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Effects of 12 Weeks of Physical-Cognitive Dual-Task Training on Executive Functions, Depression, Sleep Quality, and Quality of Life in Older Adult Women: A Randomized Pilot Study

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Abstract: This study aims to examine the effects of 12 weeks of physical-cognitive dual-task training on cognition, depression, sleep quality, and quality of life in older women (n = 44; 66.20 ± 4.05 years). Of these, 22 were randomly allocated to the dual-task training (DT) group, and 22 participated in the activities of the education control group (CG). Assessments were performed at baseline, at the end of 12 weeks of intervention, and after 12 weeks of follow-up using the following instruments: Trail Making Test parts A and B, ΔTMT (B-A), Stroop test parts A, B, C, and ΔStroop (C-B), Geriatric Depression Scale (GDS), sleep quality (PSQI), quality of life (SF-36). The results showed a positive and significant time-group interaction for two cognitive domains (TMT and Stroop). No time-group interaction effect was indicated for depression and sleep quality perception. There was a positive and significant interaction effect between time and group for three SF-36 subcategories (physical function, physical role, and general health). Our training protocol was not able to improve depressive symptoms and sleep quality. On the other hand, DT training was able to promote the performance of executive functions and the physical and mental component summary of the quality of life with lasting effects of up to 12 weeks after the intervention.

Keywords: aging; cognition; executive function; health perception

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Citation: Nascimento, M.d.M.; Maduro, P.A.; Rios, P.M.B.; Nascimento, L.d.S.; Silva, C.N.; Kliegel, M.; Ihle, A. Effects of 12 Weeks of Physical-Cognitive Dual-Task Training on Executive Functions, Depression, Sleep Quality, and Quality of Life in Older Adult Women: A Randomized Pilot Study. *Sustainability* **2023**, *15*, 97. https://doi.org/10.3390/su15010097

Academic Editors: Gabriela Topa and Gianpiero Greco

Received: 30 October 2022
Revised: 28 November 2022
Accepted: 18 December 2022
Published: 21 December 2022

1. Introduction

Physiological aging brings a series of biopsychosocial changes that can potentiate functional decline, impairing the adaptation to the environment and affecting older adult people's mental health [1]. Among the changes is also a decrease in cognition effectiveness, including executive function (EF), which is considered a set of integrated cognitive skills responsible for controlling and regulating common everyday actions, such as thoughts, emotions, and conflicts [2]. All these functions are essential for an older person to remain active and independent over time [3].

Changes in the functioning of EFs imply restrictions in the execution of tasks that require attention, working memory, and conceptual reasoning, as well as visual, spatial, and language skills [4,5]. With aging, the ability to coordinate motor and cognitive tasks simultaneously, called dual-task (DT), is affected [6]. DT activities are constantly present in our daily lives, demanding attentional resources. However, due to the set of physical and cognitive changes that occur in the brain during aging, EF can be harmed [7]. Systematic review studies [8,9] and meta-analyses showed that physical exercises based on principles of cognitive stimulation [10,11], such as DT training, are an effective method to increase the cognitive performance of older adults. In this training, there is the simultaneous execution of two independent tasks, which can be measured separately and have different purposes [12]. In practice, two distinct tasks compete for one or more sets of cognitive resources, causing cognitive-motor interference (CMi), consequently demanding more brain functions [13].

The advantage of DT training over single-task training is greater stimulation of neural networks, an active principle of neuroplasticity [14]. This process is described as the dual-task paradigm [15], understood as the behavior of a primary task performed concurrently with a secondary (concurrent) task. A recent systematic review and meta-analysis study provided evidence on the results of randomized controlled trials regarding the effectiveness of different types of cognitive motor-training interventions in healthy older adults [16]. According to the authors, DT training is able to benefit gait and balance performance. On the other hand, due to the heterogeneity between the types of intervention, the underlying mechanisms of this training are still unclear.

DT training is a useful clinical marker for identifying cognitive decline [17,18], mainly in executive functions (planning, inhibiting, and switching/coordinating) [19,20]. Another advantage of the DT principle is its ability to detect the risk of falls, differentiating fallers from non-fallers [15,21]. A systematic review confirmed the potential of DT training to benefit balance performance in older adults [22]. This training is capable of generating significant improvements in body sway during single support (static balance), as well as in the alignment of the center of gravity during double support (dynamic balance) [23]. Therefore, the effects of DT training on neural plasticity [24,25] benefit gait parameters (i.e., speed, cadence, step length), in turn reducing postural sway (swing phase) and consequently the risk of falling [26,27].

Previous studies have associated changes in gait performance in the DT condition in older adults with sleep behavior [28], as well as sleep with cognitive performance during aging [29]. When it comes to the health of the older population, participation in physical exercise programs is not limited to promoting physical skills. Subjective well-being and mental health play an important role [30], which includes the improvement of sleep quality [31], the reduction of depressive symptoms [32], and, therefore, the promotion of the perception of quality of life (QoL) [33]. In an RCT that evaluated the effects of 24-week DT training with progression from variable priority to fixed priority on the quality of life and depressive symptoms in community-dwelling older adults [34], the authors found a significant effect of training time on the reduction of depression, in addition to an increase in the perception of the physical and mental domains of QoL.

With regard to the novel contribution of this pilot study, to the best of our knowledge, to date, no study has concomitantly investigated the effects of physical-cognitive DT training on cognition, depression, sleep, and QoL in older adult women. Thus, the aim of this pilot study was (1) to examine the effect of a 12-week physical-cognitive DT training program on the cognition of a group of older women and (2) to investigate the benefits of DT training for mental health, specifically, depression, sleep quality, and perceived QoL. We hypothesized that, comparatively, members of the physical-cognitive DT training would perform better on all assessments after 12 weeks of intervention, as well as retain better gains after 12 weeks of follow-up than members of the control group. Our focus on the female population is justified by the fact that in Brazil, where this investigation was carried out, a multifaceted phenomenon called the feminization of aging has been observed [35]. Because of this, the number of older women (≥60 years old) is greater than that of men [36]. Comparatively, Brazilian women have a higher risk of falling than men [37] and are more susceptible to mental disorders. A population-based study carried out in Brazil (n = 848; 18–64 years old) found a significant association between poor sleep quality and mental disorders, especially in older adult women [38]. The findings suggested a negative influence of health status (i.e., body functionality and physical and mental well-being) on the performance of daily activities.

2. Methods

2.1. Study Design

The present study followed the structure for a future project of more complex interventions in the health area [39], so at this stage, it was considered a randomized pilot study. The activities took place between 2018 and 2019. The team of evaluators responsible for the procedures of all evaluations was blinded. Assessments were performed at baseline (T1). Subsequently, participants were randomly assigned (1:1) into a dual-task (DT) or control (CG) group, and the single-sequence randomization was generated by a web-based survey randomizer (www.randomizer.org (accessed on 30 July 2018). The process was conducted by a blinded investigator to the objectives of the study and recruitment. To compare the effectiveness of the intervention, post-intervention assessments (T2) were performed after 12 weeks of intervention. Finally, follow-up assessments (T3) were performed to detect potential long-term effects of the intervention on study variables. During the follow-up period, members of both groups were instructed to perform only their daily activities and no physical or cognitive training.

2.1.1. Sample

A priori calculation for sample size using G*Power3 based on a previous study [40] was performed considering: repeated measures analysis of variance (ANOVA) within-between interaction factors, f = 0.20, alpha error probability = 0.05, power = 0.80, number of groups = 2; the number of measurements = 3. Forty-two participants were required to achieve appropriate statistical power.

2.1.2. Eligibility

Participants were contacted by invitation in WhatsApp groups, Facebook, and in the city's exclusive older adult groups. The inclusion criteria adopted were: being female, being ≥60 years old, being independent in activities of daily living, walking without assistance, not participating in any regular physical training program or having participated in the last six months before the initial interview, achieving a score > 52 (out of 56) on the Berg Balance Scale [41], having the ability to walk unaided for 10 min at a minimum speed of 1 m/s, and scoring ≥25 (out of 30) on the Mini-Mental State Examination (MMSE) [42]. Exclusion criteria were: cardiovascular or musculoskeletal diseases, history of stroke, severe neurological diseases (such as Parkinson's, dementia, and multiple sclerosis), as well as significant hearing or visual impairments. All participants were informed about the objectives and risks of the study. Those who agreed to participate signed a consent form in accordance with the Declaration of Helsinki before undergoing any assessment. Participants in this investigation did not receive any financial compensation.

2.2. Intervention

2.2.1. Dual-Task Training

Members of the dual-task group performed physical training simultaneously with cognitive tasks (Table 1). The program was based on the principle of variable priority, which is when the focus of attention is shifted between motor tasks (gait, balance) and cognitive tasks [43]. The basis used to construct the dual-task interference patterns associated with motor tasks (gait and balance) followed the principles of the previous study [12,44]. Training took place twice a week (60-min sessions) for 12 weeks. The procedures were monitored by a team of four professionals trained in the area of Physical Education.

Table 1. Descriptive summary of activities, training strategies, and equipment used.

Focus	Training Tasks	Method and Progression
Gait	(a) Tasks: walking with short or long steps, over obstacles, on the heel or tiptoe; (b) Sensory input: impaired vision, enhancement of somatosensory integration; (c) Directions: forward, backward, left/right, diagonal.	(a) Circuit with 5 stations; (b) Intensification of the task through fast or slow walking, inclusion of turns (180° and 360°); (c) Equipment: ropes, bows, balls, foam mattress, ramp, steps.
Static balance	(a) Tasks: biped, semi-tandem, tandem, single-leg, weight on the feet (heels, lateral, medial, or toes).	(a) Circuit with 5 stations; (b) Simulation of daily life tasks in a static position (increased demand for hip or ankle strategies); (c) Surface: soft, hard, stable, unstable, or reduced.
Dynamic balance	(a) Tasks: during normal gait, narrow gait, lap gait, tandem gait.	(a) Circuit with 5 stations; (b) Challenges: addition of arm movements outside the center of pressure (COP), gait backward; (c) Surface: soft, hard, stable, unstable, or reduced.
Cognitive task	Tasks: (a) add and subtract: for example, solve math problems with a countdown (100, 97, 94, 91, 89, . . .), (b) verbal fluency: name fruits, people, or cities starting with different letters of the alphabet; (c) working memory: memorizing a sequence of 3–5 different words and after reproducing; (d) reaction time: react as quickly as possible to questions or images (Stroop effect).	(a) Increase the difficulty of the category, expand the count or elements of memorization; (b) Inverting the order of the sequence of words or numbers (back to front); (c) Variation of response time; (d) Alternating combination of series or length of tasks; (e) Alternating combination of incongruent and congruent task.

All training sessions presented the following methodology:

- Phase I: A warm-up at the beginning of each session (10 min) with supervised walking exercises on a flat surface, general joint mobilization, and stretching exercises;
- Phase II: Dual-task training (40 min), consisting of balance and gait exercises arranged in four stations, with a 10-min permanence in each station, 4 sets/8–12 repetitions per exercise. Over 12 weeks, the following training strategies were used: (1) two concurrent motor tasks (e.g., walking with hand engagement manipulating objects), (2) walking and simultaneously performing a cognitive task with internal interference factors (Stroop, calculations, fluency verbal, memorization), (3) walking on an unstable and/or reduced surface with the simultaneous requirement of visual tasks, word spelling and/or countdown, (4) in posture activities: semi-tandem standing with eyes open or closed (with changes in arm movement or cognitive tasks), (5) walking across obstacles or overcoming them (with a simultaneous resolution of cognitive tasks);
- Phase III: Return to calm (10 min) with relaxation and breathing exercises, lying on the floor. The training protocol was performed in a fitness room (20 × 20 m). Progression of cognitive-motor difficulty/load level occurred every two weeks (after four training sessions). To enhance the social component, DT training was performed in groups of 5-6 people at each station of the circuit, switching to a new station every eight minutes. Table 1 summarizes the four approaches that integrated the DT training, as well as the strategies used for the progression of tasks.

2.2.2. Education Control Group

Members of the CG participated in a set of thematic workshops developed by the interdisciplinary team of the University of the Third Age. The themes covered during the 12 weeks were of interest to the older population, such as nutrition, prevention of falls, rational use of medication, older citizen's rights, arts, music, singing, and the use of technologies (mobile phones, WhatsApp, Instagram, YouTube, Facebook). At the end of each meeting, discussions were held on the topics of the day, and the methodology adopted by the team was detailed in a previous publication [45]. The activities took place twice a week (60-min sessions). During all phases of the pilot study, this group did not receive any specific training for physical or cognitive functions.

2.3. Adherence

In this pilot study, participants from both groups attended at least 75% of the training sessions [46]. During the 12 weeks of intervention, the DT group's adherence to the training was 94%, while GC members had 92% of attendance at the thematic workshops. Once a month, participants in both groups were also asked about their satisfaction with the activities. To ensure everyone's adherence during the follow-up period, the team maintained weekly contact via WhatsApp or by phone. During this period, the participants received three booklets with cultural and health information and were instructed not to perform any type of physical or cognitive training, just to continue with their daily activities. Both during the first 12 weeks and at follow-up, there were no adverse events, including falls.

2.4. Outcome and Measurements

Prior to randomization, sociodemographic data (e.g., age, education), history of falls, medications, and comorbidities were self-reported. We also proceeded with the assessment of height and weight to calculate the body mass index (BMI), as well as the Brazilian version of the MMSE [47], considering the following scores: 20 points for illiterates, 25 points for individuals with education between 1–4 years, 26.5 points for those aged 5–8 years, 28 points for 9–11 years of education, and 29 points for those with more than 11 years of education.

2.4.1. Primary Outcome

Our primary results were pre-defined as the time spent performing the cognitive tests Trail Making Test [48] and Stroop Color Word Test [49]. The Trail Making Test (TMT) has two parts (A and B). The TMT-A involves processing a speed visual scanning task. Participants were asked to draw lines as quickly as possible and sequentially connect a set of consecutively numbered circles (from 1–25) posted randomly on a page. TMT-B assessed working memory, cognitive flexibility, set-shifting, and task-switching. The task consisted of connecting the same number of circles; however, the displayed sequence required alternating numbers and letters (1, A, 2, B, 3, C...). TMT-A and TMT-B were timed. For the analysis, the time in seconds was considered: a longer time to complete the tests indicated a poor performance of the EF. In the present pilot study, the difference in scores (ΔTMT = score TMT-B − score TMT-A) was also considered. In this way, the EF was more accurately assessed because it did not just consider the performance of Part B, which is more complex than Part A. Thus, a high ΔTMT score indicates a worse outcome [50].

The second cognitive test used was the Stroop Color Word Test, more specifically, parts A, B, and C [49]. It assesses EFs through selective attention skills, mind monitoring, and selective attention inhibition, in particular, the ability to suppress an overlearned response (automatic reading of a word while the color of the incongruous word must be named). The exam consists of three cards (18×11.5 cm): on Card A, participants were asked to read the names of the colors printed in black ink; on Card B, the task was to name the colors of the rectangles; on Card C (interference task) they should name the colors ignoring the word printed on the card. Performance was measured by the time taken in seconds to complete tasks. We also calculated the interference effect by the difference in time between the incongruent condition and the congruent condition (ΔStroop = score Card C − score Card B): shorter times indicated better performance [51].

2.4.2. Secondary Outcomes

They were assessed by three instruments: the Geriatric Depression Scale (GDS), the Pittsburgh Sleep Quality Index (PSQI), and the 36-Item Health Survey Short Form (SF-36).

Version GDS-15 was used to examine somatic complaints [52]. Their scores range from 0–5 (no depressive symptoms), 6–10 (mild depression), and 11–15 (severe depression). With the PSQI scale, sleep quality was assessed [53]. The scale has seven dimensions (sleep quality, latency, duration, efficiency, nocturnal sleep disturbances, use of sleep medications, and daytime sleepiness). The total score can range from 0–21. High values indicate worse sleep quality; a score of five points was used as a cutoff point. The perception of QoL was accessed through the Brazilian version of the SF-36 questionnaire [54]. This is a multifunctional health instrument divided into 8 individual domains, which comprise 2 distinct high-order summary scales: (1) physical component summary (PCS), including physical functioning (PF): limitations in physical activity due to health problems; role physical (RP): limitations in usual activities due to health problems physical, body pain (BP): bodily pain perceptions; general health (GH): general health perceptions, and (2) mental component summary (MCS), which include: vitality (VT): energy and fatigue; social functioning (SF): limitation in social activities due to physical or emotional problems; role emotional (RE): limitation in usual activities due to emotional problems; and mental health (MH): perceptions associated with mental health. The scores on each of the 8 scales range from 0-100, higher scores indicate better QoL. In the present pilot study, we used the PCS and MCS scores, which summarize the scores of their respective 4 scales.

2.5. Covariates

The following variables were assumed as possible confounding factors and, therefore, controlled in the serial analysis of the mediation: sex, age, number of falls in the last 12 months, years of education, number of types of medication consumed daily, diabetes, and hypertension.

2.6. Statistics

Initially, normality was tested with the Shapiro-Wilk test. The main characteristics of the participants, such as demographic and anthropometric data (numerical variables), were presented as means and standard deviations, while medications, education, and co-morbidities (categorical variables) were presented by the number of cases and proportions in percent. Continuous variables with a normal distribution (TMT, Stroop) were presented as means and standard deviations and analyzed using the T-test for independent samples. Continuous variables without normal distribution (GDS, PSQI, SF-36) were presented as medians and interquartile ranges (IQR) and analyzed by the Mann-Whitney U test. All categorical data were analyzed using the Chi-square test. Three-way repeated measures analysis of variance (ANOVA) was used to assess differences between and within groups in the study phases (baseline, post-training, and 12-week follow-up). In this analysis, we considered the DT versus CG intervention as a factor between the groups and the measurement time as a factor within the group (comparison 2 × 3). Intergroup effect sizes were calculated using partial eta squared [55], categorized as small (η_p^2 = 0.01), medium (η_p^2 = 0.06), and large (η_p^2 = 0.14). Separate ANOVAs were performed to more accurately control for the locus of significant difference between two points at the three times (T1, T2, or T3) of assessments, using Bonferroni's post hoc test. The significance level adopted in all cases was $\alpha < 0.050$. The analyses were performed using the Statistical Package for Social Sciences (SPSS) software version 24.0.

3. Results

Overall, 75 people were considered for registration. Of these, 50 met the inclusion criteria and were randomized. Thus, 25 participants were allocated to each group. During the study, six participants were excluded, one due to health problems, another one moved to a new city, and four of them dropped out without providing a reason. Finally, 44 people (DT = 22, CG = 22) completed the entire 24-week study and were included in the analysis (Figure 1). The adherence of the DT and CG groups to the training activities was 92.4% and 94.3%, respectively.

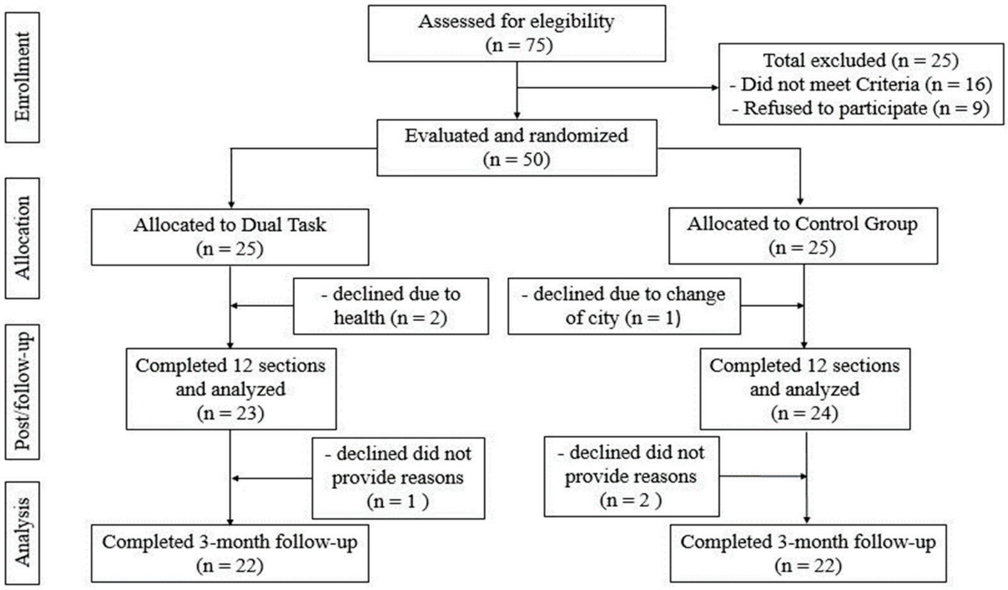

Figure 1. Flowchart of the pilot study design.

3.1. *Sample Characteristic*

At baseline (Table 2), no significant difference between groups was found for demographic characteristics, anthropometrics, medications, history of falls, or comorbidities ($p > 0.050$). The mean age was 66.20 ± 4.05. Both groups indicated preserved cognitive performance on the MMSE (25.30 ± 2.68 points), average schooling between 3–4 years, daily consumption of 1–2 types of medication, and low history of falls in the last 12 months (0.16 ± 0.37). Among the self-reported comorbidities, the most prevalent was rheumatism (72.7%), followed by diabetes mellitus, hypertension, visual acuity, hearing, and osteoporosis (50.0%).

3.2. *Intervention Effects*

3.2.1. Cognitive Assessments

The repeated measures ANOVA showed a significant interaction effect between time and group for the following tests (Table 3): TMT-A [F(2,84) = 5.066, $p = 0.008$, $\eta_P{}^2 = 0.080$], TMT-B [F(2,84) = 39.558, $p = 0.000$, $\eta_P{}^2 = 0.099$], ΔTMT (B-A) [F(2,84) = 9.754, $p = 0.001$, $\eta_P{}^2 = 0.095$], Stroop A [F(2,84) = 2.109, $p = 0.014$, $\eta_P{}^2 = 0.040$], Stroop B [F(2,84) = 3.278, $p = 0.039$, $\eta_P{}^2 = 0.057$], Stroop C [F(2,84) = 6.253, $p = 0.003$, $\eta_P{}^2 = 0.088$], and Stroop (C-B) [F(2,84) = 2.654, $p = 0.008$, $\eta_P{}^2 = 0.074$]. Separate ANOVA analyses indicated that compared to the GC, from T1 to T2, members of the DT group took a shorter time to complete the TMT-A test, improving their performance by 14.0% (Figure 2A). On the other hand, from T2 and T3, the test execution time worsened by 8.7%. However, in general, the analysis from T1 to T3 showed an improvement of 12.2% in the performance of the EFs. TMT-B performance improved by 14.6% from T1 to T2, as well as from T1 to T3 by 14.3% (Figure 2B). ΔTMT (B-A) indicated an improvement in the performance of EFs from T1 to T2 by 11.5%, as well as from T1 to T3 by 10.5% (Figure 2C).

Table 2. Main characteristics of participants in the baseline.

Variable	Dual-Task (*n* = 22)	Control Group (*n* = 22)	*p*-Value
Age (years)	66.14 ± 4.15	66.27 ± 4.04	0.913 †
BMI (kg/m^2)	27.68 ± 3.93	28.18 ± 4.67	0.703 †
Falls (12 months)	0.27 ± 0.19	0.185 ± 0.21	0.132 †
Medication			0.161 †

Table 2. *Cont.*

Variable	Dual-Task (*n* = 22)	Control Group (*n* = 22)	*p*-Value
1–4 types (f)	20 (90.9%)	19 (86.3%)	
>4 types (f)	2 (9.0%)	3 (13.6%)	
Education level			0.574 †
1–4 years	3 (13.6)	4 (18.1)	
≥5 years	19 (86.3)	18 (81.8)	
MMSE	25.27 ± 1.38	25.32 ± 3.57	0.688 †
Comorbidities			
Diabetes mellitus			0.545 *
Yes (f)	4 (18.1%)	18 (81.8%)	
Hypertension			0.680 *
Yes (f)	9 (40.9%)	13 (59.0%)	
Visual acuity			0.761 *
Yes (f)	20 (90.9%)	2 (9.0%)	
Hearing			0.550 *
Yes (f)	11 (50.0%)	12 (54.5%)	
Labyrinthitis			0.079 *
Yes (f)	4 (18.1%)	2 (9.0%)	
Osteoporosis			0.294 *
Yes (f)	14 (63.6%)	8 (36.3%)	
Rheumatism			0.488 *
Yes (f)	6 (27.2%)	16 (72.7%)	

Data are expressed as mean (M) ± standard deviation (SD) or frequency (f); kg = Kilograms; cm = centimeters; MMSE = Mini-Mental State Examination; BMI= Body Mass Index; kg/m^2 = kilograms/square meter; Data indicated normal distribution by the Shapiro–Wilk test. † $p < 0.050$ = Mann-Whitney U test, * $p < 0.050$ = chi-squared (χ^2) test.

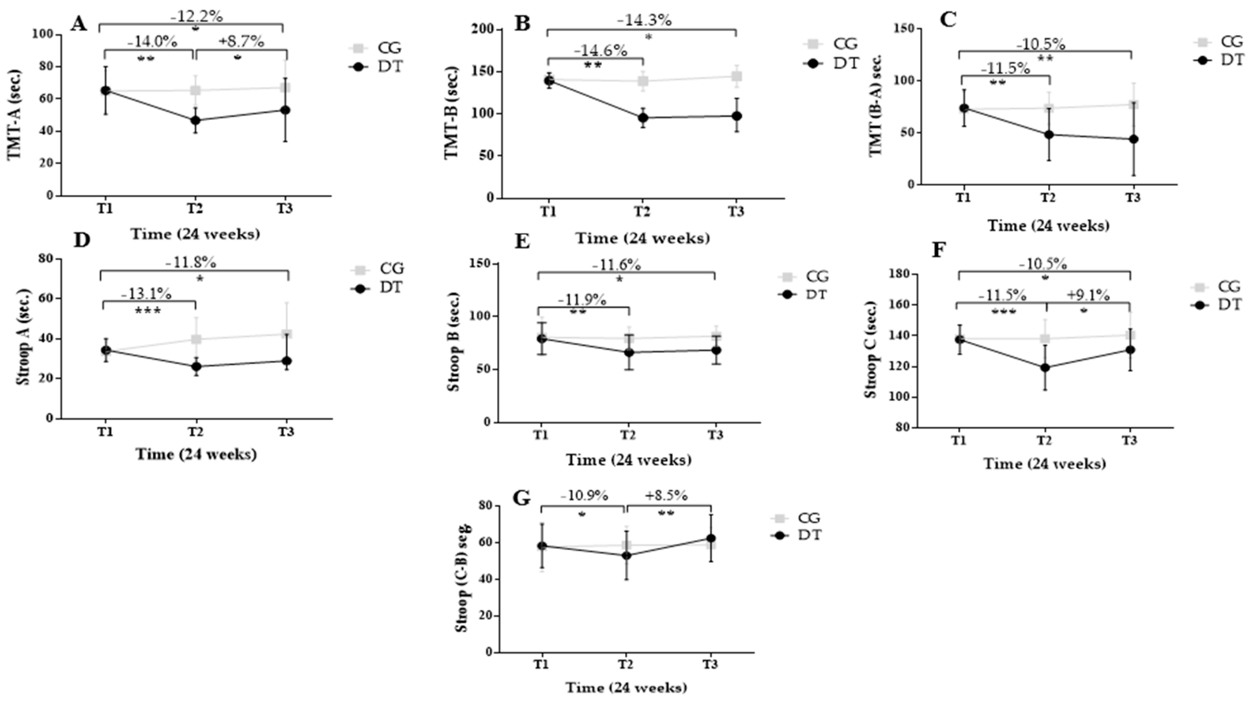

Figure 2. Key differences for the time × intervention contrast of each measure of cognitive tests over 24 weeks: (**A**) TMT-A = Trail Making Test-part A; (**B**) TMT-B = Trail Making Test-part B; (**C**) ΔTMT (B-A): Delta Part B–Part A; (**D**) Stroop A = Stroop Test part I; (**E**) Stroop B = Stroop Test part II; (**F**) Stroop C = Stroop Test part III; (**G**) ΔStroop (C-B): Delta Stroop C–Stroop B. Data indicated normal distribution by the Shapiro–Wilk test. Error bars indicate ± standard deviation. Bonferroni post hoc test * $p < 0.050$, ** $p < 0.010$, *** $p < 0.001$.

Table 3. Comparison of results of DT and CG groups for assessments of cognition, depression, sleep, and quality of life.

	Dual-Task			**Group Control**			**Time**			**Time * Group** [†]		
	(Baseline) $n = 22$	**(12 Weeks)** $n = 22$	**(24 Weeks)** $n = 22$	**(Baseline)** $n = 22$	**(12 Weeks)** $n = 22$	**(24 Weeks)** $n = 22$	**F**	p	η_p^2	**F**	p	η_p^2
Cognition (s)												
TMT-A	65.45 ± 14.71 [a,b]	46.86 ± 7.71 [c,†]	53.32 ± 19.64 [†]	65.00 ± 12.55	65.45 ± 9.10	67.18 ± 17.08	8.738	<0.001	0.096	5.066	0.008	0.080
TMT-B	139.59 ± 8.95 [a,b]	95.55 ± 11.42	97.68 ± 20.70	140.86 ± 9.80	139.05 ± 11.78	144.68 ± 13.00	36.794	<0.001	0.099	39.558	<0.001	0.099
ΔTMT (B-A)	74.13 ± 17.58 [a,b]	48.68 ± 25.12	44.36 ± 34.95	73.09 ± 16.76	74.04 ± 15.42	77.50 ± 20.69	6.301	0.006	0.081	9.754	<0.001	0.095
Stroop A	34.36 ± 5.72 [a,b]	26.14 ± 4.48	28.95 ± 4.36	33.73 ± 5.27 [b]	39.77 ± 10.81	42.36 ± 15.68	2.622	0.028	0.050	2.109	0.014	0.040
Stroop B	79.18 ± 14.95 [a,b]	66.23 ± 16.60	68.45 ± 13.13	80.41 ± 18.22	79.45 ± 10.74	81.59 ± 9.58	3.482	0.036	0.060	3.278	0.028	0.057
Stroop C	137.59 ± 9.54 [a,b]	119.36 ± 14.63 [c,†]	122.00 ± 13.53	138.18 ± 8.47	138.23 ± 12.44	140.55 ± 14.83	6.781	0.040	0.091	6.253	0.039	0.088
Stroop (C-B)	58.41 ± 11.82 [a]	53.13 ± 13.21 [c,†]	53.55 ± 12.73	57.77 ± 13.45	58.78 ± 10.21	58.96 ± 9.36	2.654	0.008	0.074	2.832	0.004	0.078
Depression												
GDS	3.00 (1–10)	1.50 (0–9)	1.50 (0–5)	3.50 (1–11)	2.50 (0–15)	3.00 (0–9)	3.043	0.068	0.049	0.820	0.415	0.016
Sleep Quality												
PSQI	5.00 (2–10)	5.00 (1–11)	5.50 (1–9)	4.00 (2–10)	4.00 (1–9)	5.00 (1–13)	1.695	0.190	0.034	1.173	0.176	0.036
SF-36												
PCS	70.67 (20–100) [a,b]	91.87 (42–100) [c,†]	86.87 (42–100) [†]	71.75 (15–100)	73.25 (0–100)	69.00 (22–100)	7.643	0.006	0.066	3.043	0.012	0.062
MCS	73.00 (25–100) [a,b]	93.75 (0–100) [c,†]	83.87 (33–100) [†]	73.50 (25–100)	75.00 (20–100)	71.62 (36–100)	6.373	0.004	0.044	1.953	0.009	0.054

Values are presented as mean ± standard deviation (SD) or median and interquartile range (IQR); s = second; TMT-A = Trail Making Test-part A; TMT-B = Trail Making Test-part B; ΔTMT (B-A): Delta Part B–Part A; Stroop A = Stroop Test part I; Stroop B = Stroop Test part II; Stroop C = Stroop Test part III; GDS = Geriatric Depression Scale; PSQI = Pittsburgh Sleep Quality Index; SF-36 = Medical Outcomes Short-Form Health Survey; PCS = Physical component summary; MCS= Mental component summary; [†] Repeated measures ANOVA (comparison 2 * 3); [a,b,c] $p < 0.050$ = Bonferroni's post hoc test ([a] = considering, significant difference baseline with 12 weeks; [b] = considering, significant difference baseline with 24 weeks; [c] = considering, significant difference 12 weeks with 24 weeks); η_p^2 = partial eta square.

The results of the post hoc test showed favorable results for the DT training. The Stroop A test pointed out an improvement in the performance of EFs from T1 to T2 by 13.1%, as well as from T1 to T3 by 11.8% (Figure 2D). The Stroop B test also showed improvement by 11.9% from T1 to T2 and by 11.6% from T1 to T3 (Figure 2E). The Stroop C test showed an improvement of 11.5% from T1 to T2 (Figure 2F). On the other hand, there was a worsening of 9.1% from T2 to T3. Between T1 and T3, Stroop C indicated an improvement of EFs by 11.2%. Regarding the interference effect (Figure 2G), members of the DT group showed a shorter time to complete the test (ΔStroop C-B), revealing a significant difference from T1 to T2 with a 10.9% improvement in the performance, followed by a worsening from T2 to T3 by 8.5%.

3.2.2. Depression and Sleep Quality

Repeated measures ANOVA (Table 3) did not show a significant interaction effect between time * group for GDS [$F(2,84) = 0.820$, $p = 0.415$, $\eta_P^2 = 0.016$], and also did not indicate a significant difference for PSQI [$F(2,84) = 1.173$, $p = 0.176$, $\eta_P^2 = 0.036$]. Separate ANOVA analysis did not point to significant results for the EGS and PSQI scales between any of the study evaluation moments ($p > 0.050$).

3.2.3. Quality of Life (QoL)

The repeated measures ANOVA indicated for the DT training a significant interaction effect between time and group for PCS [$F(2,84) = 3.043$, $p = 0.012$, $\eta_P^2 = 0.062$], as well as for MCS [$F(2,84) = 1.953$, $p = 0.009$, $\eta_P^2 = 0.054$] (Table 3). Separate ANOVA analysis showed that the physical domain (PCS) of QoL of the DT group improved by 7.8% from T1 to T2 and improved by 10.5% from T2 to T3. On the other hand, based on the difference between T1 and T3, there is an overall improvement in PCS of 8.3% (Figure 3A). Regarding the mental domain (MCS) of QoL, there was an improvement of 7.8% from T1 to T2, followed by a reduction (worsening) of 11.1% from T2 to T3. Overall, from T1 to T3, DT training improved MCS by 8.7% (Figure 3B).

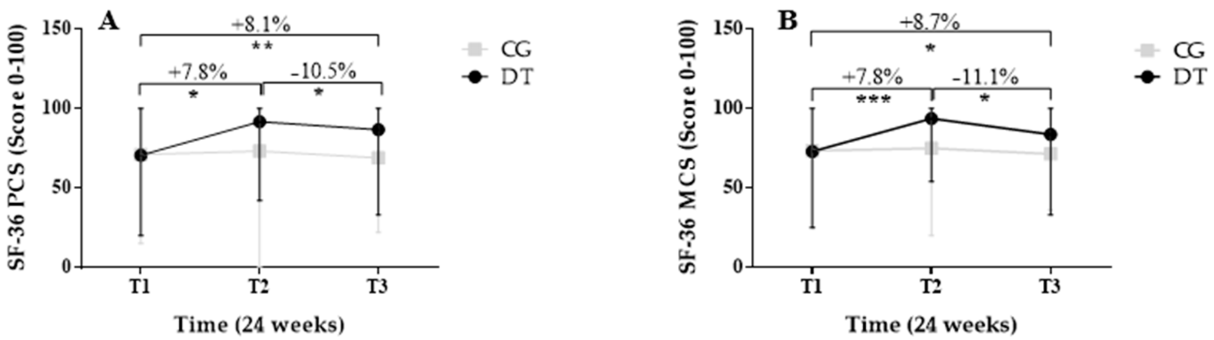

Figure 3. Key differences for each measurement at time points over 24 weeks for the physical and mental components of the SF-36 questionnaire. Error bars indicate ± standard deviation. Note: SF-36 = Medical Outcomes Short-Form Health Survey; (**A**) PCS = Physical component summary; (**B**) MCS = Mental component summary. Bonferroni post hoc test * $p < 0.050$, ** $p < 0.010$, *** $p < 0.001$.

4. Discussion

This pilot study aimed to examine the effects of 12 weeks of dual-task cognitive and physical training on cognition, depression, sleep quality, and QoL in older women. Although our results have shown a medium effect size, we confirm our premise that members of the DT group would have better results in the cognitive performance exam (i.e., executive function) and precept of QoL than members of the CG at the end of 12 weeks of intervention, as well as better performance after 12 weeks of follow up. From this perspective, our findings can be used to calculate the proper size of the necessary sample for future studies. However, our results were in line with previous studies, which highlighted the benefits of dual-task physical-cognitive training to counteract aging-related declines in inhibitory control [40,56] in actions that require set-shifting [57,58], visuospatial planning [59], working memory [60,61], long-term visual memory [62], processing speed [63], and attentional control [64]. On the other hand, no significant difference in depressive symptoms and sleep quality was observed between the groups throughout the study.

In terms of underlying mechanisms, improvements in cognitive functions can be explained by the ability of DT training to induce brain plasticity [58]. In the present study, an increase in cognitive demand (secondary task) occurred, specifically during the performance of gait and balance exercises (primary task) [40,65]. Thus, due to the increase in simultaneous stimuli, probably different brain regions were readapted and reorganized, as in gray matter, more specifically, the prefrontal cortex [66,67], hippocampus [68], and subcortical regions in the basal ganglia [69], and cerebellum [68]. The effects of our physical-cognitive dual-task training were significantly supported by the TMT-B score, which is considered a test capable of detecting executive dysfunction [70], and also by the ΔTMT procedure. The findings corroborate a similar investigation that used the dual-task paradigm to improve older adult cognitive function [71] and supported the hypothesis that EF could be improved after 12 weeks of DT training, as well as that gains could be maintained considerably until the end of follow-up.

One of the strategies used in the DT training was the interference task, which consisted of inhibiting the reading of the word and only naming its color during the tasks of walking forwards or backwards (free in the room) or on a reduced surface (dynamic balance). Possible cognitive alterations resulting from these tasks were examined by the Stroop test. Overall, our results suggested that the DT training protocol had the potential not only to induce cognitive plasticity in older adult participants but also to promote considerable retention of gains up to 12 weeks after the end of the intervention (Figure 2A–G). It is known that skills captured through training can be transferred to a new dual-task situation [72]. Cognitive inhibition, for example, is a fundamental component of everyday life, benefiting response control (inhibition of dominant responses and external lapses), as well as motor planning and body coordination in dual-task situations [73].

We did not include imaging exams (e.g., functional magnetic resonance imaging) to verify the exact locus of CMi-induced brain changes. Therefore, our results should be interpreted with caution regarding structural changes in the brain. On the other hand, based on a 12-week RCT (73.0 $\pm$ 4.8 years), which performed a physical-cognitive dual-task exercise program to improve cognitive function and brain activation [61], the authors found improvement in short-term visual memory (ΔTMT) performance after the intervention, which is associated with the amplification of neural networks in dorsolateral prefrontal regions.

According to the analysis, the physical-cognitive dual-task was not able to promote significant changes in depressive symptoms and sleep quality. One explanation for this is that members of both groups already in baseline assessments indicated low values for depression and adequate sleep quality. On the other hand, the results suggested that both participation in DT training and educational dynamics were effective in maintaining the participants' mental health for six months. A cross-sectional study (64.7% women; 71.5 $\pm$ 5.8 years) found an association between poor sleep quality and decreased gait speed, and increased gait variability under DT conditions [28]. These results suggested that specific brain regions regulate both gait and sleep. Previous studies have suggested that an increase in gait variability is indicative of a higher risk of falls in the older adult population [74,75]. Moreover, a clinical recommendation is that DT training can concurrently benefit sleep quality, gait, and postural control, reducing the risk of falling [28]. Therefore, further studies are needed to analyze the long-term effects of DT training on depression and sleep quality in older adult women. In the case of the older population, physical exercise programs based on DT principles have a high potential to benefit the perception of QoL [40,71]. One explanation is the improvement after training that is perceived by older adults (gait, muscle strength, flexibility, balance), followed by an increase in well-being during the performance of their daily tasks [71]. In a randomized controlled clinical trial (60-80 years), which compared the effects of 24 weeks of dual-task training with progression from variable to fixed priority, followed by a 24-week follow-up [34], with improved perception of QoL over time for both groups in all domains of the SF-36. However, only the physical function and general mental health domains indicated levels of significance in the comparison between the groups. Older adult fallers undergoing DT training (three times a week for six weeks) showed that SF-36 scores improved by 23.6% (p = 0.001) immediately after training. One month after the intervention, there was a reduction in scores of 17.24% [71]. The authors attributed the initial results to the likely influence of DT training on the daily life routine (i.e., improved levels of functionality).

The present pilot study has several limitations. Firstly, we recognize that the size of the effect indicated for cognitive and QV tests is a limitation of this pilot study. Thus, due to the small sample size, it is possible that differences may have influenced (i.e., potential bias) comparisons between groups at any of the measurements of measurement. Secondly, the participants do not fully reflect the entire older adult population residing in the communities. In general, most of the participants were 60 years old and were physically and cognitively healthy. This does not allow the generalization of the results to broader age groups. Thirdly, only women were included, so it would be important for future studies to also explore the effects of DT training on the EFs of older adult men and possibly compare the results with women of the same age group. Fourthly, we did not include imaging studies to accurately verify the effects of the intervention on different brain regions. Finally, perhaps interventions with greater training during the week (i.e., three sections) can reflect new comparisons and more significant results.

5. Conclusions

Results suggested that our physical-cognitive DT training program increased cognitive performance (i.e., executive functions) and quality of life (i.e., physical and mental components) of older adult women. Although the effects were not large, it was possible to verify that the suggested pilot program showed potential. A possible strategy to improve the effects of physical-cognitive DT training is to increase the number of training sessions during the week to three days instead of two days, mainly when the population is cognitively healthy, as was the case in this investigation. A strength of this pilot study was the training protocol, which did not require expensive equipment and showed the potential to ensure participant compliance over 12 weeks. Our training did not cause changes in the participants' depressive symptoms and sleep quality. We attribute these results to the low levels of depression and good sleep quality that the participants already had at baseline. It is suggested that future studies explore the effects of physical-cognitive DT training on other important functions of cognitive aging, such as memory, verbal fluency, attention, orientation, and logical reasoning. In addition, it is important to carry out population-based studies to broaden the understanding of the effects of physical-cognitive DT training in older adult women. Finally, the findings presented may contribute to the planning of future specific physical-cognitive training programs for the cognitively healthy older population.

Author Contributions: Conceptualization, M.d.M.N.; methodology, M.d.M.N., P.A.M. and A.I.; software, M.d.M.N.; validation P.M.B.R., P.A.M., L.d.S.N., C.N.S. and A.I.; data curation, M.d.M.N. and P.A.M.; writing—original draft preparation, M.d.M.N., M.K. and A.I.; writing—review and editing, P.M.B.R., P.A.M., L.d.S.N. and C.N.S.; visualization, M.d.M.N., P.A.M., P.M.B.R., L.d.S.N. and C.N.S.; supervision, P.A.M., M.K. and A.I.; project administration, M.d.M.N., M.K. and A.I.; funding acquisition, M.K. and A.I. All authors have read and agreed to the published version of the manuscript.

Funding: We acknowledge support from the Swiss National Centre of Competence in Research LIVES–Overcoming vulnerability: life course perspectives, which is funded by the Swiss National Science Foundation (grant number: 51NF40-185901). Moreover, AI acknowledges support from the Swiss National Science Foundation (grant number: 10001C_189407).

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and had been approved by the local ethics committee before the start of the data collection. The actions were approved by the Human Research Ethics Committee of the Federal University of Vale do São Francisco in Brazil (number 2,866,845, Brazil Platform).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study before participation.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author.

Acknowledgments: We thank all the older adults at the University of the Third Age, Federal University of Vale do São Francisco (UNIVASF), in the city of Petrolina, Brazil, who participated in the activities of this study, as well as in the Physical Education course at UNIVASF.

Conflicts of Interest: The authors declare no conflict of interest.

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