Journal of Exercise Science & Fitness 22 (2024) 383–389

Contents lists available at ScienceDirect

Journal of Exercise Science & Fitness

journal homepage: www.elsevier.com/locate/jesf

Enhancing physical and cognitive function in older adults through walking & resistance exercise: Korean national aging project randomized controlled study

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A R T I C L E I N F O

Keywords:
Aging
Cognition
Exercise
Muscle strength
Older adults
Physical function

A B S T R A C T

Background: The rapid aging of Korea's population underscores the urgent need for effective programs to enhance the well-being and longevity of the elderly. This study presents preliminary results from the Korean project, examining the impact of cost-effective and accessible exercise programs on functional performance of older people and to determine the long-term maintenance of intervention.

Methods: We randomized 90 older adults aged ≥65 years to the walking group (WG), resistance + walking (RWG), or active control (CG) group. We designed a 12-week main intervention (supervised resistance training 2 d/week and individual walking exercise) and a 12-week follow-up through self-directed exercise (same protocol but unsupervised). The participants' mini mental state examination, color-word Stroop test and 5-time sit to stand, timed up & go, handgrip strength, and knee extensor strength tests were assessed at pre, post, as well as follow-up.

Results: For the RWG group, significant improvements were found in timed up & go ($P < 0.001$), and 5-time sit to stand ($P < 0.001$) compared to CG, with benefits maintained at follow-up. Both RWG and WG showed significant enhancements in knee extensor power (RWG: $P < 0.0001$; WG: $P < 0.001$) and flexor power (RWG: $P < 0.01$; WG: $P = 0.018$) compared to CG. Although cognitive performance did not show significant group-by-time interactions, RWG exhibited improvements in the Stroop Color and Color-Word tests at follow-up compared to baseline.

Conclusion: A resistance training program combined with walking effectively enhanced functional performance in older adults, providing lasting benefits over 12 weeks on physical functions, such as strength and endurance. However, it showed limited benefits on cognitive performance.

1. Introduction

South Korea has struggled with the burden of rapid aging and is expected to become a super-aged society by 2025 with over 20 % of the population being 65 years or older.[1] Interest in geriatric diseases and healthy aging has increased to minimize the burden on society and prepare for this demographic shift.[2]

Muscle atrophy, an aging related determinant, is associated with significant functional impairment, injuries, and musculoskeletal disorders.[3,4] Moreover, aging is accompanied by alterations in cognitive performance due to increased oxidative stress, chronic inflammation, and declining growth factor levels.[5] Therefore, we must increase our knowledge of the mechanisms underlying alterations in muscle, cognition, and structure during aging as well as how to design specific intervention strategies. Exercise can enhance lifespan and longevity by influencing physiological mechanism (Fig. 1).[6] Both aerobic and resistance training can delaying cognitive decline and prevent dementia by promoting the release of growth factors, enhancing synaptic plasticity, and supporting neuronal survival.[7] Moreover, by boosting both neuromuscular activation and vascular function, exercise plays a significant

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https://doi.org/10.1016/j.jesf.2024.07.002
Received 18 February 2024; Received in revised form 5 July 2024; Accepted 23 July 2024
Available online 25 July 2024

role in improving muscle metabolism, such as insulin resistance and mitochondrial dysfunction. Additionally, exercise contributes to better muscle contractile function, strength, and can counteract age-related changes.[8] However, variations among studies have led some to question the consistency and sufficiency of the evidence.

Controversy persists over which type of exercise yields greater functional and physiological benefits in the elderly.[9] Resistance exercise is acknowledged as a valuable asset for promoting healthy aging, however, it is noteworthy that among Korean seniors, walking exercise is the most preferred physical activity which may enhances fitness of older adults.[10,11] While exercise has been recognized as a beneficial non-pharmaceutical intervention, approximately 60 % of elderly individuals are considered physically inactive.[12,13] Many healthcare organizations struggle to implement new interventions effectively, as these programs, despite achieving initial success, often fail to become habitual for participants, challenging the sustainability of evidence-based interventions.[14]

In this study we aimed to compare the effects of walking, combined exercise (resistance + walking) and active control on functional and cognitive performance over a 12-week period in older adults. This study also aims to assess the participants retention of these changes after a 12-week follow-up when compared to baseline values.

2. Methods

2.1. Participants

This randomized controlled trial (RCT) received ethical approval from the Institutional Review Board (SNUIRB No. 2106/002–009). Exclusion criteria included high-intensity exercise for more than 3 months, high cardiorespiratory fitness, BMI <18.5 or >30 kg/m^2, excessive alcohol consumption (>210 g/week for men and >140 g/week for women), current smoking, recent surgery, and recent health supplements. A total of 90 older adults aged ≥65 years were recruited, randomized, and allocated to one of three groups (n = 30 *3). After providing informed consent, a simple randomization method was implemented, whereby participants selected random numbers from a table according to their registration order and were then randomly assigned to one of three groups. Due to the nature of the research, neither participants nor researchers were blinded to allocation. The study design is illustrated according to the CONSORT flow diagram (Fig. 2).

2.2. Exercise interventions

For the 24-week study duration, we followed the American College of Sports Medicine (ACSM) recommendation for physical activity in older adults[15]. Three groups were administered different exercise protocols: 1) combined resistance and walking (RWG); 2) walking (WG); and 3) active control (CG). Accordingly, subjects in the RWG performed the resistance and walking protocols, while those in the WG adhered to the walking protocol only and those in the CG did not change their exercise habits and performed only light-intensity stretching at home. We provided smartwatches (Mi Watch Lite; Xiaomi, Pekin, China) to participants in WG and RWG exclusively for monitoring steps and physiological data (e.g., heart rate, calories, exercise time) during exercise.

The walking exercise protocol involved participants engaging in an outdoor walking program individually by maintaining their total steps per week according to national walking guidelines for the older adults, with intensity modified per NIH age group recommendations.[16,17] For the resistance exercise protocol, we conducted, 50 min secessions twice per week, center-based progressive resistance training with Thera-Band®.[18] To ensure progressive overload and adaptation, we reassessed the participants' individual rated perceived exertion (RPE) and handgrip strength (HGS) results every 3 weeks. If there was progress in either of these measures, we adjusted the resistance level of the elastic bands, number of repetitions and the exercise difficulty. Details of the exercise protocol are outlined in Table 1.

We designed a 12-week main intervention followed by another 12-week of self-directed exercise as a follow-up period. The main 12-week exercise period was a supervised program, during which we constantly provided feedback on participants' performance. In the follow-up period, the participants were expected to conduct the same stated exercise protocol independently without our supervision. However, we contacted them by phone twice every month to keep them on the program and be in a position to track their performance.

2.3. Outcome measures

Participant characteristics were collected at baseline (week 0), post-intervention (week 12), and follow-up (week 24). In the final analysis we used data of subjects who participated in all three time-point

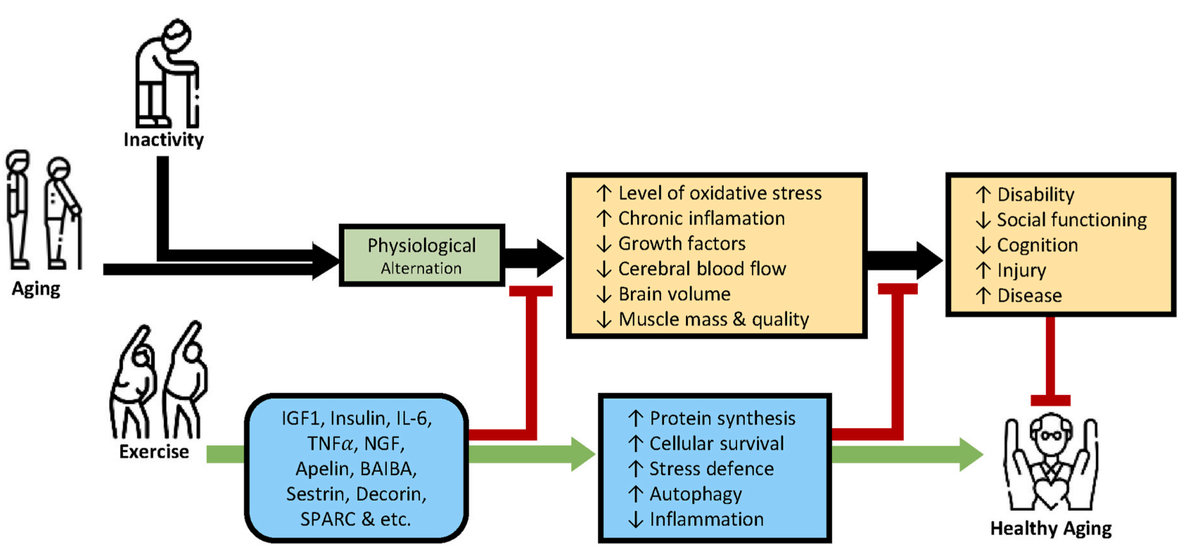

Fig. 1. The potential effects of exercise of promoting healthy aging were discovered through a literature search. Aging leads to physiological alterations that inactivity could decrease a subject's quality of life. However, exercise increases the circulation of biomarkers through the body that are associated with protein synthesis, immunity, stress, and inflammation defense, prevent the accumulation of oxidative stress and chronic inflammation, and block decreased growth hormone levels, muscle loss, and cognitive disfunction. Thus, overall exercise could lead to healthy aging.

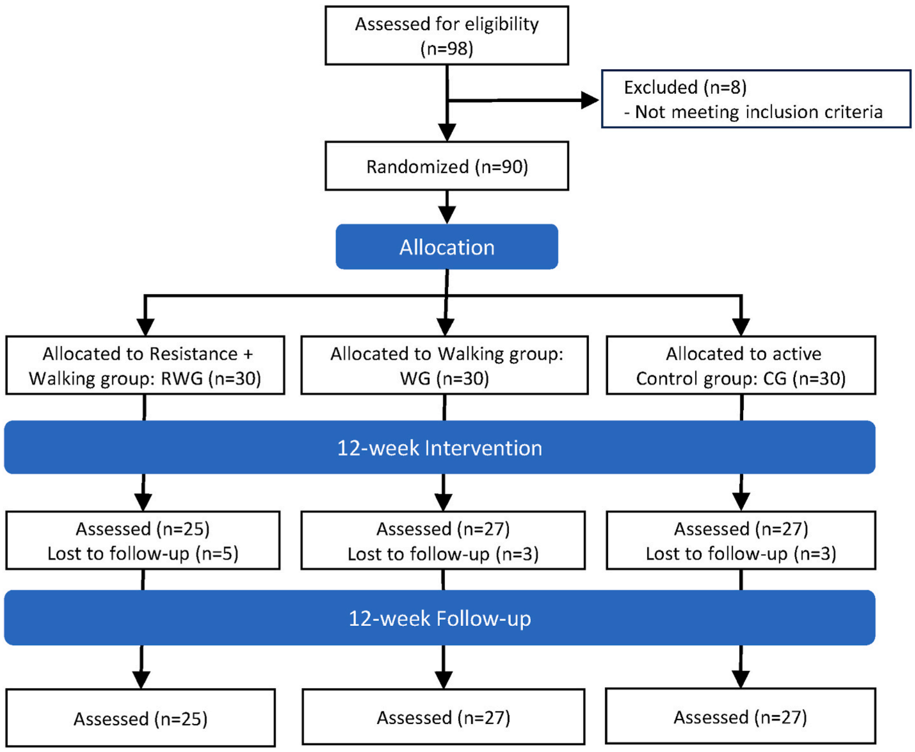

Fig. 2. An overview of the study flow, which included a 12-week exercise program as the main intervention period, followed by a 12-week self-directed exercise follow-up period.

Table 1
Walking and resistance exercise protocols.

Walking Exercise Protocol		
Age group	**Weekly Steps Goal**	**Intensity**
60s	35,000–50,000	Moderate
70s	30,000–45,000	Moderate
80s	20,000–35,000	Moderate

Resistance Exercise Protocol: 2 day/week			
Exercise Type	**Exercises**	**Intensity (RPE)**	**Repetitions**
Upper Body	Bicep curl, chest fly, triceps extension	12-14 (Moderate)	8–12
Lower Body	Toe and heel raise, lying leg abduction, squat	12-14 (Moderate)	8–12
Core	Dead bug, pelvic lift, plank	12-14 (Moderate)	8–12

assessments. The basic characteristics of the subjects were collected through detailed questionnaires. We assessed resting blood pressure (InBody 720, InBody Co. Ltd, Seoul, Korea), overall diet quality (using the recommended food score (RFS)),[19] physical activity level (using a global physical activity questionnaire (GPAQ)),[20] and ability to independently perform instrumental activities of daily living (IADLs).[21] Anthropometric measurements were recorded using the bioelectrical impedance device (InBody 720, InBody Co. Ltd, Seoul, Korea).

We conducted cognitive function tests, using the Korean version of Color-Word Stroop test (CWST), to evaluate one's ability to inhibit cognitive interference.[22] Subjects were instructed to quickly read three different pages (Color, Word, and Color-Word), each with 100 stimuli, within 40 s. Raw and interference scores were calculated as the main variables of interest.[23] Furthermore, we administered the 30-point Mini–Mental State Examination (MMSE) questionnaire, to indicate cognitive impairment (score >24: no cognitive impairment, 20–23: mild cognitive impairment, and <19: dementia).[24]

To assess frailty, we conducted the SARC-F (strength, assistance with walking, rising from a chair, climbing stairs, and falls) questionnaire.[25] The results of SPPB (balance, 4-m gait at usual speed, and five times sit to stand test (5xSST)),[26] and TUG test[27] were recorded using an electronic SPPB toolkit (eSPPB, Dyphi Inc., Daejeon, Korea).[28] We measured the maximum voluntary muscle strength of the upper body using a digital hand grip dynamometer as an HGS test (TKK 5401 GRIP D; Takei, Japan); and to assess lower body strength, an isokinetic dynamometer was used on the preferred leg. Participants performed 5 extensions and flexions at 60°/s for knee muscle strength and 15 repetitions at 180°/s for endurance.[29] After providing the optimal rest time, modified Åstrand bike test was conducted to assess maximal aerobic capacity (VO_2 peak).[30]

2.4. Statistical analysis

SPSS software (IBM SPSS Statistics 26.0) was used for the statistical analysis whilst the graphs were produced in GraphPad Prism (version 9.5.0). Statistical significance was accepted at values of $P < 0.05$. The normality of data distribution was evaluated by the Shapiro–Wilk test. We detected outlier data and used statistical methods to transform the values for better management. To compare the groups at baseline, we used one-way analysis of variance (ANOVA) for continuous variables and used the Chi-Square test for categorical variables. For the analysis of interaction effects and inter-group differences, two-way repeated measure ANOVA were applied. We adjusted for Tukey's multiple comparison post-hoc test for the intergroup contrast at each time points and calculated Cohen's d to determine effect sizes.

3. Results

A total of 79 participants successfully completed the study. Baseline characteristics of participants are shown in Table 2. During the main intervention phase, participants in the RWG reached 105 % of the minimum age-adjusted weekly steps goal criteria, while participants in the WG reached 106 %. However, the engagement in walking exercise

Table 2
Baseline characteristics of the participants.

Variable	RWG (n = 25)	WG (n = 27)	CG (n = 27)	*P*
Gender: Male/Female (n)	5/20	12/15	8/19	0.160
Age (years)	73.0 ± 4.6	73.9 ± 4.2	74.3 ± 5.9	0.655
≥65–69 (n)	7	3	7	
70s (n)	15	21	12	
80s (n)	3	3	8	
Resting heart rate (bpm)	76.7 ± 12.0	79.3 ± 9.0	75.5 ± 11.0	0.422
Alcohol consumption (SD/wk)	0.2 ± 0.6	0.6 ± 2.0	0.5 ± 1.3	0.561
RFS (score)	26.48 ± 9.89	29.81 ± 7.05	27.63 ± 9.27	0.383
Sarcopenia: SARC-F (score)	0 [0]	0 [1]	0 [1]	0.160
IADLs (score)	0 [0.1]	0 [0.1]	0 [0.3]	0.647
Activity level (METs - min/wk)	1235.2 ± 959.5	1688.2 ± 1056.3	1071.1 ± 925.0	0.064
Height (cm)	157.7 ± 6.2	159.2 ± 9.8	156.2 ± 8.9	0.434
BMI (kg/m^2)	23.4 ± 2.8	24.1 ± 2.2	24.7 ± 4.5	0.426
Skeletal muscle mass (kg)	20.7 ± 3.1	22.3 ± 4.6	21.1 ± 4.9	0.395
Body fat (kg)	19 ± 4.7	19.8 ± 4.7	19.2 ± 4.2	0.799
SPPB (score)	12 [0]	12 [1]	12 [1]	0.715
MMSE (score)	27 [2]	27 [5]	26 [4]	0.146
Comorbidities (n)	10	11	10	
Hypertension	7	8	9	
Diabetes Mellitus	3	5	2	
Hyperlipidemia	4	4	2	
Hypothyroidism	0	1	1	

The data are presented as mean ± SD or Median [IQR]. Recommended food score (RFS); Instrumental activities of daily living (IADLs); Short physical performance battery (SPPB); Mini-Mental State Examination (MMSE); Combined resistance and walking group (RWG); Walking group (WG); Control group (CG).

decreased to 94 % for RWG and 95 % for WG in follow-up period. Notably, adherence to resistance exercise alone was high at 96 %. Following the exercise protocol, the calorie expenditure results from the two mentioned exercise interventions did not differ, which indicates a similar exercise volume (Fig. 3). We did not observe any significant effects of the intervention on muscle mass. However, we indicated lifestyle changes through the RFS score, where all groups had significantly higher scores at follow-up compared to baseline (RWG: Mean dif. = 4.01; WG: Mean dif. = 3.56; CG: Mean dif. = 4.89).

As shown in Fig. 4, after the 12-week intervention, RWG participants showed a significant improvement in HGS (Mean dif. = 1.01, Fig. 4a). ANOVA indicated a significant group-by-time interaction on TUG ($F = 7.308$, $P < 0.001$, Fig. 4b) with a large effect size ($d = 0.876$). Differences were detected in RWG ($P < 0.001$) and WG ($P < 0.01$) compared to CG after 12 weeks, and these changes were preserved at follow-up (RWG: $P < 0.0001$; WG: $P < 0.01$). Although the effects on the 4-m gait test were unclear after 12 weeks, RWG showed significantly

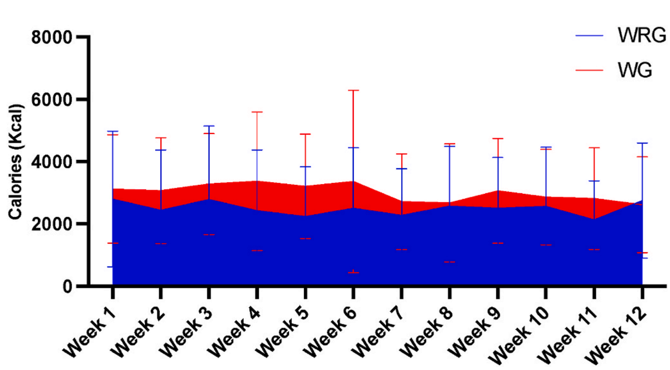

Fig. 3. Comparing weekly calorie expenditure during exercise intervention. No significant differences found between two groups. RWG; resistance + walking group, WG; walking group.

better follow-up performance compared to baseline (Mean dif. = -0.31, Fig. 4c). For the 5xSST, a significant interaction was observed ($F = 8.694$, $P < 0.001$, Fig. 4d) with a large effect size ($d = 0.956$). Significant changes were noted in RWG compared to CG after 12 weeks ($P = 0.043$) and at follow-up compared to WG ($P < 0.01$) and CG ($P < 0.001$). No interaction effect was found in VO_2 peak between groups, but CG showed a significant decline at follow-up compared to baseline (Mean dif. = -1.57, Fig. 4e). While, RWG exhibited prolonged time to exhaustion at VO_2 peak post-intervention compared to baseline (Mean dif. = 30.40, Fig. 4f).

The results of the isokinetic knee test showed significant effects of the intervention on knee muscle strength, power, and endurance (Fig. 5). There was a significant interaction in knee extension muscle strength ($F = 3.269$, $P = 0.013$, $d = 0.585$, Fig. 5a), with significant post-intervention differences in RWG ($P < 0.01$) and WG ($P = 0.030$) compared to CG. While no interaction effects were seen in knee flexor muscles, significant differences were observed between RWG and CG after 12 weeks of exercise ($P < 0.01$) and at follow-up ($P = 0.048$, Fig. 5b). Both knee extensors ($F = 10.089$, $P < 0.001$, $d = 1.031$) and flexors ($F = 6.149$, $P < 0.001$, $d = 0.803$) showed a significant interaction in power. Knee extensors' power improved significantly in RWG and WG compared to CG after 12 weeks (RWG vs. CG: $P < 0.0001$; WG vs. CG: $P < 0.001$), and at follow-up (RWG vs. CG: $P < 0.01$; WG vs. CG: $P < 0.001$, Fig. 5c). Knee flexor power improved in both RWG ($P < 0.01$) and WG ($P = 0.018$) compared to CG after 12 weeks (Fig. 5d). RWG also showed significant improvements at follow-up compared to CG ($P = 0.015$). A significant interaction was observed in the endurance of knee extensor and flexor muscles; however, there were no differences between groups at each time point (Fig. 5e and f).

Regarding cognitive performance, the results did not indicate any significant group-by-time interaction in either the MSSE or SCWT. However, participants in the RWG showed significant improvement in the Stroop Color test post-intervention (Mean dif. = 3.86) and at follow-up (Mean dif. = 4.35, Fig. 6b). In contrast, the score of CG participants dropped significantly at follow-up compared to baseline (Mean dif. = -3.96, Fig. 6b). For the SCWT, only the RWG showed significantly higher performance at follow-up (Mean dif. = 3.33, Fig. 6c) when compared to baseline. Detailed results of data analysis are available in Supplementary Tables 1 and 2

4. Discussion

This study examined the effects of walking exercise alone or combined with resistance training, and compared these effects with control group after 12-week main intervention and 12-week follow-up period, among older adults. The primary findings of this study indicate that the combined resistance and walking exercise regimen led to significant benefits in muscle strength, power, endurance, and certain cognitive functions. RWG outperformed both the WG and the control group at follow-up in the 5xSST, and significant better performance in HGS, TUG, and knee muscle test. Furthermore, RWG participants showed better performance in cognitive tasks such as the CWST. Secondly, physical improvements in the 4-m gait test, 5xSST, and knee muscle endurance were sustained at follow-up, highlighting the lasting impact of the intervention.

Our study was conducted during the COVID-19 pandemic, a period marked by worldwide government-imposed social distancing measures to contain the outbreak. These measures resulted in reduced physical activity, leading to muscle loss and decreased strength, which is an independent risk factor for mortality.[31] We believe our exercise program utilizes the most common and inexpensive exercises which do not require costly equipment and could be part of one's daily routine.[10] Walking and resistance exercise with elastic bands are highlighted as cost-effective exercise-based fall prevention programs, including lower-limb strengthening exercises, as supported by several studies due to their affordability and minimal equipment requirements, making

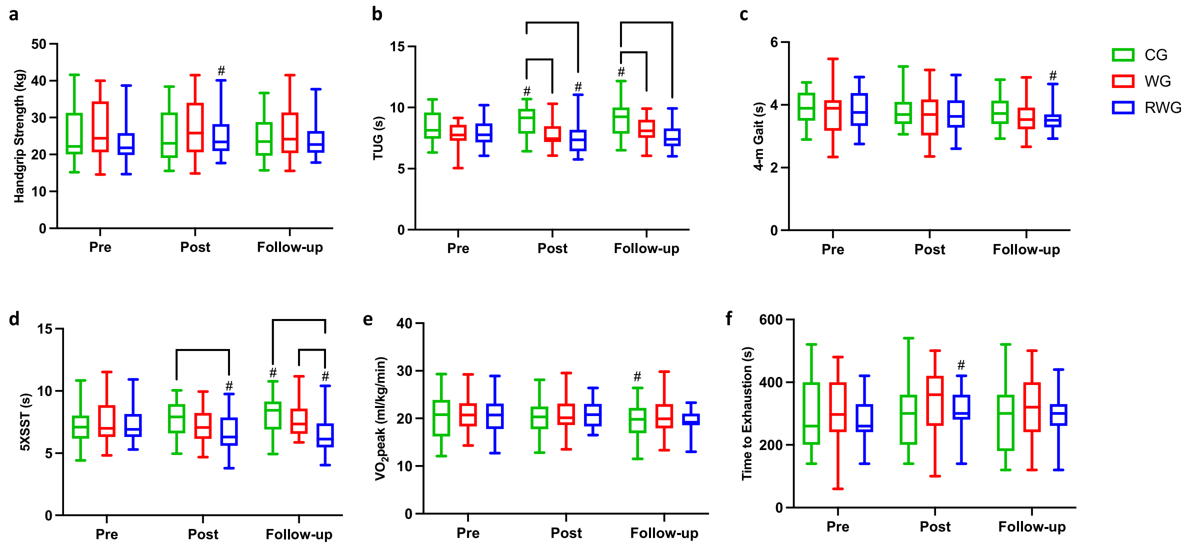

Fig. 4. Changes of physical performance post-intervention and after 12 weeks follow-up. Value are presented as mean ± SD. RWG; resistance + walking group, WG; walking group, CG; control group, 5xSST; 5-time sit to stand test, TUG; timed-up & go test, HGS; handgrip strength. *P ≤ .05, **P ≤ .01, ***P ≤ .001; significant differences between groups. # Indicates within-group significant differences compared to baseline.

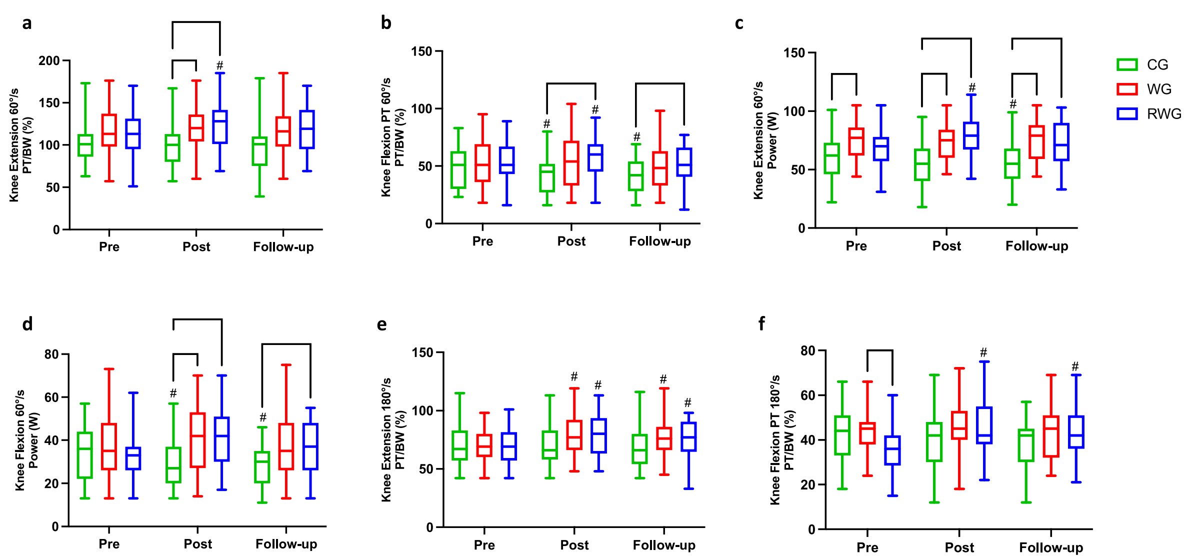

Fig. 5. Changes of knee muscle strength, power and endurance post-intervention and after 12 weeks follow-up. Value are presented as mean ± SD. RWG; resistance + walking group, WG; walking group, CG; control group, PT/BW; Peak torque per body weight. *P ≤ .05, **P ≤ .01, ***P ≤ .001; significant differences between groups. # Indicates within-group significant differences compared to baseline.

them perfect for home and community use.[32] Although overall health benefits of exercise have been reported in many aspects, more research is still required in this path to discover the effect on various physical and functional aspects, especially in the older population.

Several meta-analyses and RCTs supported an association between improvements in physical function and cognitive enhancement after regular exercise.[4,9,33,34] Recent studies have indicated that combined exercise training shows small-to-moderate beneficial effects when compared with strength training (on 30-s chair stand test) and no-exercise controls (on TUG, 30-s chair stand, and 6min walk tests) in older adults.[34] Though we did not find differences between RWG and WG post-intervention, in overall compared to the older control group, the combined exercise group showed a larger impact on both TUG and 5xSST (Fig. 4b–d).

The decline in muscle strength is a well-known consequence of the aging process and low muscle strength is linked to several health factors, including reduced functional status, limitations in IADLs, diminished cognitive function, higher morbidity, and mortality. HGS, extensively studied in the literature, can serve as a screening tool for identifying impairments in the older adults and there is a correlation between knee extension forces and gait speed.[35] Regarding HGS, participants in the RWG gained significantly more strength than WG (Fig. 4a). Furthermore, in comparison to the control group, we observed significant improvements in favor of the combined exercise in lower extremities' strength, power, and endurance (Fig. 5), which led to better physical performance in TUG and 5xSST (Fig. 4b–d). In line with our findings, De Liao, Chun et al. reported a significant reduction in TUG after 12 weeks of resistance training in obese women with sarcopenia.[36] However, Tsekoura et al. found that resistance training alone, without aerobic exercise, also significantly reduced TUG.[37] In our study the differences between WG and RWG regarding lower muscle strength were not found after the intervention (Fig. 5a and b). Similarly, a 24-week combined exercise on older adults only showed a significant increase in knee extensor torque within the resistance group and no differences with

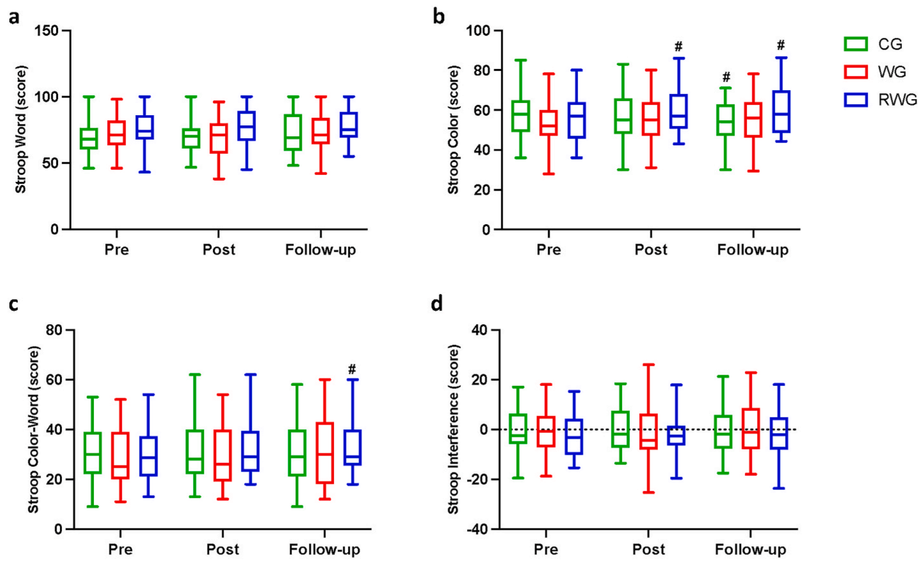

Fig. 6. Changes of cognitive function Post-intervention and after 12 weeks followup. Value are presented as mean ± SD. RWG; resistance + walking group, WG; walking group, CG; control group. # Indicates within-group significant differences compared to baseline.

multicomponent training group.[38]

According to reviews, combining exercises, including aerobic ones, can enhance executive functioning in older adults regardless of exercise type or intensity, and the magnitude of the effects on executive function was larger for sedentary participants.[39] A recent study reported that both combined exercise and walking significantly lower the risk of dementia.[40] Additionally, cognitive improvements were reported in healthy adults following long-term interventions lasting more than 12 months.[9,39] However, we could not identify any significant impact of exercise on the cognitive function tools that were assessed (Fig. 6). This might be due to the absence of cognitive impairment among our participants (MMSE 26.72 ± 2.26), leaving little room for measurable improvement within the intervention timeframe.

A significant aspect of our study evaluated the maintenance of our exercise program after the 12-week intervention. We reported that the improvements in functional performance remained during a self-directed exercise period when compared to baseline values. While a previous study involving a 12-month follow-up with 175 older participants had suggested that frequent supervision may be necessary to ensure consistent exercise performance on their own.[41] Two potential limitations of our study are the unsupervised nature of the walking exercise, where participants in the WG were engaged in self-paced walking exercises individually without controlled speed. This lack of group exercise and supervision may introduce biases into our findings. Additionally, our study's participants, including the control group, generally exhibited higher levels of physical activity compared to sedentary community-dwelling older adults. Therefore, detecting cognitive improvements in our participants might be influenced by their healthy condition. Future studies are needed to control the level of habitual physical activity and supervision in all groups, including control subjects, to isolate the pure intervention effect. Additionally, employing various cognitive function assessment tools, such as brain imaging or EEG signal analysis during the CWST, could lead to more distinguished results.

5. Conclusion

These findings suggest that a combined resistance and walking exercises may have broader and longer-lasting benefits on physical and cognitive function. The improvements in strength and endurance performance suggest their combined effect enhances functional capacity and can be maintained over 12 weeks. However, it showed limited benefits on cognitive performance. This underscores the importance of exercise programs for promoting both physical and cognitive health in older adults.

Author contributions

W.S. developed the theory and conceptual framework and oversaw the project. P.J., Y.S., X.L., provided critical feedback in protocol design and helped shape the research. W.S., P.J., X.L., Y.S., D.H.K., S.H.A., and Y.S.K. had specific contributions to designing the exercise protocol. All authors reviewed the manuscript, while P.J. took the lead in writing the manuscript and data analysis.

Funding

This research was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean governemnt (MSIT) (No. 2020M3A9D8038660).

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Wook Song reports financial support was provided by National Research Foundation of Korea (NRF). If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jesf.2024.07.002.

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