

## Article

# The Effect of Flywheel Resistance Training on Executive Function in Older Women: A Randomized Controlled Trial

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## Abstract

**Background/Objectives:** Executive function, which includes inhibitory control, working memory, and cognitive flexibility, tends to decline with aging. While traditional resistance training (TRT) has shown positive effects in mitigating these declines, limited evidence is available regarding flywheel resistance training (FRT). This study aimed to evaluate and compare the effects of TRT and FRT on executive function in older women. **Methods:** In this randomized controlled trial (clinicaltrials.gov NCT05910632), 29 older women were allocated into two groups: TRT (n = 15) and FRT (n = 14). The intervention lasted eight weeks with two weekly sessions conducted at the Federal University of Viçosa. The TRT group performed exercises using machines and free weights, while the FRT group used a multi-leg isoinertial device. Executive function was assessed using the Victoria Stroop Test (inhibitory control), Digit Span Test (working memory), and Trail Making Tests A and B (cognitive flexibility). Data were analyzed using a Multivariate Analysis of Covariance ( $p < 0.05$ ). **Results:** No significant changes were observed in inhibitory control ( $p = 0.350$ ). Working memory improved significantly within both groups in forward ( $p = 0.002$ ) and backward ( $p = 0.002$ ) span tasks. For cognitive flexibility, Trail Making Test A showed no significant changes ( $p > 0.05$ ), but Test B showed significant within-group ( $p = 0.030$ ) and between-group ( $p = 0.020$ ) improvements. The B-A difference was also significant ( $p = 0.040$ ). **Conclusions:** Both resistance training modalities enhanced working memory and cognitive flexibility. However, FRT produced greater improvements in cognitive flexibility, suggesting potential advantages in cognitive aging interventions.

**Keywords:** eccentric action; executive function; older women; female; strength training

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## 1. Introduction

Executive function is a set of cognitive skills that guide behaviors and thoughts toward goal achievement [1]. It consists of three main components: working memory, inhibitory control, and cognitive flexibility. Working memory retains and manipulates essential information, inhibitory control suppresses inappropriate impulses, and cognitive flexibility adapts responses to new stimuli [2].

Women are more susceptible to cognitive decline, especially after menopause [3]. Changes in executive function can lead to memory decline and increase the risk of mild cognitive impairment and dementia, affecting the quality of life of older women [3]. Globally, dementia affected more than 55 million people in 2019, with nearly 10 million new cases each year, according to the World Health Organization. The cost of care in Europe alone totaled USD 439 billion in 2019, and in Brazil, approximately two million people live with some form of dementia according to the WHO [4,5]. These data highlight the impact of cognitive decline on public health and the economy [3].

Given the high cost of medications, their limited efficacy, frequent adverse effects, and low adherence rates among older adults, non-pharmacological interventions have gained prominence [6,7]. Physical exercise is recommended for older women due to its positive effects on executive function, accessibility, safety, and low cost [6]. It improves cerebral circulation, stimulates neuroplasticity, and activates neurotransmitters such as dopamine, which aids in impulse control and motivation [8].

Studies have demonstrated the benefits of resistance training (RT) on the executive function of older women [8,9]. RT can reduce homocysteine levels, a neurotoxic amino acid that impairs cognitive performance and is associated with the risk of dementia and brain injuries. Additionally, muscle contraction stimulates the release of brain-derived neurotrophic factor (BDNF) and insulin-like growth factor (IGF-1), which promote neural growth and cognitive improvement [9,10].

In a randomized controlled trial (RCT) conducted with 50 older adults, 60% of whom were women, participants were divided into a TRT group and a control group (which did not exercise). After 12 weeks of intervention, with a frequency of three sessions per week, improvements in working memory and conflict resolution performance were observed in the TRT group [11]. Another RCT with frail older women investigated the acute effects of low-intensity, high-velocity TRT and found an acute improvement in episodic memory, although no changes were observed in inhibitory control [9].

However, in the search for promising alternatives for older women, eccentrically reinforced resistance training has gained interest [12–14]. This training involves a forced lengthening of the muscle–tendon unit during the eccentric phase [12]. To target eccentric action, a flywheel device can be used, which operates as follows: during the concentric phase, a cable unwinds from the flywheel, generating kinetic energy, and during the eccentric phase, the cable is pulled back to the axis in response to the applied force [13]. FRT, characterized by its capacity for eccentric overload and velocity-dependent stimulus, may offer cognitive benefits beyond those of traditional training. The high neural demand, motor complexity, and need for sensorimotor coordination associated with eccentric tasks have been linked to increased prefrontal activation and executive control engagement [14,15]. These unique features make FRT a promising modality for investigating neurocognitive adaptations in older adults [14,15].

This training modality promotes muscular adaptations that are equal to or even superior to other training methods [14,16]. FRT offers advantages such as significant strength gains and greater hypertrophy with low energy expenditure [16–19]. Therefore, the effects of resistance training, particularly FRT, on the executive function of older women remain unknown. Thus, the objective of this RCT was to evaluate the effect of an FRT program on the executive function of older women. We hypothesized that FRT performed over eight weeks will improve the executive function of community-dwelling older women in Viçosa, Minas Gerais.

## 2. Materials and Methods

### 2.1. Study Design

This was a parallel-group RCT that followed the recommendations of the SPIRIT 2013 Statement [20] and the CONSORT Statement for non-pharmacological interventions to structure the study [21]. The methodological quality was assessed using the Tool for the Assessment of Study Quality and Reporting in Exercise Training Studies (TESTEX) [22].

### 2.2. Study Outcomes

Sociodemographic information, chronic diseases, and sedentary behavior time were recorded using a questionnaire developed by researchers. The primary outcome of this study was executive function. Secondary outcomes included adverse events, insulin-like growth factor 1 (IGF-1) levels, and muscle strength indicators, specifically one-repetition maximum (1RM) and maximal voluntary isometric contraction (MVIC).

### 2.3. Sample Size Calculation

Participants were recruited for an RCT evaluating the effects of FRT on the physical and mental health of older women (NCT05910632). The sample size calculation considered a 95% confidence level, an alpha error of 0.05, a minimum power of 90%, and a 1:1 ratio between groups, resulting in a minimum sample size of 22 women. To account for sample losses, the final sample consisted of 29 older women. The calculation was performed using EPIDAT software, version 4.2.

### 2.4. Blinding and Registration

The principal investigator and outcome assessor were blinded. However, the older women and the professionals conducting the training were not blinded. A two-week familiarization period preceded the interventions. Outcomes were assessed before the familiarization period and one week after the training program was completed. The study was approved by the Ethics Committee of the Federal University of Viçosa (UFV) under approval number 1.21.139 and registered as a clinical trial (NCT05910632). All procedures adhered to the principles of the Declaration of Helsinki [23] and Resolution 466/12 [24].

### 2.5. Participants

Recruitment took place between March and July 2023 through social media, radio, and flyers. Inclusion criteria were women aged 60 years or older who were literate, with normal or corrected-to-normal vision, who participated in a minimum of 4 h of sedentary behavior per day, and who signed the informed consent form. Exclusion criteria included contraindications for physical exercise, neurological diseases, or participation in exercise programs in the past three months. Randomization was performed in blocks of 2 and 4, using opaque envelopes for concealment. The study flowchart is shown in Figure 1. Baseline characteristics of the participants are presented in Table 1.

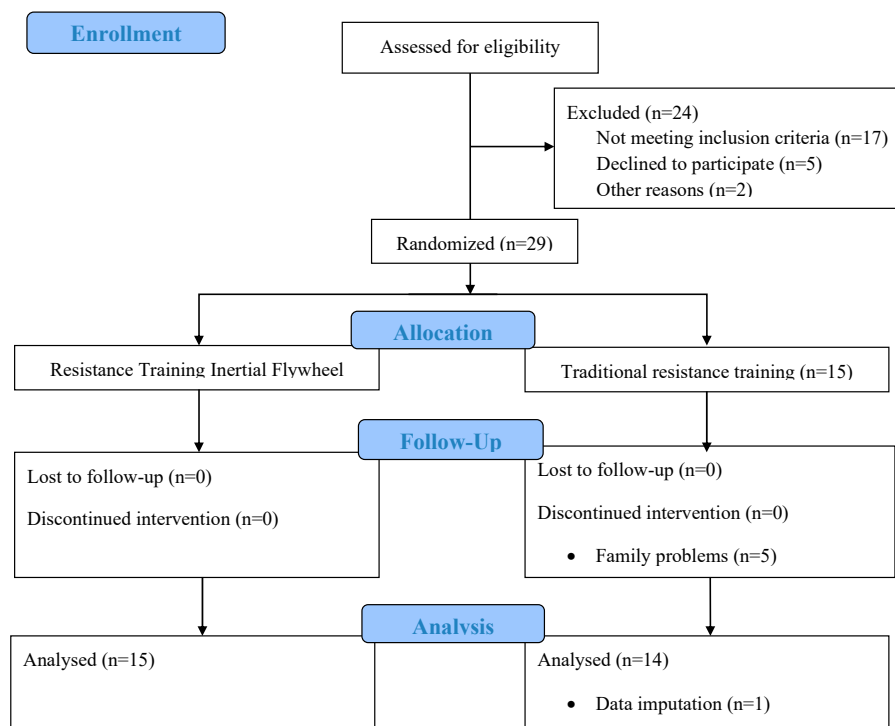


Figure 1. Flowchart for study.

Table 1. Sample characteristics pre-intervention.

| Variable                   | TRT (n = 15) | FRT (n = 14) | p    | IC 95%     |
|----------------------------|--------------|--------------|------|------------|
| Age (years)                | 66.4 ± 5.5   | 64.2 ± 4.3   | 0.26 | −1.6; 5.9  |
| Resting HR (bpm)           | 65.1 ± 3.5   | 70.0 ± 11.7  | 0.87 | −7.7; 9.1  |
| SBP (mmHg)                 | 138.0 ± 3.8  | 134.2 ± 10.8 | 0.45 | −6.2; 13.6 |
| DBP (mmHg)                 | 84.0 ± 4.0   | 82.1 ± 9.7   | 0.70 | −8.0; 11.8 |
| MAP (mmHg)                 | 102.0 ± 2.8  | 99.5 ± 8.6   | 0.51 | −5.1; 10.1 |
| Waist circumference (cm)   | 92.0 ± 11.1  | 94.6 ± 14.5  | 0.59 | −12.4; 7.2 |
| Body mass (kg)             | 65.1 ± 13.6  | 73.1 ± 15.9  | 0.15 | −19.3; 3.2 |
| BMI (kg/m <sup>2</sup> )   | 27.3 ± 4.9   | 29.5 ± 5.9   | 0.29 | −6.3; 1.9  |
| Number of NCDs             | 1.2 ± 1.0    | 1.5 ± 0.6    | 0.24 | −1.0; 0.2  |
| Sedentary behavior (h/day) | 5.5 ± 2.1    | 6.5 ± 2.5    | 0.25 | −2.8; 0.7  |

Data are presented as mean ± standard deviation (M ± SD), relative and absolute frequency. Abbreviations: TRT—traditional resistance training; FRT—inertial flywheel resistance training; HR—heart rate; BPM—beats per minute; SBP—systolic blood pressure; DBP—diastolic blood pressure; MAP—mean arterial pressure; mmHg—millimeters of mercury; cm—centimeters; kg—kilograms; BMI—body mass index; kg/m<sup>2</sup>—kilograms per square meter; NCD—non-communicable chronic disease; h—hour.

### 2.6. Resistance Training Program

The resistance training program followed the Consensus on Exercise Reporting Template (CERT) model [25]. The FRT group used the multi-leg isoinertial equipment (Physical Solutions, São Paulo, Brazil), while the TRT group used weight machines and free weights to perform the exercises. The interventions were conducted individually or in groups of up to three older women under the supervision of undergraduate and graduate students trained in physical education.

Adherence to the exercise program was measured by the number of sessions attended. Out of the 16 total sessions (100%), a minimum attendance of 75% (12 sessions) was expected.

Perceived exertion was assessed using the OMNI-RES scale. Participants in the TRT group were instructed to maintain a moderate to high intensity, scoring between 6 and 10 on the scale. In the FRT group, participants were instructed to maintain high intensity (score of 10 on the OMNI-RES scale). Each participant reported their perceived exertion after each exercise set and provided an overall perception at the end of the session. The total perceived exertion was calculated as the mean of all recorded perceptions divided by the number of participants in each group.

Each training session consisted of six exercises (leg extension, leg curl, bicep curl, seated row, lateral raise, front raise, and standing calf raise) for both groups. Any adverse event related to the intervention was recorded in the participant's database.

Both training groups underwent eight weeks of interventions, with two non-consecutive sessions per week (e.g., Monday and Thursday), resulting in a 72 h rest interval within the week (e.g., Monday to Thursday) and a 96 h interval between the second session of one week and the first of the following week. The training protocols were structured as follows: the TRT group performed four sets of twelve repetitions, with a time under tension of one second for the concentric phase and two seconds for the eccentric phase, with 60 s of rest between sets and 120 s between exercises.

The FRT group performed four sets of eight repetitions, with the concentric phase executed at maximum speed and braking applied in the final third of the eccentric phase, with 120 s of rest between exercises and sets. The concentric phase was executed at maximal voluntary speed to generate kinetic energy in the flywheel. Participants applied maximal effort to break the wheel during the final third of the eccentric phase. The flywheel used had a fixed inertia of 0.055 kg·m<sup>2</sup>, allowing resistance to be modulated by effort level rather than external load. This inertia value was selected based on prior evidence indicating its safety and effectiveness in older adults, particularly when eccentric overload is applied in multi-joint movements [14,16].

Regarding load progression, the TRT group increased the load whenever more than 12 repetitions could be performed or when the perceived exertion was below the expected level. In contrast, the FRT group did not progress in terms of mobilized weight, maintaining a fixed load of 0.55 kg. The same inertia value (0.055 kg·m<sup>2</sup>) was applied to all six exercises throughout the program based on its demonstrated safety and neuromuscular efficacy in older adults [14,16]. The interventions and data collection procedures were conducted at the Department of Physical Education at UFV.

## 2.7. Evaluation Measures

### 2.7.1. Executive Function

Executive function was assessed using the Victoria Stroop Test [26] (inhibitory control), the Digit Span Forward and Backward Test (working memory) [27], and the Trail Making Test Parts A and B (cognitive flexibility) [28].

### 2.7.2. Blood Sampling and IGF-1 Analysis Procedures

Blood samples were collected between 7:00 and 8:00 a.m. following an 8 h overnight fast. All participants were seated in a resting position during venipuncture. Samples were drawn from the antecubital vein using BD Vacutainer® SST™ II Advance tubes (Becton, Dickinson and Company, Franklin Lakes, NJ, USA) containing a gel separator. After the blood was collected, it was left to clot at room temperature (~22 °C) for 30 min. The samples were then centrifuged at 3000 rpm for 10 min to separate serum.

The serum was immediately aliquoted into cryovials and stored at  $-80\text{ }^{\circ}\text{C}$  until analysis. Serum IGF-1 concentrations were determined in duplicate using a fully automated chemiluminescence immunoassay system (Liaison<sup>®</sup> XL, DiaSorin Inc., Saluggia, Italy). The assay had a sensitivity of 6 ng/mL and an intra-assay coefficient of variation (CV) of 4.3%. All analyses were performed by a trained laboratory technician blinded to group allocation [29].

### 2.7.3. Adverse Events

Training-related events were categorized based on severity using the “Common Terminology Criteria for Adverse Events” version 5.0 (CTCAE v5) [30].

### 2.7.4. Strength Measurement

MVIC of the quadriceps femoris was assessed bilaterally. Participants were seated with hips and knees at  $90^{\circ}$  flexion and instructed to perform maximal contraction of each leg for 5 s. Two attempts per leg were recorded, with a 2 min rest period between efforts. The highest value from each leg was considered. A strain gauge load cell (MK<sup>®</sup>, model CSL/ZL-1T, MK Controle, Brazil) with a 1000 Hz sampling frequency was used [31].

The one-repetition maximum (1RM) test was conducted using a knee extension machine (Nevada Pro-T fitness<sup>®</sup>; Madrid, Spain). Participants performed a warm-up at 30% of MVIC and then progressively increased load until only one repetition was possible. A maximum of five attempts was permitted with 2 min rest intervals [31].

Both tests targeted the quadriceps femoris muscle. The MVIC test was conducted before the 1RM test, followed by a 5 min rest period to avoid fatigue. A brief warm-up at 30% of estimated effort was performed before MVIC. Participants were seated with their trunk stabilized by holding the handles of the apparatus. Although MVIC was used to monitor neuromuscular activation, only 1RM results were reported as it was the primary outcome. MVIC data can be provided upon request.

All strength tests were conducted in the morning at the Human Morphophysiology Laboratory, supervised by trained research staff.

## 2.8. Statistical Analysis

Normality of quantitative variables was assessed using the Shapiro–Wilk test, and variance homogeneity was verified using Levene’s test. The statistical tests confirmed a normal distribution ( $p > 0.05$ ), and the data were presented as means and standard deviations. Baseline comparisons between groups were conducted using Student’s *t*-test for independent samples. Statistical differences were confirmed assuming equal variances and were further supported by a 95% confidence interval analysis.

The frequency of adverse events per participant was recorded before and after sessions and analyzed descriptively using absolute frequency and proportion. The chi-square test was used to compare proportions between groups.

To evaluate intra- and intergroup differences, a Multivariate Analysis of Covariance (MANCOVA) was conducted. This analysis examined the relationship between multiple dependent variables and independent variables (group and time), controlling for covariates such as years of education, monthly income, number of children, number of chronic non-communicable diseases, and sedentary behavior time.

Effect size was measured using partial eta squared ( $\eta^2$ ), with values interpreted as follows: 0.01 (small effect), 0.06 (moderate effect), and 0.14 or higher (large effect). Additionally, statistical power was rigorously evaluated, maintaining the conventional threshold of 80% ( $1 - \beta = 0.80$ ).

Intragroup changes were calculated by subtracting the final mean of the initial mean for each variable.

Missing data were addressed using multiple imputation procedures in SPSS version 25. Five imputations were generated, with missing values being replaced based on the observed distribution of each variable.

The significance level was set at  $\alpha = 5\%$ . Analyses were conducted using SPSS version 25 for Windows.

### 3. Results

After an eight-week training period, it was found that 12 (85.7%) participants in the FRT group completed 16 training sessions. Additionally, one participant completed 14 sessions and another 12 sessions due to unforeseen commitments and travel during the study. In the TRT group, 13 (86.6%) women completed the maximum number of training sessions. However, one participant in the TRT group completed only nine sessions due to urgent personal matters (e.g., family illness or caregiving responsibilities). These participants were not excluded, and missing data were managed using multiple imputation procedures. Another completed 13 sessions due to an unscheduled surgical procedure. The data from the elderly woman who did not complete the minimum of 12 sessions were used for analysis. Table 1 presents the data of the participants before the interventions.

To control for training efficiency, a one-repetition maximum (1RM) test was used. It was found that the strength levels of the volunteers improved. The mean pre-intervention 1RM in the TRT group was  $31.1 \pm 11.3$  kg, and post-intervention, it was  $36.6 \pm 12.0$  kg. The mean 1RM in the FRT group pre-intervention was  $33.6 \pm 9.5$  kg, and post-intervention, it was  $43.4 \pm 11.6$  kg. A statistically significant difference was found within groups ( $p = 0.005$ ) in strength levels for the one-repetition maximum, but no difference was found between groups ( $p = 0.303$ ) post-intervention.

The adverse events reported during the study included dizziness, blurred vision, muscle pain, and knee discomfort. On two separate occasions, exercises were interrupted due to adverse events: one participant had a drop in blood pressure, and another reported dizziness. Additionally, non-training-related events were reported by two elderly participants who experienced a fall.

To control for physical effort during activities, the OMNI-RES scale was used. Both the FRT and TRT groups maintained a score of 7 on the scale, indicating an effort level perceived as “somewhat difficult” or “difficult.” The exercises that presented the highest perceived effort were leg flexor, leg extensor, and seated row in the TRT group and leg extensor, leg flexor, and front raise in the FRT group.

Table 2 presents the results of the interventions with resistance training on the executive function indicators of the volunteers. A reduction in the scores of the Victoria Stroop Test was observed in both groups, but no statistically significant difference was found within groups ( $p = 0.673$ ;  $\eta^2 = 0.07$ ;  $\beta = 0.51$ ) or between groups ( $p = 0.350$ ;  $\eta^2 = 0.19$ ;  $\beta = 0.87$ ).

The Digit Span test showed a within-group difference, both in the direct order ( $p = 0.002$ ;  $\eta^2 = 0.19$ ;  $\beta = 0.91$ ) and in the reverse order ( $p = 0.025$ ;  $\eta^2 = 0.10$ ;  $\beta = 0.062$ ).

In the Trails A and B tests, differences between groups were observed in the time taken to complete part B ( $p = 0.02$ ;  $\eta^2 = 0.01$ ;  $\beta = 0.61$ ). Furthermore, a difference between groups was also observed when the difference in completion times between part B and part A was calculated ( $p = 0.047$ ;  $\eta^2 = 0.08$ ;  $\beta = 0.51$ ). The FRT group showed superior improvement in this variable.

Regarding IGF-1, no significant difference between groups was found ( $p = 0.28$ ;  $\eta^2 = 0.02$ ;  $\beta = 0.18$ ). The TRT group had a pre-intervention mean of  $105.3 \pm 33.9$  ng/mL and a post-intervention mean of  $105.7 \pm 31.1$  ng/mL, while the FRT group had

a pre-intervention mean of  $109.7 \pm 37.7$  ng/mL and a post-intervention mean of  $111.4 \pm 33.4$  ng/mL.

**Table 2.** Effect of interventions on executive function variables and biomarkers in elderly women.

|                                   | TRT (n = 14) |               | FRT (n = 15) |              | Intragroup |          |             | Intergroup |          |             |
|-----------------------------------|--------------|---------------|--------------|--------------|------------|----------|-------------|------------|----------|-------------|
|                                   | Pre          | Post          | Pre          | Post         | p          | $\eta^2$ | 1 - $\beta$ | p          | $\eta^2$ | 1 - $\beta$ |
| Victoria Stroop Test (s)          | 18.1 ± 9.7   | 13.7 ± 6.9    | 15.7 ± 5.4   | 12.4 ± 5.3   | 0.673      | 0.07     | 0.51        | 0.350      | 0.19     | 0.87        |
| Digit Span (Direct Order-Score)   | 7.9 ± 1.6    | 9.4 ± 1.7     | 7.4 ± 1.7    | 8.7 ± 1.9    | 0.002      | 0.19     | 0.91        | 0.067      | 0.07     | 0.44        |
| Digit Span (Indirect Order-Score) | 6.2 ± 1.7    | 6.8 ± 1.4     | 5.3 ± 1.4    | 6.1 ± 2.3    | 0.025      | 0.10     | 0.62        | 0.083      | 0.06     | 0.41        |
| Trail Making Test Part A (s)      | 68.8 ± 54.0  | 57.0 ± 26.7   | 61.0 ± 29.8  | 50.9 ± 25.1  | 0.164      | 0.04     | 0.27        | 0.241      | 0.02     | 0.21        |
| Trail Making Test Part B (s)      | 184.9 ± 96.8 | 158.7 ± 96.6  | 177.9 ± 94.0 | 138.7 ± 89.6 | 0.037      | 0.09     | 0.56        | 0.024      | 0.10     | 0.61        |
| Trail Making Test B-A (s)         | 116.0 ± 77.4 | 101.7 ± 65.0  | 116.8 ± 69.6 | 87.8 ± 67.2  | 0.071      | 0.06     | 0.42        | 0.047      | 0.08     | 0.51        |
| IGF-1 (ng/mL)                     | 105.3 ± 33.9 | 105.7 ± 31.10 | 109.7 ± 37.7 | 111.4 ± 33.4 | 0.843      | 0.01     | 0.05        | 0.288      | 0.02     | 0.18        |

Data are presented as mean ± standard deviation (m ± SD), relative and absolute frequency. Abbreviations: TRT—Traditional Resistance Training; FRT—Inertial Resistance Training with Flywheel; IGF-1: Insulin-like Growth Factor; p—Statistical Significance;  $\eta^2$ —Partial Eta Squared; 1- $\beta$ —Statistical Power; s—seconds; ng/mL—Nanograms per Milliliter. A significance level of  $p < 0.05$  was used to determine statistical significance.

#### 4. Discussion

This study aimed to evaluate the effects of two resistance training (RT) protocols (traditional and inertial flywheel) on executive function, serum IGF-1 levels, and adverse effects in elderly women. After 16 sessions, the main findings were as follows: (1) inhibitory control and IGF-1 serum concentrations did not change regardless of RT type; (2) both protocols induced significant within-group improvements in working memory and cognitive flexibility; and (3) FRT produced greater improvements in cognitive flexibility.

Although IGF-1 is known to be stimulated by resistance training and is associated with neuroplastic changes [12,32], our study did not observe significant changes in serum IGF-1 levels in either group. Several factors may explain this: first, participants had baseline IGF-1 values within the normal range, which may have limited further increases [29]; second, the intervention duration (eight weeks) might have been insufficient to induce measurable endocrine adaptations; and third, the FRT group used a fixed inertial load, possibly limiting stimulus intensity [11,29,33]. The absence of significant changes in IGF-1 levels may reflect the complexity of hormonal responses to mechanical loading. While some studies report increased IGF-1 following resistance training, others have found inconsistent or null effects, particularly when exercise intensity or duration is limited [34]. This reinforces the notion that neuromuscular improvements do not always parallel systemic hormonal adaptations [34].

Inhibitory control did not show significant improvements following the interventions. An RCT that conducted RT for 10 weeks identified improvements in executive function only for exercises performed on unstable surfaces, indicating greater vestibular, cognitive, and muscular activation [35]. This suggests that exercises that challenge balance and stability may increase vestibular, cognitive, and muscular activation, which more intensively stimulates executive function. The absence of significant effects on inhibitory control could reflect the specificity of this executive function, which may require longer interventions, higher task variability, or the inclusion of balance or dual-task challenges to show measurable improvements [36,37].

In an RCT with 155 elderly women divided into three groups (muscle tone and balance training, TRT once or twice a week), inhibitory control, as assessed by the Stroop

test, improved in both TRT groups after 12 months but did not improve after 6 months of training [38]. Conversely, the study by Cassilhas et al. [33], conducted over six months, randomly assigned 62 elderly individuals into three groups: a control group (no TRT), experimental group 1 (moderate intensity TRT), and experimental group 2 (high intensity TRT). The results indicated that moderate or high-intensity TRT improved cognitive performance in both long- and short-term memory tests. These findings suggest that the type, intensity, and duration of training and individual characteristics may differently influence executive function.

However, our results may have differed with a longer intervention period. Other factors may interfere with the stimulus to inhibitory control. One study investigating cognitive decline found that higher education levels and greater physical fitness were related to better performance on the Stroop task in 498 Brazilian elderly individuals (67.26% women) [39]. In our study, only six women had completed higher education and had high levels of sedentary behavior, which may explain the results.

Working memory improved significantly within groups. An RCT conducted with 50 elderly participants (60% women) who completed 3 weekly TRT sessions for 12 weeks showed significant improvement in working memory in the TRT group [23]. However, another high-intensity TRT program conducted three times a week for 16 weeks in 45 elderly individuals (30 women) with cognitive frailty did not show significant improvements in working memory compared to a control group (balance and stretching) [40].

The physiological mechanisms behind cognitive health gains from TRT are not fully understood [19]. Studies suggest that RT contributes to brain plasticity, especially in areas related to executive function, through increased IGF-1 and reduced homocysteine levels [9,11]. This improvement in working memory is essential for elderly individuals as it is linked to learning, problem-solving, decision-making, and the ability to store and process information efficiently. Although IGF-1 did not change significantly, improvements in executive function may also stem from non-endocrine mechanisms such as increased neural recruitment, greater attentional engagement, and enhanced sensorimotor coordination during FRT. Flywheel training involves novel motor challenges, which may promote cortical activation, synaptic remodeling, and neurovascular plasticity, particularly in the prefrontal cortex [39,41]. These factors could independently support cognitive gains, especially in tasks involving cognitive flexibility [15,42].

Both TRT and FRT promoted significant increases in cognitive flexibility. However, FRT showed greater improvements in cognitive flexibility post-intervention. A study evaluating the effects of low- and high-speed RT during 24 sessions in elderly individuals with reduced mobility found that high-speed training improved cognitive flexibility, which corroborates our findings [41]. The author suggests that explosive muscle contractions, such as those performed during high-speed RT, recruit fast-twitch fibers similarly to or even more than TRT. This characteristic is also present in FRT, and a possible explanation for the improvements in executive function is related to the muscle contractions that stimulate the release of neurogenic myokines, which promote BDNF expression in the hippocampus and induce improvements in brain plasticity and structure [26]. The greater improvements in cognitive flexibility observed in the FRT group can also be explained by the increased motor complexity and attentional demand involved in flywheel training. These demands activate higher-order cortical regions, including the prefrontal cortex, and may promote neuroplastic adaptations independent of hormonal changes [15,43].

Moreover, FRT involves greater motor complexity, requiring more attention and coordination, which may lead to superior neural adaptations [12,13]. Protocols with novel components have been associated with more intense stimulation of executive function [2,42].

Even performing unloaded movements may contribute to brain activation by requiring attention and motor coordination [13].

Another key point is that the greater activation of fast-twitch fibers (type II), compared to TRT, may enhance the production of IGF-1 and promote neuroplasticity, especially regarding type II fiber recovery and cortical adaptation [33,42].

These fibers are the most affected by the natural aging process, and their reduction is one of the primary causes of sarcopenia [18]. A feature of FRT is the preferential use of high-threshold motor units, which occurs due to high mechanical stress when resisting stretching under tension. These fibers are the most susceptible to damage compared to slow-twitch fibers, and as a response to muscle recovery, signaling occurs that stimulates the production of IGF-1 to restore damaged fibers [44].

Although no significant changes in IGF-1 were detected, cognitive improvements—particularly in the FRT group—may have resulted from neuromuscular activation patterns, enhanced attentional demand, and cortical engagement induced by eccentric overload protocols. These mechanisms are consistent with the recent literature on cognitive–motor interaction in aging [15,42].

Finally, cognitive flexibility is directly related to inhibitory control and working memory [1] and enables adaptation to new situations, problem-solving, creativity, and planning. Maintaining this function reduces dependence on caregivers and improves quality of life [2].

In addition to cognitive benefits, resistance training with eccentric emphasis can provide significant functional gains, enhancing the quality of life in elderly individuals [45]. FRT produces strong mechanical stress, requires less motor unit activation, presents lower oxygen consumption, and generates less energy expenditure [12,13,16]. These contributions may be positive for elderly individuals, helping to maintain good adherence to training programs.

This study reinforces the current literature and introduces a new approach for professionals to use in improving working memory and cognitive flexibility in elderly women. It is worth noting that the inertial flywheel device is not entirely accessible, and alternative available methods should be explored to achieve eccentric training.

The strengths of our study include being the first RCT to investigate the effects of an inertial flywheel compared to TRT on executive function in elderly women. Additionally, checklists were used to ensure training quality, and the protocol was published in the clinical trial repository to ensure transparency. Limitations include the short intervention period (eight weeks), a lack of dietary control, and the fact that the level of education of the elderly women was not considered, although this was included as a covariate in the analyses to minimize confounding factors. The OMNI-RES scale used to assess perceived exertion, although explained to participants, may still have been influenced by individual interpretation. Although multiple imputations were applied to manage missing data, the assumptions underlying this method (e.g., missing at random) must be considered when interpreting results. Post-intervention assessments were conducted seven days after the final training session. This time gap may have allowed transient adaptations, such as acute IGF-1 elevation or short-term cognitive enhancements, to decline before measurement. Therefore, some acute or subacute responses might have been underestimated. Another important limitation is the absence of a control group without any exercise intervention. This restricts the ability to determine whether the observed improvements were due solely to training effects or influenced by other uncontrolled factors. Future trials should include a true control condition to strengthen causal interpretation. Another limitation concerns the use of a fixed flywheel inertia ( $0.055 \text{ kg}\cdot\text{m}^2$ ) in the FRT group. While chosen for safety and comparability, this may have limited progressive neuromuscular adaptation over time.

Future trials should consider individualized or progressive loading strategies to optimize both physical and cognitive responses to FRT [14,46].

## 5. Conclusions

This randomized controlled trial suggests that an eight-week program of FRT may be more effective than TRT in enhancing cognitive flexibility in older women despite similar effects on other executive functions and IGF-1 levels. These findings highlight the potential of eccentric-based interventions as a cognitively engaging alternative for this population. Further research with longer interventions and additional neurophysiological measures is recommended to confirm and extend these results.

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**Data Availability Statement:** The data that support the findings of this study are available from the corresponding author (PF) upon reasonable request.

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