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ORIGINAL RESEARCH

EFFECTS OF HIGH-SPEED POWER TRAINING ON NEUROMUSCULAR AND GAIT FUNCTIONS IN FRAIL ELDERLY WITH MILD COGNITIVE IMPAIRMENT DESPITE BLUNTED EXECUTIVE FUNCTIONS: A RANDOMIZED CONTROLLED TRIAL

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Abstract: *Background:* Physical frailty and impaired executive function of the brain show similar pathophysiology. Both of these factors lead to dysfunction of neuromuscular and abilities in elderly. High-speed power training (HSPT) has been determined to have positive effects on neuromuscular function and gait performance, as well as executive function in the elderly. *Objectives:* The purpose of this study was to investigate the effects of 8-week HSPT on neuromuscular, gait and executive functions in frail elderly with mild cognitive impairment (MCI). Design, setting and participants: We performed a randomized controlled trial of frail elderly from community and medical center in republic of Korea. Forty-two physically frail elderly with MCI were randomly allocated to control (n=22, age=74.22±4.46) and intervention groups (n=18, age=73.77±4.64). The intervention group was subjected to HSPT, 3 times weekly for 8 weeks. *Measurements:* Isometric contraction of knee extension and flexion with electromyography (EMG) was measured to determine the neuromuscular function such as knee extensor strength, rate of torque development, movement time, pre-motor time, motor time, rate of EMG rise, and hamstrings antagonist co-activation. Additionally, the 4.44-meter gait and timed up-and-go (TUG) test were administered to assess gait performance. A frontal assessment battery was measured in this study. *Results:* The 8-week HSPT regimen improved the knee extensor strength from 1.13±0.08 to 1.25±0.07 ($p<0.05$), the 200-ms RTD from 3.01±0.3 to 3.55±0.24 ($p<0.05$) and the rate of EMG rise from 166.48±13.31 to 197.94±11.51 ($p<0.05$), whereas the movement time and motor time were statistically decreased from 921.69±40.10 to 799.51±72.84, and 271.40±19.29 to 181.15±38.08 ($p<0.05$), respectively. The 4.44-m gait speed and TUG significantly decreased from 6.39±0.25 to 5.5±0.24, and 11.05±0.53 to 9.17±0.43 respectively ($p<0.05$). *Conclusion:* The findings of this study suggest the favorable effects of 8-week HSPT on the neuromuscular function and the gait performance in the frail elderly with MCI without increase in the executive function.

Key words: Frailty, High-speed power training, Mild cognitive impairment, Neuromuscular functions, Randomized controlled trial.

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Introduction

Frailty is associated with aging that is characterized by declined neuromuscular and gait functions, resulting in adverse outcomes such as falls, physical disabilities, hospitalization, dependence, and mortality (1). Particularly, the frailty affects dysfunction of neuromuscular functions including muscular strength, rate of torque development (RTD), pre-motor time, motor time, movement time, rate of electomyogram (EMG) rise and hamstrings antagonist co-activation related to gait performance in the frail elderly (2).

Mild cognitive impairment (MCI) is defined by the transition state from normal cognition to dementia (3). MCI is best illustrated by Alzheimer's disease, which typically decreases the executive functioning necessary for gait performance in the elderly (4).

Physical frailty and MCI may regress simultaneously due to the shared pathophysiological mechanisms (5). Previous study has reported that the physical frailty combined with MCI exacerbates the risk of physical disability more than frailty or MCI alone in the elderly (6). The frailty and MCI significantly increase the possibility of physical dependence and the risk of severe dementia (7).

The elastic band-based high-speed power training (HSPT) entailing high-speed movement was proposed as one of the safe and low-intensity exercise modalities (8). HSPT was performed via concentric contractions of 1 second duration and eccentric contractions lasting approximately for 3 seconds, using an elastic band (9). For instance, Yoon et al. (2017) reported that the frail elderly instructed to conduct HSPT showed significant improvements on timed up and go (TUG) and knee extensor strength as well as executive functions after 12 weeks (10).

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However, the efficacy of HSPT with elastic band on the neuromuscular, gait and executive functions in the frail elderly with MCI, has not been yet demonstrated. Thus, the purpose of this study was to investigate the effects of HSPT on neuromuscular, executive and gait performance in the frail elderly group with MCI. We hypothesized that the elastic band-based HSPT improves the neuromuscular, gait and executive function in the frail elderly with MCI.

Methods

Subjects

The study involved 65 participants institutionalized to reside in D-gu (Seoul, Republic of Korea) and meeting the following criteria: age, over 65 years; MCI, 0.5 score out of 3 on the Clinical Dementia Rating (CDR) scale, and 1.0~2.0 out of 18 in the Clinical Dementia Rating-Sum of Boxes (CDR-SOB) (11); frailty, 3 out of 5 on the Fried frail phenotype scale developed by the Department of Neuropsychiatry at SMG-SNU Boramae Medical Center (1)). Scores of 0 and 3 on the CDR represent normal cognitive condition and severe dementia, respectively. Scores 0 and 16.0-18.0 scores in the CDR-SOB suggest normal cognitive condition and severe dementia, respectively. Participants with mental, visual muscular disorder, depression, dementia, 10-meter walking failure without a cane or helper, and joint fracture and surgery were excluded from this study, including those diagnosed with mild cognitive impairment (n = 12), frail elderly (n = 7), and healthy older adults (n = 4) called "Robust".

Following general screening, the subjects' body composition was analyzed. The participants were subjected to the Korean version of Mini-Mental State Examination (MMSE-K), and frontal assessment battery test. Other parameters such as isometric knee extensor strength, RTD, pre-motor time, motor time, movement time, rate of EMG rise, hamstrings antagonist co-activation, and 4.44-meter gait speed were evaluated. Further, a pre-test TUG was administered.

The 42 screened participants were separated into control and intervention groups (CON, n = 22; EX, n = 20) with randomization process blocked using a randomized number generating software (2). The intervention group was exposed to elastic band-based HSPT for 8 weeks at the Seoul National University. The control group was provided with physical training lectures and health management by telephone and/or messages. During the training, 2 participants dropped out, due to lack of training time. No other adverse events were reported. Reid K.F. et al. (2014) showed that training adherence rate corresponded to 82% (12). The adherence rate corresponded to 91.7% in this study. After the completion of 8 weeks of intervention, all the subjects underwent post-test evaluation for consistency with pre-test observations.

Prior to this randomized controlled trial, the purpose, procedure, and possible risks of the current study were communicated verbally and in writing to the subjects, who then signed informed consent. The study was approved by the institutional review board (IRB) of B hospital under Seoul national university (BRMH No. 16-2016-26).

Neuromuscular Functions

The neuromuscular functions of the dominant leg were measured using an HUMAC NORM isokinetic dynamometer (CSMi Solutions, Stoughton MA, USA). The neural functions of the subjects were also measured, which included movement time, pre-motor time, motor time, hamstrings antagonist co-activation and the rate of EMG rise using an EMG device (TeleMyo 2400T, Noraxon co., USA). The muscular functions were measured in terms of peak torque and RTD of knee extensor. Before the tests, the torque value from the isokinetic dynamometer was synchronized to the EMG device in advance.

The isokinetic dynamometer was set to a seated position with a hip angle of 85° and knee joint angle was flexed 90° for the test. The standard "zero" degree angle represented complete extension of the knee joint (13). The subjects were advised to sit on a chair with electrode-skin pads (3.6 mm x 2.4 mm, 220 mm) placed on the dominant leg for measurement of neural variables. Two electrode-skin pads were attached to the rectus femoris and biceps femoris (2). The electrode pads were attached to the dominant leg of the subject based on the criteria recommended by SENIAM (14). The subjects sat on the chair of the isokinetic dynamometer, with the torso and the thigh fastened by a harness included in the isokinetic dynamometer and were fixed by a Velcro strap. The subjects were instructed to perform isometric maximal contraction of the dominant leg in 3 trials for 3 seconds each (2).

Gait Functions

The 4.44-m gait speed was defined as the one item on the frailty scale (1). Three lines were drawn parallel and each interval distance between the first and the second lines nearest to the subject was selected as 4.44 m, and the interval between the second and third lines was considered as 1 m, for a total distance of 5.44 m (1). The subjects stood on the first line and walked toward the third line immediately following the "go" signal by the expert (1).

The TUG test was conducted by measuring the time taken by the subject rising from the chair immediately following the "go" verbal signal by the expert, walking a distance of 3 m, turning around on the line, walking back to the chair, and sitting down on the chair (15).

Executive Function

The executive function of the frontal lobe was tested using the frontal lobe test consisting of six parts: Conceptualization, Mental flexibility, Motor programming, Behavioral self-control, Inhibitory control, and Primitive reflex (16). In this study, the Korean version of frontal lobe battery (FAB-K) was measured in both groups and the questionnaire was translated by Kim (17). Inter-rater and test-retest reliability scores of the translated FAB-K were 0.98 and 0.82, respectively (17). The values were

Table 1
The outcomes of characteristics in the subjects

	Control group (n=22)	Intervention group (n=18)	P-value
Age (yrs)	74.2±4.4	73.7±4.6	0.758
Height (cm)	157.3±6.8	156±10.2	0.621
Weight (kg)	60.6±1.9	61.0±2.1	0.896
Sex, n (%)			
Female	13 (59.1%)	11 (61.1%)	0.934
Male	9 (40.9%)	7 (38.9%)	0.919
MMSE-K (score)	23.4±1.3	23.8±2.9	0.551
Education, n (%)			
≤6 (6yrs)	9 (40.9%)	10 (52.6%)	0.503
7-12 (6yrs)	9 (40.9%)	6 (40.0%)	0.697
≥13	4 (18.2%)	2 (11.1%)	0.565
Fall history, n (%)			
No	18 (81.8%)	15 (77.8%)	0.958
Yes	4 (18.2%)	3 (22.2%)	0.909
Frailty indicators, n (%)			
Weight loss	1 (4.5%)	2 (11.1%)	0.563
Exhaustion	9 (40.9%)	5 (27.8%)	0.285
Physical inactivity	5 (22.7%)	6 (33.3%)	0.763
Slow walking speed	7 (31.8%)	8 (44.4%)	0.796
Weak grip	10 (45.5%)	11 (61.1%)	0.827

MMSE-K Korean version of Mini-Mental State Examination; All data are expressed as mean ± standard deviation (SD) and/or n (%). Significant values are based on independent t-test in mean ± SD, and on x2-test in nominal variables. Significant value is <.05.

scored using a scoring system in which the highest score was 18, and the lowest was zero (18).

Exercise Intervention

HSPT was conducted based on frequency, intensity, type, and time (8). The frequency of this intervention involved 10~12 repetitions of two to three sets, 3 times weekly and the intensity was selected using a 6-20 rated perceived exertion (RPE) index ranging from 12 to 13, indicating "Light hard" to "Somewhat hard" levels (10). The training intervention was carried out for a total of 50 minutes per session, including a 10-minute warm-up involving stretching, while the main exercise lasted for 30 minutes, followed by a 10-minute cooling down. The resting period between the different stretches was 30 seconds, and 1 minute between sets.

The intervention group was subjected to 1-week body-weight training in the early phase of intervention for familiarization of the main training in this study (19). The 1-week body-weight training program was composed of 8 movements such as seated row exercises, one-leg press, applied pec dec flys or lateral raises, seated leg raises, normal squats, full squats, wide squats, and bridging exercises. The subjects in the intervention group were trained in 8 movements with an elastic band from 2 to 4 weeks (seated row, one-leg press, applied pec deck flys, seated leg raise, lateral raise, semi-squats, normal squats, and bridging) and the movements were slightly altered from 5 to 8 weeks in order to maintain "somewhat" training intensity (seated row, one-leg press, applied pec deck flys, seated leg raise with 5-s hold-up, lateral raise, normal squats, wide squats, and bridging). The intensity of the exercise training was progressively increased with the number of repetitions and sets (10). The intervention group was instructed to perform concentric contractions for 1 second and eccentric contractions for 3 seconds by an exercise expert during the training. The exercise expert provided the technique and velocity of the training for the intervention group by using verbal counting signals.

The subjects in the control group were offered a small group lecture to encourage physical activity, in addition to exercise counseling and exercise Q & A sessions by the expert.

Statistical Analysis

The IBM SPSS windows-based statistical software version 23.0 was used in this study. All values were expressed as means ± SD. Independent Student's t-test and x2 of nominal variables were carried out to verify statistical homogeneity. The results of training intervention-related effects were analyzed by a two-

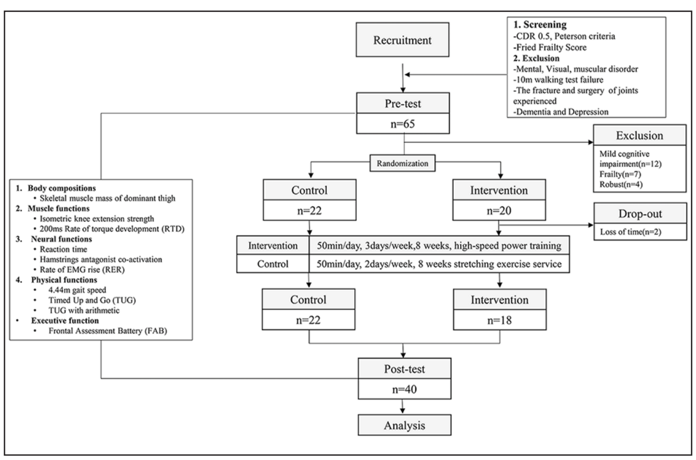
Table 2
The outcomes of neural functions (A) and executive function (B) in pre and post tests

	Control group (n=22)		Intervention group (n=18)	
	Pre	**Post**	**Pre**	**Post**
A				
Movement time (ms)	906.36±36.27	1010.04±65.89	921.69±40.10	799.51±72.84*,$
Pre-motor time (ms)	700.64±36.62	757.34±56.37	663.82±40.48	626.96±62.32
Motor time (ms)	205.67±17.45	252.70±34.44	271.40±19.29	181.15±38.08*,#
Antagonist co-activation (% pEMG)	25.28±3.75	25.04±3.72	27.89±4.14	26.32±3.48
Rate of EMG rise (% pEMG•s^{-1})	169.30±12.04	161.82±10.41	166.48±13.31	197.94±11.51*,#,$
B				
FAB (score)	11.72±2.11	11.77±2.22	11.38±2.56	12.16±1.79
Conceptualization (score)	1.63±0.95	1.54±0.85	1.72±0.89	1.50±0.78
Mental flexibility (score)	1.27±0.63	1.40±0.59	1.11±0.75	1.22±0.80
Motor programming (score)	2.18±1.05	2.36±0.95	2.22±1.16	2.88±0.32
Self-control of behavior (score)	2.18±0.79	2.45±0.80	2.33±0.90	2.44±0.70
Inhibitory control (score)	1.31±0.77	1.04±0.89	1.11±1.02	1.22±1.00
Primitive reflex (score)	2.95±0.21	2.95±0.21	2.83±0.38	2.88±0.32

FAB Frontal Assessment Battery; % pEMG percentage of peak EMG amplitude; All data are expressed as mean ± standard deviation (SD); #<0.05 compared pre with post training in intervention group; $<0.05 compared intervention group with control group at post-test; *<0.05 measured in two-way repeated measures ANOVA between time and group

way repeated ANOVA with automatic post-hoc testing (group x time). Statistical differences in all values were considered significant based on p<.05 using a confidence interval of 95%.

Figure 1
The procedure of recruitment, screening, randomized allocation, tests, intervention for this experimental period

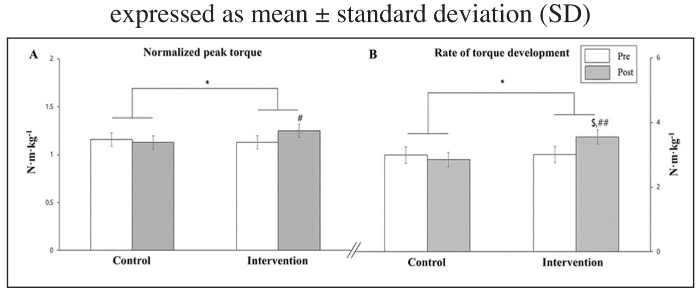


Results

We measured the age, height, weight, MMSE-K scores, level of education, falling history and frailty indicators in the homogeneity examination of subjects in the control and intervention groups. All variables showed no significant differences in both groups at the baseline (p>0.05) (Table 1).

Following 8 weeks of HSPT, significant interaction between time and group effects were detected in knee extension peak torque and 200 ms RTD (p<0.05) (Figure 2). Statistically significant differences between pre- and post-time of knee extension peak torque were found within the training groups (p<0.05; 95% CI:0.019 to 0.212). Statistically significant differences between pre- and post-time of the RTD within the training groups were detected (p<0.001; 95% CI:0.148 to 0.920). Also, the RTD in the intervention group increased higher than in the control group at post-time (p<0.05; 95% CI:0.043 to 1.357) (Figure 2).

Figure 2
The outcomes of normalized peak torque (A) and rate of torque development (B) in pre and post tests
Control group n=22, intervention group n=18; All data are expressed as mean ± standard deviation (SD)



#<0.05 compared pre with post training in intervention group, ##<0.01 compared pre with post training in intervention group; $<0.05 compared intervention group with control group at post-test; *<0.05 measured in two-way repeated measures ANOVA between time and group

In this study, movement time, pre-motor time, motor time, hamstrings antagonist co-activation and rate of EMG rise were measured before and after training. The movement time, motor time and rate of EMG rise showed significant two-way interaction between groups and times ($p<0.05$), respectively. However, the pre-motor and hamstrings antagonist co-activation were not changed significantly between groups and times. The movement time between control and intervention groups was changed statistically at post-time ($p<0.05$; 95% CI: -409.38 to -11.67). Pre- and post-time of the motor time changed statistically within the intervention group ($p<0.05$; 95% CI: -169.21 to -11.27). The rate of EMG rise between intervention and control groups increased statistically significantly at post-time ($p<0.05$; 95% CI:4.68 to 67.54). Also, the increase in pre and post-time of the rate of EMG rise were significantly altered within the intervention group ($p<0.05$; 95% CI:2.89 to 60.01) (Table 2-A). However, the frontal assessment battery was not statistically significant in the results (Table 2-B).

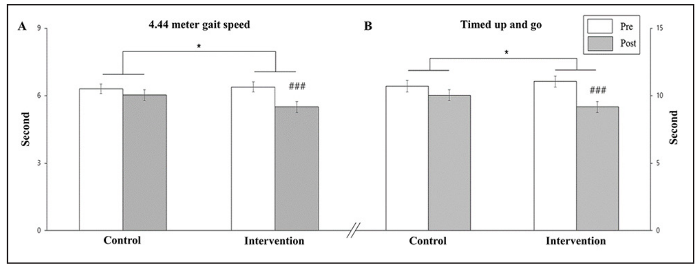
In this study, the variables of the 4.44-m gait speed and TUG test were statistically significant in the two-way interaction across groups and times before and after training inventions ($p<0.05$). Significant differences in time values of both variables within the training groups were confirmed in this study. The 4.44-m gait speed was significantly increased between pre- and post-time in the intervention group compared with the control group ($p<0.001$; 95% CI:-1.33 to -0.44). The TUG test was increased statistically between pre- and post-time in the intervention group compared with the control group ($p<0.001$; 95% CI:-2.62 to -1.14) (Figure 3).

Discussion

The primary results of this study are as follows: the 200 ms RTD, and the rate of EMG rise in the dominant knee extensor of the intervention group with concurrent frailty and MCI were increased significantly, and the motor time decreased statistically after 8-week HSPT intervention. However, the statistical increase in the knee extensor peak torque was observed directly in the result. In contrast, the pre-motor time, hamstrings antagonist co-activation and frontal assessment battery scores remained unchanged statistically. Nevertheless, the statistical decrease in the 4.44-m gait speed and the TUG test showed a slightly positive result.

Ringsberg K. et al. (1999) reported that the older women aged 75 showed a statistically significant relationship between isometric knee extensor strength and gait speed (20). Karttunen N. et al. (2012) demonstrated that the men and women averaged 75-year old with limited mobility showed significant relationship statistically in poor isometric knee extensor strength (21). A few studies suggested similar results consistent with our findings in that the quadriceps muscle strength and RTD in the intervention group increased favorably compared to the control group after 8 weeks of resistance training (19, 22). It has been reported that these changes in muscle strength and RTD may be attributed to neural changes or adaptations in the elderly (23). According to another study, the HSPT intervention in the elderly significantly improved walking ability and TUG test compared to the control group (24).

Figure 3
The outcomes of 4.44 m gait speed (A) and Timed up and go (B) in pre and post tests



Control group n=22, intervention group n=18; All data are expressed as mean ± standard deviation (SD). ###<0.001 compared pre with post training in intervention group; $<0.05 compared intervention group with control group at post-test; *<0.05 measured in two-way repeated measures ANOVA between time and group

The rate of EMG rise was similar to other studies. A study by Reid et al. (2015) reported a significant increase in the rate of EMG rise among the elderly averaged 77-year old who conducted HSPT at 40% of 1RM for 16 weeks compared to the elderly who underwent HSPT at 70% of 1RM (12). It can be inferred that the low-intensity HSPT may influence the apparent increase in the rate of EMG rise because the abilities to recruit motor units and maximal motor unit-firing rate were developed parallel to the increased RTD associated with recruiting motor units (25).

In this study, the movement time and motor time of the intervention group were lower than in the control group although the pre-motor time was not changed significantly in both groups. LaRoche et al. (2007) demonstrated that the motor time in highly active elderly participants averaged 80.4 metabolic equivalent-hours per week (Methwk-1) was statistically lower than the motor time in non-active elderly participants averaging 19.6 Methwk-1 (26).The motor time represents the excitation and contraction movements, which are linked to tight elastic and lax structures of the muscle-tendon unit (26). The results of this study indicate that the 8-week HSPT in the frail elderly group with MCI may show an increase in release or re-uptake velocity of calcium from sarcoplasmic reticulum, creatine kinase or actomyosin ATPase, following decline in the excitation-contraction coupling time (27). The decline in motor time may be associated with the increased RTD, which may explain the relationship between the excitation-contraction coupling and explosive muscle strength (28). Also, the decline in movement time may be caused by the decrease in the motor time.

Hamstrings antagonist co-activation can be explained using two different controversial concepts in older adults: muscle strength adaptation for improved stability in aging versus diminished muscle strength (29). In this study, hamstrings antagonist co-activation was not altered statistically, in contrast to LaRoche et al. (2008) who demonstrated that isokinetic resistance training in older adults for 8 weeks significantly decreases hamstrings antagonist co-activation (2). The increased activity of Renshaw's cell regulating Ia inhibitory interneuron caused by the activity of Ib inhibitory interneuron from the Golgi tendon led to the increased hamstrings antagonist co-activation (30).

In this study, the frontal lobe functioning test did not show statistically significant changes. However, other studies conducted for a period of 12 to 16 weeks have reported that various interventions improved the executive functioning in the frontal lobe (1). Future research investigations need to extend the duration of the intervention to improve the executive function of the frontal lobe in the frail elderly with MCI.

This present study has several limitations. The subjects of this study were recruited from a localized area and the following parameters were not controlled: sleep, diet, physical activity and equity between genders. Additionaly, the error in the placement of EMG electodes cannot be fully neglected during the pre- and post tests in each measurement.

In summary, the 8-week HSPT regimen improved the knee extensor strength, the 200-ms RTD and significantly increased the rate of EMG rise, whereas the motor time was statistically decreased in this study. The 4.44-m gait speed and TUG decreased favorably. However, the pre-motor time, hamstrings antagonist co-activation, and executive function did not show significant improvement. Aside from the unimproved variables, the elastic band-based HSPT might be considerably meaningful for the frail elderly with MCI to improve neuromuscular and gait functions.

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Conflict of interest: On behalf of all the authors, the corresponding author states that there is no conflict of interest.

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