition, they watched neutral videos. Mood (Brunel Mood Scale), workload (National Aeronautics and Space Administration Task Load Index), MF-visual analogue scale (MF-VAS), RPE, psychomotor vigilance, distance cycled, power output, heart rate, and blood lactate were measured. ***Results:*** In part 1, the cognitive task increased lift-induced RPE ($P = .011$), increased MF-VAS ($P = .002$), and altered mood ($P < .001$) compared with control. EMG did not differ between conditions. In part 2, the cognitive tasks increased RPE ($P < .001$), MF-VAS ($P < .001$), and mental workload ($P < .001$), but reduced cycling time-trial power ($P = .032$) and distance ($P = .023$) compared with control. Heart rate and blood lactate did not differ between conditions. ***Conclusion:*** A state of MF induced by cognitive load, alone or intermixed with physical load, increased RPE during weight lifting and training and impaired subsequent cycling performance.

Keywords: training load, strength training, anaerobic training, neuroperformance, sport performance, cognitive performance

Mental fatigue (MF) is a psychobiological state induced by demanding cognitive tasks that is characterized by subjective tiredness or lack of energy and impaired cognitive function.[1,2] Exercise physiologists have confirmed its potential to impair physical performance[2] and sport-specific psychomotor performance.[3] Interestingly, in these studies, poorer performance was not accompanied by any peripheral physiological changes but, rather, by increased rating of perceived exertion (RPE). Therefore, RPE has been proposed as the cause of reduced endurance performance for tasks that are vulnerable to MF.[2]

In contrast, physical activities that require brief bursts of strength/power, such as sprints, jumps, and maximum voluntary contractions, appear to be largely unaffected by MF.[2,4,5] For example, there is evidence that MF does not impair strength and power exercises lasting up to 3 minutes.[2,6] Conversely, MF can impair submaximal resistance strength exercise. One study documented that MF hastened the time to failure when performing a submaximal contraction at 20% maximum voluntary contraction.[7] Similarly, other studies noted that cognitive tasks impaired subsequent performance of calisthenic exercises, including fewer push-ups and sit-ups as well as shorter wall-sits.[8,9] Taken together, these findings suggest that MF could negatively impact resistance training. Despite the large body of research concerning the effects of MF on physical performance, there is scant evidence on the effect of MF on resistance exercise performance. Recent studies found that MF, induced by cognitive tasks, reduced the number of repetitions and sets of resistance exercise performed.[10,11] Accordingly, there is preliminary evidence that weight training may be negatively impacted by MF.

Impairments in physical performance that accompany states of MF appear to be uncoupled from physiological changes, such as oxygen consumption, heart rate (HR), and blood lactate.[2] However, the role of muscle activity is less clear-cut. Some studies report no effect of MF on electromyography (EMG),[6,7,12,13] whereas other studies document increased vastus lateralis[14] and rectus femoris[15] EMG when in a state of MF. Accordingly, further research is warranted to better understand the effect of MF on muscle function.

The vast majority of studies on MF and physical performance have examined the effect of a classic cognitive task (eg, Stroop) designed to induce MF, on a subsequent exercise task. However, in sport a variety of cognitive tasks, which vary in terms of duration and scheduling relative to the sporting activity, such as coach briefings, social media, work commitments, and the mental demands of sport itself,[11,16] have been identified as sources of MF. During physical training with scheduled rest breaks (eg, resistance training, high-intensity interval training, and track sprinting) and multistage competitions, athletes may engage in cognitive activities (eg, social media or games on a smartphone) during these inactive periods and thereby put themselves in a mental state that impairs any subsequent physical performance. In other words, such athletes can be considered as engaging in a form of intermixed mental and physical loading. To date, no laboratory study has

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Ring https://orcid.org/0000-0001-9921-0435
Staiano (walterstaiano@gmail.com) is corresponding author, https://orcid.org/0000-0002-1269-0016

examined the effect of such intermixed loading on performance. Moreover, studies that have examined the effect of performing the cognitive task during the physical exercise task (ie, concurrent loading) are rare.[17,18] Importantly, the evidence generated by these studies is mixed, and therefore, the effect of a cognitive load added to a physical load on subsequent physical performance awaits clarification. To address this gap in our understanding of the MF–performance relationship, we explored the effect of intermixed mental and physical loads, which were designed to create a state of cognitive and physical fatigue, on a subsequent physical endurance task.

The purposes of the current 2-part study were 3-fold. Our first study purpose (part 1) was to determine the effect of a prior isolated cognitive task on subsequent MF, mental alertness, and perceived effort associated with performing a series of submaximal weight lifting exercises. We hypothesized that cognitive loading with an isolated cognitive task would induce MF, reduce mental alertness, and increase RPE during weight lifting. Our second study purpose (part 2) was to determine the effect of cognitive tasks intermixed with resistance training exercises on MF, alertness, and perceived effort. We hypothesized that intermixed cognitive and physical training would increase cognitive load, induce MF, reduce alertness, and increase sessional RPE of the training session. Finally, our third study purpose was to determine the effect of intermixed cognitive and physical training on subsequent cycling time trial (TT) performance. We hypothesized that the cognitive loading and MF produced by the intermixed cognitive and physical training would reduce subsequent cycling power output and distance covered.

Methods

Participants

Sixteen (9 men and 7 women) healthy and fit (mean [SD], age 27 [5] y, height 172 [7] cm, weight 63 [8] kg, peak power output [PPO] 305 [45] W, peak oxygen uptake [VO_2peak] 60 [4] mL·kg^{-1}·min^{-1}) participants were recruited and provided informed consent. The study protocol was approved by the Ethics Committee of the School of Sport and Physical Education at Valencia University in accordance with the Declaration of Helsinki. All participants received written instructions describing the study protocol but were naïve to its aims and hypotheses.

Experimental Design

This 2-part study employed a randomized crossover design. Each part comprised 3 laboratory sessions (see Figure 1), with a familiarization session, followed by 2 counterbalanced testing sessions (MF and control condition [CON]). Twenty-four hours prior to each visit, participants were instructed to drink 35 mL of water per kilogram of body weight, sleep for at least 7 hours, refrain from the

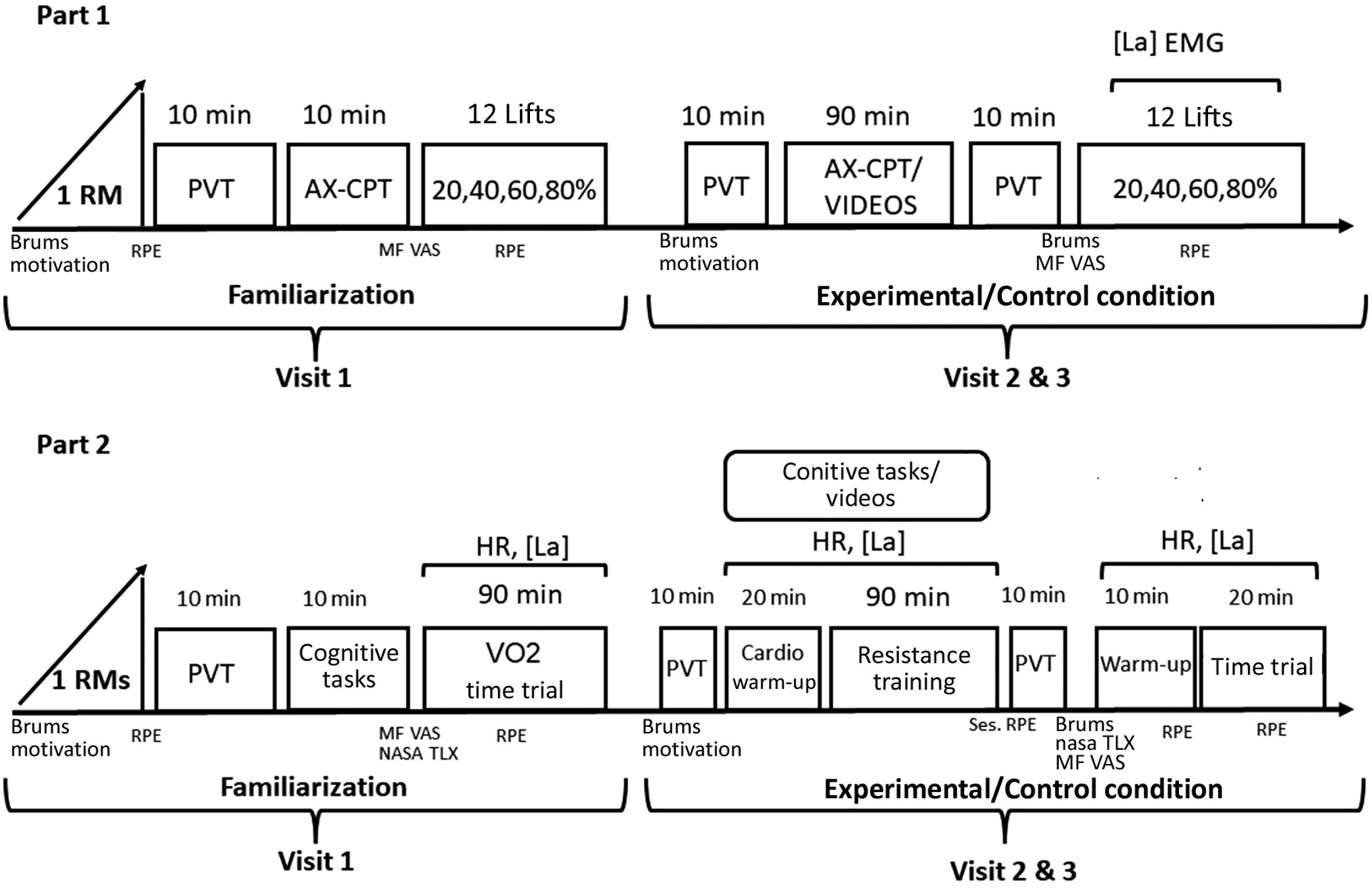

Figure 1 — Schematic of the experimental protocol. AX-CPT indicates AX Continuous Performance Task; HR, heart rate; [La], blood lactate; MF, mental fatigue; NASA-TLX, National Aeronautics and Space Administration Task Load Index; PVT, psychomotor vigilance test; RM, repetition maximum; RPE, rating of perceived exertion.

consumption of alcohol and caffeine, and avoid any vigorous exercise. 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 for visit 3. At the beginning of all visits, participants were asked to complete a checklist to verify they had complied with instructions. Participants were also asked to declare whether they had taken any medication/drug, or had an acute illness, injury, or infection. Time of testing, environmental conditions, and exercise equipment settings were also standardized.

Procedure

Part 1

In the familiarization session, we obtained each participant's anthropometric measures; gave instructions about questionnaires, cognitive tasks, and ratings (see "Measures" section); and recorded their 1-repetition maximum (1RM) for their dominant leg. We used a modified CR10 Borg scale for RPE, and emphasized that the rating should be based exclusively on effort, defined as how hard they had to drive their leg to lift the weight and not on any burning or pain sensation in their leg. Subsequently, they lay down on a leg extension bench with the backrest inclined 20°. The RPE scale was presented above the participant's head in their line of sight. A screen prevented them from seeing their lower body, weights, and researchers. As the capacity to generate force varies between individuals, task difficulty was normalized to each participant's 1RM for dominant leg extension. After a few warm-ups, the weight was gradually increased until it was too heavy for the participant to lift. The heaviest successfully lifted weight was recorded as the 1RM (42.0 [3.1] kg). Participants performed leg extensions over a range of 125° to 180° knee angles. A researcher, blind to the study aims, provided verbal encouragement throughout the protocol and asked the participant to provide their RPE after every lift. After establishing the 1RM, participants practiced lifting weights corresponding to 20%, 40%, 60%, and 80% 1RM.

In the 2 testing sessions, participants completed mood, MF, and motivation scales (see "Measures" section), and then performed a computerized 10-minute psychomotor vigilance test (PVT) to assess their mental alertness and readiness to perform.[19] Reaction time (in milliseconds), for responses between 100 and 500 ms, and number of lapses, defined as responses slower than 500 ms, were computed. Participants completed the testing session under one of 2 counterbalanced conditions: MF induced by a cognitive task, and CON. In the MF condition, participants performed a 90-minute AX Continuous Performance Task (AX-CPT) using the SOMA-NPT app (Sswitch) on a tablet computer. In the CON, participants watched a 90-minute emotionally neutral video about cars.[1] After each 90-minute task, participants completed a second 10-minute PVT, rated mood and MF, and performed a series of leg extension exercises. Each of the 4 weights (20%, 40%, 60%, and 80% 1RM) was lifted 3 times in random order, separated by a 2-minute rest. During each lift, participants held their leg in an extended position for 3 seconds before bringing it back down. They rated their physical effort using the RPE scale immediately after each lift. Leg EMG was recorded for the vastus lateralis muscle during each lift. The mean scores for each of the 3 lifts were computed. Blood lactate was measured at rest before any lifting.

Part 2

In the familiarization session, participants completed mood, MF, and motivation scales (see "Measures" section); were instrumented; performed a 10-minute PVT; and were familiarized with the questionnaires, scales, and tasks. Next, their 1RM (see protocol above) for each of 6 weight training exercises (lateral machine, chest press, leg press, leg curl, crunch, and biceps curl) was determined and seat position recorded. The CR10 RPE scale was used to assess perceived effort during the 1RM tests. After a 30-minute rest, participants completed an incremental cycling exercise test (2 min at 50 W plus 50 W increments every 2 min) until volitional exhaustion on an electromagnetically braked cycle ergometer (High-Performance Ergometer, Schoberer Rad MeBtechnik) to measure $\dot{V}O_2$peak and PPO. After a 30-minute rest, participants were familiarized with the TT cycling test.

In the 2 testing sessions, participants completed mood, MF, and motivation scales; performed a 10-minute PVT; cycled for 20 minutes at 30% of PPO (resistance training warm-up); completed a series of 6 resistance exercises (resistance training); performed a 10-minute PVT; completed mood, workload, MF, and sessional RPE ratings; rested for 10 minutes; cycled for 10 minutes at a 40% of PPO to warm-up; and then performed a 20-minute TT (see Figure 1). The resistance exercises comprised 3 sets of 12 repetitions at 70% (defined as a moderate-intensity training session[20]) of 1RM, separated by a 2-minute rest between sets and a 5-minute rest between exercises. In the TT, participants were asked to cycle as fast as possible. They started with a selected gear but could change gear thereafter. They could see the elapsed time on a watch, but they were blind to the power produced and distance covered. No verbal encouragement was provided. Blood lactate was measured at rest (before starting the TT warm-up), after TT warm-up, and at completion of the TT. HR and RPE were recorded at rest (before the TT warm-up); at the end of the TT warm-up; and during minutes 1, 4, 8, 12, 16, and 20 of the TT.

Participants completed each testing session under 1 of 2 counterbalanced conditions: MF or CON. In the MF condition, participants performed 1 of 3 response inhibition[21] cognitive tasks (flanker task, go/no-go task, and AX-CPT) using the SOMA-NPT app (Sswitch). The tasks were completed during the first cycling warm-up (20 min), the 2-minute rests between sets, and the 5-minute rests between exercises. In the CON, participants watched emotionally neutral videos about cars[1] during these warm-ups and rests. Overall, participants completed cognitive tasks or watched videos for 69 minutes, comprising 20 minutes of resistance training warm-up plus 49 minutes between resistance training exercises.

Measures

Psychological and Perceptual Measures

Motivation regarding the whole testing session was measured by rating the statement "I am motivated to perform the test" using a 5-point Likert scale, with anchors of 0 (not at all) and 4 (extremely). Subjective workload was measured using the mental and physical demand and frustration, and effort subscales of the National Aeronautics and Space Administration Task Load Index.[22] Mood was measured using the Brunel Mood Scale (BRUMS).[23] MF was measured using an MF visual analogue scale (MF-VAS): Participants indicated how mentally fatigued they were on a scale anchored by "not all exhausted" and "completely exhausted" by placing a mark on a 10-cm line.[3] CR-10 Borg scale has been used to assess perceived exertion during weight lifting and the cycling TT, while sessional RPE (using the same scale) has been used to assess overall effort during resistance training.[20]

Physiological Measures

Blood lactate concentration (mmol/L) was determined (Lactate Pro LT-1710, Arkray) from a 5-µL sample of index finger whole fresh blood at rest, after warm-up, and at completion of the TT. Cycling HR was measured using a sensor (H10, Polar Electro Oy). The EMG of the vastus lateralis muscle of the dominant leg was recorded with pairs of 10-mm-diameter circular silver chloride surface electrodes (Swaromed Nessler Medizintechnik) with a 20-mm interelectrode (center to center) distance. Signal processing was performed using AcqKnowledge software (BIOPAC Systems Inc), and the root mean square, a measure of EMG amplitude, was calculated during the last 2 seconds of holding the weight.

Statistical Analysis

Data are reported as mean (SD). Assumptions of statistical tests for normal distribution and sphericity of data were checked. In part 1, separate 2 condition (MF and CON) by 4 task load (20%, 40%, 60%, and 80% 1RM) analyses of variance (ANOVAs) were performed on RPE and leg EMG. Separate 2 condition (MF and CON) by 2 time (precondition and postcondition) ANOVAs were conducted on the BRUMS subscales, MF-VAS, reaction time, and lapses during the PVT. Paired *t* tests compared motivation and blood lactate between conditions. In part 2, a series of 2 condition (MF and CON) by 2 time (pretraining and posttraining) ANOVAs were conducted on the BRUMS, MF-VAS, PVT reaction time, and lapses. Separate 2 condition (MF and CON) by 6 time (1, 4, 8, 12, 16, and 20 min) ANOVAs were performed on power, RPE, and HR during the TT. Paired *t* tests compared conditions for motivation, National Aeronautics and Space Administration Task Load Index, blood lactate, and distance covered. Significant interactions were followed up with Tukey tests as appropriate. If significant interactions were not found, key main effects were reported. Significance was set at $P < .05$ (2-tailed). The effect sizes for the ANOVAs were calculated as partial eta squared (η_p^2), with small = .02, medium = .13, and large = .26. For *t* tests, Cohen *d* was calculated as the effect size, with small = 0.20, medium = 0.50, and large = 0.80. Data analysis was conducted using the Statistical Package for Social Sciences (SPSS, version 27).

Results

Part 1

Motivation, Mood, and MF

Motivation before weight lifting did not differ between MF (3.3 [1.1]) and CON (3.2 [1.4]) conditions ($t_{15} = 0.37$, $P = .72$, $d = 0.08$). Separate 2 condition by 2 time ANOVAs on the BRUMS subscales yielded interaction effects for anger ($F_{1,14} = 18.76$, $P < .001$, $\eta_p^2 = .22$), fatigue ($F_{1,14} = 31.11$, $P < .001$, $\eta_p^2 = .11$), vigor ($F_{1,14} = 8.91$, $P = .012$, $\eta_p^2 = .39$), and boredom ($F_{1,14} = 21.76$, $P < .001$, $\eta_p^2 = .22$), but not confusion, depression, and tension (Figure 2A). Follow-up tests revealed that, compared with the CON condition, the MF condition (ie, AX-CPT) created a state of increased anger ($P = .031$), fatigue ($P = .022$), and boredom ($P = .025$), as well as decreased vigor ($P = .007$). A 2 condition by 2 time ANOVA on the MF-VAS ratings produced an interaction effect ($F_{1,14} = 13.55$, $P = .002$, $\eta_p^2 = .21$); MF increased from pre (1.1 [0.4]) to post (6.7 [1.0]) cognitive task ($P = .011$), whereas MF did not change from pre (1.5 [0.8]) to post (2.1 [0.9]) video task ($P = .51$).

Cognitive Performance

Fatigue-related alertness and readiness were assessed by PVT performance. Separate 2 condition by 2 time ANOVAs generated interaction effects for both RT ($F_{1,14} = 5.73$, $P = .032$, $\eta_p^2 = .11$) and lapses ($F_{1,14} = 5.05$, $P = .041$, $\eta_p^2 = .09$; Figure 2B). Response speed was slower in postassessment than preassessment for both MF ($P = .014$) and CON ($P = .045$) conditions, and was slower post-MF than post-CON. Moreover, the number of lapses increased from pre- to postassessments in the MF condition (1.3 [0.8] < 4.4 [1.3], $P = .041$) but not in the CON (0.9 [1.0] = 1.2 [0.8], $P = .11$).

Perception and Physiology

A 2 condition by 4 task load ANOVA on RPE during weight lifting (Figure 2C) showed main effects for condition ($F_{1,14} = 8.62$, $P = .011$, $\eta_p^2 = .52$) and task load ($F_{1,14} = 5.35$, $P = .042$, $\eta_p^2 = .15$), but no interaction effect ($F_{1,14} = 2.66$, $P = .14$, $\eta_p^2 = .10$). RPE was higher in the MF condition compared with the CON condition and increased progressively with task load. ANOVA on leg EMG detected a task load effect ($F_{1,14} = 6.68$, $P = .021$, $\eta_p^2 = .17$), but no condition effect ($F_{1,14} = 0.81$, $P = .82$, $\eta_p^2 = .09$), or condition by load effect ($F_{1,14} = 1.76$, $P = .19$, $\eta_p^2 = .09$; Figure 2D). EMG increased with task load without differences between conditions. Finally, blood lactate concentration at rest before starting the weightlifting exercises did not differ between the MF (0.8 [1.3] mmol/L) and CON (1.1 [1.5] mmol/L) conditions ($t_{15} = 0.92$, $P = .37$, $d = 0.21$).

Part 2

Motivation, Mood, MF, and Workload

Motivation before resistance training did not differ between the MF (3.5 [1.4]) and CON (3.4 [1.2]) conditions ($t_{15} = 0.25$, $P = .81$, $d = 0.08$). The 2 condition by 2 time ANOVAs on the BRUMS subscales completed in postresistance training found interaction effects for fatigue ($F_{1,14} = 17.32$, $P < .001$, $\eta_p^2 = .19$) and vigor ($F_{1,14} = 22.55$, $P < .001$, $\eta_p^2 = .19$). Fatigue increased in the MF (pre = 1.5 [1.1], post = 7.9 [1.7], $P = .012$) and CON (pre = 1.2 [1.2], post = 4.9 [1.7], $P = .02$) conditions, with higher postcondition fatigue in the MF condition than CON condition. Similarly, vigor decreased in the MF (pre = 11.5 [1.6], post = 2.4 [1.5], $P = .001$) and CON (pre = 12.5 [1.2], post = 4.9 [1.4], $P = .013$) conditions and was lower for MF than CON. No main or interaction effects were noted for the anger, depression, frustration, tension, and boredom subscales. The National Aeronautics and Space Administration Task Load Index subscales completed after resistance training (Figure 3A) revealed higher mental demand ($t_{15} = 5.11$, $P < .001$, $d = 6.33$), effort ($t_{15} = 4.65$, $P < .001$, $d = 0.32$), and frustration ($t_{15} = 2.60$, $P = .022$, $d = 0.76$) during the MF than CON condition. No condition difference was noted for physical demand ($t_{15} = .44$, $P = .67$, $d = 0.57$). A 2 condition by 2 time ANOVA on the MF-VAS ratings yielded an interaction ($F_{1,14} = 11.14$, $P = .001$, $\eta_p^2 = .31$). Follow-up tests indicated that, compared with pretest, participants were more mentally fatigued at posttest in both MF (pre = 0.9 [1.5], post = 7.1 [1.8], $P = .001$) and CON (pre = 1.1 [1.6], post = 3.9 [1.3], $P = .025$) conditions, and importantly, MF was higher in the postassessment in the MF condition.

Cognitive Performance

The PVT performance measures (ie, indices of alertness and readiness) were subjected to 2 condition by 2 time ANOVAs. The interaction for reaction time ($F_{1,14} = 6.76$, $P = .021$, $\eta_p^2 = .16$)

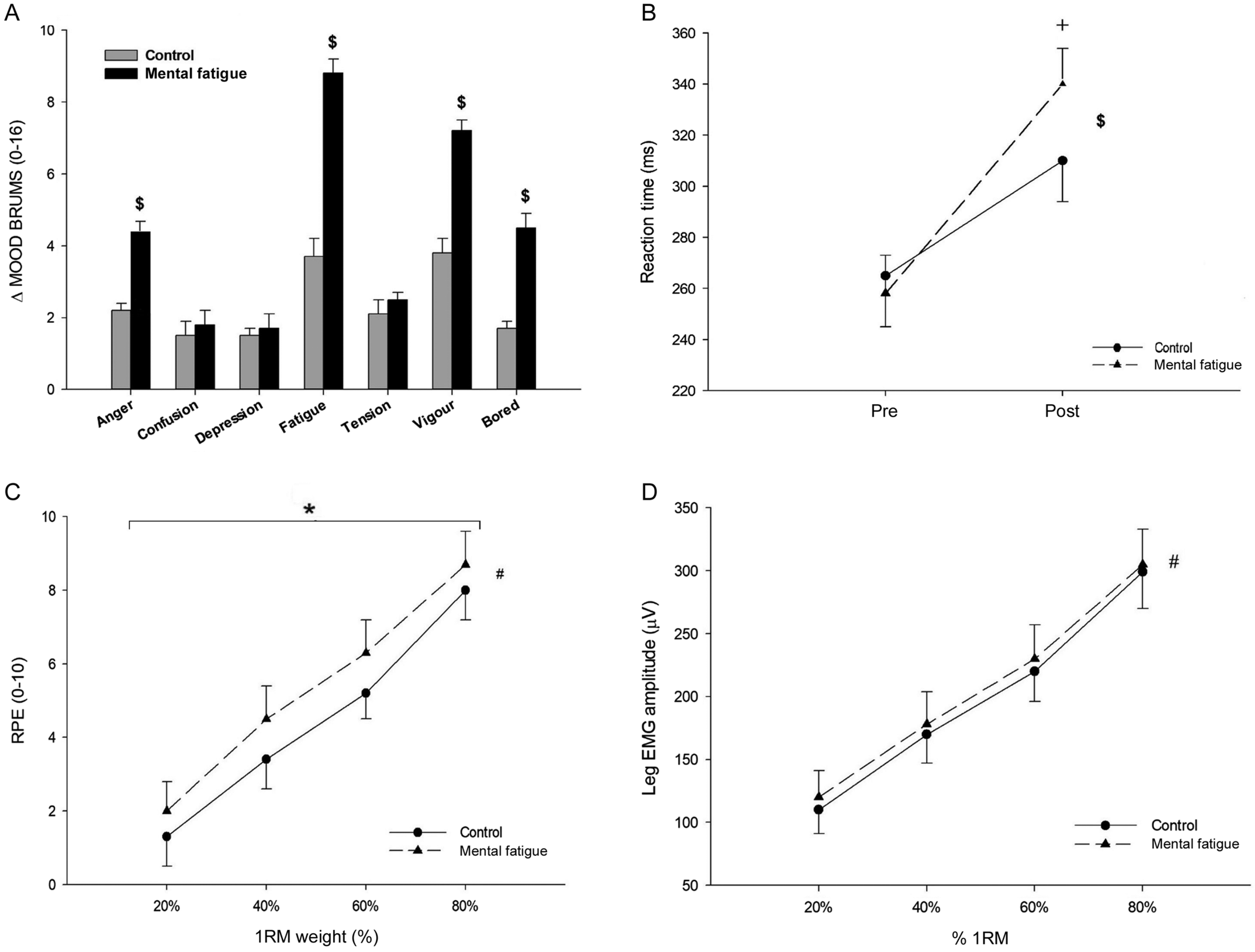

Figure 2 — Study part 1. (A) Mean (95% CI) BRUMS mood subscales for the 2 experimental conditions. *Note.* Bars represent the Δ difference between the values at post and pre. Negative scores were positively reversed. (B) Mean (95% CI) reaction time during the Psychomotor Vigilance Test before and after the 2 conditions. (C) Mean (95% CI) RPE during the weight lifting performance at different task loads in percentage of the 1RM. (D) Mean (95% CI) RMS of the vastus lateralis during the weight lifting performance at different task loads in percentage of the 1RM in both experimental conditions. §Significant condition × time interaction. *Significant main effect of condition. #Significant main effect of time. +Significant simple main effects. 1RM indicates 1-repetition maximum; BRUMS, Brunel Mood Scale; RMS, root mean square; RPE, rating of perceived exertion.

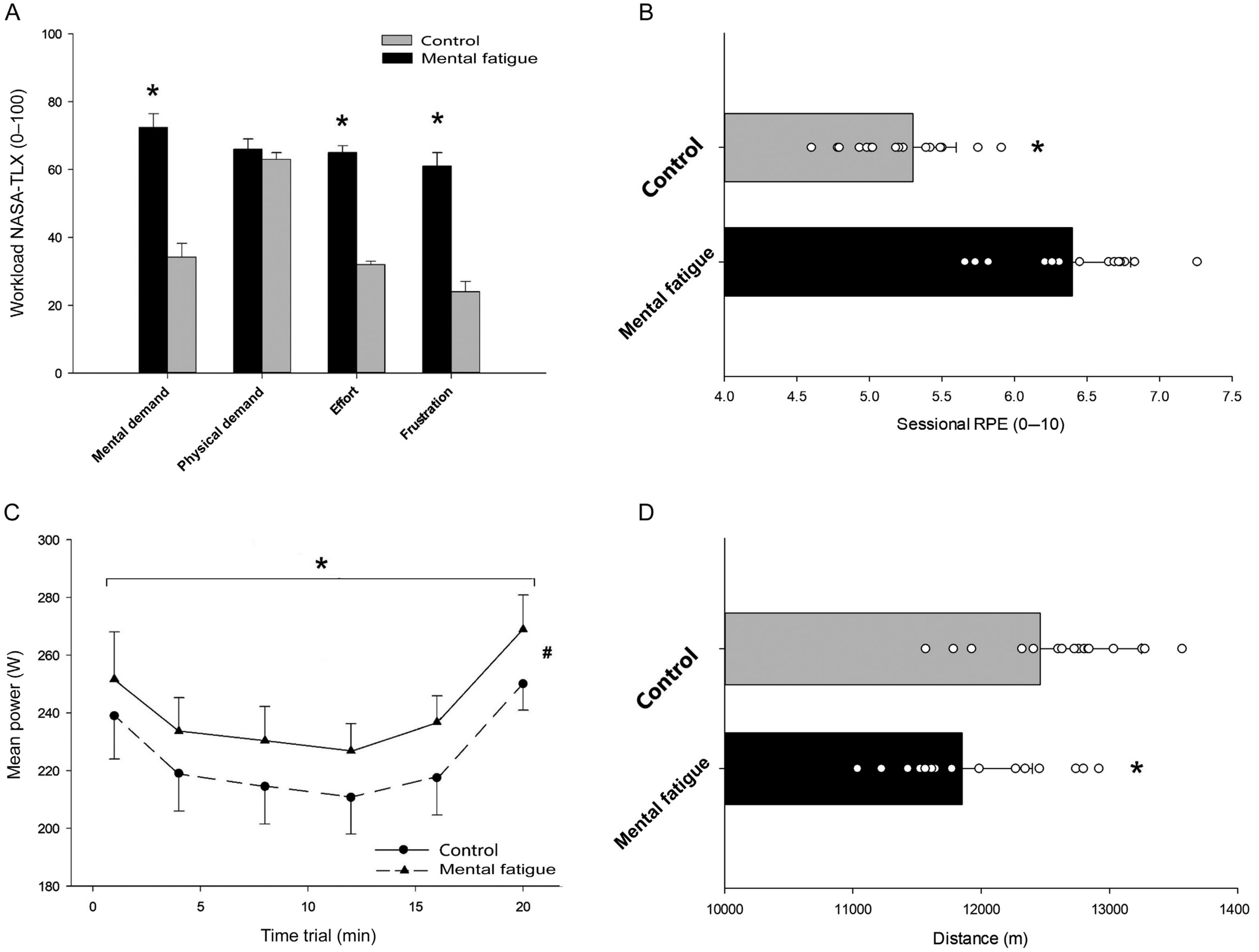

Figure 3 — Study part 2. (A) Mean (95% CI) NASA-TLX subscales related to the resistance training session in both conditions. (B) Mean (95% CI) sessional RPE of the resistance training session in both conditions. (C) Mean (95% CI) power profile during the 20-minute time trial in both conditions. (D) Mean (95% CI) distance covered during the 20-minute time trial in both conditions. §Significant condition × time interaction. *Significant main effect of condition. #Significant main effect of time. +Significant simple main effects. NASA-TLX indicates National Aeronautics and Space Administration Task Load Index; RPE, rating of perceived exertion.

and follow-up tests showed that participants responded slower after resistance training in the MF condition (pre = 265 [18] ms, post = 333 [21] ms, $P = .021$) but not the CON condition (pre = 275 [22] ms, post = 288 [18] ms, $P = .12$). No significant effects were detected for lapses (grand mean: 1.8 [1.1]).

Perception and Physiology

Sessional RPE at completion of the resistance training session was higher in the MF condition compared with CON ($t_{15} = 6.17$, $P < .001$, $d = 1.62$; Figure 3B). The condition by time ANOVA on RPE during the TT detected a time effect ($F_{1,14} = 21.79$, $P < .001$, $\eta_p^2 = .43$) but no condition effect ($F_{1,14} = 0.55$, $P = .47$, $\eta_p^2 = .00$) or condition by time effect ($F_{1,14} = 0.43$, $P = .58$, $\eta_p^2 = .09$). RPE increased similarly in both conditions over time (grand mean: first min 12.9 [0.9], fourth min 14.3 [1.1], eighth min 15.1 [0.8], 12th min 16.4 [1.2], 16th min 17.7 [1.1], and 20th min 19.1 [0.3]).

ANOVA yielded main effects of time confirming that HR ($F_{1,14} = 22.79$, $P < .001$, $\eta_p^2 = .43$) and lactate ($F_{1,14} = 6.65$, $P = .023$, $\eta_p^2 = .13$) increased during the 20-minute TT. Overall, HR increased from 162 (3) in minute 1 to 185 (4) in minute 20, while lactate concentration rose from 0.9 (1.0) mmol/L at rest to 1.8 (1.4) mmol/L at the end of warm-up to 11.3 (1.1) mmol/L at completion of the TT. No main effect of condition or interaction effects was found.

Physical Performance

Performance during the 20-minute TT, a measure of physical endurance, was impaired by MF. The 2-condition by 6-time ANOVA yielded a main effect of condition for power ($F_{1,14} = 5.65$, $P = .032$, $\eta_p^2 = .19$); participants produced less power while cycling on the bike in the MF condition compared to CON (Figure 3C). They also cycled a shorter distance in the MF (11,850 [550] m) than CON (12,460 [790] m) condition, ($t_{15} = 2.68$, $P = .023$, $d = 0.40$; Figure 3D).

Discussion

The overall aim of the present study was to investigate the effects of cognitive load, both alone and combined with physical load on the subsequent experience and performance of weightlifting, resistance training, and endurance tasks. Our findings demonstrated that a state of MF, induced by the cognitive tasks, made weightlifting and resistance exercises feel harder and impaired subsequent cycling TT performance.

Our first study purpose was to determine the effect of an isolated cognitive task on MF and perceived effort during subsequent weightlifting exercise. In support of our hypothesis, we found that completing a 90-minute AX-CPT created a state of increased MF, as confirmed by the BRUMS and MF-VAS fatigue ratings. Our finding that the AX-CPT increased self-reported fatigue is broadly in line with previous studies that used this manipulation to induce MF.[1,2] Moreover, we corroborated our subjective data using behavioral data from a vigilance probe task, the PVT. In particular, we found that the 90-minute AX-CPT impaired performance on a subsequent 10-minute PVT. Our finding that the AX-CPT slowed response speed, both in terms of the mean reaction time and the number of lapses (ie, responses > 500 ms), provides objective evidence of fatigue-related falls in alertness and readiness attributable to the prior cognitive task. Similar effects of a cognitive task on PVT performance have been noted in the literature.[19,24]

Given evidence that a state of MF can alter RPE associated with a subsequent physical task,[2] we expected that a prolonged AX-CPT, which increased MF (see above), would increase RPE during subsequent weightlifting. In support of our hypothesis, we found that the 90-minute AX-CPT increased the perception of how heavy a lifted weight felt, right across a broad range of weights that varied between 20% and 80% of leg extension 1RM. In this paradigm, the RPE scale reflected the effort required to lift and hold the weight. The evidence showed that MF augmented RPE; participants judged the weight to be from 7% to 15% heavier than during the standard CON condition. The current evidence shows when participants rate the effort needed to hold a submaximal weight MF affects the perceived heaviness of the lifted weight. Although this contrasts with studies that failed to observe any effect of MF on maximum voluntary contraction,[2,5] when the participants were asked to lift and hold a submaximal load for as long as they could (as seen in previous studies[7]), those who were mentally fatigued performed worse. Accordingly, it seems that although MF does not affect brief (< 1 s) maximal weightlifting, it makes the degree of effort required feel harder when the weight to lift (or the load to push) is submaximal and lasts longer (a few seconds). In sum, our findings are compatible with evidence from previous studies[1,2,17] showing that a state of MF, induced by a demanding cognitive task, makes physical exercise feel harder.

Our second study purpose was to determine the effect of cognitive tasks intermixed with resistance training exercises on MF, alertness, and perceived effort. As hypothesized, we showed that intermixed mental plus physical loading induced MF and increased sessional RPE. In particular, indices of subjective MF (ie, BRUMS and MF-VAS fatigue ratings) and objective MF (ie, PVT reaction times) confirmed that the battery of cognitive tasks (ie, flanker task, go/no-go task, and AX-CPT) produced a state of increased MF. Importantly, the sessional RPE was 22% higher with cognitive plus physical loading than control (ie, physical loading alone), indicating that MF made weight training feel harder. This result is in line with a previous study showing that concurrent mental and physical loading made the physical exercise harder.[17] In the present study, the protocol incorporated both concurrent loading (cognitive tasks during the warm-up) and intermixed loading (cognitive tasks between the exercise sets) so that the brain was constantly engaged throughout the resistance training session while the body was able to recover between tasks, sets, and repetitions. A previous study[25] showed that MF accumulated during a week of physical training impacted overall sessional RPE for the whole week; the study used the cumulative effect of the weekly physical training as load to induce MF. In the present study, we proved how combining mental and physical load can produce an increase in overall training load (sessional RPE), even in a single session. It is worth mentioning that the resistance training was of medium intensity with a relatively high number of repetitions (ie, 12) and with a fixed protocol to complete, and which produced an increased RPE for a specific given load, whereas in other similar studies,[10,11] the performance was maximal with no changes in RPE and they observed a reduction in the number of repetitions lifted.

Our third study purpose was to determine the effect of intermixed mental and physical loading on subsequent cycling TT performance. In support of our hypotheses, we found that intermixed loading increased fatigue and impaired physical performance. Participants in the MF condition cycled at a lower power output throughout the TT. The present results are in line with previous studies using MF and self-regulated closed-loop physical tests, such as TT.[2] It is worth noting that the MF manipulation did not impact RPE during the cycling TT, which is broadly similar to previous studies in this context.[26,27] This is because TTs require participants to cycle as fast as possible for a specific amount of time, and therefore, one would expect to see an effect of MF on power output performance (for further comparison of TTs and TTEs, see study by Marcora et al[1]). Although the RPE did not change during the TT, it is clear participants who use RPE to pace themselves were pushing on the pedal with less power when they were mentally fatigued. As demonstrated in a previous study,[28] MF and cardiorespiratory parameters may not be the limiting factor in endurance performance in this context. Indeed, we did not observe any physiological differences in the present study. Therefore, we argue that the current reduction in TT performance reflects a central effect, namely, altered RPE, due to MF. Although MF does not always affect cycling performance, and may depend on the level of cyclists and the type of load applied,[26] we observed a 5% impairment in overall cycling performance. When comparing such a decrement with previous studies, it is important to mention that the present TT was performed following resistance training, and thus, participants were not in a fresh state. Nevertheless, when participants were mentally and physically fatigued (MF condition) they produced less power and covered less distance compared with when they were only physically fatigued (CON condition).

It is worth noting that the EMG response was not influenced by the MF manipulation which provides indirect support for the hypothesis that MF-related changes in performance happen at a central rather than peripheral level.[1] However, we note that our EMG findings agree with some[12,13] but contrast with other studies.[6,14] We speculate that the type and length of task used and the exercise performed and its modality may account for the discrepancy. For instance, the present task required lifting within a small angle range and holding different weights for 3 seconds, whereas previous tasks required pushing and holding a low load for as long as possible, cycling, or different muscle groups. We speculate that when simple movements are involved and the task is submaximal and short in duration (a few seconds), no differences in EMG are detected. However, when the duration of exercise or the complexity of the muscle contraction performance increases, such as happens with more complex movements, MF may impact motor control and intra/intermuscular coordination. Similarly, in part 2, we did not see any effect of MF on blood lactate and HR during the cycling TT. These results are in line with previous studies[26,27] and support the general idea[2] that MF affects performance via a central mechanism and alters RPE through processes other than peripheral physiological activity.

Practical Applications

The MF and performance relationship has attracted attention in sport science because MF has the potential to make physical performance in sport feel harder and negatively impact performance. The growing literature in this context encourages researchers and practitioners to develop and implement strategies to mitigate the effect of MF.[29] The present study suggests that reducing the cognitive load experienced before and during a resistance training session may help the experience of and performance during training and thereby potentially boost subsequent performance. Scenarios, such as the warm-up, training and competing multiple times in the same day, and multistage sport (ie, triathlon and biathlon), may benefit from reducing the cognitive load of the previous activity. The present results suggest the relevance of the type of activity performed during the warm-up (concurrently), and between sets, and repetitions (intermixed) to the overall training load of the session. Previous studies have shown the deleterious effect of smartphone use prior to resistance training.[11] On the other spectrum, several studies have shown the potential benefit of nutritional, psychological, behavioral, and environmental strategies to counteract the effect of MF.[29] One possible strategy is brain endurance training, which aims to cognitively overload brain areas involved in perception of effort and fatigue, and which has been shown to combat MF and increase resilience posttraining.[21,30] Based on our findings, we would recommend that coaches and performance directors put in place practices that reduce exposure to mentally fatiguing activities, such as smartphone use, prior to and during training and competitions. They should also consider brain endurance training as a long-term solution to increase robustness and resilience to MF.

Conclusions

In the present study, we proved that additional cognitive loading (inducing MF), either alone or mixed with physical loading, can make weight and resistance training harder and impair subsequent physical endurance performance.

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