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Mental fatigue impairs the number of repetitions to muscular failure in the half back-squat exercise for low- and mid- but not high-intensity resistance exercise

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Abstract

The study aimed to analyze the acute effect of mental fatigue on the maximum number of repetitions in a resistance exercise session with different intensities in resistance-trained adults. Eighteen young men aged between 18 and 25 years old (age, 22.1 ± 2.0 years; body weight, 82.5 ± 6.6 kg; height, 177.4 ± 5.2 cm; half-back squat 1-RM, 106.7 ± 21.9 kg) were recruited for the study. Each participant performed two trials (i.e., control and mental fatigue) in a random and balanced order for 30-min. The participants performed three sets of half back-squat exercise to failure, with intensities of 50%, 70%, and 90% of 1RM with a passive recovery interval of 5-min between sets. The intensity was randomized and counterbalanced, and the order was maintained in both conditions for the same subject. We assessed resistance training using the number of repetitions to failure and perceived effort and checked the mental fatigue subjectively and objectively. The participants in the mental fatigue condition presented a significantly increased perception of mental fatigue ($p < 0.05$) and reduced pupil diameter ($p < 0.05$). The number of repetitions were significantly lower for the 50 ($p < 0.05$) and 75% 1RM ($p < 0.05$) in the mental fatigue condition, but the 90% 1RM remained similar ($p > 0.05$). Also, the perceived effort showed significantly higher results for the 50 ($p < 0.05$) and 75% 1RM ($p < 0.05$) in the mental fatigue condition, but the 90% 1RM remained similar ($p > 0.05$). Then, this study showed that mental fatigue reduced resistance exercise performance for low- and mid-intensity but not for high-intensity.

KEYWORDS

cognitive effort, effort, ego depletion, perceived effort, physical performance, strength training

Highlights

- Mental fatigue reduces the number of repetitions to failure during low- and moderate-intensity resistance exercise.

- Mentally fatigued individuals experience a higher-than-normal perception of effort during low- and moderate-intensity resistance exercise.
- Measuring mental fatigue immediately before a resistance exercise session might be a rapid and valuable tool to autoregulate the exercise intensity and/or volume of resistance training sessions.

1 | INTRODUCTION

The cognitive effort required by demading cognitive tasks (Giboin et al., 2019) might cause mental fatigue (Marcora et al., 2009). Mental fatigue is a psychobiological state induced by cognitive effort with symptoms such as tiredness, lack of energy, higher than normal perception of effort, and reduced cognitive ability resulting in impaired performance (Rubio-Morales et al., 2022; Smith et al., 2018; Sun, Soh, Mohammadi, et al., 2022). Although it is possible to find several tools for measuring mental fatigue in the literature, it might be tricky because of the complex psychobiological nature of this state (Smith et al., 2019). Therefore, it is common to use both approaches (i.e., psychological and physiological) to analyze mental fatigue levels (Filipas et al., 2021; Fortes et al., 2021). For example, increased subjective mental fatigue (Smith et al., 2019), impaired response time in inhibitory control tasks (Gantois et al., 2021; Rubio-Morales et al., 2022), and reduced pupil diameter (Bafna et al., 2021) could be concomitantly used when assessing mental fatigue.

Mental fatigue has been known to impair endurance and cognitive performance as shown by reduced time to exhaustion, motor control, planning, response time, and decision-making skill (Brown et al., 2020; Sun et al., 2021; Van Cutsem et al., 2017). Interestingly, the impairments only occur for physical tasks lasting more than 30-s, which means the short and all-out ones are unaffected (Van Cutsem et al., 2017). However, it is still unclear which types of exercises are affected by mental fatigue and which variables might mediate its responses (Martin et al., 2019; Sun, Soh, Norjali Wazir, et al., 2022). In a study by Meyer et al. (2022), the authors found that the perception of effort increases in a scalar manner relative to the percentage of maximal subject capacity in a physical task (i.e., the maximum number of repetitions or total distance), which means that mental fatigue might have a negative effect independently of the physical task performed. It corroborates recent findings of dynamic resistance exercises that show a reduction in the number of repetitions performed to failure in mentally fatigued individuals (Gantois et al., 2021; Queiros et al., 2021). It seems that, similarly to endurance exercise, individuals performing resistance exercise (i.e., half back-squat) disengage early from the physical task due to a higher-than-normal perception of effort (Marcora et al., 2009; Pageaux et al., 2015).

These investigations used an intensity load of 40% (Graham et al., 2017), 60% (Queiros et al., 2021), and 70% 1RM (Gantois et al., 2021) in multiple set lower limbs exercise. Previous studies have used low to mid intensity-load, which allows the individual to remain in the task longer than 30-s. However, the effects of mental fatigue in high-intensity exercise have only been tested for endurance (Martin et al., 2015). Also, those studies measured the perception of effort only at the beginning and end of each set, lacking information about the perception of effort time-course during the sets. The psychobiological model might explain the rise in the perception of effort (Morree, 2015). The model suggests that a higher-than-normal perception of effort following a cognitive demand is caused by increased adenosine in the anterior cingulate, prefrontal, and central motor cortices (Marti et al., 2018). Thus, whether participants are similarly affected by mental fatigue independently of the type of exercise (i.e., endurance or resistance exercise), the number of repetitions should be reduced for low- and moderate- but remain similar in the high-intensity exercise when the individual is mentally fatigued.

The rationale of the present study considers that low- and mid-intensity (i.e., 50% and 70% 1RM) resistance exercises are affected by mental fatigue by a higher-than-normal perception of effort, causing the individual to disengage from a task earlier than expected. This phenomenon has been reported in different types of exercise (Fortes et al., 2020; Gantois et al., 2021; Marcora et al., 2009). However, similar to other types of exercise with high load and short duration, no effect of mental fatigue is expected during high-intensity resistance exercise (Van Cutsem et al., 2017). Thus, we aimed to analyze the acute effect of mental fatigue on the maximum number of repetitions in a resistance exercise session with different intensities in resistance-trained adults. Considering previous findings (Gantois et al., 2021; Graham et al., 2017; Queiros et al., 2021), we hypothesized a higher-than normal perception of effort and an impaired number of repetitions for 50 and 70, but not for the 90% of 1RM intensity in resistance-trained and mentally fatigued adults.

2 | METHODS

2.1 | Experimental design

Each subject performed two trials (i.e., control and mental fatigue), separated by at least 72 h and distributed in a random and balanced order established using a website (randomizer.org). The order was maintained for both sessions for the same subject. The participants were unaware of the order of the conditions. The physiological (pupil diameter) and perceptual (subjective mental fatigue) measures were taken before, during, and immediately after the initial manipulation (i.e., Stroop Color task or documentary), as illustrated in Figure 1. Subsequently, a half back-squat exercise session measured the number of repetitions to failure for different intensities (i.e., 50%, 70%, and 90% 1RM). The rating of perceived exertion (RPE) was measured at every two repetitions.

2.2 | Subjects

We calculated the sample size for a two-way fully-repeated measure analysis of variance (ANOVA). The sample size was estimated using G*Power software version 3.1.9.2 (Universität Kiel) with α = 0.05, power = 0.80, moderate interaction effect [$\eta p^2 = 0.08$ (Effect size f = 0.29)] based on the study of Gantois et al. (2021). Eighteen resistance-trained young men aged between 18 and 25 years old (age, 22.1 ± 2.0 years; body weight, 82.5 ± 6.6 kg, height, 177.4 ± 5.2 cm, half-back squat 1-RM, 106.7 ± 21.9 kg; data as mean ± SD) were recruited for the study. No withdrawals and adverse events were reported, and adherence was 100% (i.e., all participants performed both conditions). As inclusion criteria, participants should be training for at least one uninterrupted year with a frequency of at least three times per week, free from neuromuscular and skeletal muscle injuries or disorders in the lower limbs, not using drugs or medications that could affect physical performance, and lifting at least 1.25 their body mass for half back-squat exercise 1RM. The average training experience of the participants was 4.5 ± 1.6 years. The study was conducted following the Declaration of Helsinki at the Universidade Federal da Paraíba, and the University's ethics committee granted ethical approval. The subjects received written instructions describing all the procedures (e.g., avoid caffeine, highly demanding cognitive tasks, and high-intensity exercises 24-h before the tests), risks, and benefits of participation in the study and signed an informed consent form.

2.3 | Procedures

2.3.1 | Cognitive manipulation

Mental fatigue. The Stroop task was used to induce mental fatigue (PsychoPy v1.85.6, University of Nottingham). The task was performed in a silent and bright room, with the participants comfortably sitting on a chair in front of a 21 inches monitor and wearing an earphone auditive damper to avoid distractions. In this task, four words (blue, yellow, red, and green) were randomly presented in Arial font 60 at the center of a computer screen. The words were inked with the colors blue, yellow, red, or green incongruently (e.g., the word blue with red ink).

Control. The control task involved watching a documentary on the same computer screen to induce mental fatigue (i.e., the Stroop task). The documentary was the same for all participants. A researcher remained in the experimental room, next to the computer, during the Stroop task and documentary, ensuring the subject's engagement with the tasks. The participants watched the documentary for 30-min.

2.3.2 | Manipulation checks

Subjective mental fatigue. The perceived rating of mental fatigue was assessed using the 100 mm visual analog scale (VAS) (McCormack et al., 1988; Wewers et al., 1990). This scale has two extremities anchored from 0 (none at all) to 100 (maximal). The participants were required to answer, "How mentally fatigued do you feel right now?".

Pupil diameter. Pupil diameter was recorded continually per 30-min during the cognitive manipulation (i.e., mental fatigue or control) with a portable Eye Tracking-XG (Applied Science Laboratories, USA) equipment with a sampling frequency of 60 Hz. During this period, the participants looked at a fixed cross with the same level of luminosity as the Stroop task letters, so there was no interference from eye reflexes to the environmental lighting. The recordings were exported to Brain Vision Analyzer (Brain Products). The eye-tracker detected and removed artifacts and blinks using a linear interpolation

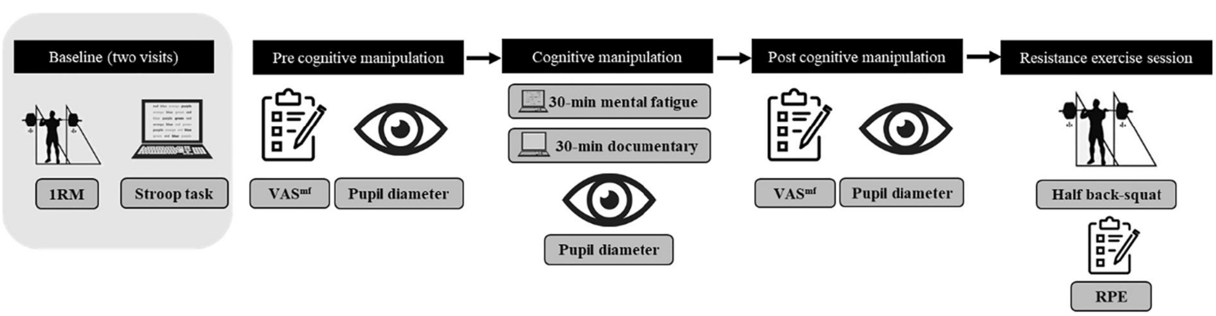

FIGURE 1 Experimental design of the study. 1RM, one repetition maximum; RPE, rating of perceived exertion; VASmf, visual analog scale for the subjective mental fatigue.

algorithm. Trials that did not contain fixation at the screen were removed from the analysis (>0.1% of the data).

Response time and accuracy. The behavioral performance in the Stroop task was measured as the mean response time (ms) and accuracy (% correct responses) over trials performed pre and post) the 30-min Stroop used to induce mental fatigue.

2.3.3 | Resistance exercise sessions

The exercise sessions began with a standardized warm-up (RPE 6–20 <10; very light) performed on a cycle ergometer (Cayenne) for five minutes. Additionally, the participants completed a standardized half back-squat warm-up consisting of two sets of six repetitions at 50% and 70% of 1 RM, respectively, with 3-min of rest between each warm-up set and 5-min rest before the resistance exercise session. The participants performed three sets of half back-squat exercise to failure (inability to perform the exercise over the full range of motion), with intensities of 50%, 70%, and 90% of 1RM with a passive recovery interval of 5-min between sets. The range of motion allowed was 90° and was limited by the squat cage (Righetto®) used in the tests. The researchers recorded the number of repetitions for each intensity and the total volume (sum of the three sets).

2.3.4 | Measures

One-repetition maximum (1RM). Participants performed the 1RM test following the American Society of Exercise Physiologists (Brown et al., 2003). Two sessions with at least a 72-h interval were required to identify the 1RM reliability values for all participants [intraclass coefficient correlation (ICC) two-way mixed absolute = 0.97 ($CI_{95\%}$ = 0.94 to 0.99)].

Number of Repetitions. The participants were asked to perform the half back squat with a 1 s tempo for both the concentric and eccentric muscle actions. Two work metrics were calculated: total repetitions per set and total volume for the resistance exercise session (sum of the total repetitions across the three sets). The total repetitions were the number of repetitions to muscular failure.

Rating of perceived exertion (RPE). We monitored RPE using a CR-10 scale (Borg, 1982) during the half back-squat exercise. Specifically, the participants were instructed to provide their RPE for every repetition. Once we found differences in the number of repetitions (e.g., 50%, 70%, and 90% 1RM), the mean RPE was compared in an iso-work (i.e., the percentage for the number of repetitions). So, we calculated the RPE mean for the 25, 50 (26–50), 75 (51–75), and 100% (76–100) of the number of repetitions for each set.

2.4 | Statistical analysis

The Shapiro-Wilk test evaluated whether the data were normally distributed. The subjective mental fatigue (i.e., visual analog scale) and pupil diameter were analyzed by a two-way repeated-measures ANOVA interaction of condition (CON × MF) and time (pre × 15- × 30-min). Another two-way repeated-measures ANOVA analyzed the interaction between condition (CON × MF) and intensity-load (50%, 70%, and 90%) for the number of repetitions, whereas a *t*-test compared the total volume (CON × MF). The Mauchly test assessed the sphericity assumption, and Greenhouse-Geiser correction was used when needed. Once the RPE and Stroop task accuracy and response time presented non-normal distribution, the General Estimated Equations (GEE) analyzed the interaction between condition (CON × MF) and %reps (25, 50, 75, 100%) for RPE and condition and time (pre and post) for Stroop's accuracy and response time. The model of GEE was chosen based on the distribution (i.e., gamma), the goodness of fit (Quasi-likelihood under the Independence Model Criterion), and residual distribution (Zeger et al., 1986). Bonferroni post-hoc was used to find the mean differences when there was a significant interaction. Partial eta squared (ηp^2) was used to determine the main effects and interaction effect sizes. The data are presented in mean, standard deviation, the 95% confidence interval of the mean differences ($CI_{95\%}$), and the 95% confidence interval of Cohen *d* effect size considering the within-subject analyses (Dankel et al., 2021).

3 | RESULTS

3.1 | Manipulation checks

Perceived mental fatigue. There were significant main effects of condition ($p < 0.001$) and time ($p < 0.001$). Moreover, an interaction was observed ($p < 0.001$). The perceived mental fatigue was not significantly different between conditions in the pre-measurements [Control = 2.50 ± 5.12 a.u.; Mental fatigue = 1.14 ± 5.30 a.u.; $CI_{95\%}$ = −1.28 (−3.07 to 0.52)]; d = 0.35 (−0.12 to 0.82), but significantly different following 15- [Control = 2.22 ± 3.67 a.u.; Mental fatigue = 24.39 ± 10.81 a.u.; $CI_{95\%}$ = −22.18 (−27.78 to −16.55); d = 1.96 (1.15 to 2.75)] and 30-min [Control = 2.50 ± 4.29 a.u.; Mental fatigue = 51.50 ± 10.90 a.u.; $CI_{95\%}$ = −0.49 (−53.97 to −44.03); d = 4.90 (3.20 to 6.60)] of cognitive manipulation, as shown in Figure 2A.

Pupil diameter. There was a significant main condition effect (p = 0.02) but not time (p = 0.06) for pupil diameter. However, a significant interaction was observed (p = 0.001). In the pre test, both conditions showed similar values [Control = 6.28 ± 0.23 mm; Mental fatigue = 6.44 ± 0.18 mm; $CI_{95\%}$ −0.17 = (−0.13 to 0.09); d = 0.07 (−0.39 to 0.53)]. However, following 15- [Control = 6.72 ± 1.96 mm; Mental fatigue = 5.22 ± 1.40 mm; p = 0.001; $CI_{95\%}$ 0.15= (0.07 to 0.23)] and 30-min [Control = 6.78 ± 1.83 mm; Mental fatigue = 5.28 ± 1.23 mm; p = 0.001; $CI_{95\%}$ 0.15 = (0.07 to 0.23)] a significant difference between conditions was found, as shown in Figure 2B.

Response time. We found a main effect of condition (p = < 0.001) and time ($p < 0.001$). Also, an interaction between condition and time ($p < 0.001$) was observed. The response time was not significantly

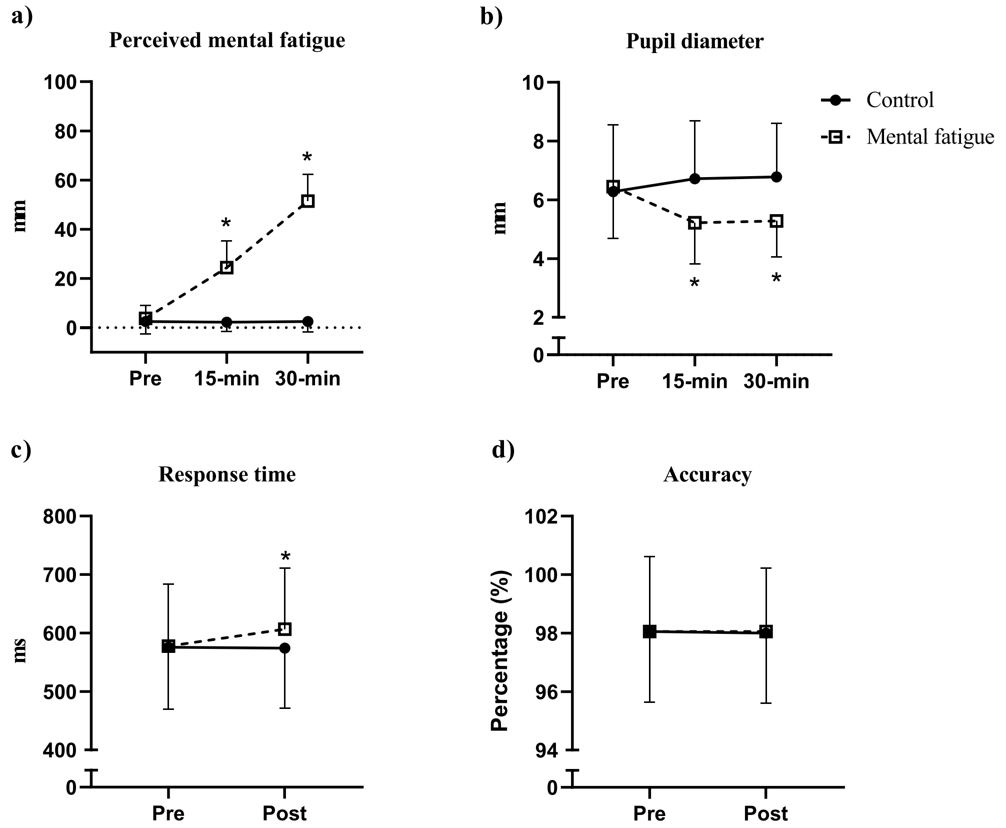

FIGURE 2 Perceived mental fatigue (A), pupil diameter (B), response time (C), and accuracy (D) manipulation checks. * = Different from control ($p < 0.05$).

different between the pre and post tests in the control condition [Pre = 575.67 ± 105.54 ms; Post = 574.17 ± 102.30 ms; $CI_{95\%}$ = 1.50 (−3.60 to 6.60)]; d = 0.18 (−0.29 to 0.64)] as well as in the pre test between conditions [Control = 575.67 ± 105.54 ms; Mental fatigue = 577.72 ± 105.76 ms; $CI_{95\%}$ = −2.06 (−10.77 to 6.66)]; d = −0.14 (−0.61 to 0.32), but significantly different in the mental fatigue condition for the pre and post tests [Pre = 577.72 ± 105.76 ms; Post = 606.50 ± 104.31 ms; $CI_{95\%}$ = −28.78 (−39.57 to −17.98); d = −1.61 (2.31 to −0.89)] and between conditions for the post test [Control = 574.17 ± 102.30 ms; Mental fatigue = 606.50 ± 104.31 ms; $CI_{95\%}$ = −32.33 (−45.99 to −18.67); d = −1.43 (−2.08 to −0.76)], as shown in Figure 2C.

Accuracy. No main effect of condition (p = 0.948) or time (p = 0.945) was observed. Also, no interaction was found between condition and time ($W_{(2,34)}$ = 0.01; p = 0.955), as shown in Figure 2D.

3.2 | Number of repetitions

50%, 70%, and 90% 1RM. There was a significant main effect of condition ($p < 0.001$) and intensity ($p < 0.001$) for the number of repetitions. Also, a significant interaction ($p < 0.001$) was found. The number of repetitions were significantly different between conditions for 50% 1RM [Control = 36.17 ± 5.50 reps; Mental fatigue = 32.28 ± 5.01 reps; $CI_{95\%}$ = 3.88 (2.66 to 5.11); d = 1.57 (0.86 to 2.26)] and 70% 1RM [Control = 15.72 ± 2.16 reps; Mental fatigue = 13.67 ± 1.81 reps; $CI_{95\%}$ = 2.06 (1.38 to 2.73); d = 1.52 (0.83 to 2.20)], but not for 90% 1RM [Control = 4.22 ± 1.11 reps; Mental fatigue = 3.94 ± 1.00 reps; $CI_{95\%}$ = 0.28 (−0.20 to 0.75); d = 0.29 (−0.19 to 0.76)], as shown in Figure 3.

Total volume. There was a significant difference between conditions for the total volume (sum of all repetitions) of the resistance exercise session ($p < 0.001$). During the mental fatigue session, participants performed less repetitions than during the Control session [Control 56.11 ± 7.31 reps; Mental fatigue = 49.88 ± 6.63 reps; $CI_{95\%}$ = 6.22 (4.30 to 8.15); d = 1.60 (0.89 to 2.30)], as shown in Figure 3.

3.3 | Rating of perceived exertion

50% 1RM. There was a significant main effect of condition ($p < 0.001$) and time ($p < 0.001$) for RPE. Also, an interaction of condition × time for RPE was found (p = 0.011). The RPE was significantly different between conditions for the 25% [Control = 4.28 ± 0.89 a.u; Mental fatigue = 4.89 ± 0.68 a.u.; $CI_{95\%}$ = −0.61 (−1.11 to −0.11); d = 0.87 (0.32 to 1.41)], 50% [Control = 5.67 ± 0.97 a.u.; Mental fatigue = 6.00 ± 0.86 a.u.; $CI_{95\%}$ = −0.78 (−1.36 to −0.20); d = 0.96 (0.39 to 1.51)], and 75% [Control = 7.00 ± 1.13 a.u.; Mental

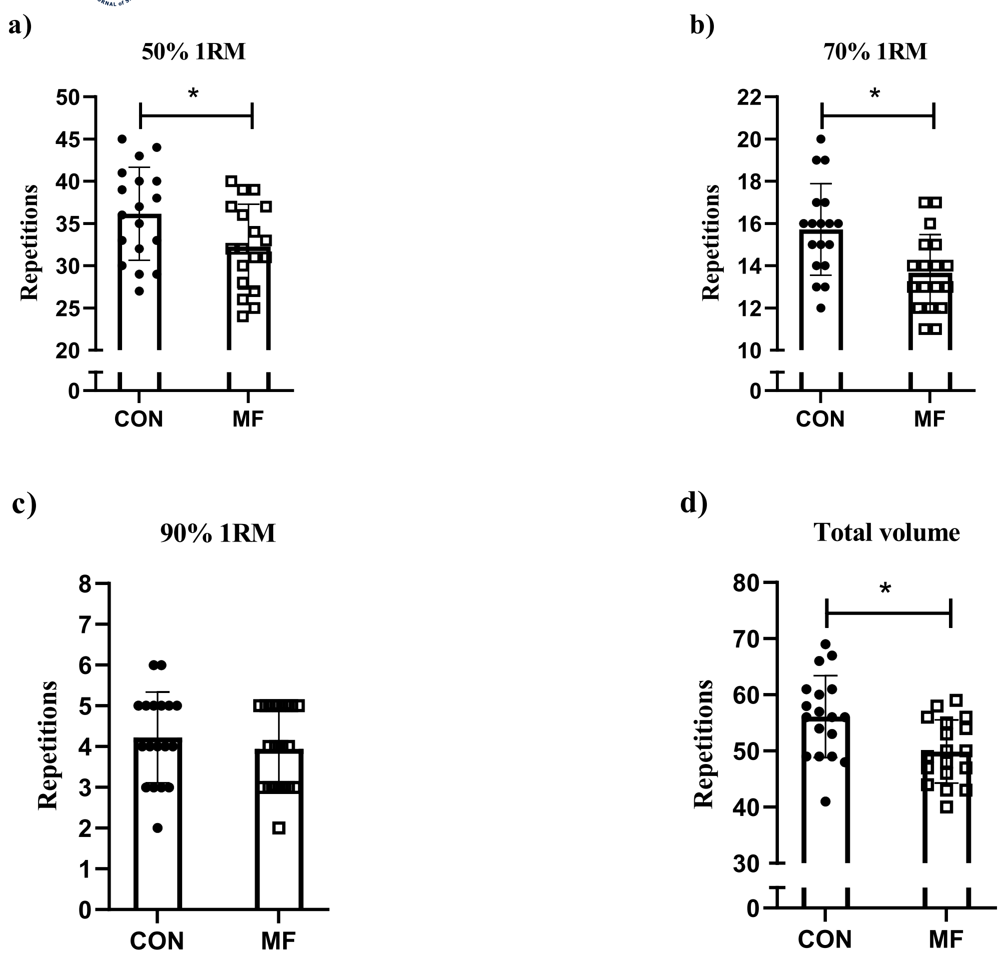

FIGURE 3 Mean and individual values of the number of repetitions in 50 (A), 70 (B), and 90% 1RM (C) intensities and total volume (D). * = Different from control ($p < 0.05$).

fatigue = 8.0 ± 0.76 a.u.; $CI_{95\%}$ = −0.89 (−1.53 to −0.24); d = 0.99 (0.41 to 1.54)] of the repetitions number, but not for the 100% [Control = 9.00 ± 0.83 a.u.; Mental fatigue = 9.50 ± 0.62 a.u.; $CI_{95\%}$ = −0.33 (−0.82 to 0.16); d = 0.48 (0.01 to 0.97)], as shown in Figure 4A.

70% 1RM. There was a significant main effect of condition ($p < 0.001$) and time ($p < 0.001$) for RPE. Also, an interaction of condition × time for RPE was found ($p < 0.001$). The RPE was significantly different between conditions for the 25% [Control = 4.50 ± 0.92 a.u.; Mental fatigue = 5.44 ± 0.98 a.u.; $CI_{95\%}$ = −0.94 (−1.52 to −0.37); d = 1.17 (0.56 to 1.77)], 50% [Control = 5.50 ± 0.92 a.u.; Mental fatigue = 7.00 ± 0.97 a.u.; $CI_{95\%}$ = −1.17 (−1.91 to −0.42); d = 1.12 (0.51 to 1.70)], and 75% [Control = 6.67 ± 1.08 a.u.; Mental fatigue = 7.33 ± 0.97 a.u.; $CI_{95\%}$ = −0.67 (−1.27 to −0.07); d = 0.79 (0.25 to 1.32)] of the repetitions number, but not for the 100% [Control = 8.00 ± 1.11 a.u.; Mental fatigue = 8.00 ± 1.06 a.u.; $CI_{95\%}$ = −0.44 (−1.06 to 0.17); d = 0.52 (0.02 to 1.01)], as shown in Figure 4B.

90% 1RM. No main effect of condition ($p = 0.685$) was found, but a main effect of time ($p < 0.001$) was observed. Also, no interaction was found between condition and time ($p = 0.258$), as shown in Figure 4C.

4 | DISCUSSION

This study aimed to analyze the number of repetitions performed with different intensity-load on resistance exercise in mentally fatigued resistance-trained adults. The results revealed increased perceived mental fatigue, response time, and altered pupil diameter after a 30-min cognitive effort, suggesting that the experimental cognitive manipulation induced mental fatigue. On the subsequent physical task, the main findings showed fewer repetitions at 50% and 70% 1RM for the mental fatigue condition. However, the conditions presented similar results at 90% 1RM, corroborating our initial hypothesis.

The findings showed increased subjective mental fatigue and reduced pupil diameter only for the mental fatigue condition. Also, we found a worsened response time following a 30-min incongruent Stroop task in the mental fatigue condition, even though accuracy remained the same. When mentally fatigued, the participants needed more time to process the information to give the correct answer, which meant an inhibitory control impairment, as observed in other studies (Rubio-Morales et al., 2022). These results corroborate scientific investigations that found similarly increased perceived mental fatigue immediately after the 30-min incongruent Stroop task (Bafna

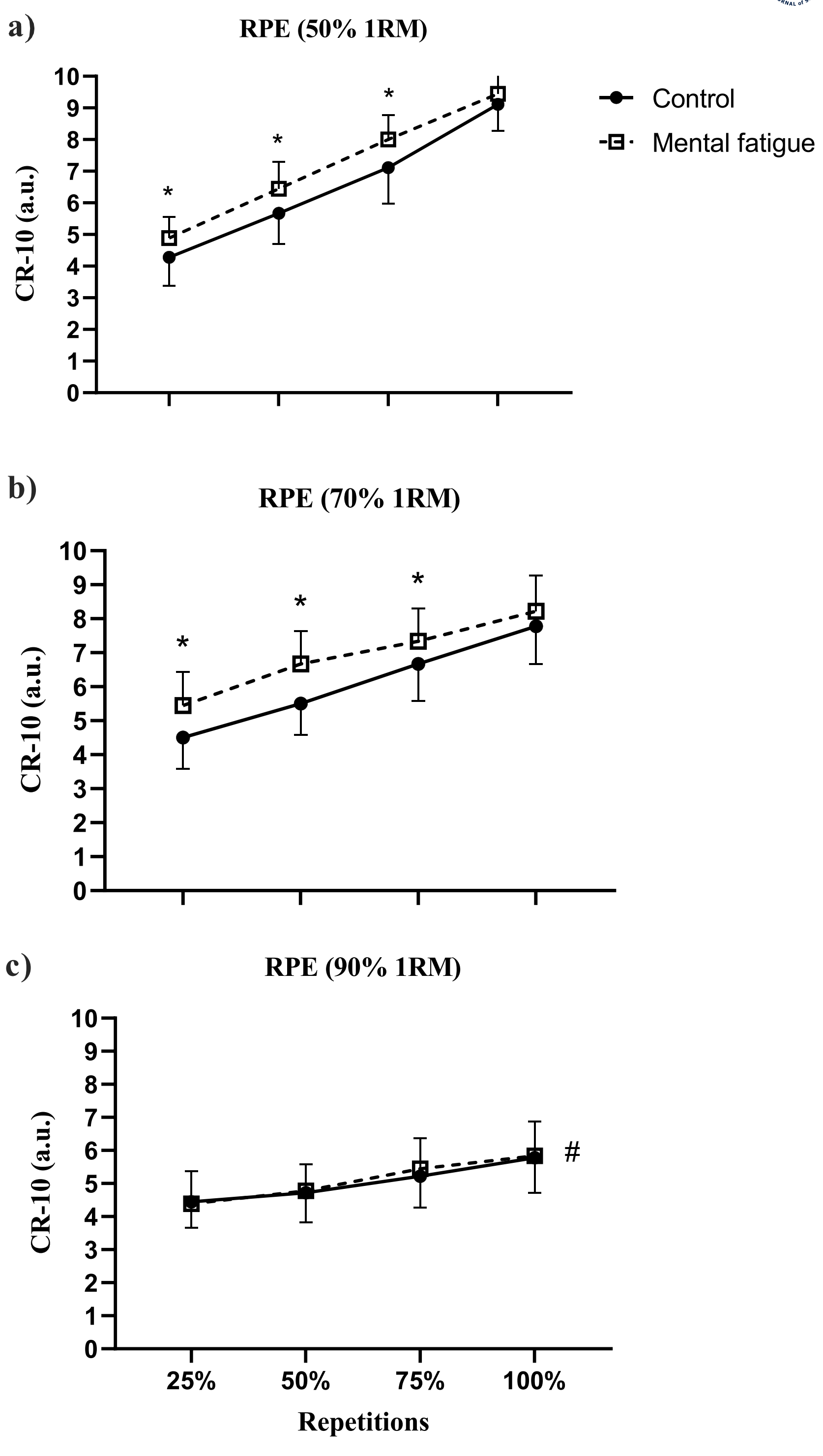

FIGURE 4 RPE for 50 (A), 70 (B), and 90% (C) 1RM intensities. RPE, rating of perceived exertion. * = $p < 0.05$ different from control; $^{\#}p < 0.05$ a main effect of time.

et al., 2021; Gantois et al., 2021; Queiros et al., 2021), reduced pupil diameter (Bafna et al., 2021), and increased response time during the Stroop task (Gantois et al., 2021). It might indicate a decrease in inhibitory control performance, which would explain the elevated values of perceived effort during physical tasks. Also, the scientific literature shows that the sensory brain system may be overloaded when multiple or repetitive stimuli are being processed (Bigliassi, 2021). Thus, it is reasonable to assume that cognitive inhibition tasks might impair sensorial and attentional control of brain systems, which might cause a detrimental effect on regulating RPE, harming the following physical tasks (Bigliassi, 2021). Additionally, our study showed that pupil diameter might be an interesting indicator of mental fatigue, and future studies should consider using this strategy to guarantee that the participants are cognitively overloaded.

The 50% and 70% 1RM results demonstrated a lower number of repetitions and higher RPE for the mental fatigue condition. Similarly, Queiros et al. (2021) and Gantois et al. (2021) found reduced repetitions to failure using comparable intensity-load in the half back-squat exercise. Queiros et al. (2021) found 18.9%, and Gantois et al. (2021) showed a 16.7% lower number of repetitions for the mental fatigue condition, while the present study showed a reduction of 12.1 (i.e., 50% 1RM) and 15.1% (i.e., 70% 1RM). These findings can be explained by a higher-than-normal increase in RPE throughout the resistance exercise session, which causes an early disengagement from exercise (Giboin et al., 2019; Pageaux et al., 2013). Then, it is possible to suggest that the negative results might be linked to a reduced attention focus capacity that mediates task intensity's role in keeping the participant engaged (Bigliassi, 2021; Hutchinson et al., 2007). Also, long-term studies verifying the effects of mental fatigue on the number of repetitions are needed. Krieger (2010) and Schoenfeld et al. (2016) observed that volume might be crucial to muscle hypertrophy, and repeated exercise sessions in a mental fatigue state could potentially reduce the number of repetitions. Then, mentally fatigued subjects would be expected to reduce their performance during the training, and its long-term effects are still unknown.

Regarding the 90% 1RM intensity-load findings, we found no difference between conditions for the number of repetitions and RPE. Interestingly, the participants reported lower than expected RPE values at the end of each set in this intensity. Although we followed the scale anchorage and familiarized the participants, we speculate that they might have confounded effort, discomfort, and pain, which could be more evident during repetitions to failure in lower intensities (Spreuwenberg et al., 2006). The protocol elicited a shorter time-to-exhaustion (i.e., lower number of repetitions to failure), which might be considered similar to all-out exercises (e.g., <30-s duration). Although diverse high-intensity exercises were investigated in the literature, previous studies found similar results between mentally fatigued and control conditions on subsequent tasks (Van Cutsem et al., 2017). Pageaux et al. (2013) found no effect of mental fatigue on a subsequent maximum voluntary contraction of the knee extensor muscles (i.e., 5-s of maximum isometric contraction) in physically active adults. Rozand et al. (2014) showed similar values between conditions in maximum voluntary contraction torque of the knee extensor muscles following a high-demand cognitive task in physically active adults, which is similar to Silva-Cavalcante et al. (2018) study that found no effect of mental fatigue on the maximum voluntary contraction of the knee extensors muscles in trained cyclists. It could be explained by the peripheral regulation (e.g., intramuscular acidosis) and different brain areas involved during high-intensity physical effort (e.g., gyrus postcentral and posterior cingulate cortex) when compared to the ones affected by mental fatigue (e.g., prefrontal cortex and anterior cingulate cortex) (Barwick et al., 2012; Fontes et al., 2015; Pires et al., 2018).

Although this study adds to understanding resistance exercise performance under mental fatigue, some limitations should be acknowledged. We lack gold standard measurements for analyzing neuromuscular fatigue (e.g., maximum voluntary contraction, maximum activation, H-reflex, and M-wave), only recruited trained male participants, and used one resistance exercise (i.e., half back-squat), which reduces the findings' generalization for females, untrained subjects, and real-context routine using multiple resistance exercises. Also, the results at 90% 1RM should be interpreted with caution. The number of repetitions might not be sensitive enough to indicate a reduction in above 90% 1RM intensities. Another factor that should be considered is that the number of repetitions to failure might be deeply affected by the previous set to failure, mainly during 50% and 70% 1RM. However, the order of the sets was randomized and equal for both conditions (e.g., mental fatigue and control). Finally, the anchorage of the rating of the perceived exertion scale might not have been clear enough once in the 90% 1RM intensity the participants lacked reaching values close to the maximum, as well as different strategies to analyze perception of effort data could have yielded diverse results (Nicolò et al., 2019). We lacked boredom measurements during the interventions (i.e., documentary and mental fatigue), which could also confound mental fatigue measurements.

While the present study induced mental fatigue using protocols that are not common in the real world for trained adults in resistance exercise, the findings have critical practical applications that may be used to avoid an impaired number of repetitions in a resistance exercise session. In addition, mentally fatigued individuals will likely experience the resistance training session more effortfully than the strength and conditioning coaches had planned. Therefore, measuring mental fatigue (e.g., subjective mental fatigue) immediately before a resistance exercise session might be a rapid and valuable solution to keep the number of repetitions with a moderate intensity load throughout resistance exercise sessions. Once mental fatigue is identified before a resistance exercise session, reducing load or avoiding repetitions close to failure might help maintain the number of repetitions planned for the physical exercise session.

In conclusion, this study demonstrated that prolonged cognitive effort causes mental fatigue that compromises the number of repetitions to failure for 50% and 70% 1RM intensity-load in resistance-trained adults. However, for a 90% 1RM intensity load, no difference was found in the number of repetitions in the half back-squat exercise. Further investigations should be performed with different levels of mental fatigue and training status in the same experimental design (e.g., trained and untrained).

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CONFLICT OF INTEREST STATEMENT

The authors report that there are no competing interests to declare.

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