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The Influence of Mental Fatigue on Physical Performance and Its Relationship with Rating Perceived Effort and Enjoyment in Older Adults

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ABSTRACT
The study investigated the influence of mental fatigue on older people's enjoyment during a series of physical exercises. Using a randomized cross-over design, participants ($n = 35$) completed a 6-minute walking test – 6MWT, a Timed Up and Go—TUG test and three sets of knee extension exercise (first set: KE1, second set: KE2, third set: KE3) under two experimental conditions (control or mental fatigue). The Nonparametric Analysis of Longitudinal Data in Factorial Experiments was used to compare the number of repetitions performed during three sets of resistance exercise between conditions. The same analysis method was applied to compare the perception of effort and enjoyment across five moments (Post-6MWT, Post-TUG, Post-KE1, Post-KE2, Post-KE3) and two conditions and the Visual Analogue Scales (VAS) across four moments (baseline, Pre-6MWT, Pre-TUG, Pre-KE) and two conditions. Mental fatigue did not affect the physical function, perception of effort and enjoyment of exercise in older people. Participants, however, reported higher enjoyment for walking and dynamic balance compared to strength exercise. Mental fatigue had no effect on the physical function, perception of effort and enjoyment of exercise of older people. Participants presented a higher enjoyment for walking and dynamic balance compared to strength exercise. Given the importance of resistance exercises for health, clinicians should prioritize resources to education programs emphasizing the benefits of resistance exercise in both short- and long-term health. Including social interaction opportunities in physical exercise programs and prescribing activities appropriate to participants' ability levels could enhance engagement and adherence.

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Cardiorespiratory function; cognitive fatigue; elderly; muscular function

Physical function is theoretically formed by four subdomains that are conceptually related (Cella et al., 2007), but distinct (Bruce et al., 2009; Dias, 2014): mobility (lower extremity), dexterity (upper extremity), axial or central (neck and back function), and complex activities that involve more than one subdomain (instrumental activities of daily living). Physical function tends to decline naturally with advancing age: older people have 25–35% smaller limb muscles and have significantly more fat and connective tissue in limb muscles compared to younger individuals (Lexell, 1995). This decline in physical function can become more severe in the presence of sarcopenia and osteopenia, which lead to impaired locomotory function, reduced balance, and increased risk of osteoarthritis, falls, and fractures (Janssen et al., 2002; Landi et al., 2012).

The benefits of physical exercise in counteracting age-related losses are well documented (Bouaziz et al., 2017; Sherrington et al., 2017). Sherrington et al. (2017), for example, showed that exercise programs involving a high dose of complex balance exercises can reduce the rate of falls by 39%. Regarding aerobic and resistance training, results of Marques et al. (2017) found that 8 months of aerobic or strength training succeeded to improve older women's balance outcomes compared to control group. Strength improvements were observed in the resistance training group, but no conclusions were made about aerobic training. Changes in knee extension and knee flexion strength were largely associated with performance in the dynamic balance test. Similar results were found in older men, where both aerobic and combined training improved functional outcomes compared to a control condition (Sousa et al., 2016). However, older adults enrolled in the combined group displayed higher improvements. Despite this, older adults tend to become less active throughout life (Health & Welfare, 2018). This is concerning, since exercise benefits are mediated by participants' adherence to the training program with high adherers performing better on instrumental activities of daily living, balance, mobility (Aartolahti et al., 2015) and cognitive tasks (Tiedemann et al., 2011) compared to their low adherers' peers.

The reasons why older adults do not regularly engage in exercise programs relate to many psychological constructs, such as self-efficacy (Schutzer & Graves, 2004)—one's belief in their ability to successfully accomplish a specific task (Bandura, 1977), and affective responses, such as pleasure while exercising (Lacharité-Lemieux et al., 2015).

While self-efficacy has been cited as critical for exercise initiation, authors have pointed out enjoyment as crucial for exercise maintenance (Schutzer & Graves, 2004), since it is considered an immediate reward compared to other delayed benefits, such as health status and functional performance (Collado-Mateo et al., 2021).

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Mental fatigue may be one factor that could influence someone's self-efficacy and enjoyment of exercise. For example, Hess and Knight (2021) indicated that chronic mental fatigue showed distinct levels of predictability in anticipating both engagement and assessment levels within different groups. As chronic mental fatigue levels increased, older adults tended to perceive greater increases in task difficulty compared to younger adults (Hess & Knight, 2021). This heightened perception of task complexity among older adults was linked to their deliberate decisions to avoid engaging in challenging activities (Hess et al., 2021).

Mental fatigue can be defined as a psychobiological state of tiredness and lack of energy induced by prolonged and/or intense periods of high cognitive demand (Boksem & Tops, 2008; Marcora et al., 2009). Mental fatigue is a common complaint among older adults (Hardy & Studenski, 2008). For instance, a study by Cohen et al. (2021) found that within a cohort of 2,361 older adults, 24.8% reported experiencing mental fatigue. This phenomenon was more prevalent among women (Cohen et al., 2021; Meng et al., 2010), as well as in older age groups (Cohen et al., 2021), with percentages reported as follows: 14.5% among individuals aged 60–69 (out of 1,004); 18.6% among those aged 70–79 (out of 839); 41.5% among individuals aged 80–89 (out of 253); and 67.2% among those aged 90–108 (out of 265). Additionally, frail older individuals* (Zengarini et al., 2015) were found to perceive higher levels of mental fatigability.

Studies involving older adults have shown that mental fatigue may be linked to a decreased activity in the prefrontal cortex (Shortz et al., 2015; Terentjeviene et al., 2018). Changes in brain activation may impair the physical function of older adults, since the ability to perform activities of daily living requires the integration of cognitive functions (de Dieuleveult et al., 2017; Santos Henriques et al., 2023). Indeed, Noé et al. (2021) indicated that mental fatigue levels significantly relate to balance disturbances when participants stood with open eyes; and Salehi et al. (2023) found decreased postural stability under mental fatigue compared to control condition. In addition, data from a systematic review and meta-analysis (Brahms et al., 2022) show that mental fatigue impairs balance in both young and older adults; but no significant differences were observed when the analysis was performed separately for each age group. However, the meta-analysis included only four studies with older adults' data, and Jackson and Turner (2017) suggested that at least five studies should be included in a random-effects meta-analysis to return valid results. Therefore, Brahms et al. (2022) highlighted what is still unknown and needs further investigation.

Moreover, to our knowledge, no studies have investigated the effects of mental fatigue on older adults' physical function and affective responses to performing resistance exercises. This study aimed to investigate the influence of mental fatigue on: 1) walking, balance and strength performance, and 2) the enjoyment experienced when performing a walking, balance, and a resistance exercise in older adults. We hypothesize that following mental fatigue participants would walk a shorter distance in the 6-minute walking test (6MWT), take longer to do the Timed Up and Go (TUG) test, as well as would execute less repetitions in knee extension exercise. We also expect that, under mental fatigue, older people would report lower scores of enjoyment and increased mental fatigue and perception of effort during resistance exercise compared to a control condition.

Methods

Experimental design

Using a randomized cross-over design, participants completed a series of physical tests (i.e., 6MWT, and balance task) followed by a brief standardized resistance exercise session in older adults. The protocol for the present study was registered online on Open Science Framework (OSF; https://osf.io/ejy8b/?view_only=ef0c6465d5eb491da3c797456708ed11, 12th April 2023), an open public data repository.

Participants

The "pwr" R package was used to determine the sample size for the present study. Specifically, the sample size calculation was based on data from a pilot study involving four participants. We calculated the number of subjects using the main measures of the number of repetitions and the RPE in the knee extension exercise. Thus, we employed the "pwr.anova.test" function with the following parameters: effect size (Cohen's $f = 0.58$ for the number of repetitions and 0.36 for RPE), number of conditions ($k = 2$), significance level ($alpha = 0.05$), and power ($power = 0.80$). The results indicated that the required sample size would be 12 for the number of repetitions and 31 for the RPE.

Considering potential sample dropout, we increased the sample size to maintain the statistical power of the study despite any unforeseen participant losses. Therefore, 44 older adults of both sexes, aged 60 years old and over, enrolled to participate in the study. Nine participants were excluded for different reasons: 1 was color blind, 5 did not want to do the strength exercise, 1 had several cardiovascular diseases (i.e., diabetes, high blood pressure and high cholesterol and family history of heart-related death), 1 had a score below the cutoff for dementia in the Addenbrooke's Cognitive Examination—Revised (ACE-R), and 1 presented significant symptoms of anxiety. Thus, 35 participants (9 male and 26 female) were included in the study (Figure 1). The study was submitted to and approved (UTS HREC REF NO. ETH22–7745) by the Research Ethics Committee of UTS, respecting all the National Health Council's standards for research with human beings. Permission to conduct the sessions for the purposes of this research was obtained by all respondents, who were informed about the purposes of this research and how their responses would be used and stored. Participants were informed beforehand that two gift vouchers of $100 would be raffled among participants at the completion of the testing.

Eligibility criteria for participants

Participants were recruited by personal invitation in the city of Sydney and they were considered eligible for enrollment if: a) were physically active—at least 30 minutes of moderate activity on most (preferably all) days (Sims et al., 2006)—and independent; b) do not present any cardiac and/or orthopedic dysfunction that could impede the physical exercise practices; c) were

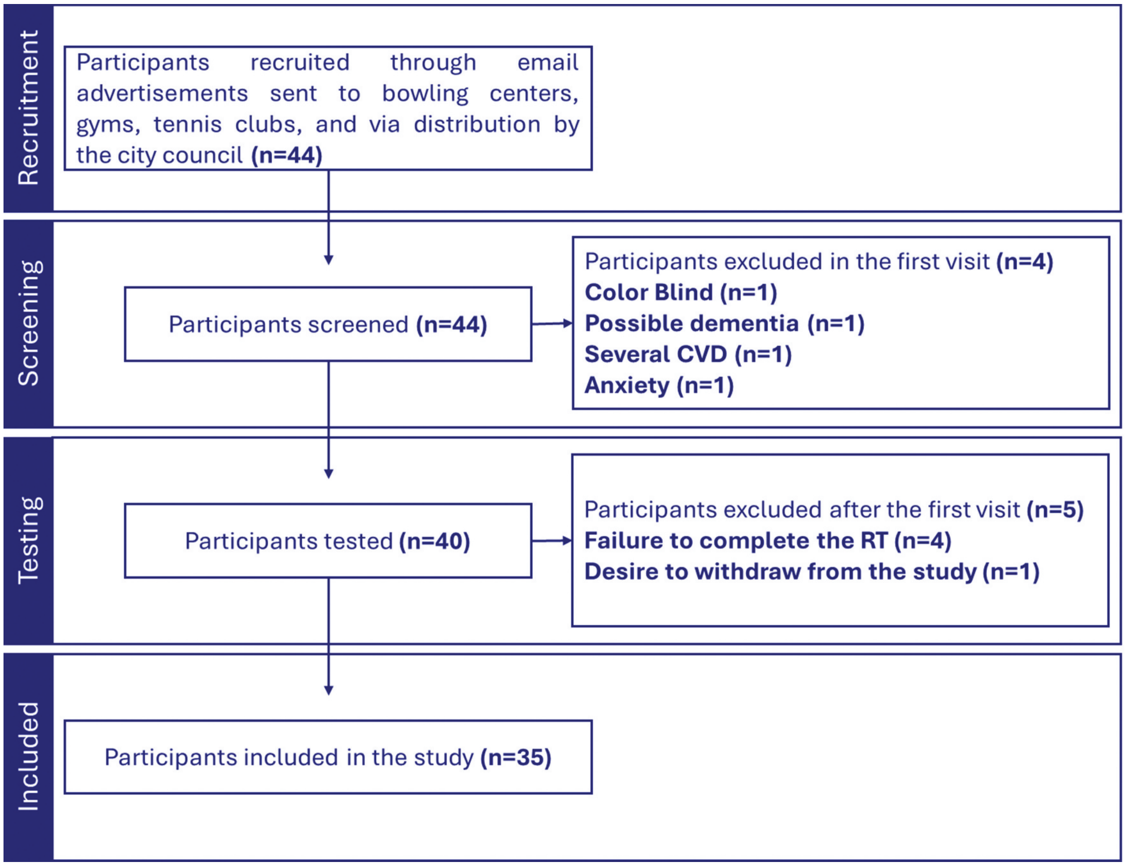

Figure 1. Flow chart of participants inclusion in the study.

not receiving hormonal replacement; d) showed normal or corrected vision; and e) were fluent English speakers. Participants with cardiovascular conditions were included if they presented medical approval to enroll in the research.

Experimental conditions

Participants performed four sessions as outlined in Figure 2a. In the first session, participants underwent several assessments: Addenbrooke's Cognitive Examination—Revised, Adult Pre-Exercise Screening System, Geriatric Depression Scale, Geriatric Anxiety Inventory; followed by measurement of height and body mass, and Stroop Test familiarization. In the second session, participants became familiar with the 6MWT and TUG. Additionally, they underwent a 10-repetition maximum (RM) test on a knee extension machine to determine exercise intensity for the experimental conditions. Lastly, in the third and fourth sessions, participants engaged in the experimental conditions (Figure 2b), following a counterbalanced randomized design:

Mental Fatigue Condition: Flanker/Reverse Flanker Test for 30 minutes, followed by the walking test, two rounds of the Stroop Test for 10 minutes each, and then balance and resistance exercises.

Control Condition: Watching a documentary for 30 minutes, followed by the walking test, two rounds of watching a documentary for 10 minutes each, and then balance and resistance exercises.

After each physical test, participants completed the feeling scale and the RPE to measure affective responses. Additionally, the VAS was administered both before and after the Flanker/Reverse Flanker Test, as well as after the 10-minute Stroop Tests, to assess subjective levels of mental fatigue, mental effort, and motivation.

A detailed description of each method used with the participants (e.g., cognitive tests, VAS, RPE, physical tests) can be found in the following sections.

Randomization

The randomization was performed using the function = randbetween(1;2) in Excel, where 1 represented the mental fatigue condition and 2 represented the control condition. Due to uncertainty regarding the number of successfully recruited participants, randomization was conducted in blocks. We randomized the order for the first 16 participants, then a new randomization was done for the next 14 and 10, respectively. After the 40th participant, randomization was carried out every 5 participants until the final participant.

Resistance exercise sessions

10 RM test

Participants underwent a 10-RM test on the knee extension machine. The 10-RM was chosen to prioritize volunteer safety

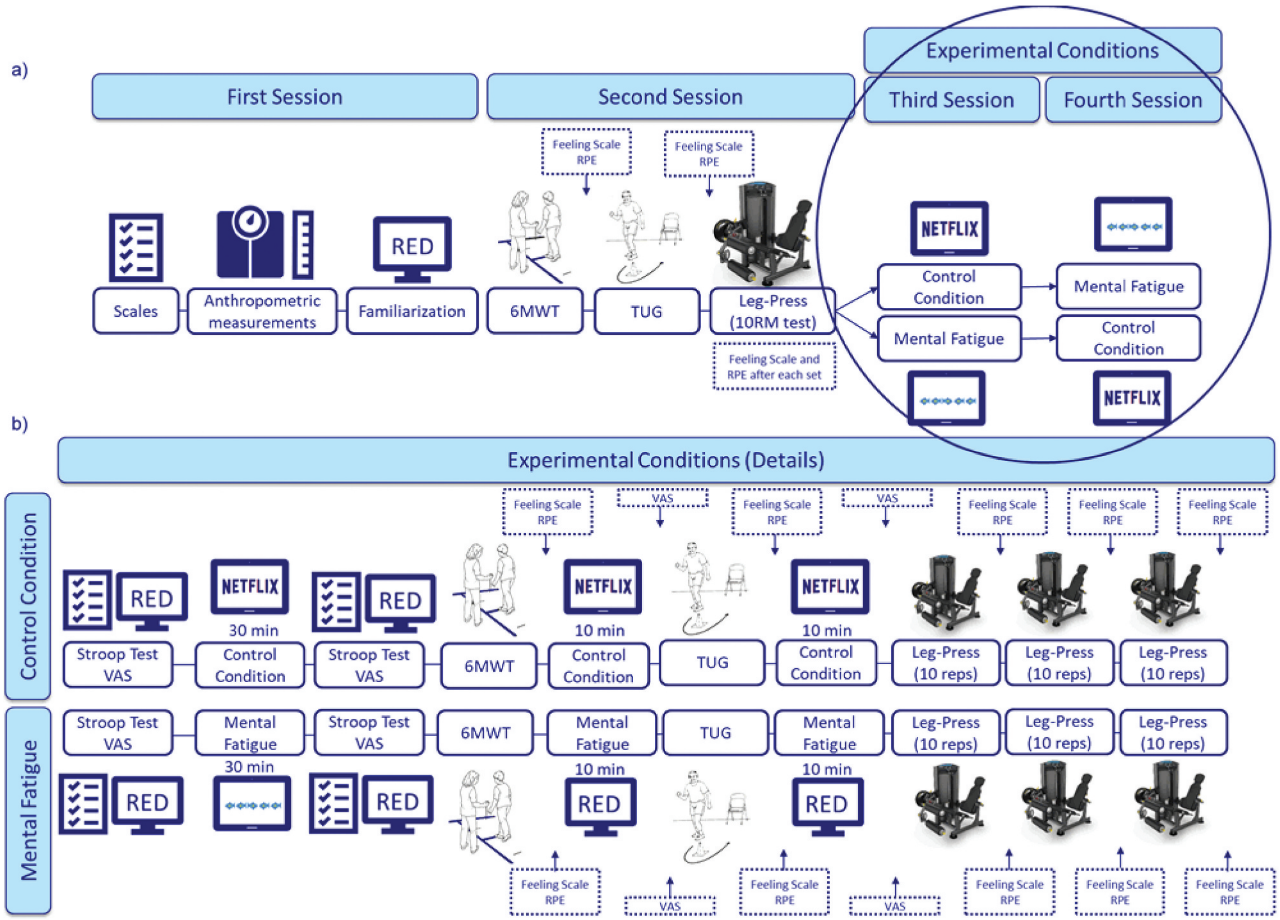

Figure 2. Study's outline.

(Pescatello, 2014). Movement duration was regulated using a metronome, allowing 1 second for the concentric phase and 2 seconds for the eccentric phase (Grosicki et al., 2014). Initially, participants performed 10 repetitions with either 5 kg or 12 kg weights, depending on their fitness level, to familiarize themselves with the rhythm. Following this, they completed two warm-up sets, with loads estimated based on the researcher's experience and the participant's RPE (measured on the Borg 10-point scale) response from the previous set. Thereafter, the 10RM load was determined in up to three attempts, with a 3-min rest interval between each attempt (Coelho-Júnior et al., 2022). Resistance was adjusted based on the participant's ability to complete one additional successful repetition with proper technique (Coelho-Júnior et al., 2022). The test concluded when participants were unable to perform more than 10 repetitions using correct technique.

The resting blood pressure was measured before commencing each visit and again 3–5 minutes after completing each assessment session as a safety precaution, particularly due to the age group involved in the study. Participants were not allowed to begin an assessment session or leave the testing facility if their blood pressure exceeded 160/100 mmHg (Grosicki et al., 2014).

Resistance exercise

Participants performed 3 sets of the knee extension at the maximum load they lifted during the 10RM test. Prior to these sets, participants warmed up with 1 set of 5 repetitions at 50% of the load selected for the 3 sets. They were instructed to sit in the machine with their back flat against the pad, ensuring their hips and knees were flexed at approximately 90º. Movement duration was regulated using a metronome set at 67 beats per minute, allowing 1 second for the concentric phase and 2 seconds for the eccentric phase of each repetition. Participants were encouraged to complete 10 repetitions per set. Resting blood pressure was measured before each visit and again 3–5 minutes after completing each assessment session. Participants were not permitted to begin an assessment session or leave the testing facility if their blood pressure exceeded 160/100 mmHg (Grosicki et al., 2014). Due to knee problems, one participant performed the exercise unilaterally.

Variable measurements

Primary outcomes

6-minute walk test. The 6MWT was used to assess the physical endurance capacity of the volunteers. The test has been validated for individuals aged 60 to 89 years old, demonstrating excellent test-retest reliability (ICC = 0.95) (Steffen et al., 2002). Testing reliability appears to improve when participants are given a practice trial beforehand (Janaudis-Ferreira et al., 2010). Participants completed the test in a 30-meter hallway, totaling 60 meters per lap ("ATS statement: guidelines for the six-minute walk test," 2002). They were instructed to walk as quickly as possible for 6 minutes, aiming to cover the greatest distance possible. The distance walked in meters was recorded at the end of the test. Standardized time updates were provided to participants at the 1st, 3rd, and 5th minutes.

Timed up and go (TUG). The TUG was used to measure volunteers' dynamic balance. The test showed good reliability in a sample of 147 older adults aged 51 to 90 years old (ICC = 0.80, 95% CI: 0.72–0.86) (Beauchamp et al., 2021). Participants sat in a chair 46 cm in height, positioned facing a cone 3.0 meters away. Upon the evaluator's signal, participants walked as quickly and safely as possible, circled the cone, and returned to the starting position (Rose et al., 2002). Each participant performed the test twice, and the shortest completion time was recorded.

Perception of effort. *The Borg CR-10 Scale* has 12 categories with values ranging from 0 ("nothing at all") to 10 ("maximal") (Borg, 1982). We used this scale to assess participants' perceived exertion following the physical assessments. The scale anchoring was done during the 10RM test.

Enjoyment. During physical exercise, individuals often undergo changes in mood (Hardy & Rejeski, 1989). Some may experience pleasure, while others may feel displeasure (Hardy & Rejeski, 1989). These feelings can also vary over time (Hardy & Rejeski, 1989). The feeling scale, developed by scientists (Hardy & Rejeski, 1989) is used to measure affective responses associated with exercise (Frazão et al., 2016; Hardy & Rejeski, 1989; Lins-Filho et al., 2019). This scale is structured in an 11-point bipolar format, ranging from + 5 to −5. Verbal descriptors are provided at the 0 point and at each odd integer: +5 = very good, +3 = good, +1 = fairly good, 0 = neutral, −1 = fairly bad, −3 = bad, and −5 = very bad. Participants indicate their current feelings. For statistical analysis, the feeling scale was converted to a 0 to 10 scale (−5 = 0, −4 = 1, −3 = 2, −2 = 3, −1 = 4, 0 = 5, +1 = 6, +2 = 7, +3 = 8, +4 = 9, +5 = 10).

Secondary outcomes

Scales

The following scales were used for pre-screening purposes:

Adult pre-exercise screening system (APSS)

The scale is a standardized method for pre-exercise screening, consisting of three stages. The first stage of the APSS involves seven questions designed to identify established cardiovascular, metabolic, or respiratory diseases, as well as signs and symptoms of these conditions or other medical issues posing significant risk when initiating or intensifying a physical activity program (Norton et al., 2018). The second stage involves self-reported information on major health risk factors for disease or conditions that may be exacerbated by exercise, including family history of coronary vascular disease, smoking status, physical activity levels, height, body mass, known hypertension, high cholesterol and/or blood glucose, recent hospitalization, prescribed medications, pregnancy or recent childbirth, and musculoskeletal symptoms (Norton et al., 2018). Stage 3 includes measurements such as resting blood pressure taken after at least five minutes of sitting, anthropometric measurements of height, weight, and waist circumference, as well as total cholesterol and blood glucose levels (Norton et al., 2018). The first stage is mandatory (Norton, 2012). In this study, we used only the first and second stages.

Addenbrooke's cognitive examination – revised (ACE-R)

The ACE-R (Mioshi et al., 2006) is a brief and reliable test battery designed to detect early stages of dementia, with a cutoff point of 82 (So et al., 2018). It is also effective in distinguishing between different subtypes of dementia, including Alzheimer's disease, frontotemporal dementia, progressive supranuclear palsy, and others. The test can be administered in 15 to 20 minutes and assesses five cognitive domains: orientation and attention (18 points), memory (26 points), verbal fluency (14 points), language (26 points), and visuospatial ability (16 points). The individual's total score is calculated by summing scores from all subtests, ranging from 0 to 100.

Geriatric depression scale (GDS)

The shortened version of the GDS was used to assess depressive symptoms (Yesavage et al., 1982). This screening inventory is designed to evaluate the presence of depressive symptoms among older individuals and is widely utilized in epidemiological research within geriatric psychiatry. The GDS short form comprises 15 items with dichotomous "yes"/"no" responses. Scores ranging from 0 to 4 are considered normal, 5 to 9 indicate mild depression, and scores above 10 suggest moderate to severe depression. The scale demonstrates good internal consistency (α = 0.94) and test-retest reliability (r = 0.85) in normative samples, and it has been validated against the Research Diagnostic Criteria (Yesavage et al., 2000).

Geriatric anxiety inventory (GAI)

The GAI (Byrne et al., 2010) is a concise tool designed to evaluate anxiety symptoms among older individuals. It consists of 20 statements, and respondents indicate their agreement or disagreement with each statement based on their feelings over the past week. Participants were identified as experiencing significant anxiety symptoms if they agree with more than 9 statements (Byrne et al., 2010).

Anthropometric measures

Body mass was measured using a digital scale (Seca, model 813) accurate to 100 g, and height was measured using a stadiometer (Seca, model 123) accurate to 0.1 cm.

Mental fatigue assessment (manipulation check)

Stroop Test

The Stroop test (1935) consists of forty-four incongruent trials, where words representing colors are printed in different colors (e.g., the word "red" printed in black), and 18 congruent trials, where words are printed in matching colors (e.g., the word "red" printed in red). Participants are required to correctly identify the options where the words are printed in their corresponding colors by pressing the button of the corresponding color. The test comprises a total of 62 stimuli, which remain on the screen until a response is given (Fortes et al., 2019, 2020), with a 500 ms interval between stimuli (Fortes et al., 2022). Stimuli disappear upon correct responses, and a new stimulus follows. An "X" appears for incorrect answers, followed by a new stimulus. Correct responses and response times are recorded at the end of the test.

Participants underwent Stroop test familiarization during their first visit to mitigate learning effects (Hooper et al., 2020). During familiarization, participants completed the Stroop test four times with a 3-minute interval between tests. This test has demonstrated reliability among older adults (Faria et al., 2024).

Visual analogue scale (VAS)

We used three separate 100 mm VAS, each with two demarcated reference points at either end of the line: 0 mm representing "none" (e.g., no mental fatigue) and 100 mm representing "extremely" (e.g., extremely mentally fatigued). These scales were used to measure mental fatigue, mental effort, and motivation to engage in further exercise (Smith et al., 2016). Participants were instructed to draw a vertical line on each scale at the point that best represented their current sensation.

Mental fatigue induction

In this study, we used three different tasks (detailed below) to induce mental fatigue. This approach was chosen to ensure participants experienced sustained mental fatigue, as earlier research indicates that its effects can last from 10 minutes (Tyler & Burns, 2008) to up to 60 minutes (Smith et al., 2019).

Flanker test

The Flanker/Reverse Flanker Test (Diamond et al., 2007; Hooper et al., 2020) was administered before the walking test to induce mental fatigue among the older adults (Faria et al., 2024). The task consists of three blocks: standard, reverse and mixed. In all three blocks, five fish are displayed in line at the center of the screen. In the standard block, the fish are blue, and participants should press the button corresponding to the direction in which the middle fish is pointing. In the reverse block, the fish are pink, and participants were instructed to press the button corresponding to the direction in which the outside fish are pointing, ignoring the middle fish. In the mixed block, both pink and blue fish are presented. Participants engaged in this task for 30 minutes.

Stroop color test

The Stroop test was conducted using a computerized version of the Stroop color-word implemented in PsychoPy (v. 2022.1.4). Participants were presented with four words (red, blue, green, black) in random order on the screen. Participants responded by selecting the appropriate color using a colored keyboard. Words appeared in alternate colored text (i.e., the word "red" would be written in green text), requiring participants to correctly identify the color presented (green in this case) by clicking on the corresponding prompt on the keyboard. The Stroop test typically incorporates both congruent trials (e.g., the word "red" written in red) and incongruent trials (e.g., the word "red" written in blue). The version administered in this study consisted entirely of incongruent trials (100% incongruent). Participants completed this task for 10 minutes prior to the TUG test. They were instructed to disregard the word's meaning and focus solely on responding to the color of the text displayed.

Stroop meaning test

Participants completed the task for 10 minutes before the knee extension exercise. The structure of the Stroop Meaning Test closely resembled that of the Stroop Color Test; however, participants were instructed to disregard the color of the letters and instead respond to the meaning of the words written.

Control condition

The control session involved watching an emotionally neutral Netflix show titled "Atypical" for 30 minutes before the walk and 10 minutes before the balance and knee extension exercise sessions.

Data analysis

We used the statistical software *R*Studio (version 3.5.3) for data analysis. The Shapiro-Wilk test was conducted to assess the normality assumptions of the data. If the data exhibited a normal distribution, descriptive statistics such as mean and standard deviation were reported. Otherwise, median and interquartile range were computed. The Friedman test was used to compare accuracy and response time between the four sets of the Stroop Test in the familiarization. Effect sizes were calculated using Kendall's W Value [(0.1 - < 0.3 (small effect), 0.3 - < 0.5 (moderate effect), and ≥ 0.5 (large effect)]. Wilcoxon's post-hoc test with Bonferroni correction was applied to determine specific pairwise differences that were statistically significant.

The student t-test was used to compare accuracy and response time in the pre- and post-experimental conditions (mental fatigue x control) of the Stroop Test. Cohen's d test was employed to determine effect sizes, classified as trivial (0–0.2), small (0.2–0.6), moderate (0.6–1.2), large (1.2–2.0), very large (2.0–4.0), and almost perfect (>4.0). Similarly, these statistical tests were used to evaluate performance differences in the 6MWT and TUG between the mental fatigue and control conditions.

The Nonparametric Analysis of Longitudinal Data in Factorial Experiments (Noguchi et al., 2012) was used to compare the difference in the number of repetitions performed during the three sets of resistance exercise between the control and mental fatigue conditions. The same test was used to compare the RPE and Enjoyment across five time points (Post-6MWT, Post-TUG, Post-KE1, Post-KE2, Post-KE3) and two conditions (mental fatigue x control), as well as the VAS scores at four time points (baseline, Pre-6MWT, Pre-TUG, Pre-KE) and two conditions (mental fatigue x control). Partial eta squared (ηp^2 : 0.01, small; 0.06, medium; 0.14, large) was used as a measure of effect size. Post-hoc Bonferroni tests were conducted to pinpoint specific differences. A significance level of $\alpha = 0.05$ was adopted for all analyses.

Results

Familiarization—Stroop Test

The Friedman Test (Figure 3) indicated no significant difference between the Stroop Test sets for all analyzed variables [Overall, W = 0.014 (small); Congruent, W = 0.036 (small); Incongruent, W = 0.016 (small)].

Regarding the response time, the Friedman Test (Figure 4) indicated significant differences across all comparisons [whole trials, W = 0.566 (large); congruent trials, W = 0.432 (moderate); incongruent trials, W = 0.525 (large)] with moderate to large effects. Except for the comparison between F3 and F4 [whole trials, $p = .154$; congruent trials, $p = .533$; incongruent trials, $p = .810$], Wilcoxon's post-hoc with Bonferroni correction showed statistical differences for all other comparisons ($p \leq .001$).

Experimental conditions

Manipulation check

The Wilcoxon Test indicated no significant differences between pre- [accuracy—whole trials, V = 106.5, $p = .364$, $r = 0.034$ (small); accuracy—congruent trials, V = 7, $p = .484$, $r = 0.089$ (small); accuracy—incongruent trials, V = 91, $p = .238$, $r = 0.068$ (small)] and posttest [accuracy—whole trials, V = 64.5, $p = .566$, $r = 0.758$ (small); accuracy—congruent trials, V = 36, $p = .375$, $r = 0.111$ (small); accuracy—incongruent trials, V = 31, $p = .323$, $r = 0.078$ (small)] for all the comparisons (Table 1).

The student t-test did not show any differences between pre- [RT—whole trials, t(34) = 0.219, $p = .828$, d = 0.021 (negligible); RT—congruent trials, t(34) = −0.009, $p = .993$, d = −0.001 (negligible); RT—incongruent trials, t(34) = 0.531, $p = .599$, d = 0.053 (negligible)] and posttest [RT—whole trials, t(33) = 1.025, $p = .313$, d = 0.107 (negligible); RT—congruent trials, t(33) = 1.565, $p = .127$, d = 0.182 (negligible); RT—incongruent trials, t(33) = 1.118, $p = .272$, d = 0.129 (negligible)] for all response time comparisons (Table 1).

The analysis of the VAS—MF data (Table 2) suggested significant differences between conditions, moments, and the interaction between moments and conditions. Bonferroni post-hoc analysis indicated that, except for Pre-6MWT x Pre-TUG ($p = .600$), Pre-6MWT x Pre-KE ($p = 1.000$) and Pre-TUG x Pre-KE ($p = 1.000$), all other comparisons were statistically different (Baseline x Pre-6MWT, $p = .0001$; Baseline x Pre-TUG, $p = .04$; Baseline x Pre-KE, $p = .006$).

Very similar results were found for VAS—ME (Table 2), with significant differences between conditions, moments, and the interaction between moments and conditions. Bonferroni post-hoc analysis indicated that, except for Pre-6MWT x Pre-TUG ($p = .14$), Pre-6MWT x Pre-KE ($p = .86$) and Pre-TUG x Pre-KE ($p = 1.000$), all other comparisons were statistically different (Baseline x Pre-6MWT, $p < .001$; Baseline x Pre-TUG, $p < .001$; Baseline x Pre-KE, $p < .001$).

Differently, the analysis of VAS—MOT indicated no significant differences between conditions or in the interaction between moments and conditions. Significant differences were found, however, for the comparison between moments. Bonferroni post-hoc analysis indicated a significant difference between the Baseline and the Pre-KE ($p = .008$), while all other comparisons were not significant different ($p > .05$).

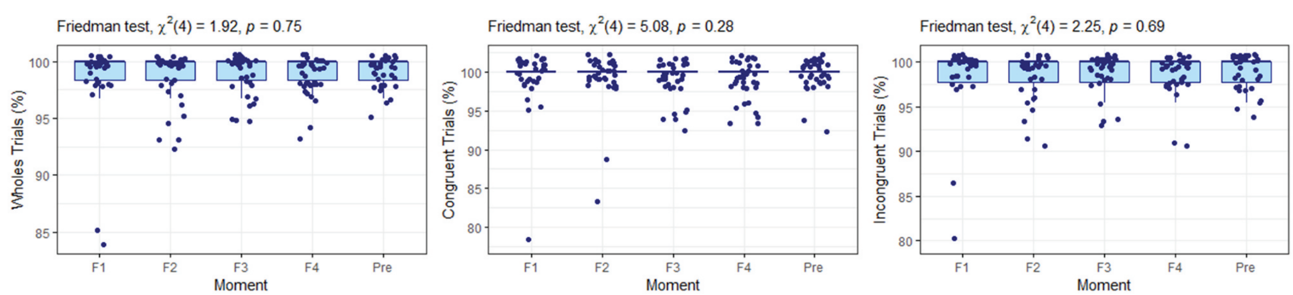

Figure 3. Boxplot of accuracy across four sets of the stroop test: overall accuracy, accuracy in congruent trials, and accuracy in incongruent trials during familiarization. **Legend**: F1, first set; F2, second set; F3, third set; F4, fourth set; Pre, Stroop pre-test in the first experimental session.

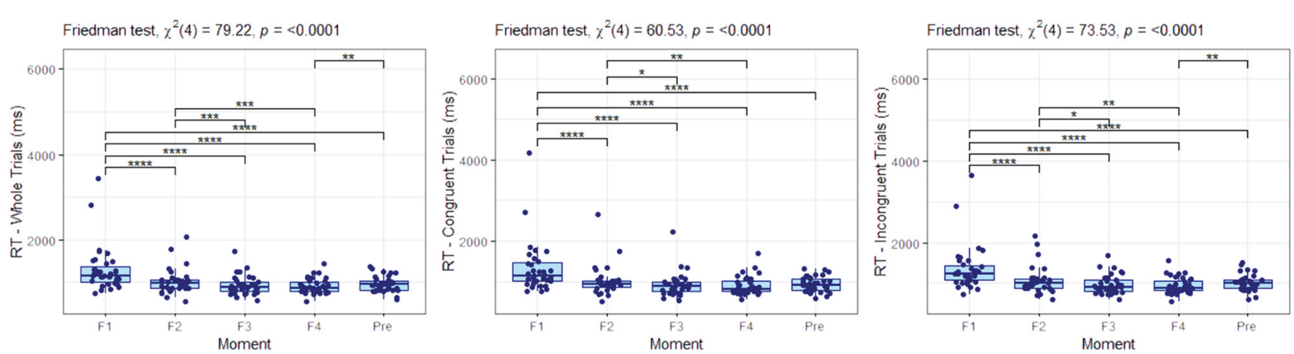

Figure 4. Boxplot of response times for the four trials of stroop test familiarization: overall response time, response time for congruent trials, and response time for incongruent trials. **Legend**: F1, first set; F2, second set; F3, third set; F4, fourth set; Pre, Stroop pre-test in the first experimental session; ms, milliseconds; RT, response time.

Table 1. Performance comparison between CNTR and MF conditions on the stroop test used for manipulation check.

	Pre				Post			
	CNTR	MF	*p*	Effect Size	CNTR	MF	*p*	Effect Size
Accuracy (%)								
Whole Trials	100 (1.6)	100 (1.6)	.36	0.03	99.20 (1.6)	100 (1.6)	.57	0.76
CONG	100 (0)	100 (0)	.48	0.09	100 (0)	100 (0)	.36	0.11
INC	100 (2.3)	100 (2.3)	.24	0.07	100 (2.3)	100 (2.3)	.32	0.08
Response Time (ms)								
Whole Trials	946.7± 185.2	942.9± 181.4	.83	0.02	902.85± 177.3	885.6± 142.3	.31	0.11
CONG	921.2± 180.7	921.4± 201.4	.99	−0.01	893.6± 173.8	864.4± 145.6	.13	0.18
INC	1009± 212.2	998.2± 198.5	.6	0.05	952.8± 204.5	928.7± 167.5	.27	0.13

Note. Legend: Mean and standard deviation were used as central and variability measures for the response time and median and interquartile range were used for accuracy; ms, milliseconds; CNTR, control; MF, mental fatigue; INC, incongruent; CONG, congruent.

Table 2. VAS scales comparison between two conditions (mental fatigue x control) across four time points (baseline, pre-6MWT, pre-TUG and pre-KE).

	VAS-MF		VAS-ME		VAS-MOT	
	CNTR	MF	CNTR	MF	CNTR	MF
Baseline	12 (19)	14 (21)	4 (13)	4 (8.5)	80 (24)	80 (36)
Pre-6MWT	10 (21.5)	66 (28)	12 (28.5)	72 (15.5)	77 (25.5)	72 (30)
Pre-TUG	12 (15.5)	50 (33)	12 (18.5)	60 (27)	74 (26.5)	74 (22.5)
Pre-KE	10 (16.5)	57 (37)	8 (20)	71 (28)	67 (53)	68 (31.5)

	Statistics		
	Condition	Moment	Interaction
VAS-MF	F = 138.20, p < .001, ηp^2 = 0.803 (large)	F = 23.93, p < .001, ηp^2 = 0.413 (large)	F = 38.77, p < .001, ηp^2 = 0.533 (large)
VAS-ME	F = 237.321, p < .001, ηp^2 = 0.875 (large)	F = 98.185, p < .001, ηp^2 = 0.743 (large)	F = 67.317, p < .001, ηp^2 = 0.664 (large)
VAS-MOT	F = 0.003, p = .955, ηp^2 < 0.001 (small)	F = 4.920, p = .011, ηp^2 = 0.126 (large)	F = 0.579, p = 630, ηp^2 = 0.017 (medium)

Note. Legend: 6MWT, 6-minute walk test; TUG, Timed up and Go Test; KE, Knee Extension; a.u., arbitrary units; VAS, Visual Analogue Scale; MF, mental fatigue; ME, mental effort; MOT, motivation; CNTR, control condition; MF, mental fatigue condition.

Performance

6MWT and TUG

The student's t-test did not suggest statistical differences between conditions for distance [t(34) = −0.166, p = .870, d = 0.016 (negligible)] and speed [t(34) = −0.139, p = .890, d = 0.013 (negligible)] in the 6MWT, nor for time [t(34) = 0.532, p = .598, d = −0.04 (negligible)] taken to perform the TUG (Figure 5).

Resistance exercise

The comparison of the number of repetitions in the resistance training exercise did not indicate a significant difference between sets, conditions, or in the interaction between sets and conditions (Table 3).

RPE

The analysis of the RPE data (Figure 6a) suggested no significant difference between conditions [F = 0.167, p = .685, ηp^2 = 0.005 (small)]. Significant differences were found, however, for the comparison between moments [F = 88.160, p < .0001, ηp^2 = 0.722 (large)], and for the interaction between moments and conditions [F = 5.013, p < .0001, ηp^2 = 0.128 (medium)]. Bonferroni post-hoc analysis indicated that, except for Post-KE1 × Post-KE2 (p = .258) and Post-KE2 × Post-KE3 (p = 1.000), all other comparisons were statistically different (p < .05). Overall, RPE was higher in the 6MWT compared to the TUG, and higher during the resistance exercise sets compared to both the 6MWT and the TUG [6MWT x TUG, p < .0001; 6MWT x KE1, p = .003; 6MWT x KE2, p < .0001; 6MWT x KE3, p < .0001; TUG x KE1, p < .0001, TUG x KE2, p < .0001; TUG x KE3, p < .0001; KE1 × KE3, p = .003].

Enjoyment

Concerning the enjoyment data (Figure 6b), the analysis did not show statistical difference between conditions [F = 3.385, p = .075, ηp^2 = 0.091 (medium)] or in the interaction between conditions and moments [F = 0.559, p = .587, ηp^2 = 0.016 (small)]. Significant differences were found, in contrast, between moments [F = 19.532, p < .001, ηp^2 = 0.365 (large)]. Bonferroni post-hoc tests indicated significant decreases in enjoyment between the 6MWT and all three sets of the resistance exercise (Set 1, p = .002; Set 2, p < .001; Set 3, p < .001). A similar pattern was observed when comparing enjoyment after the TUG with enjoyment after the resistance exercise (p < .0001 for all sets).

Discussion

This study is the first, as far as we know, to investigate the effects of mental fatigue on participants' pleasure to exercise. The study also aimed to investigate the influence of mental fatigue on walking, balance and strength performance. We

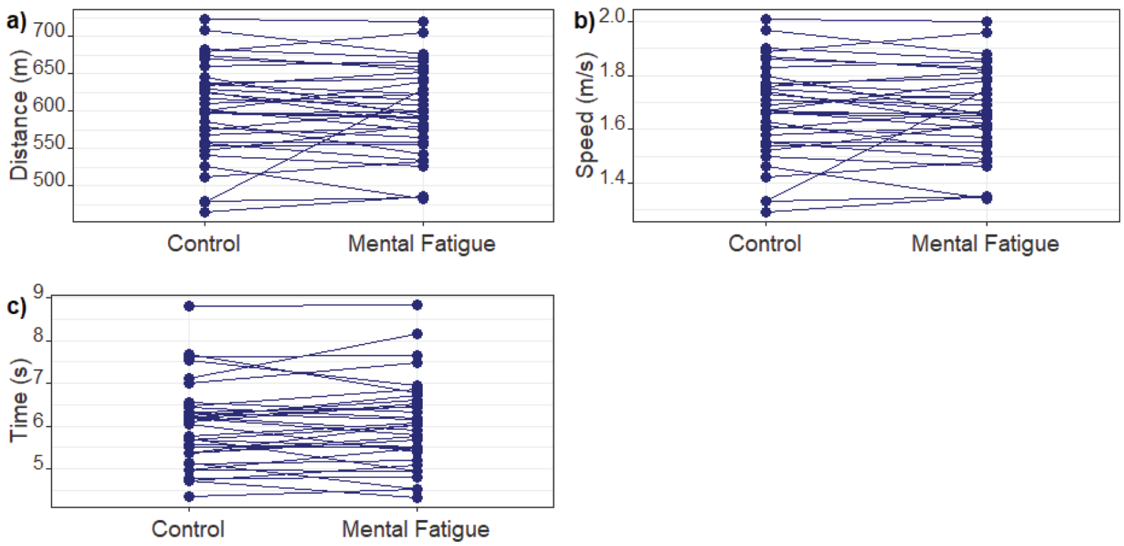

Figure 5. Distance and speed in the 6MWT, and time in the TUG. Legend: 6MWT, 6-minute walk test; TUG, Timed Up and Go test; m, meters; m/s, meters per seconds; s, seconds.

Table 3. Comparison of the number of repetitions in the resistance exercise between control and mental fatigue conditions.

	Set		
	1	2	3
CNTR	9.86±0.55	9.83±0.51	9.89±0.32
MF	9.80±0.53	9.66±0.68	9.69±0.72
Statistics			
Condition	F = 4.322, p = .05, ηp^2 = 0.113 (medium)		
Sets	F = 0.868, p = .425, ηp^2 = 0.025 (medium)		
Interaction	F = 0.531, p = .590, ηp^2 = 0.015 (small)		

Note. Legend: CNTR, control; MF, mental fatigue.

hypothesize that following mental fatigue, participants would walk a shorter distance in the 6MWT, take longer to complete the TUG test, and perform fewer repetitions in knee extension exercise. We also expect that under mental fatigue, older people would report lower enjoyment scores and increased mental fatigue and perceived effort during resistance exercise compared to the control condition.

Familiarization

The results suggested a ceiling effect for accuracy in the Stroop Test, likely due to the task's simplicity, which involves reading short words and identifying basic colors. These tasks are relatively easy for cognitive-preserved older adults making it challenging to discern varying levels of performance (Terwee et al., 2007) in both learning and pre-posttest sessions. Therefore, our findings support the notion that accuracy can serve as a control variable to assess participants' engagement in the task (Hooper et al., 2022).

Regarding the response time, our results showed significant differences with moderate to large effect sizes. Response time

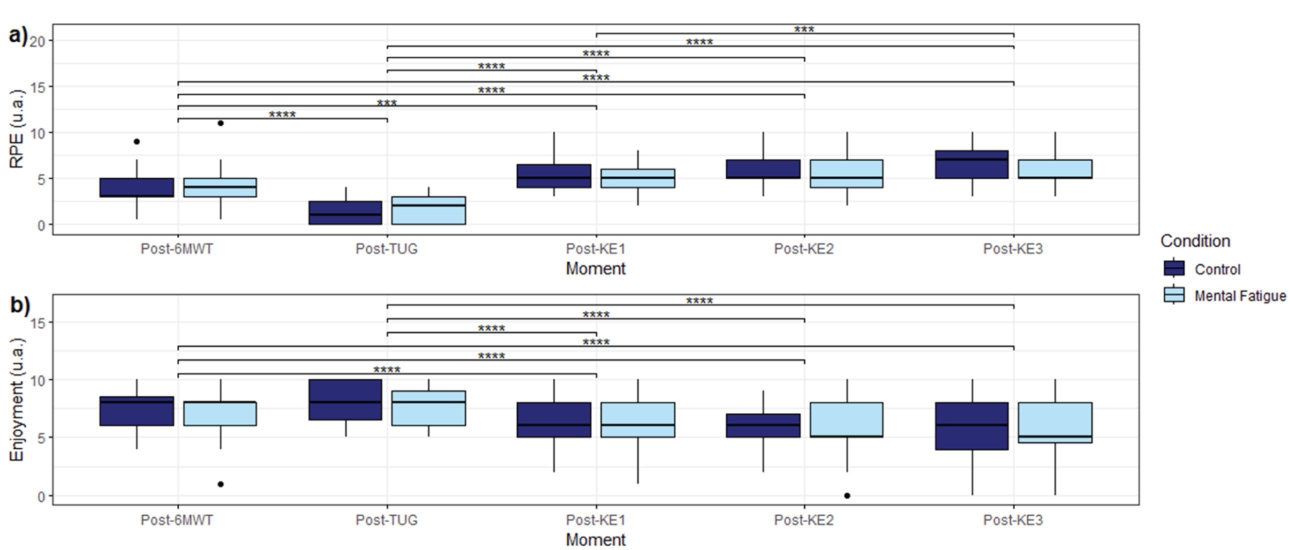

Figure 6. Boxplots comparing enjoyment between control and mental fatigue conditions at each moment. Legend: KE1, first set of the knee extension exercise; KE2, second set of the knee extension exercise; KE3, third set of the knee extension exercise; 6MWT, 6 min walking test; TUG, Timed Up and Go Test; ****, $p < .0001$; ***, $p < .001$.

significantly decreased from F1 to F3 and stabilized from F3 to F4 across all measurements. Despite participants' familiarity with the Stroop task, the increase in response time from F4 to Pre suggests that not all specific details of the test were recalled. This could be attributed to the extended interval between sessions (i.e., familiarization in the first session, experimental sessions on the third and fourth days, with intervals ranging from a few days to two weeks) or possibly because the number of incongruent practice trials in our Stroop Task was insufficient. Since no differences were found in the congruent analyses, and considering that: 1) we faced challenges in persuading older adults to travel to the laboratory four times within a shorter time interval, and; 2) learning effects have been observed even with sessions held in shorter intervals (Hausknecht et al., 2007), we hypothesized that increasing the number of incongruent practice trials in our Stroop Test might effectively address this limitation.

Manipulation check

Supporting our hypothesis, participants reported greater mental fatigue and mental exertion on the VAS following all cognitive tasks compared to watching the Netflix show (control). There were no differences between conditions in motivation levels for performing the upcoming task. As an additional analysis, we segmented Flanker Test accuracy and response time into 20 blocks. Interestingly, accuracy in the first block was significantly lower compared to blocks 5, 16, 17, 19 and 20 in the whole trials analysis. Similarly, response time significantly decrease from block 1 to 20 suggesting sustained engagement in the task over the 30-minute induction period. Performance in the Stroop Test, however, consistent with previous studies (Brahms et al., 2022; Faria et al., 2024), did not change under mental fatigue conditions in older adults.

Some authors argue for the importance of combining subjective and objective indicators due to significant limitations associated with subjective measures. These limitations include participants potentially responding in ways researchers expect (Hassan et al., 2023) and difficulties some participants may have in understanding the concept of mental fatigue (Fortes et al., 2019). However, it is important to note that mental fatigue does not always lead to behavioral impairment, and age-related improvements in resilience (Feldman, 2020) appear to act as a protective factor.

Induction

In the present study, we used three different tasks to induce mental fatigue. We adopted this strategy to reinforce participants' mental fatigue, as previous research has shown that its effects can last from 10 minutes (Tyler & Burns, 2008) to up to 60 minutes (Smith et al., 2019). Therefore, following the resistance exercise, that endures 20 minutes approximately, participants would likely no longer be experiencing mental fatigue.

The additional tasks, however, did not yield higher VAS—MF scores compared to those reported after the Flanker Test. In summary, mental fatigue levels were higher after the Flanker Test compared to both versions of the Stroop Test used, with the Stroop Color inducing lower levels of mental fatigue compared to the Stroop Meaning. This outcome can likely be attributed to participants' familiarity with the Stroop Color task and the absence of time constraints in both Stroop tests, unlike the Flanker Test, which was performed under time pressure.

Despite instructing participants in the VAS to indicate their current levels of mental fatigue and emphasizing that responses should not be influenced by previous tasks, our results support the notion that feelings of mental fatigue are task-related (Dallaway et al., 2022) and influenced by the duration of task performance (Dallaway et al., 2022; Fortes et al., 2019).

Performance, perception of effort and enjoyment

The results of the present study did not indicate significant differences in performance across all administered physical tests; thereby refuting our hypothesis. This is, to our knowledge, the second study to analyze the effects of mental fatigue on the aerobic capacity of older adults. Goodwin et al. (2018) similarly found no differences between cognitive fatigue and non-cognitive fatigue days. Despite that, the authors noted that 6 out of 9 participants exhibited lower VO2 peak on cognitive days compared to non-cognitive days. However, it is important to note that their study lacked a control condition on non-cognitive days, and the randomization process was not clearly defined, which increases the risk of bias.

Regarding the balance task, a recent meta-analysis suggested impaired performance under mental fatigue condition compared to control (Brahms et al., 2022). However, subgroup analysis by age indicated no differences between conditions for older participants, which supports the notion that older people are more resilient to mental fatigue. Another possible explanation for the lack of difference is that balance tasks typically involve multiple muscle groups, and the effects of mental fatigue may be influenced by the nature of the physical task performed. Tasks focusing on isolated muscles, for instance, might be more sensitive to mental fatigue than tasks involving global movements (Giboin & Wolff, 2019) such as dynamic balancing. This sensitivity is likely due to differences in automatic control mechanisms, with isolated muscle tasks requiring higher levels of attentional control (Giboin & Wolff, 2019).

In this context, building on the findings of Behrens et al. (2018), Brahms et al. (2022) argue that dual tasks may amplify the effects of mental fatigue. However, Behrens et al. (2018) found impaired performance in a balance dual-task from the pre- to the post-mental fatigue moments. They did not find differences between control and mental fatigue conditions for both single and dual-tasks (Behrens et al., 2018; Fletcher & Osler, 2021). Therefore, while the idea seems plausible, this conclusion may be inappropriate as it could be influenced by the passage of time rather than the experimental condition.

Some might speculate that the balance task we adopted is too simplistic to detect differences; however, previous studies have shown its appropriate reliability (Beauchamp et al., 2021). Therefore, if differences do exist, the test should be capable of detecting them. Moreover, although some studies using more precise measures have claimed to observe effects of mental fatigue on balance, the authors compared moments (pre- and posttest) while disregarding the lack of differences between experimental conditions (Fletcher & Osler, 2021; Varas-Diaz et al., 2020). Once again, this discrepancy might be attributed to a nocebo effect.

We also did not find differences in the number of repetitions during the knee extension exercise. Studies involving mental fatigue and strength exercise in young adults typically instruct participants to exercise until failure (Gantois et al., 2021; Queiros et al., 2020). However, we opted for a fixed number of repetitions because most older individuals do not exercise to failure.

We hypothesized mental fatigue would impair physical functions and affective responses due to its association with increased adenosine release, an inhibitory neurotransmitter known to elevate the perceived exertion and reduce motivation (Martin et al., 2018; Smith et al., 2018). In the present study, however, RPE and enjoyment did not differ between conditions across all measurements. Findings regarding RPE and mental fatigue are inconsistent in the literature. Two studies found no differences (Santos et al., 2019; Vanden Noven et al., 2014), one indicated that cognitive demand decreased RPE (Pereira et al., 2015), one collected the data but did not report results (Shortz et al., 2015) and several others did not use the scale (Fletcher & Osler, 2021; Morris & Christie, 2020a, 2020b; Shortz & Mehta, 2017).

Concerning enjoyment, to our knowledge, this study is the first to investigate the effects of mental fatigue on older adults' enjoyment of exercise. We propose two potential explanations for our findings: 1) older adults' resilience to mental fatigue, and 2) the release of exercise-related neurotransmitters counteracting the effects of adenosine. First, as previously mentioned, older adults appear to possess compensatory neural mechanisms that mitigate the effects of mental fatigue. Shortz et al. (2015), for example, observed attenuated patterns of pre-frontal cortex activation in older adults. Second, physical exercise is known to trigger the release of catecholamines. The release of catecholamines and cognitive performance are both modulated by exercise intensity. During periods of rest and low-intensity exercise, the gradual and steady release of catecholamines can diminish alertness and focus, leading to cognitive decline (McMorris, 2016, 2021; McMorris et al., 2016). Contrastingly, moderate-intensity physical activity, stimulates specific receptors in key brain regions like the locus coeruleus, ventral tegmental area, and substantia nigra, thereby enhancing of cognitive functions (McMorris, 2016, 2021; McMorris et al., 2016). While the effects of high-intensity exercise are less clear, heightened levels of central catecholamines during such activities may lead to prolonged release, suppressing intermittent bursts and potentially impairing cognitive performance (Albuquerque et al., 2023; McMorris, 2016, 2021; McMorris et al., 2016). Therefore, although our mental fatigue induction may have increased adenosine levels, moderate intensity exercise could have mitigated these effects by promoting the release of catecholamines.

While not a primary focus of the present study, we discovered that participants enjoyed more and reported lower RPE during the 6MWT and TUG compared to the resistance exercise. This finding aligns with previous research indicating that older people generally prefer other forms of physical exercise (Van Roie et al., 2015), such as aerobic exercise (Kekäläinen et al., 2018) or team sports (Pedersen et al., 2017), over resistance exercise. Progressive resistance exercise offers major benefits for older people physical function and health by enhancing muscle mass, strength and power (Damluji et al., 2023; Latham et al., 2004; Liu & Latham, 2009). It is recommended that older people engage in resistance exercise at least twice a week (Damluji et al., 2023). However, a minority of older adults regularly participate in resistance training (Bennie et al., 2017). Various strategies have been explored to increase adherence to resistance exercise among older adults, including manipulating training variables such as intensity (Van Roie et al., 2015) and periodization (Conlon et al., 2018), which have shown limited impact on enjoyment and adherence. Potential solutions may involve educational programs emphasizing the importance of resistance exercise for short and long-term health, incorporating opportunities for social interaction, and tailoring activities to participants' abilities (Gluchowski et al., 2022).

Limitations

No studies are without limitations. First, this study adopted a quasi-experimental research design, which does not allow for the determination of causative effects and can result in a greater risk of bias. Second, the main outcome of this study was assessed through a subjective scale, which may lead participants to respond in ways they believe the researchers expect (Hassan et al., 2023). Third, neither the researchers nor the participants were blinded to the experimental conditions. However, we implemented several strategies to mitigate these biases: 1) participants were informed that the study was investigating the effects of different cognitive stimuli on their physical function, and 2) we emphasized at every stage that there were no correct answers encouraged participants to be as honest as possible. Despite these efforts, we recognize that the lack of true experimental research in this field persists. Researchers should collaborate to increase the human resources available for such projects, produce higher-quality studies, and provide more reliable results to guide public health decisions.

Future studies

Fatigue can be perceived in two distinct ways: as a trait, which refers to a predisposition to experience fatigue, or as a state, which represents the immediate and momentary experience of fatigue (Wylie et al., 2022). The literature leaves no doubt that older people experience mental fatigue as a trait, as mental fatigue is a symptom of many chronic diseases (Linnhoff et al., 2019; Lou, 2009; Lou et al., 2001; Vancampfort et al., 2023). However, it remains unclear whether the state of mental fatigue is a significant issue for healthy older people. Therefore, it may be beneficial to take a step back and conduct qualitative and mixed-methods studies to understand whether mental fatigue as a state affects healthy older individuals and warrants attention and resources.

Conclusion

Mental fatigue did not affect the physical function, perception of effort, or enjoyment of exercise among older people. Participants, however, showed a stronger preference, indicated by higher enjoyment, for walking and dynamic balance compared to strength exercise.

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Data availability statement

The data that support the findings of this study are openly available in Open Science Framework at https://osf.io/ejy8b/?view_only=ef0c6465d5eb491da3c797456708ed11.

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