Article

Perceptual and Motor Skills
0(0) 1–20

DOI: 10.1177/00315125211016233
journals.sagepub.com/home/pms
SAGE

Mental Fatigue From Smartphone Use Reduces Volume-Load in Resistance Training: A Randomized, Single-Blinded Cross-Over Study

Petrus Gantois[1], Dalton de Lima-Júnior[1], Leonardo de Sousa Fortes[1,2], Gilmário Ricarte Batista[1], Fábio Yuzo Nakamura[1,3], and Fabiano de Souza Fonseca[4,5]

Abstract

We investigated the acute effects of mental fatigue induced by 30-minute use of smartphone social network apps on volume load in resistance training among recreationally trained adults. Sixteen (n = 16) adults of both sexes performed three sets of a half back-squat exercise to failure with 80% of 15RM, interspersed with 3-minutes of passive recovery between sets, before and after two different cognitive tasks:

[1]Associate Graduate Program in Physical Education of Federal University of Paraíba, João Pessoa-PB, Brazil
[2]Graduate Program in Cognitive Neuroscience and Behavior of Federal University of Paraíba, João Pessoa-PB, Brazil
[3]Research Center in Sports Sciences, Health Sciences and Human Development (CIDESD), University Institute of Maia (ISMAI), Maia, Portugal
[4]Department of Physical Education of Federal Rural University of Pernambuco, Recife-PE, Brazil
[5]Graduate Program in Physical Education UFPE, Recife-PE, Brazil

Corresponding Author:
Petrus Gantois, Associate Graduate Program in Physical Education, Federal University of Paraiba, João Pessoa, Brazil.
Email: pgm.gantois@gmail.com

(a) use of smartphone social network apps; and (b) watching a documentary. We assessed mechanical variables and ratings of perceived exertion during the strength exercise. Relative to the documentary-viewing control condition, a 30-minute exposure to smartphone social network apps led participants toward increased perception of mental fatigue ($p = 0.004$) and lower volume-load during the strength exercise ($p = 0.006$). There were no significant differences in perceived exertion between conditions ($p = 0.54$), participants' motivation ($p = 0.277$), intra-set mechanical variables ($p > 0.05$), or blood lactate concentrations ($p = 0.36$). Our findings of an isolated possible higher-than normal RPE without changes in physiological variables, accompanying the lower volume-load in the mentally-fatigued participants support psychological, rather than physiological, bases for mental fatigue effects.

Keywords
mental fatigue, resistance exercise, perceived exertion, concentric mean velocity, volume-load

Introduction

Resistance training (RT) is one of the main modern conditioning programs for promoting strength, power, and muscle size gains (Marshall et al., 2021; Schoenfeld et al., 2021). To maximize gains in these programs, trainers may manipulate their prescriptions of certain variables (e.g., number of sets and repetitions, intensity, rest time, and movement velocity), as these parameters determine the magnitude of the trainees' physiological, mechanical, and psychological responses during an exercise program (American College of Sports Medicine, 2009). Among these RT prescription parameters, the number of repetitions performed for a given load intensity in a session (i.e., load) is known as the most important variable in RT, since volume-load plays the main role in muscle size gains (Schoenfeld et al., 2017). To help individual trainees maintain a high volume-load during their RT sessions, it is necessary to investigate possible performance limiting factors.

The main factor that reduces performance during RT sessions is cumulative fatigue, due to an increased number of repetitions in consecutive sets of resistance exercises (Sanchéz-Medina & González-Badillo, 2011; Gantois et al., 2021). Typically, the scientific literature in this area has been based on a mechanical fatigue model (i.e., decreased availability of muscle bioenergetics or force generation capacity) that reduces working capacity during a RT session (Costa et al., 2021; Gorostiaga et al., 2012). In this sense, it has been well-established that intra-set assessment of movement velocity provides reliable information about the exerciser's fatigue status (Sanchéz-Medina & González-Badillo, 2011).

However, previous studies on whole-body endurance showed that an increased rating of perceived exertion (RPE), rather than changes in muscle energetic mechanisms, was associated with reduced exercise tolerance in mentally fatigued individuals (Marcora et al., 2009; Pageaux et al., 2014; 2015). Data from those studies highlighted the brain's role in underlying cognitive processes that mediate human exercise performance. In contrast to studies on whole-body endurance, it is still unknown whether mental fatigue (MF) affects performance during multi-sets of resistance exercise. Considering the importance of intra-session performance during RT in eliciting chronic adaptations, mental fatigue warrants further study.

MF refers to a psychobiological state characterized by a sensation of tiredness and lack of energy that an individual might experience after a prolonged high-demanding mental or cognitive task (Marcora et al., 2009). Previous studies demonstrated that MF negatively affects whole-body endurance through a higher-than-normal RPE at the same submaximal exercise intensity (MacMahon et al., 2014; Marcora et al., 2009; Pageaux et al., 2015). Those results are consistent with a psycho-biological model of exercise performance based on motivational intensity theory (Marcora, 2008). Briefly, the psycho-biological model postulates that time-to-exhaustion on an endurance task is driven by two cognitive components – RPE and motivational factors. Thus, when an individuals' motivation level is unaffected during exercise, mentally fatigued persons disengage from the task when maximum effort is achieved (Marcora, 2008).

The underlying mechanisms of MF are not fully understood. Some proposed that highly demanding cognitive tasks are related to high adenosine and low dopamine levels in the brain's prefrontal cortex, especially the anterior cingulate cortex (ACC) (Pageaux et al., 2014; Smith et al., 2018). This area of the prefrontal cortex is associated with several executive functions, such as decision making based on effort during exercise, allocation of attention focus, and processing of information inherent to the environment (Lorist et al., 2005; Marcora et al., 2009). Given residual fatigue following consecutive sets of a resistance exercise, mentally fatigued individuals might experience a higher-than-normal RPE, compromising their performance in the RT session. However, this hypothesis relies on whole-body endurance studies (Marcora et al., 2009; Pageaux et al., 2014; Smith et al., 2015); the effects of MF in typical RT performance are still uncertain.

Prior MF studies have relied on cognitive tasks such as the Stroop Color Word task and AX-Continuous Performance Test (AX-CPT) (Marcora et al., 2009; Pageaux et al., 2014; Smith et al., 2015). Although these earlier investigations contributed to an understanding of the effect of MF on human performance, these are laboratory tasks that may be novel to participants; they may lack ecological validity. Inducing mental fatigue with universally common tasks that participants are apt to encounter in daily life has more direct relevance. One such task might be smartphone use, as this is a common modern tool among young adults, with 3.6 billion smartphone users worldwide (Statista, 2020). Some researchers have reported that prolonged exposure time to smartphones negatively affected cognitive functions (Fortes et al., 2019; 2021; Wilmer et al., 2017).

In a recent literature review, Wilmer et al. (2017) suggested that exposure time to smartphones affects a wide range of cognitive functions, and recently, Fortes et al. (2019) showed that 30- and 45-minute exposure times to smartphone networking apps acutely reduced inhibition control and passing decision-making among professional soccer players. More recently, Fortes et al. (2021) also found that 30-minutes of continuous social media on smartphones induced mental fatigue in high-level swimmers (e.g., impaired Stroop task response time and increase perceived mental fatigue). Taken together, these data suggest that prolonged use of smartphones induces MF and impairs exercise performance. This prior research motivated the current study; and, to the best of the authors' knowledge, this is the first study to investigate the effects of MF caused by prolonged exposure time to smartphone networking apps on performance during multi-sets of resistance exercise in recreationally trained adults. Based on whole-body endurance studies (Marcora et al., 2009; Pageaux et al., 2014; Smith et al., 2015) and the negative effects of prolonged social media use on cognitive and athletic performance (Fortes et al., 2019; 2021), we hypothesized that (a) a 30-minute exposure to smartphone social network app use would reduce session volume-load and lead to higher RPE during the session, but (b) there would be no effect of this smartphone use exposure on the participants' intra-set mechanical performance or a change in their metabolic demand (blood lactate). This pattern of results would suggest that perceived effort changes, rather than biological changes. determined the reduced performance in mental fatigue conditions.

Methods

Participants

Twenty young adults of both sexes aged 18-36 years old participated in this study. After four individuals withdrew from the study for personal reasons, the final sample was comprised of 16 participants (8 women, 8 men; M age = 24.8, SD = 4.2 years old; M weight = 73.1, SD = 9.6 kg; M height = 1.69, SD = 0.12 meters; M Weight lifted at 15 Repetition Maximum (15 RM) in back-squat exercise = 75.2. SD = 20.3 kg). All participants were recreationally strength-trained as defined by Rhea (2004) (i.e., individuals consistently trained for 1-5 years at $\geq$3 times per week). The volunteers had no history of any muscular or joint injury and had abstained from any ergogenic substance to increase strength and/or muscle mass gains in the last six months. They had previous experience with training to muscle concentric failure and with perceptual scales, and all of them were habituated to performing half back-squat exercise in their training routines. The study was approved by the local Ethics and Research Committee following the ethical principles contained in the Declaration of Helsinki. All participants signed an informed consent form.

Study Design

This study employed a counter-balanced, single-blinded, and randomized crossover design involving two experimental conditions (e.g., smartphone [experimental] vs. watching documentary [control]) with a one-week washout interval between conditions. The order of the presentation of these conditions was randomized. To induce MF, participants spent 30-minutes on social networks through smartphone apps (e.g. Facebook®, Twitter®, Instagram®), whereas, in the control condition, they watched a documentary for 30-minutes.

The study was conducted in four different sessions with two visits to the laboratory in the first week (with a 48-hour interval in-between) and one visit per week in the next two sessions (with a one-week wash-out period) (see Figure 1). During the first two visits, we familiarized participants with the experimental procedures and performed the test-retest reproducibility of the 15RM test in the half back-squat exercise. During the final two visits, participants performed either an experimental condition to induce MF or a control treatment.

Upon arrival for the experimental treatments, participants were asked to complete a pre-test checklist, ensuring compliance with the provided instructions, as well as a psychometric tool related to perceived recovery and MF status, and to undertake resting heart rate variability (HRV) assessment.

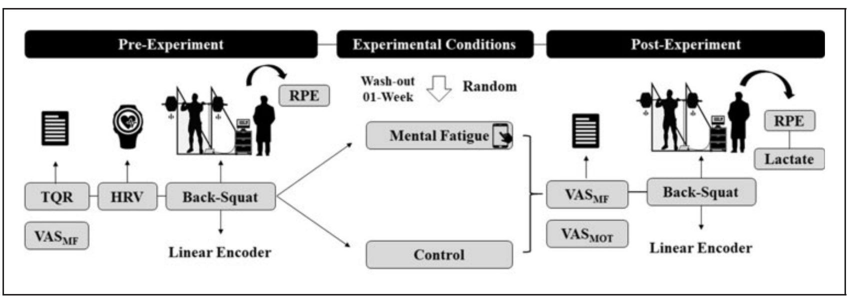

Figure 1. Experimental Setup. TQR = total quality recovery; HRV = heart rate variability; VAS = visual analogue scale; MF = mental fatigue; MOT = motivation; RPE = rating of perceived exertion.

Following the HRV assessment, the half back-squat exercise to muscle failure (three sets with 80% of 15RM) was performed over three sets to verify if the mechanical variables and the number of repetitions during the multi-sets resistance exercise were similar to the non-mentally fatigued state. Thereafter, the experimental conditions were administered in a quiet room.

After the experimental condition, participants completed a visual analog scale (VAS) regarding perceived MF and motivation status. Participants then performed three exercise sets with 80% of 15RM (~10-minutes after the experimental conditions) preceded by a standardized warm-up (~5-minutes). During the back-squat exercise, we monitored mechanical variables (i.e., power output and movement velocity) and RPE. Blood lactate was only measured 2-minutes after the last repetition of the resistance exercise session.

Procedures

Experimental and Control Sessions. Before each session, participants were instructed to attend all conditions in a well-rested state (i.e., sleep for at least eight hours and to abstain from any physical exercise and alcohol ingestion in the 48-hours before the sessions). Additionally, caffeine, nicotine, and smartphone use (e.g., social media) were to be avoided for at least three hours before the sessions (Azevedo et al., 2016; Fortes et al., 2021). A previous study showed that subjective mental fatigue recovered post-60 minutes of mental fatigue induced by 45-minutes of the Stroop task and almost recovered after 45-minutes of the AX-CPT task (Smith et al., 2019). Thus, we requested that participants avoid cognitive tasks for at least three hours before each experimental condition (e.g., social media). These data were self-reported before each condition. Sessions were performed from 3:00 to 8:00 p.m., at the same time of day for each participant.

In experimental sessions, as noted above, we induced MF with 30-minutes of continuous activity engaging in social media networks (e.g., Facebook®, Instagram®, Twitter®) through smartphone apps. Participants were strongly encouraged to stay in continuous activity on the smartphone (reading texts, writing messages, and posting information on social networks). A research member not involved in any other study procedure accompanied the participants during the experimental condition to ensure that participants maintained their networking activities. Thus, the research members involved in the strength exercise protocol were blinded to the participant's condition (mental fatigue vs. control). This procedure was adopted to minimize possible biases during the strength exercise protocol arising from the knowledge of the condition being tested.

During the control condition sessions, the participants watched 30-minutes of the documentary "Secrets of NASA: 1° Season- Eps 05" (Discovery Channel®, Brazil) on a full-HD screen 14" notebook (Positivo® 5650, Brazil). This documentary was selected based on its similar content to a film adopted in a previous study that reported neutral emotional demands (Smith et al., 2015).

15RM Test and Resistance Exercise Protocol. The 15RM test defined the exercise load (Haff & Triplet, 2015); it was performed over two non-consecutive days with a 48-hour interval in-between (test-retest). During each session, participants made two attempts with an interval of 10-minutes between trials. The intraclass coefficient correlation (ICC) and the coefficient of variation (CV) were: ICC = 0.98 (0.94 to 0.99); and CV = 2.0% (0.02 to 0.34). Verbal encouragement was provided during the 15RM test but not during the experimental conditions. The concentric phase of the movement was performed at the maximum intended velocity.

The 15RM test and resistance exercise performed in the experimental conditions were preceded by a standardized half back-squat warm-up, which included two sets of 15 repetitions of 50% and 80% 15RM load, respectively. The resistance exercise included three sets of back-squat exercise to muscle failure with 80% of 15RM in a Smith Machine (Righetto®, Brazil), interspersed with three minutes of passive recovery between sets. Failure was considered as voluntary exhaustion.

During the half back-squat exercise, participants' feet were slightly wider than shoulder-width, and their toes were pointed forward or slightly outward. The bar was placed in the upper portion of the trapezius muscle, slightly above the posterior portion of the deltoid muscle. The participants squatted down until the thighs were parallel with the floor (90°) and briefly stopped before the concentric phase. The bar displacement was monitored for each participant by a Linear Encoder (Cefise®, Brazil). Participants evidenced no mean difference in their bar displacements between the two conditions (Experimental $M = 32.1$, $SD = 6.1$ cm; Control $M = 32.4$, $SD = 6.1$ cm; paired t-test [$p = 0.78$]).

Mechanical Measures. The absolute peak and average power output and movement velocity ($m{\cdot}s^{-1}$) during the back-squat exercise were assessed using an Encoder Linear Peak Power (CEFISE®, Brazil). This equipment consists of a linear transducer that was attached to the Smith-machine bar (Righetto®, Brazil) to record the displacement of the bar (mm) and convert it into a digital signal to transfer it to Peak Power 4.0 software (CEFISE®, Brazil). To quantify the mean power produced during the back-squat exercise, the velocity of the displacement (ms) of the bar and the load (kg) lifted were considered.

Heart Rate Variability. The R-R intervals recordings were assessed while the participants were seated for 10-minutes, using a portable heart rate monitor (H10, Polar Electro Oy®, Finland), and they were downloaded via a validated smartphone app (Elite HRV app®) (Perrotta et al., 2017). Data were analyzed during the last five minutes after excluding the first five minutes, allowing for heart rate stabilization (Task Force of the European Society of Cardiology, 1996). In this study, we assessed the time domain HRV indices including the square root of the mean squared differences of successive RR intervals (RMSSD) and the standard deviation of the R-R intervals (SDNN). These HRV indices were evaluated before participants engaged in any experimental conditions since it has been consistently reported that low-HRV indices are related to fatigue status (Kassiano et al., 2021; Nakamura et al., 2021).

Perceptual Responses: VAS, Total Quality Recovery (TQR), and RPE. Subjective ratings of MF (referring to the treatment task) and motivation (referring to the upcoming RT session) were assessed using the 100-mm VAS as previously adopted (Smith et al., 2016). We used VAS as it is a sensitive and practical tool to assess mental fatigue (Fortes et al., 2021; Smith et al., 2019). These scales have two extremities anchored at “none at all” and “maximal,” respectively. No other descriptor was presented in the VAS. Participants were instructed to perform a vertical line along the 100-mm scale to indicate their current perceived status. To quantify the values, we measured the millimeter distance from the “none at all” extremity toward the end of the line as indicated by the individual. In order to overcome the potential bias related to uncertainty over the definition of ‘mental fatigue,’ a standardized definition of mental fatigue was provided: “Reduced ability to perform cognitive and behavioral tasks with subjective feelings of tiredness and lack of energy” (Boksem & Tops, 2008; Marcora et al., 2009).

We used the TQR scale proposed by Kentta and Hassmen (1998) and adapted and validated to the Brazilian Portuguese language by Osiecki et al. (2015) before each experimental condition in order to assess the level of perceived recovery. The TQR scale ranged from six (nothing recovered) to 20 (fully recovered), with higher values indicating increased recovery perception. We used this scale to ensure that participants performed both visits in similar perceived recovery status.

We monitored RPE during the back-squat exercise using a CR-10 scale (Foster et al., 2001). Specifically, at every five repetitions performed during each set, the participants were instructed to provide their RPE. Since we found within- and between-subjects’ differences in the number of repetitions and comparing RPE in an iso-work (i.e., number of repetitions) was not feasible, we compared the mean RPE value in pre- and post-experimental conditions.

Blood Lactate Concentration. We assessed blood lactate concentration only two minutes after the last post-experimental back-squat repetition. Blood lactate analysis was based on samples of $\sim$15 μl of the blood collected from the participant’s earlobe without hyperemia. These samples were immediately dropped into a strip (BM lactate, Roche®, Brazil), and the blood lactate level was indicated after one minute with portable equipment (Accutrend Plus, Roche®, Brazil). The CV of this device falls within 1.8-3.3% for low, medium, and high blood lactate levels, respectively (Baldari et al., 2009).

Statistical Analysis

Data are presented as means and standard deviations. Shapiro-Wilk test and standardized skewness and kurtoses were used to verify the shapes of the data distributions. Levenes' test verified the homoscedasticity of variances. We used paired t-tests to compare the TQR, HRV, motivation, and blood lactate concentration, and we used repeated measures of analysis of variance (ANOVA) followed by Bonferroni post hoc testing to verify the interaction (condition $\times$ time) effects for RPE, number of repetitions, volume load, and mechanical variables. We used partial eta-squared (np^2) and Cohen's *d* effect size (ES) to determine practical significance of findings. We defined the threshold for the ES as small (0.2 to 0.5), medium (>0.5 to 0.8), or large (>0.8) (Cohen, 1988). Moreover, we conducted a post hoc power analysis for a two-way (time $\times$ conditions) analysis of variance interaction effect on both the mechanical variables and volume-load. We found that the final sample resulted in statistical power (1-β) greater than 84.5%. Analyses were performed in the SPSS 20.0 version (IBM® Corporation, USA) and the statistical significance level was set at 5%.

Results

HRV measures during the pre-experiment were not different across experimental conditions ($p > 0.05$). Specifically, RMSSD values were $M = 54.94$, $SD = 32.68$ and $M = 55.44$, $SD = 33.27$ during mental fatigue and control conditions ($p = 0.91$ and CI 95% = −8.71 to 9.17), respectively. SDNN values were $M = 69.56$. $SD = 29.79$ and $M = 68.44$, $SD = 2.72$ during mental fatigue and control conditions ($p = 0.84$ and CI 95% = −12.54 to 10.29), respectively. No statistical difference was found for perceived recovery scores during pre-experimental conditions (*M* mental fatigue = 16.94, $SD = 2.57$; M control condition = 17.27. $SD = 2.72$ [$p = 0.62$ and CI 95% = −1.0 to 1.63]). Furthermore, blood lactate concentrations after resistance exercise were similar between experimental conditions (M smartphone = 7.51. *SD* =3.76 vs. *M* control = 7.64, $SD = 3.62$; $p = 0.36$).

Data for the number of repetitions and the total volume-load performed pre- and post-experimental conditions are shown in Figure 2. There was a main effect for time for the number of repetitions ($F_{(2,30)} = 34.3$; $p < 0.001$; $np^2 = 0.70$), with participants in both conditions performing progressively fewer repetitions across consecutive sets. An interaction effect was significant ($F_{(5,75)} = 3.0$; $p = 0.015$; $np^2 = 0.17$), and post hoc analyses revealed fewer repetitions in Sets 1 and 3 at the post-experiment ($p < 0.05$) in the smartphone relative to the control condition. Between-condition ES findings post-experiment were: Set 1 = 0.44 (small), Set 2 = 0.16 (trivial), and Set 3 = 0.49 (small); and volume-load = 0.25 (small).

The volume-load performed was higher at pre-test than at post-test for both conditions ($F_{(1,15)} = 32.6$; $p < 0.001$; $np^2 = 0.68$), and there was a significant interaction effect ($F_{(1,15)} = 10.1$; $p = 0.006$; $np^2 = 0.40$), such that the volume-load performed in the smartphone condition was lower than in control condition ($\Delta = -29\%$ vs. -14.8%).

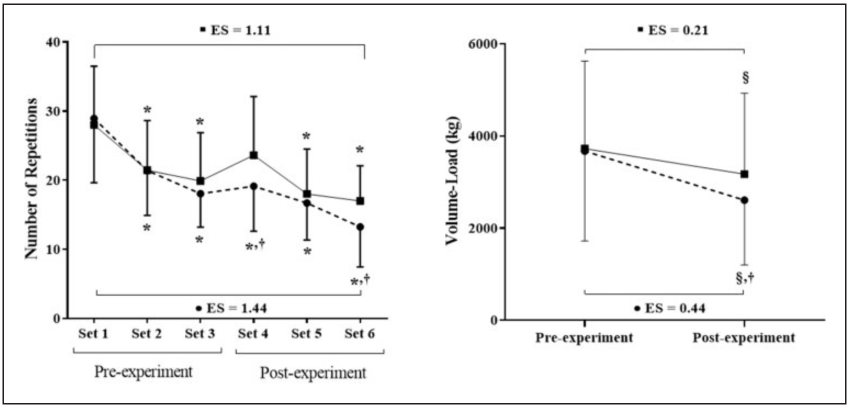

Figure 2. The Number of Repetitions and the Total Volume-Load at the Pre- and Post-Experimental Conditions. ES = effect size; * = statistically different from set 1 ($p < 0.05$); † = statistically different from control in the same time ($p < 0.05$); § = statistically different from pre-experiment ($p < 0.05$).

The subjective scores for MF, RPE and motivation are presented in Figure 3. There was a significant interaction effect for perceived MF ($F_{(1,15)} = 11.83$; $p = 0.004$; $np^2 = 0.46$), with participants reporting increased MF after using the smartphone (experimental condition) compared to watching a documentary (control condition). There was no significant condition difference noted in motivation before the back-squat exercise ($t_{(15)} = 1.12$; $p = 0.277$). A main effect for time was observed for the RPE score ($F_{(1,15)} = 17.5$; $p = 0.001$; $np^2 = 0.54$), with higher RPE values at post-testing for both conditions, and there were no main or interaction effects between conditions found for RPE ($p > 0.05$).

The mechanical variables during the back-squat exercise at pre- and post-experiment are displayed in Figure 4. A main effect for time was found for all mechanical variables analyzed ($p < 0.05$), showing a reduced performance across consecutive sets. No condition or interaction effects were observed for these variables ($p > 0.05$). Within-subjects ES showed a small to moderate decrement in power output and movement velocity for both conditions.

Discussion

The main finding of this study was that MF induced by prolonged (i.e., 30-minute) use of smartphone social network apps reduced participants' total volume-load during a multi-set session of resistance exercise when compared to a control condition of documentary viewing ($\Delta = -29\%$ vs. -14.8%). Moreover, participants reported similar RPE scores and mechanical

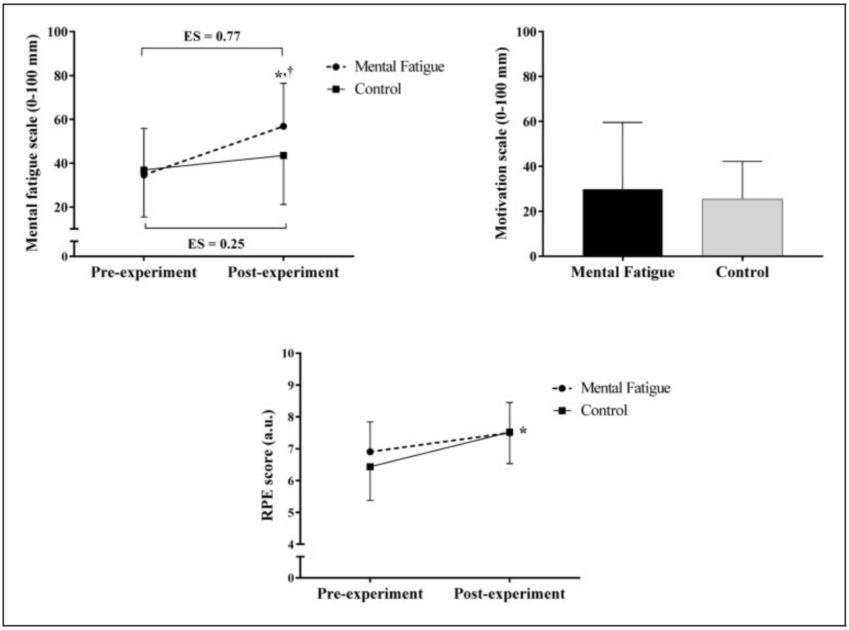

Figure 3. Subjective Measures of Mental Fatigue and RPE Score Pre- and Post-Experimental Conditions and Motivation Before Resistance Exercise Trial. ES = effect size; * = statistically different from pre-experiment ($p < 0.05$); † = interaction (condition × time) effect ($p < 0.05$).

performance (power output and movement velocity) during exercise, even though they performed fewer volume-load repetitions following the experimental versus the control condition. To the best of the authors' knowledge, this is the first study to investigate the effects of MF on muscular performance during multi-set resistance exercise that adopted a natural or ecological approach to inducing MF (i.e., via smartphone apps).

Participants' higher perceived MF in the smartphone condition suggests that it is experienced as a highly demanding cognitive task. As hypothesized, the use of smartphone social network apps caused a MF state in which participants reported an increased subjective feeling of mental tiredness. It has been proposed that smartphone use negatively affects cognitive function (Wilmer et al., 2017). Fortes et al. (2019) found an increase in response time and reduction in accuracy on an inhibitory control task following smartphone use periods at least equal to 30 minutes among soccer players, similar to a more controlled laboratory cognitive task such as the Stroop task (Gantois et al., 2020). These data support the idea that using smartphone apps might impair executive function. Fortes et al. (2021) showed that both performances in the Stroop task and perceived mental fatigue (VAS) were compromised after 30 minutes of social

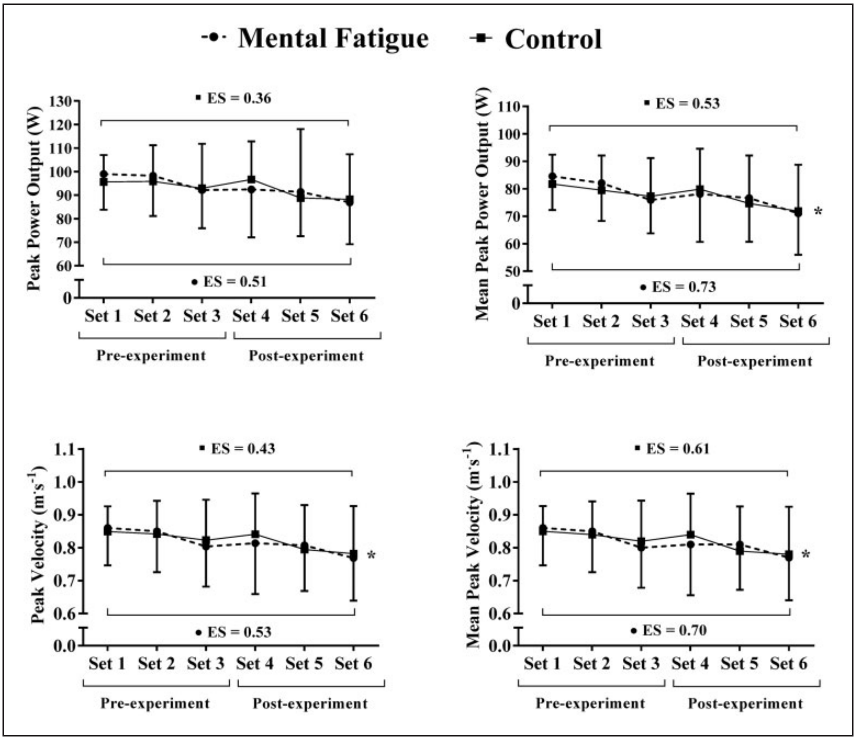

Figure 4. Peak and Average Power Output and Movement Velocity During the Back-Squat Sets at Pre- and Post-Experiment According Experimental Conditions. ES = effect size; * = Simple main time effect ($p < 0.05$).

media on a smartphone in a group of high-level swimmers. This data highlights the sensitivity of VAS as a simple and feasible tool to assess mental fatigue instead of laboratory cognitive tasks (Smith et al., 2019).

Although the continuous prolonged use of social media on smartphones increases subjective mental fatigue when compared to the control condition, it is unclear whether their cumulative effect would impair physical performance during resistance exercise. For instance, a previous study showed that team sports athletes reported that mental fatigue is a largely cumulative phenomenon (Russell et al., 2019). However, this statement needs to be experimentally addressed, and future studies are required in order to assess the time course and cumulative effects on physical and cognitive performance of using social media.

In accordance with the psychobiological model, mentally fatigued participants performed a lower volume-load in the resistance exercise protocol when compared to the control condition. Since during resistance exercise, RPE increases linearly with the number of repetitions (Hackett et al., 2017), we might assume that the same participant would perform a similar number of repetitions, at a given load at the same level of perceived effort, but RPE differences from mentally fatigued participants ($\Delta = -29\%$) did not differ from those of non-mentally fatigued participants ($\Delta = -14.8\%$) at a lower volume-load. Although the RPE during resistance exercise was not significantly different between our two conditions, participants performed a lower volume-load after the MF condition. Their report of similar levels of perceived exertion while performing less work may indicate higher-than-normal RPE in the MF condition (Smith et al., 2015).

Given the lack of change in participants' motivation before the half back-squat exercise, a possible explanation for their reduced volume-load after experiencing MF is the higher-than-normal RPE during exercise. According to the psychobiological model, motivation and perception of effort determine performance, although the periphery (e.g., afferent feedback and heart rate) might present an influence as well (Pageaux, 2014). Mental fatigue seems to affect the perception of effort only in many studies in which motivation remained similar (Filipas et al., 2020; Martin et al., 2016). Thus, similar levels of motivation before exercise are desired to avoid bias.

While there have been few previous investigations on the effect of MF on muscle endurance during resistance exercise, our data are consistent with previous reports on whole-body endurance exercises (MacMahon et al., 2014; Marcora et al., 2009; Pageaux et al., 2014). These studies showed that MF impaired endurance performance (i.e., time trial, overall speed, and time to exhaustion) due to higher-than-normal RPE for the same exercise intensity. Although the assessment of the underlying mechanisms of social media use on MF is far beyond the scope of the current study, it has been proposed that engagement in high-order cognitive tasks is related to the level of adenosine and dopamine in brain areas (prefrontal cortex and anterior cingulate cortex). The neurotransmitters act directly in executive functions related to decision-making based on effort during exercise (Lorist et al., 2005; Marcora et al., 2009; Smith et al., 2015; 2018). Considering that mentally fatigued individuals might experience higher-than-normal RPE for the same exercise intensity, it is likely that the reduction in the number of repetitions over sets during resistance exercise after the use of smartphones in our study occurred due to the greater perception of effort caused by MF. Of note, however, the limited performance found before and in the current study occurred without any change in metabolic responses to exercise (Marcora et al., 2009; Pageaux et al., 2013). Therefore, our results expand current knowledge by demonstrating that the adverse effects of MF on whole-body endurance exercise induced by higher-than-normal RPE also explain the reduction in the number of repetitions in sets until the muscular failure in resistance exercise.

Volume-load is one of the most effective variables of resistance training (RT) to promote strength and hypertrophy gains (Izquierdo et al., 2006; Martorelli et al., 2017). RT has a dose-response effect on power, strength, muscle hypertrophy, and health outcomes (Figueiredo et al., 2018; Schoenfeld et al., 2017). Therefore, RT practitioners should be encouraged to avoid the prolonged use of social networks on smartphones before training sessions in order to maintain a greater volume-load. However, it is still not known whether an acute decrement on volume-load during complete multi-set RT affects long-term adaptations; this requires further research.

Unlike with mental fatigue, there have been consistent reports in the literature that muscle fatigue during resistance exercise is caused by both central and peripheral physiological changes (Boerio et al., 2005; Kent-Braun & Le Blanc, 1996). In the current study, our participants showed a similar muscle peak, mean power output, and velocity achieved during the resistance exercise after both MF and control conditions even though there was a lower volume-load performed in the MF versus the control condition. These results are in line with previous studies showing that maximal strength, power output, and anaerobic work were unaffected by MF (Martin et al., 2015; Pageaux et al., 2013; Rozand et al., 2014). Moreover, Pageaux et al. (2015) demonstrated that MF compromised the whole-body endurance exercise through higher-than-normal RPE rather than alterations in the maximal voluntary contraction. One possible explanation for those results is that MF has a limited effect on cortical areas involved with maximal muscle activation (Pageaux et al., 2013; 2015).

Although future studies are still necessary to understand the relationship between MF and RPE, one possible explanation for similarly perceived exertion even for a lower volume of repetitions performed following the experimental MF condition in comparison to the control condition is that highly-demanding cognitive tasks affect frontal brain ACC activity (Lorist et al., 2005; Martin et al., 2018). Lorist et al. (2005) found that such cognitive tasks reduced the ERN/Ne (error-related negativity) amplitude, an electrophysiological index that relies predominately on the ACC area (Carter et al., 1998). As we did not measure brain activity during our experimental conditions, we can only speculate that the lower volume-load in the smartphone condition may have at least partly related to the negative effect of MF on this cortical area, associated with effort-based decision making. Pageaux et al. (2014) proposed that highly demanding cognitive tasks may increase the adenosine accumulation in the ACC, leading to higher-than-normal RPE during subsequent endurance exercise. Azevedo et al. (2016) showed that caffeine (an antagonist of adenosine) attenuates the negative effects of MF (↓RPE and ↑endurance performance), suggesting that adenosine limits human performance during the MF state. More studies are needed to investigate the ability of caffeine to counteract the negative effects of MF, especially during multi-sets resistance exercise.

Limitations and Directions for Future Research

Among the limitations of this study, although VAS is a sensitive tool and widely used to detect MF, the lack of any objective and neurophysiological measures to verify the degree the participants' reports of MF induced by the use of smartphone social network apps limits the meaning of our findings. Future investigations should further analyze MF induced by smartphone use by applying direct neurological measures of cognitive demand, such as the amplitude of electroencephalogram (EEG) recorded brain waves (alpha and theta). Also, our data assessed the impact of this means of inducing MF on only one exercise, limiting our ability to generalize these results to a complete, multi-exercise RT session and during other muscular training methods (e.g., maximal strength, explosive strength, and hypertrophy training). To the best of our knowledge, this is one of the first studies to induce MF using a protocol with high ecological validity (exposure time to a smartphone), and more research is needed to confirm our hypothesis that continuous exposure to smartphone app use is associated with MF. Therefore, futures studies are required to investigate the effect of mental fatigue induced by prolonged use of social media and laboratory-based cognitive tasks (e.g., Stroop and AX-CPT tasks), to increase understanding of mental fatigue on resistance exercise performance. Furthermore, it is crucial to consider that the RPE score was not matched by the amount of work performed, and future studies should consider the analysis of RPE repetition-by-repetition or use the level of effort (e.g., velocity loss percentage) as an adjustment variable to report along with the RPE scores. Finally, it has been suggested that the amount of cognitive load should be individualized to ensure a comparable level of mental fatigue (Holgado et al., 2020).

Conclusion

Results from this study showed that prolonged exposure to smartphones (about 30 minutes) induced participants' perceived MF and compromised (by approximately 15%) their number of repetitions during resistance exercise when compared with a control condition of simply viewing a documentary. Since volume-load is the most important acute means of measuring muscular effort during resistance training, the fact that smartphone exposure induced perceived MF and acutely affected exercise performance has important practical implications. Although smartphone technology is present in adults' daily lives, our findings suggest that its prolonged use before resistance training sessions should be avoided if the goal is to increase or maintain total volume-load in order to build muscle strength. Finally, our findings broaden variables of interest when testing MF effects on human performance, especially when studying MF from daily, ecologically valid activities.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iDs

Petrus Gantois https://orcid.org/0000-0002-1995-2103
Dalton de Lima-Junior https://orcid.org/0000-0003-1542-604X
Leonardo de Sousa Fortes https://orcid.org/0000-0002-0778-769X

References

American College of Sports Medicine. (2009). American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Medicine and Science in Sports and Exercise, 41*(3), 687–708.

Azevedo, R., Silva-Cavalcante, M. D., Gualano, B., Lima-Silva, A. E., & Bertuzzi, R. (2016). Effects of caffeine ingestion on endurance performance in mentally fatigued individuals. *European Journal of Applied Physiology*, *116*(11-12), 2293–2303. http://dx.doi.org/10.1007/s00421-016-3483-y

Baldari, C., Bonavolonta, V., Emerenziani, G. P., Gallotta, M. C., Silva, A. J., & Guidetti, L. (2009). Accuracy, reliability, linearity of Accutrend and Lactate Pro versus EBIO plus analyzer. *European Journal of Applied Physiology*, *107*(1), 105–111. http://dx.doi.org/10.1007/s00421-009-1107-5

Boerio, D., Jubeau, M., Zory, R., & Maffiuletti, N. A. (2005). Central and peripheral fatigue after electrostimulation-induced resistance exercise. *Medicine & Science in Sports & Exercise*, *37*(6), 973–978.

Boksem, M. A., & Tops, M. (2008). Mental fatigue: Costs and benefits. *Brain Research Reviews*, *59*(1), 125–139. http://dx.doi.org/10.1016/j.brainresrev.2008.07.001

Carter, C. S., Braver, T. S., Barch, D. M., Botvinick, M. M., Noll, D., & Cohen, J. D. (1998). Anterior cingulate cortex, error detection, and the online monitoring of performance. *Science*, *280*(5364), 747–749. http://dx.doi.org/10.1126/science.280.5364.747

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Routledge.

Costa, B. D.V., Ferreira, M. E. C., Gantois, P., Kassiano, W., Paes, S. T., de Lima-Júnior, D., Cyrino, E., & de Sousa Fortes, L. (2021). Acute effect of drop-set, traditional, and pyramidal systems in resistance training on neuromuscular performance in trained adults. *Journal of Strength & Conditioning Research, 35*(4), 991–996. https://doi.org/ 10.1519/JSC.0000000000003150

Figueiredo, V. C., de Salles, B. F., & Trajano, G. S. (2018). Volume for muscle hypertrophy and health outcomes: The most effective variable in resistance training. *Sports Medicine*, *48*(3), 499–505. http://dx.doi.org/10.1007/s40279-017-0793-0

Filipas, L., Martin, K., Northey, J. M., La Torre, A., Keegan, R., & Rattray, B. (2020). A 4-week endurance training program improves tolerance to mental exertion in untrained individuals. *Journal of Science and Medicine in Sport*, *23*(12), 1215–1219. http://dx.doi.org/10.1016/j.jsams.2020.04.020

Fortes, L. S., Lima-Junior, D., Nascimento-Júnior, J. R. A., Costa, E. C., Matta, M. O., & Ferreira, M. E. C. (2019). Effect of exposure time to smartphone apps on passing decision-making in male soccer athletes. *Psychology of Sport and Exercise*, *44*, 35–41. http://dx.doi.org/10.1016/j.psychsport.2019.05.001

Fortes, L. S., Lima-Júnior, D. D., Gantois, P., Nasicmento-Júnior, J. R., & Fonseca, F. S. (2021). Smartphone use among high level swimmers is associated with mental fatigue and slower 100-and 200-but not 50-meter freestyle racing. *Perceptual and Motor Skills*, *128*(1), 390–408. http://dx.doi.org/10.1177/0031512520952915

Foster, C., Florhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker, S., & Dodge, C. (2001). A new approach to monitoring exercise training. *The Journal of Strength & Conditioning Research*, *15*(1), 109–115.

Gantois, P., de Souza Fonseca, F., de Lima-Júnior, D., da Cunha Costa, M., de Vasconcelos Costa, B. D., Cyrino, E. S., & de Sousa Fortes, L. (2021). Acute effects of muscle failure and training system (traditional vs. rest-pause) in resistance exercise on countermovement jump performance in trained adults. *Isokinetics and Exercise Science*, *29*(1), 11–19. http://dx.doi.org/10.3233/IES(2021)23

Gantois, P., Caputo Ferreira, M. E., Lima-Junior, D. D., Nakamura, F. Y., Batista, G. R., Fonseca, F. S., & Fortes, L. D. S. (2020). Effects of mental fatigue on passing decision-making performance in professional soccer athletes. *European Journal of Sport Science*, *20*(4), 534–543. http://dx.doi.org/10.1080/17461391.2019.1656781

Gorostiaga, E. M., Navarro-Amézqueta, I., Calbet, J. A., Hellsten, Y., Cusso, R., Guerrero, M., Granados, C., González-Izal, M., Ibãnez, J., & Izquierdo, M. (2012). Energy metabolism during repeated sets of leg press exercise leading to failure or not. *PloS One, 7*(7), e40621. https://doi.org/10.1371/journal.pone.0040621

Hackett, D. A., Cobley, S. P., Davies, T. B., Michael, S. W., & Halaki, M. (2017). Accuracy in estimating repetitions to failure during resistance exercise. *Journal of Strength and Conditioning Research*, *31*(8), 2162–2168. http://dx.doi.org/10.1519/JSC.0000000000001683

Haff, G. G., & Triplet, T. N. (2015). *Essentials of strength training and conditioning* (4th ed.). Human Kinetics.

Holgado, D., Troya, E., Perales, J. C., Vadillo, M. A., & Sanabria, D. (2020). Does mental fatigue impair physical performance? A replication study. *European Journal of Sport Science*, *30*, 1–9. http://dx.doi.org/10.1080/17461391.2020.1781265

Izquierdo, M., Ibañez, J., González-Badillo, J. J., Häkkinen, K., Ratamess, N. A., Kraemer, W. J., French, D. N., Eslava, J., Altadill, A., Asiain, X., & Gorostiaga, E. M. (2006). Differential effects of strength training leading to failure versus not to failure on hormonal responses, strength, and muscle power gains. *Journal of Applied Physiology*, *100*(5), 1647–1656. http://dx.doi.org/10.1152/japplphysiol.01400.2005

Kassiano, W., de Vasconcelos Costa, B. D., Lima-Júnior, D., Gantois, P., de Souza Fonseca, F., da Cunha Costa, M., & de Sousa Fortes, L. (2021). Parasympathetic nervous activity responses to different resistance training systems. *International Journal of Sports Medicine*, *42*(01), 82–89. http://dx.doi.org/10.1055/a-1219-7750

Kent-Braun, J. A., & Le Blanc, R. (1996). Quantitation of central activation failure during maximal voluntary contractions in humans. *Muscle & Nerve*, *19*(7), 861–869. https://doi.org/drc2nr

Kentta, G., & Hassmen, P. (1998). Overtraining and recovery. A conceptual model. *Sports Medicine*, *26*(1), 1–16. https://doi.org/d4s5wt
Lorist, M. M., Boksem, M. A., & Ridderinkhof, K. R. (2005). Impaired cognitive control and reduced cingulate activity during mental fatigue. *Brain Research. Cognitive Brain Research*, *24*(2), 199–205. http://dx.doi.org/10.1016/j.cogbrainres.2005.01.018
MacMahon, C., Schucker, L., Hagemann, N., & Strauss, B. (2014). Cognitive fatigue effects on physical performance during running. *Journal of Sport & Exercise Psychology*, *36*(4), 375–381. http://dx.doi.org/10.1123/jsep.2013-0249
Marcora, S. M. (2008). Do we really need a central governor to explain brain regulation of exercise performance? *European Journal of Applied Physiology*, *104*(5), 929–931; author reply 933–925. http://dx.doi.org/10.1007/s00421-008-0818-3
Marcora, S. M., Staiano, W., & Manning, V. (2009). Mental fatigue impairs physical performance in humans. *Journal of Applied Physiology*, *106*(3), 857–864. http://dx.doi.org/10.1152/japplphysiol.91324.2008
Marshall, J., Bishop, C., Turner, A. N., & Haff, G. (2021). Optimal training sequences to develop lower body force, velocity, power, and jump height: A systematic review with meta-analysis. *Sports Medicine*, http://dx.doi.org/10.1007/s40279-021-01430-z
Martin, K., Meeusen, R., Thompson, K. G., Keegan, R., & Rattray, B. (2018). Mental fatigue impairs endurance performance: A physiological explanation. *Sports Medicine*, *48*(9), 2041–2051. http://dx.doi.org/10.1007/s40279-018-0946-9
Martin, K., Thompson, K. G., Keegan, R., Ball, N., & Rattray, B. (2015). Mental fatigue does not affect maximal anaerobic exercise performance. *European Journal of Applied Physiology*, *115*(4), 715–725. http://dx.doi.org/10.1007/s00421-014-3052-1
Martin, K., Staiano, W., Menaspà, P., Hennessey, T., Marcora, S., Keegan, R., Thompson, K. G., Martin, D., Halson, S., & Rattray, B. (2016). Superior inhibitory control and resistance to mental fatigue in professional road cyclists. *PloS One*, *11*(7), e0159907. http://dx.doi.org/10.1371/journal.pone.0159907
Martorelli, S., Cadore, E. L., Izquierdo, M., Celes, R., Martorelli, A., Cleto, V. A., Alvarenga, J. G., & Bottaro, M. (2017). Strength training with repetitions to failure does not provide additional strength and muscle hypertrophy gains in young women. *European Journal of Translational Myology*, *27*(2), 6339. http://dx.doi.org/10.4081/ejtm.2017.6339
Nakamura, F. Y., Torres, V. B. C., da Silva, L. S., Gantois, P., Andrade, A. D., Ribeiro, A. L. B., & Batista, G. R. (2021). Monitoring heart rate variability and perceived well-being in Brazilian elite beach volleyball players: A single-tournament pilot study. *Journal of Strength & Conditioning Research*. http://dx.doi.org/10.1519/JSC.0000000000003654
Osiecki, R., Rubio, T. B. G., Coelho, R. L., Novack, L. F., Conde, J. H. S., Alves, C. G., & Malfatti, C. R. M. (2015). The total quality recovery scale (TQR) as a proxy for determining athletes' recovery state after a professional soccer match. *Journal of Exercise Physiology*, *18*(3), 6.
Pageaux, B., Marcora, S. M., & Lepers, R. (2013). Prolonged mental exertion does not alter neuromuscular function of the knee extensors. *Medicine & Science in Sports & Exercise*, *45*(12), 2254–2264. http://dx.doi.org/10.1249/MSS.0b013e31829b504a

Pageaux, B. (2014). The psychobiological model of endurance performance: An effort-based decision-making theory to explain self-paced endurance performance. *Sports Medicine*, *44*(9), 1319–1320. http://dx.doi.org/10.1007/s40279-014-0198-2

Pageaux, B., Lepers, R., Dietz, K. C., & Marcora, S. M. (2014). Response inhibition impairs subsequent self-paced endurance performance. *European Journal of Applied Physiology*, *114*(5), 1095–1105. http://dx.doi.org/10.1007/s00421-014-2838-5

Pageaux, B., Marcora, S. M., Rozand, V., & Lepers, R. (2015). Mental fatigue induced by prolonged self-regulation does not exacerbate central fatigue during subsequent whole-body endurance exercise. *Frontiers in Human Neuroscience*, *9*, 67. http://dx.doi.org/10.3389/fnhum.2015.00067

Perrotta, A. S., Jeklin, A. T., Hives, B. A., Meanwell, L. E., & Warburton, D. E. (2017). Validity of the elite HRV smartphone application for examining heart rate variability in a field-based setting. *Journal of Strength and Conditioning Research*, *31*(8), 2296–2302. http://dx.doi.org/10.1519/JSC.0000000000001841

Rhea, M. R. (2004). Determining the magnitude of treatment effects in strength training research through the use of the effect size. *Journal of Strength & Conditioning Research, 18*, 918–920. https://doi.org/10.1519/14403.1

Rozand, V., Pageaux, B., Marcora, S. M., Papaxanthis, C., & Lepers, R. (2014). Does mental exertion alter maximal muscle activation? *Frontiers in Human Neuroscience*, *8*, 755. http://dx.doi.org/10.3389/fnhum.2014.00755

Russell, S., Jenkins, D., Rynne, S., Halson, S. L., & Kelly, V. (2019). What is mental fatigue in elite sport? Perceptions from athletes and staff. *European Journal of Sport Science*, *19*(10), 1367–1376. http://dx.doi.org/10.1080/17461391.2019.1618397

Sanchez-Medina, L., & González-Badillo, J. J. (2011). Velocity loss as an indicator of neuromuscular fatigue during resistance training. *Medicine and Science in Sports and Exercise, 43*(9), 1725–1734. https://doi.org/10.1249/MSS.0b013e318213f880

Schoenfeld, B. J., Ogborn, D., & Krieger, J. W. (2017). Dose-response relationship between weekly resistance training volume and increases in muscle mass: A systematic review and meta-analysis. *Journal of Sports Sciences*, *35*(11), 1073–1082. http://dx.doi.org/10.1080/02640414.2016.1210197

Schoenfeld, B. J., Grgic, J., Van Every, D. W., & Plotkin, D. L. (2021). Loading recommendations for muscle strength, hypertrophy, and local endurance: A re-examination of the repetition continuum. *Sports*, *9*(2), 32. http://dx.doi.org/10.3390/sports9020032

Smith, M. R., Marcora, S. M., & Coutts, A. J. (2015). Mental fatigue impairs intermittent running performance. *Medicine & Science in Sports & Exercise*, *47*(8), 1682–1690. http://dx.doi.org/10.1249/MSS.0000000000000592

Smith, M. R., Coutts, A. J., Merlini, M., Deprez, D., Lenoir, M., & Marcora, S. M. (2016). Mental fatigue impairs soccer-specific physical and technical performance. *Medicine & Science in Sports & Exercise*, *48*(2), 267–276. http://dx.doi.org/10.1249/MSS.0000000000000762

Smith, M. R., Thompson, C., Marcora, S. M., Skorski, S., Meyer, T., & Coutts, A. J. (2018). Mental fatigue and soccer: Current knowledge and future directions. *Sports Medicine*, *48*(7), 1525–1532. http://dx.doi.org/10.1007/s40279-018-0908-2

Smith, M. R., Chai, R., Nguyen, H. T., Marcora, S. M., & Coutts, A. J. (2019). Comparing the effects of three cognitive tasks on indicators of mental fatigue. *The*

Journal of Psychology, *153*(8), 759–783. http://dx.doi.org/ 10.1080/00223980.2019.1611530

Statista. (2020). *Number of smartphone users worldwide from 2016 to 2023 (in billions)*. https://www.statista.com/statistics/330695/number-of-smartphone-users-worldwide/

Task Force of the European Society of Cardiology. (1996). The North American Society of Pacing Electrophysiology. Heart rate variability. Standards of measurement, physiological interpretation, and clinical use. *European Heart Journal*, *17*, 354–381.

Wilmer, H. H., Sherman, L. E., & Chein, J. M. (2017). Smartphones and cognition: A review of research exploring the links between mobile technology habits and cognitive functioning. *Frontiers in Psychology*, *8*, 605. http://dx.doi.org/10.3389/fpsyg.2017.00605

Author Biographies

Petrus Gantois is a PhD Student from the Associate Graduate Program in Physical Education of the University of Pernambuco and University of Paraíba. His current research focuses on the effects of training methods on athletic performance and their physical, physiological, and cognitive determinants.

Dalton de Lima-Júnior is a PhD Student from the Associate Graduate Program in Physical Education of the University of Pernambuco and University of Paraíba. Member of The Research Group in Applied Psychology of Sport and Exercise (GEPAEE) and the Research Group in Exercise Science and Sports Performance (GEPEXDES). His current research focuses on Mental Fatigue, Resistance Training, and Sports Performance.

Leonardo de Sousa Fortes is an Associate Professor in the Department of Physical Education at Federal University of Paraíba. He completed his PhD in Psycology at Federal University of Juiz de Fora. His main research interests are on the effects of mental fatigue, perceptual-cognitive training and neuromodulation on neuromuscular, endurance, and perceptual-cognitive skill performance in athletes and non-athletes.

Gilmário Ricarte Batista is a Professor in the Department of Physical Education at Federal University of Paraíba. He completed his PhD in Health Sciences at Federal University of Rio Grande do Norte. Research area of interest include kinanthropometry and human performance and game analysis in team sports.

Fábio Yuzo Nakamura is a Professor at University Institute of Maia. He completed his PhD in Motricity Sciences at Paulista State University. His main research interest are on sports sciences, exercise physiology, and strength & conditioning in athletes and non-athletes.

Fabiano de Souza Fonseca is a Professor in the Department of Physical Education at Federal Rural University of Pernambuco. He completed his PhD at Federal University of Minas Gerais. The main research interest include neuromuscular performance, training methods, and variables associated to sports performance.