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Review

Effects of electrical muscle stimulation exercise on lower limb muscles and lumbar movement in older adults with disabilities: A pre- and post-test controlled experimental study

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Abstract: In older adults with disabilities, muscle weakness reduces mobility and causes postural issues. Electrical muscle stimulation (EMS) training is effective for increasing strength by inducing involuntary skeletal muscle contractions. Thus, this study aimed to examine changes in lumbar movement, muscle activity during walking, and maximum muscle strength of lower-limb joints based on an 8-week EMS exercise program for older adults with physical disabilities. Sixteen older adults (aged 56–78 years) with physical disabilities were selected and randomly assigned to either the exercise group (EG, n = 8) or the control group (CG, n = 8). EG participants were instructed to wear EMS suits and participate in an elastic band and bare-body exercise program, whereas CG participants performed the exercise program without the EMS suits. Lumbar range of motion (ROM), body circumference, partial volume, maximum muscle strength, and muscle activity were measured. Statistical analysis was performed using SPSS 28.0 for Windows, with the critical value of α = 0.05. Compared to CG participants, EG participants had a superior ROM, body volume, partial volume, maximum muscle strength (knee joints), and muscle activity while walking. These positive outcomes highlight the efficacy of combining EMS with an exercise program for strength and rehabilitation training in older adults with physical disabilities.

Keywords: muscle function; range of motion; muscle activity; ambulation; rehabilitation; lower-limb strength

1. Introduction

Individuals with physical disabilities often experience difficulties in exercise due to impaired mobility resulting from congenital or acquired motor and sensory nerve damage (Sunnerhagen, 2007). Nevertheless, overcoming these challenges and engaging in physical activity are extremely important for improving health, maintaining physical strength, and facilitating rehabilitation as well as functional recovery (Hong and Cha, 2000).

Low participation in physical activities among people with physical disabilities results from a lack of optimal early rehabilitation knowledge regarding impaired physical abilities and rehabilitation risk factors (Ministry of Culture, Sports and Tourism, 2015). Muscle weakness in individuals with physical disabilities is a significant factor contributing to decreased mobility and is a primary cause of postural impairment in patients with central nervous system disorders, such as stroke, spinal cord injuries, traumatic brain injuries, and musculoskeletal disorders (Orr, 2010). Stroke is related to reduced muscle strength and body balance, along with restricted range of motion (ROM), leading to decreased ambulatory capacity and increased risk of falls (Lamb et al., 2003). Various modalities, including treadmill training (Lau and Mak, 2011), therapeutic horseback riding (Maguire et al., 2012), strength training (Yang, et al., 2006), electrical stimulation (Teasell, et al., 2003), and aquatic training (Lee and Kang, 2009), have been used to improve balance and ambulation by increasing muscle strength in patients with stroke.

Among various rehabilitation assistance training methods, electrical muscle stimulation (EMS) training, which had been previously used for rehabilitation purposes, is effective in increasing strength and joint ROM by inducing involuntary skeletal muscle contractions and changes in active potentials (Doucet et al., 2012). Moreover, repeated micro-electrical stimulation of muscles promotes vascular flexibility, increases blood flow in muscle fibers (Kaplan et al., 2002), enhances muscle strength (Granat et al., 1993), and enhances the recruitment of motor units in the neuromuscular junction (Petersen et al., 2002; Vanderthommen et al., 2002). However, excessive artificial muscle contractions through electrical stimulation can cause muscle fatigue due to overuse and a disrupted natural sequence of muscle recruitment (Doucet et al., 2012; Vanderthommen and Duchateau, 2007). Therefore, micro-electrical stimulation has been recommended as a novel exercise method (Lin and Yan, 2011). Notably, researchers have found that EMS training is effective in boosting muscle strength in individuals with physical disabilities (Kemmler et al., 2014; Song et al., 2016; von Stengel et al., 2015). In addition, recent studies have focused on the effects of exercise programs using small tools on lower-limb muscle function and ambulation in older adults with physical disabilities (Ada et al., 2006; Cramp et al., 2006; Moreland et al., 2003; Ouellette et al., 2003).

Individuals with physical disabilities involving paralyzed upper extremities cannot perform motor tasks (Popović et al., 2014) due to a lack of appropriate force generation and control associated with brain injuries (Trombly, 1992). This may cause a deficiency in specific experiences through exercise on the affected part of the body (Arya et al., 2015). Additionally, lower-back muscle weakness primarily involves weak extensor and flexor muscles, with dysfunctional lower-back extensor muscles often leading to back pain (Mayer et al., 1989). Three-dimensional whole-body scanning, as a relatively recent method, is used to analyze body width, thickness, shape, and size. It measures body figure based on spinal alignment, deformities, tilt angle, proportions, and body imbalances to predict health or morbidity (Treleaven and Wells, 2007). In addition, it can be a noninvasive means for quick and accurate diagnosis of scoliosis (Schmitz et al., 2002).

Ambulation, requiring good balance, comprises a series of repetitive movements in which one of the lower limbs is used to maintain a stable stance and the other to propel the body forward through a complex interplay of the nervous and musculoskeletal systems (Downey et al., 1992). Ambulation in individuals with physical disabilities can be affected by factors such as decreased balance, muscle weakness, reduced joint ROM and stability, psychological problems, and muscle fatigue. Particularly, decreased balance adversely affects ambulation by diminishing the weight-bearing capacity of the paralyzed side (Stolze et al., 2004). Primitive coordination patterns can lead to the loss of selective muscle control in the lower extremity joints. This, in turn, may cause an overuse of the non-paretic side of the body to compensate for slow movements (Mauritz, 2002). Furthermore, the most significant factor causing muscle fatigue while walking in individuals with physical disabilities is muscle weakness on the paralyzed side. Muscle fatigue is associated with changes in the level of neural activity due to decreased central nervous system function (Hachisuka et al., 1997; Patten et al., 2004). Moreover, reduced lower-limb muscle strength can further limit the ambulatory ability of individuals with physical disabilities. Bache et al. reported that lower-limb muscle weakness is closely associated with ambulation, balance, and stable upright posture (Bache et al., 2003) and Yang et al. (2006) stated that increased lower-limb muscle strength is related to improved functional performance.

Prior research has been limited to clinical studies verifying EMS training effects on muscle strength enhancement, pain relief, fatigue induction in the muscular nervous system, and improvement of muscle function in older adults with physical disabilities. Identifying the positive impacts of EMS training related to rehabilitation in this population is essential. Thus, the purpose of this study was to examine changes in lumbar movement, muscle activity during walking, and maximum muscle strength of lower-limb joints in older adults with physical disabilities and to compare an 8-week exercise program with EMS to the same program without EMS.

2. Materials and methods

2.1. Research design and participants

Table 1. Physical characteristics of participants.

Group	**Age (years)**	**Height (m)**	**Body weight (kg)**	**Body mass index (kg/m^2)**	**physical activity (month)**	**Type of disability**
EG (*n* = 8)	65.43 ± 5.31	1.59 ± 4.62	68.73 ± 10.60	26.86 ± 1.96	12.13 ± 4.47	brain lesion (*n* = 3), speech impairment (*n* = 1) physical disability (*n* = 4)
CG (*n* = 8)	65.14 ± 6.30	1.56 ± 5.26	68.87 ± 7.52	28.88 ± 4.04	11.88 ± 3.85	brain lesion (*n* = 3), visual impairment (*n* = 1) physical disability (*n* = 4)

EG: exercise group, CG: control group. Data are presented as Mean (M) ± Standard Deviation (SD).

This study was guided by a control group pre- and post-experimental research design. Sixteen older adults with physical disabilities were selected and randomly assigned to either the exercise group (EG, *n* = 8) or the control group (CG, *n* = 8). More specifically, eight participants had orthopedic disabilities, six participants had brain lesions, one participant had visual impairment, and one participant had a language disorder. Among them, 11 participants had a severe disability, and five had a mild disability. Details of the research subjects are shown in **Table 1**. The study participants could perform daily physical activities, walk unaided, and had no history of surgery due to musculoskeletal problems within the last 12 months. Participants were recruited from the elderly people with disabilities who participated in exercise at the local welfare centers. Their physical characteristics are presented in **Table 1**. The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of Silla University Life Ethics Committee Member (Protocol code: 1041449-202306-HR-004; Approval date: 7 April 202). All participants voluntarily took part in this study and provided informed consent.

2.2. Exercise program

Among individuals with physical disabilities participating in periodic exercise, the EG engaged in an 8-week program that included wearing an EMS suit, elastic-band exercises, and lower-limb strength exercises. In contrast, the CG participated in the same exercise program but without the EMS suit. All participants provided informed consent after a thorough explanation of the measurement procedure and study objectives. The participants in the EG utilized a suit designed for EMS training during the 8-week intervention period, while both groups followed the specified exercise program (**Table 2**).

Table 2. Eight-week exercise regimen.

	Band leg extension	Leg curls	Bodyweight squats	Dumbbell squats	Pause squats (3 sec)	Bodyweight lunges	RPE
Weeks 1–2	15-15-20	15-15-20	10-10-15			10-10-15	11
Weeks 3–4	15-15-20	15-15-20	15-20-20		10-10-10	15-20-20	12
Weeks 5–6	20-20-20	20-20-20	20-25-25		15-15-15	20-20-20	13
Weeks 7–8	20-20-20	20-20-20		20-25-25	10-15-15	20-20-20	14

RPE: rate of perceived exertion.

Figure 1. EMS training suit and types of exercise.

EMG: electrical muscle stimulation, EMS: electrical muscle stimulation.

The exercise program included elastic-band and bodyweight exercises (band leg extension, leg curls, bodyweight squats, dumbbell squats, pause squats, and bodyweight lunges). In contrast, the elastic-band training program was structured into warm-up (5 min), main exercise routine (40 min), and cool-down (5 min) sessions

(**Figure 1**). The training was conducted for 50 min daily, thrice a week, for a total duration of 8 weeks. Considering that the participants had weak cardiovascular functions, adequate warm-up and cool-down exercises were included with light repetitive exercises using body weight to improve joint ROM. The resistance level of the Thera-band (The Hygienic Corp., USA) used in this study was determined based on the band's elongation rate. Before the exercise commenced, the band length for each participant was determined by calculating the band's elongation rate as follows: {(stretched length − relaxed length)/relaxed length} × 100. The band was then used for the exercises. The exercise intensity increased every 2 weeks.

The participants in the EG underwent the exercise program while wearing an EMS suit for 8 weeks, and the frequency of the suit was set at 25 Hz (duty ratio cycle of 10%) for 15 min and 5 Hz (duty ratio cycle of 5%) for 5 min, to deliver EMS to the designated muscle areas (lower extremity muscle group: abdominals, pectoralis major, iliacus, femoris muscles, and hamstrings) during designated periods (three times a week, for 1 hour each). The intensity of EMS was consistently stimulated at these frequency levels throughout the exercise. No adverse effect was detected during exercise.

2.3. Measurements

A set of pre- and post-test measurements were performed to investigate the effects of the EMS training suit on older adults with physical disabilities. Before commencing the exercise program, the participants engaged in a light warm-up exercise, then performed the body composition measurement, followed by ROM measurement, three-dimensional whole-body scanning, maximum strength assessment, and gastrocnemius and tibialis anterior activities during ambulation. We secured reliability and validity with an intraclass correlation of 0.835 (95% CI: 0.758–0.915)) based on a previous study when the rater made the measurements (Drouin et al., 2004; Hambali et al., 2021; Jeon et al., 2023; Kim et al., 2023; Nel et al., 2020; Thurston, 2021).

First, Lumbar and hip ROM was measured using a goniometer (KASCO, Korea). Left and right trunk flexion in the lumbar coronal plane and hip extension and flexion in the sagittal plane were measured. An upright posture was set at 0º, left and right lateral trunk flexion was measured thrice, and the average was used for analysis. Hip ROM was measured thrice for hip extension and flexion at 0º upright position, and the average was used for analysis. Left and right lumbar flexion and the sum of hip extension and flexion were used as the ROM values.

Afterwards, 3D scanning was conducted using PFS-304A (PMT Innovation, Korea). The 3D scanner has a camera module rotated at 360° by the motor mounted on the top of the scanner to capture the measurements of the participants in a stationary position (**Figure 2**). Therefore, the participants maintained an A-pose posture according to ISO-7250 (anatomical posture) during the measurement to ensure accurate measurements and prevent any distortions or blind spots that may occur without the A-pose (such as measurements not taken if the arms were held too close to the body or against it). Body circumferences and partial volumes were measured in the correct anatomical posture for accurate comparative analysis, and the data were stored in Excel. The maximum strength of the knee joints was measured for knee flexors and extensor muscles.

Figure 2. Range Of Motion (left), A-pose (center), and maximum strength measurement (right).

Next, Knee muscle function was assessed based on knee joint extension and flexion strength using Biodex (Biodex Medical Systems, Inc., USA), according to the manufacturer's instructions. The ROM was set as the maximum possible ROM, and the test was performed at two angular velocities: 60°/s and 180°/s for muscle strength and endurance, respectively. A 30-s rest was observed between angular velocity measurements. The 60°/s and 180°/s angular velocity measurements were performed 5 and 10 times, respectively. Peak torque/BW (%) values during extension and flexion were used to evaluate muscle strength and endurance (**Figure 3**).

Lastly, Muscle activity was measured using an electromyogram (Noraxon Inc., USA). After removing hair from two sites bilaterally (gastrocnemius and anterior tibialis), the sites were cleaned with an alcohol swab, and four surface electrodes were attached within 2 cm. The locations of the electrodes were set based on the electromyography (EMG) manufacturer guidelines (SENIAM guidelines). As for the measurement of gastrocnemius and tibialis anterior activities, a cone was placed at the beginning and end of a 10-m space, and the participants were asked to walk at a normal pace with the highest value used for analysis (**Figure 3**). EMG signals were set to a sampling rate of 2000 Hz, and raw data were bandpass-filtered at a frequency of 40–450 Hz and then rectified. Smoothing was applied using the root mean square (RMS) method. The analysis time window was set at 50–100 ms. After connecting the EMG device to surface electrodes, the maximum voluntary isometric contraction (MVIC) of both the gastrocnemius and anterior tibialis muscles was measured. Raw data were acquired for each muscle during a 5-m walk, and the average values were used for analysis. The standardization formula is as follows (Sun and Park, 2022).

Figure 3. EMG electrode sites on the anterior tibialis and gastrocnemius.

EMG: electrical muscle stimulation.

$$\text{Muscle activation} = \frac{\text{EMG}_{\text{raw}}}{\text{EMG}_{\text{MVIC}}} \times 100(\%) \tag{1}$$

EMG_{raw}: RMS of muscle activity during motion;
EMG_{MVIC}: RMS of muscle activity at MVIC.

2.4. Statistical analysis

The collected data were analyzed using SPSS software version 28.0 (IBM Corp., Armonk, NY, USA). The mean and standard deviation of each variable were computed. Levene's test was applied to determine homogeneity, and using the Kolmogorov–Smirnov test, the normality of the data was tested (*p*-values of all variables > 0.05); thus, parametric statistics were applied. Two-way repeated measures ANOVA was conducted to assess variations between periods and groups. Subsequent post-hoc analyses utilized the Bonferroni multiple comparison method, with a significance level set at $\alpha = 0.05$. The effect size of the two-way repeated measures ANOVA was calculated as the partial eta squared ($\eta2$). A partial eta squared value of 0.01 indicates a small effect size, a value of 0.06 indicates a medium effect size, and a value of 0.14 indicates a large effect size.

3. Results

After 8 weeks of the exercise program combined with EMS suits, significant differences in lumbar ROM were observed between the two groups ($F = 10.863$, $p = 0.01$). Participants in the EG exhibited significant time-dependent changes in hip ROM ($F = 10.132$, $p = 0.01$) (**Table 3**).

Table 3. Changes in lumbar and hip ROM after EMS.

ROM	Group	Pre	Post		*F* (*p*)	*η2*
	EG	72.62 ± 20.95	78.82 ± 14.31	Time	0.341 (0.57)	0.019
Lumbar				Group	10.863 (0.01) *	0.135
	CG	81.94 ± 20.58	87.43 ± 22.00	Time × group	0.929 (0.35)	0.010
	EG	104.43 ± 27.03	124.92 ± 12.37	Time	10.132 (0.01) *	0.139
Hip				Group	0.169 (0.68)	0.020
	CG	104.91 ± 20.41	115.20 ± 24.92	Time × group	1.113 (0.31)	0.011

EG: exercise group, EMG: electrical muscle stimulation, CG: control group, ROM: range of motion. * $p < 0.05$.

3D scanning of the value differed between groups in terms of time for the lower abdomen ($F = 4.040$, $p = 0.05$), hip ($F = 4.814$, $p = 0.05$), and thick thigh ($F = 4.239$, $p = 0.05$). There was a statistically significant difference between the groups for Group in thick thigh ($F = 4.842$, $p = 0.04$) and for the Time x Group interaction in the lower abdomen ($F = 10.028$, $p = 0.01$) and thick thigh ($F = 4.706$, $p = 0.05$). Additionally, there were statistically significant differences in changes in the partial volume and waist-hip ratio in the lower abdomen, hip, and thick thigh ($p < 0.05$) (**Table 4**).

Table 4. Changes in body circumference and partial volume after EMS.

Variables		**Group**	**Pre**	**Post**		***F* (*p*)**	***η2***
Value (cm)	Lower abdomen	EG	118.77 ± 8.79	107.05 ± 4.955	Time	4.040 (0.05) *	0.043
					Group	0.119 (0.73)	0.009
		CG	122.26 ± 27.73	128 ± 14.46	Time × group	10.028 (0.01) *	0.126
	Hip	EG	122.37 ± 8.40	104.91 ± 8.40	Time	4.814 (0.05) *	0.037
					Group	2.001 (0.09)	0.025
		CG	122.29 ± 24.62	117.37 ± 12.51	Time × group	2.000 (0.09)	0.025
	Thick thigh	EG	68.42 ± 5.90	61.21 ± 10.07	Time	4.239 (0.05) *	0.061
					Group	4.842 (0.04) *	0.064
		CG	74.80 ± 18.76	69.24 ± 7.01	Time × group	4.706 (0.05) *	0.063
Partial volume (ℓ)	Lower abdomen	EG	9.70 ± 1.38	11.23 ± 1.59	Time	5.763 (0.04) *	0.067
					Group	5.001 (0.04) *	0.066
		CG	9.85 ± 2.14	11.43 ± 2.22	Time × group	5.098 (0.04) *	0.065
	Hip	EG	10.64 ± 3.80	13.55 ± 2.97	Time	4.726 (0.05) *	0.057
					group	4.318 (0.04) *	0.055
		CG	11.39 ± 1.85	12.08 ± 3.03	Time × group	4.923 (0.04) *	0.057
	Thick thigh	EG	5.46 ± 1.76	6.49 ± 1.41	Time	4.305 (0.04) *	0.052
					Group	4.010 (0.04) *	0.043
		CG	5.93 ± 0.86	6.49 ± 1.04	Time × group	4.310 (0.04) *	0.055
Waist-hip ratio		EG	0.41 ± 0.03	0.37 ± 0.04	Time	4.628 (0.05) *	0.049
					Group	4.372 (0.05) *	0.045
		CG	0.46 ± 0.02	0.43 ± 0.04	Time × group	5.132 (0.05) *	0.051

EG: exercise group, CG: control group. * $p < 0.05$.

As for the maximum knee joint strength, in the EG, time effects ($F = 11.409$, $p = 0.01$ and $F = 12.435$, $p = 0.01$) and time × group interaction effects ($F = 4.765$, $p = 0.04$ and $F = 4.886$, $p = 0.04$) were observed for the right 60°/s extension and flexion, respectively. Furthermore, significant time effects were noted for 180°/s extension ($F = 5.883$, $p = 0.03$), and significant time effects and time × group interaction effects were observed for flexion ($F = 4.008$, $p = 0.05$). For the left knee, statistically significant differences between time, group, and time × group interactions were found in 60°/s extension, 180°/s extension, and flexion ($p < 0.05$). There was no statistically significant difference in left 60°/s flexion (**Table 5**).

Table 5. Changes in lower-limb maximum strength after EMS.

Variables	**Group**	**Pre**	**Post**		***F* (*p*)**	***η2***
Right extension 60°/s	EG	80.98 ± 26.33	129.32 ± 46.51	Time	11.409 (0.01) *	0.113
				Group	1.092 (0.18)	0.019
	CG	65.03 ± 36.78	93.48 ± 34.44	Time × group	4.765 (0.04) *	0.024

Table 5. (*Continued*).

Variables	**Group**	**Pre**	**Post**		***F* (*p*)**	***η2***
Right flexion 60°/s	EG	47.32 ± 29.68	73.18 ± 27.77	Time	12.435 (0.01) *	0.127
				Group	0.688 (0.42)	0.039
	CG	45.17 ± 22.52	52.48 ± 19.62	Time × group	4.886 (0.04) *	0.050
Right extension 180°/s	EG	57.63 ± 13.61	81.23 ± 28.28	Time	8.694 (0.01) *	0.080
				Group	1.824 (0.20)	0.031
	CG	47.03 ± 20.59	66.70 ± 16.61	Time × group	3.072 (0.07)	0.018
Right flexion 180°/s	EG	40.72 ± 12.73	54.52 ± 18.86	Time	5.853 (0.03) *	0.061
				Group	0.897 (0.36)	0.022
	CG	34.12 ± 18.07	46.92 ± 13.90	Time × group	4.008 (0.05) *	0.026
Lift extension 60°/s	EG	114.02 ± 59.01	133.34 ± 34.21	Time	6.713 (0.03) *	0.051
				Group	4.218 (0.05) *	0.039
	CG	59.80 ± 25.69	89.11 ± 51.03	Time × group	4.340 (0.05) *	0.041
Lift flexion 60°/s	EG	55.70 ± 31.17	59.74 ± 18.36	Time	0.484 (0.50)	0.007
				Group	1.378 (0.27)	0.009
	CG	41.76 ± 17.54	43.74 ± 23.23	Time × group	0.115 (0.74)	0.004
Lift extension 180°/s	EG	72.56 ± 26.34	86.90 ± 19.38	Time	4.175 (0.05) *	0.055
				Group	4.031 (0.01) *	0.051
	CG	60.16 ± 26.72	60.30 ± 34.23	Time × group	4.897 (0.03) *	0.048
Lift flexion 180°/s	EG	51.24 ± 23.34	57.41 ± 17.83	Time	5.082 (0.04) *	0.054
				Group	4.674 (0.04) *	0.047
	CG	39.68 ± 9.23	40.91 ± 14.01	Time × group	4.313 (0.04) *	0.046

EG: exercise group, CG: control group, * $p < 0.05$.

As for muscle activity during ambulation, statistically significant differences were found in time effects ($F = 4.535$, $p = 0.05$; $F = 4.788$, $p = 0.05$; $F = 5.329$, $p = 0.04$) and time × group effects ($F = 4.169$, $p = 0.05$; $F = 4.552$, $p = 0.04$) in the right tibialis anterior, medial gastrocnemius, and left tibialis anterior muscles, respectively. Significant time effects ($F = 4.472$, $p = 0.04$), group effects ($F = 4.548$, $p = 0.05$), and time × group interaction effects ($F = 4.106$, $p = 0.05$) were found for left gastrocnemius muscle activities (**Table 6**).

Table 6. Changes in gastrocnemius and anterior tibialis activities during ambulation after EMS.

Variables	**Group**	**Pre**	**Post**		***F* (*p*)**	***η2***
Right anterior tibial muscle (%)	EG	70.22 ± 2.26	73.89 ± 4.28	Time	4.535 (0.05) *	0.044
				Group	0.003 (0.95)	0.002
	CG	72.30 ± 6.59	72.05 ± 5.73	Time × group	2.11 (0.18)	0.010
Right lateral gastrocnemius muscle (%)	EG	66.96 ± 9.38	74.57 ± 8.01	Time	4.788 (0.05) *	0.041
				Group	0.010 (0.92)	0.009
	CG	70.27 ± 8.93	72.08 ± 9.60	Time × group	4.169 (0.05) *	0.034

Table 6. (*Continued*).

Variables	**Group**	**Pre**	**Post**		***F* (*p*)**	***η2***
Left anterior tibial muscle (%)	EG	65.48 ± 9.54	73.51 ± 6.52	Time	5.329 (0.04) *	0.036
				Group	0.171 (0.68)	0.010
	CG	70.62 ± 6.76	71.43 ± 8.03	Time × group	4.552 (0.04) *	0.049
Left lateral gastrocnemius muscle (%)	EG	62.63 ± 8.17	73.92 ± 8.17	Time	4.472 (0.04) *	0.034
				Group	4.548 (0.05) *	0.036
	CG	63.58 ± 9.50	64.03 ± 12.61	Time × group	4.106 (0.05) *	0.035

EG: exercise group, CG: control group, * $p < 0.05$.

4. Discussion

In this study, we investigated the effects of EMS training on ROM, body circumference, partial volume, maximum strength of the lower-limb joints, and the gastrocnemius and anterior tibialis muscle activities during ambulation. Older adults with physical disabilities underwent an 8-week EMS training program (thrice/week, 50 min/session). Previous studies have indicated that older adults with disabilities experience improvements in muscle strength, ROM, and ambulatory capacity (An et al., 2020; Gong, 2008); achieve recovery and maintain independent functioning (Kim and Koo, 2017); and enjoy increased quality of life through continuous participation in such exercise programs (Shin, 2015).

Participants with physical disabilities who wore EMS training suits and participated in the exercise program exhibited an increase of approximately 6° (8%) and 20° (17%) in lateral lumbar and hip ROM, respectively, as compared with individuals with disabilities who did not wear EMS suits. Compared to the group that did not receive EMS training (CG), the ROM was 8% and 17% greater in the lumbar region and hip joint, respectively, in the group that received it. Park suggested that lumbar stabilization exercise for 4 weeks significantly changed the lumbar ROM (Park et al., 2005), and Kim et al. (2007) reported that the same exercise for 8 weeks led to improvements in lower-back flexibility. The primary function of the iliopsoas muscle is to straighten the spine to maintain posture against hip flexion on the ipsilateral side and gravity, ensuring stable spinal lordosis (Bang, 2016). Kim demonstrated significant changes in hip joint flexion mobility in the experimental group that underwent iliopsoas myofascial release, as compared with the control group (Kim, 2012). Gilbey et al. reported that an 8-week exercise program before surgery improved pain, stiffness, physical function, hip joint flexion ROM, and muscle strength in patients with limited hip joint ROM (Gilbey et al., 2003). Furthermore, Kim reported the positive effects of a 4-week lumbar stabilization exercise and low-frequency EMS on lumbar pain and stability (Kim, 2021). EMS training led to an immediate improvement in strength performance and flexibility (Buonsenso et al., 2023), Consistent with the findings of previous research, our results revealed that exercise and EMS improved the lumbar and hip ROM, with greater improvements observed in the group that used the EMS suits combined with exercise.

Lumbar, hip, and thigh circumferences were compared between both groups, revealing a reduced circumference with increased partial volume in the EG compared with that in the CG. 3D body scanners are used to classify body shapes and estimate the risk of metabolic diseases according to body composition (Huxley et al., 2010; Sobhiyeh et al., 2020). Previous studies have suggested that areas beyond the lower back, hips, and thighs are areas of localized subcutaneous fat accumulation. Local fat deposition occurs in the gluteal region, lateral lower lumbar, lateral thigh, lateral femur inferior to the greater trochanter, and posterior and medial upper arm (Delavier and Gundill, 2003). The waist-hip ratio is a better index for cardiovascular diseases than body mass index (Huxley et al., 2010). In this study, the abdominal, hip, and thigh circumferences were reduced with increased partial volume in the EG, suggesting a decrease in subcutaneous fat and an increase in the partial volume of lumbar, hip, and thigh muscles. Our results align with the findings of a study that applied EMS and explained its therapeutic potential for reducing fat thickness (Lee and Choi, 2014). Abdominal EMS training can significantly improve muscle mass and upper body muscle strength performance, as well as significantly reduce body fat percentage in healthy subjects(Lee et al., 2023). Based on these results, 8-week EMS with exercise affects the body circumference and partial volume in individuals with disabilities, highlighting its potential as an adjunct training and treatment technique for abdominal obesity, musculoskeletal disorders, and neurological disorders in clinical or sports settings.

Participation in an 8-week muscle resistance-training program caused significant improvements in knee joint functions in individuals with knee joint dysfunctions (Park, 2015). Laughlin et al. suggested that decreasing knee flexion could protect the knee by counteracting the anterior pull of the quadriceps when the hamstrings bend the knees (Laughlin et al., 2011). This implies that muscle resistance training is a useful exercise for enhancing muscle strength through repeated knee extension movement. Fujita et al. reported that repetitive standing training is an effective method for improving knee extensor strength (Fujita et al., 2019). Resterschot et al. discovered that repetitive sit-to-stand exercises were effective in improving knee extensor strength (Regterschot et al., 2014), Hence, innovative, time-efficient, joint-friendly, and highly individualized exercise technologies (such as EMS) may be a good choice for the elderly with time constraints, physical limitations, or little enthusiasm, who are exercising less than the recommended amounts for impact on muscle mass, strength, and function (Oliveira et al., 2020). Possibly because the repetitive use of the knee joint extensor muscles to stabilize the trunk support surface changes from a broad surface to a narrower surface as one stands from a sitting position. Similarly, knee muscle strength is enhanced through repeated sit-to-stand training as the knee joint extensors are repeatedly used to stabilize the trunk based on the support surface. Improved knee joint extensors were observed in the CG, presumably due to the repeated use of the knee joint extensor muscles against a given resistance.

Decreased lower-limb muscle strength due to impaired ambulatory ability can cause a higher risk of falls and reduced capacities for gait speed, stair climbing, and posture maintenance (Brown et al., 1988). Consequently, insufficient energy output from the lower-limb muscles can increase the risk of damage to supporting tissues, such as the cartilage, tendons, and bones (Hah and Yi, 2010). Muscle strength and endurance play pivotal roles in ambulation and mobility (Park et al., 2001). To compensate for reduced muscle strength, strengthening the leg and lower back muscles could enhance stability during ambulation (Aruin and Latash, 1995). In this study, the maximum muscle activity in both legs improved after EMS training, as observed in the EG. Thus, combining EMS with bodyweight exercise is expected to promote gait stability by improving the activities of muscles required for ambulation—namely, the gastrocnemius and anterior tibialis muscles.

Overall, the 8-week EMS training combined with the exercise program increases flexibility by increasing lumbar and hip ROM, enhances maximum knee joint strength, and improves gait by increasing the anterior tibialis and gastrocnemius muscle activities, suggesting that the program can contribute to enhancing motor capacities of older adults with physical disabilities. Thus, such a program is beneficial for exercise and rehabilitation training for older adults with disabilities. However, this study had limitations. The sample size of this study was not sufficient for statistical analyses, possibly influencing the generalizability of research results. Meanwhile, using a repeated measure of ANOVA instead of a series of paired t-tests is appropriate because of the reduced possibility of type-I errors. In future studies, we will conduct long-term studies by measuring various variables with a larger sample size.

5. Conclusion

In this study, older adults with physical disabilities underwent an 8-week EMS training program, when combined with targeted exercise therapy, resulted in significant improvements in several domains in older adults with physical disabilities. Participants in the EMS group had improved lumbar and hip range of motion (ROM), decreased body circumference with increased fractional volume, and significantly increased maximal knee joint strength. EMS training also increased activity in key muscles such as the tibialis anterior and gastrocnemius during walking. These improvements suggest that EMS may be a valuable tool in rehabilitation and strength training in combination with structured exercise, contributing to better mobility and reduced fall risk in this population. Future studies with larger sample sizes and longer follow-up periods are recommended to further validate these findings and explore the sustained impact of EMS on functional mobility and muscle health in older adults with physical disabilities.

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