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# Effect of robot-assisted gait training on gait automaticity in Parkinson disease
## A prospective, open-label, single-arm, pilot study

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## Abstract

Gait automaticity is reduced in patients with Parkinson disease (PD) due to impaired habitual control. The aim of this study was to investigate the effect of robot-assisted gait training (RAGT) on gait automaticity as well as gait speed and balance in patients with PD.

This study was a prospective, open-label, single-arm, pilot study. We planned to recruit 12 patients with idiopathic PD. Participants received 12 sessions of RAGT using exoskeleton-type robotic device. Sessions were 45-minute each, 3 days a week, for 4 consecutive weeks using an exoskeleton-type gait robot. The primary outcome was the percentage of dual-task interference measured by the 10-Meter Walk Test (10MWT) under single and dual-task (cognitive and physical) conditions. Secondary outcomes were the Berg Balance Scale and Korean version of the Falls Efficacy Scale-International. All measures were evaluated before treatment (T0), after treatment (T1), and 1-month post-treatment (T2).

Twelve patients were enrolled and 1 dropped out. Finally, 11 patients with idiopathic PD were analyzed. The mean age of 11 patients (5 males) was $66.46 \pm 5.66$ years, and disease duration was $112.91 \pm 50.19$ months. The Hoehn and Yahr stages were 2.5 in 8 patients and 3 in 3 patients. Linear mixed-effect model analysis showed a significant change over time only in single-task gait speed of the 10MWT ($P = .007$), but not in dual-task gait speed, dual-task interferences, and Korean version of the Falls Efficacy Scale-International. Cognitive dual-task interference significantly increased ($P = .026$) at T1, but not at T2 ($P = .203$). No significant changes were observed for physical dual-task interference at T1 and T2. Single-task gait speed of the 10MWT was significantly increased at T1 ($P = .041$), but not at T2 ($P = .445$). There were no significant changes in the dual-task gait speed of 10MWT. A significant improvement was observed in Berg Balance Scale score at T1 and T2 ($P = .004$ and $P = .024$, respectively).

In this pilot study, despite improvement in walking speed and balance, gait automaticity in patients with PD was not improved by RAGT using an exoskeleton-type robot. Additional therapeutic components may be needed to improve gait automaticity using RAGT in patients with PD.

**Abbreviations:** 10MWT = 10-Meter Walk Test, BBS = Berg Balance Scale, H&Y stage = Hoehn and Yahr stage, IQR = interquartile range, KFES = Korean version of the Falls Efficacy Scale-International, LMM = Linear Mixed-effect Model, PD = Parkinson Disease, RAGT = Robot-Assisted Gait Training, T0 = Before Treatment, T1 = After treatment, T2 = 1-Month post-treatment.

**Keywords:** exoskeleton device, gait, Parkinson disease, rehabilitation

## 1. Introduction

In the early stage of Parkinson disease (PD), dysfunction of the sensorimotor area of the basal ganglia typically occurs, leading to habitual control dysfunction.[1] Therefore, habitual behavior, such as walking, requires conscious effort and gait automaticity is reduced.[2] Rehabilitation approaches using external cues such as somatosensory, auditory, and visual cues have widely been used for improving gait automaticity.[3–6] As a somatosensory input,

repetition of a normal gait pattern could reinforce the function of the neural circuits that contribute to gait pacing.[7–9] In addition, motor factors associated with the dual-task walking deficit in PD, such as balance, physical fatigue, single-task mobility, and freezing of gait may be improved by rehabilitation.[10]

Robot-assisted gait training (RAGT) is a method of rehabilitation that repeats a normal gait pattern with high intensity. The gait robot was developed under the expectation that repetitive gait training would cause the brain and spinal cord plasticity and resolve the gait disturbance caused by the central nervous system disease.[11] Various types of lower limb rehabilitation robots have been developed, and exoskeletal type robots with treadmills and end-effector type robots are used with patients for rehabilitation.[12] Among these, treatments using the exoskeletal robot are thought to improve physical function, and to appropriately input the proprioceptive cue to increase gait automaticity.[9,13,14] A recent systematic review and meta-analysis suggested a significant effect of RAGT on improvement of walking independence in patients with subacute stroke within 3 months.[15] On the other hand, there is a lack of evidence and guidelines for use of RAGT in patients with PD.

Previous randomized controlled trials have demonstrated controversial results on the effects of RAGT in patients with PD. Some studies have reported that RAGT improved gait velocity, stride length, and balance compared with a treadmill or conventional gait training.[16,17] Another report suggested the duration of the therapeutic effect of RAGT is longer than in conventional therapy.[9] However, another studies demonstrated that RAGT was not superior to equal intensity treadmill training or balance training.[18–20] Gait analysis on the RAGT group showed significant improvements on several parameters, such as step length, gait velocity, and cadence, as compared to the control group in which only step length improved.[14,21]

These previous studies only evaluated gait and balance functions in patients with PD. Therefore, it is unclear whether the effects are a result of repeated and intense physical exercise or due to alleviation the pathophysiology of PD associated with basal ganglia dysfunction. A study on gait automaticity, which can be evaluated by dual-task interference during walking, may provide a clue for the therapeutic mechanism of RAGT in patients with PD. Therefore, the purpose of this pilot study was to investigate the effect of RAGT on gait automaticity, as well as gait speed and balance in patients with PD.

## 2. Methods

### 2.1. Study design and setting

This study was a prospective, open-label, single-arm, pilot study to investigate the effect of RAGT on gait automaticity in patients with PD. The trial was conducted at a university hospital in South Korea from December 2016 to February 2018. Participants underwent 12 sessions of RAGT. They were evaluated before treatment (T0), immediately after treatment (T1), and at 1-month following the end of treatment (T2).

### 2.2. Sample size estimation and participants

We planned to recruit 12 patients according to the recommended sample size for a pilot study.[22] Participants were recruited at the outpatient clinic of a university hospital.

Inclusion criteria were

1) diagnosis of idiopathic PD,

2) Hoehn and Yahr (H&Y) stage 2.5 or 3, and

3) Korean version of the Mini-mental State Examination ≥24.

Exclusion criteria were

1) severe dyskinesias or "on-off" fluctuations,

2) need of PD medication change during the study period,

3) sensory dysfunction in the lower limbs,

4) vestibular disorders or paroxysmal vertigo,

5) neurological or orthopedic problems affecting the lower extremities, and

6) other severe medical problems such as cardiovascular disease.

### 2.3. Primary and secondary outcomes

The primary outcome measure was percentage (%) of dual-task interference on gait velocity during 10-Meter Walk Test (10MWT). In this study, the effect of the dual-task on gait velocity was calculated as the raw difference between single and dual-task performance.[23]

Percentage of dual −task interference (%)

$$\frac{(Dual-task\ performance - Single-task\ performance)}{Single-task\ performance}$$

The secondary outcomes were the gait speed of 10MWT under single and dual-task conditions, Berg Balance Scale (BBS), and Korean version of the Falls Efficacy Scale-International (KFES). The 10MWT was used to measure gait speed over 10 m. A 2-m buffer was used to minimize acceleration and deceleration, respectively.[24] The time to walk the 10 m was recorded. Gait speed was measured twice in 3 conditions. First, participants completed the 10MWT with a comfortable speed. Second, the Wechsler Forward Digit Span was used as the simultaneous cognitive task.[25] This task has been validated in previous studies for evaluating working memory to assess cognitive dual-task.[23,26,27] The participant was assessed for the maximum forward digit span achieved in 2 out of 3 attempts in a sitting position before walking. During the walk, participants listened to strings of digits and repeated them. Error rate in recalling the strings of digits is the ratio of the number of failures to the number of successes. Third, participants were required to carry a tray with 2 cups of water for the concurrent physical task.[28–30] We used the average completion times of 2 trials in each condition.

Balance function was evaluated using BBS. The BBS consists of 14 items and a higher BBS score indicates the better balance.[31] The KFES was also used to measure fear of falling. KFES is evaluated by grading 1 to 4 points with 16 items and the higher the KFES score, the greater the fear of falling.[32,33]

### 2.4. Intervention

Sessions were 45-minute each, 3 days a week, for 4 consecutive weeks using an exoskeleton-type robotic device for gait training (Walkbot_S; P&S Mechanics, Seoul, Korea). The exoskeleton-type gait robot provided a normal gait pattern on a treadmill by controlling movements of the hip, knee, and ankle joints on both sides. All participants started at an initial speed of 1.5 km/h, and the speed was gradually increased to between 2.0 km/h and 2.2 km/h depending on the participant's condition with no body-weight support. Actual training time of 1 session was about

## Table 1

**Baseline characteristics of participants (N = 11).**

| | |
|---|---|
| Male/female (n) | 5/6 |
| Age (yr) | 66.46 ± 5.66 |
| Disease duration (mo) | 112.91 ± 50.19 |
| Hoehn and Yahr stage 2.5/3 (n) | 8/3 |
| MMSE-K (score) | 28.55 ± 0.93 |

MMSE-K = Korean version of the Mini-mental State Examination.

30 minute, except 10 to 15 minute to get in and out of the exoskeleton.

### 2.5. Ethics

The study protocol was approved by the Institutional Review Board of Seoul National University Hospital (IRB No. 1809–126–975) and registered at ClinicalTrials.gov (NCT02993042). All participants provided written informed consent. The study was performed in accordance with the principles of Good Clinical Practice and the Helsinki Declaration.

### 2.6. Statistical analysis

Data are expressed as means and standard deviations for continuous variables and medians and interquartile ranges (IQR) for ordinal variables. As the study contained repeated measures and missing data, linear mixed-effect models (LMM) were used to test changes in outcomes over time. Time was included in the model as an explanatory factor. Covariates were utilized including age, sex, H&Y stage, and disease duration. The intercept was treated as a random effect. The model was simplified based on the Akaike information criterion. The Shapiro–Wilk test was performed to determine the normal distribution of measurement outcomes. Wilcoxon signed ranks-test was also used to evaluate changes from T0 to T1 and T2. A P value less than .05 was considered significant. IBM SPSS Statistics 21.0 for Windows (IBM, Armonk, NY) was used for the analysis.

## 3. Results

Twelve participants were enrolled and 11 were finally analyzed because 1 participant dropped out due to rapidly deteriorating dyskinesias. Average age was 66.46 ± 5.66 years, and average disease duration was 112.91 ± 50.19 months (Table 1). The H&Y stages were 2.5 in 8 patients and 3 in 3 patients. One participant was lost at 1-month follow-up (T2). Total 41 patients were screened for eligibility of the study inclusion. Twenty-nine patients were excluded because of a diagnosis other than idiopathic PD (n = 15), H&Y stage 1.5 or 4 (n = 5), previous history of stroke (n = 3), severe "on-off" fluctuations (n = 1),

vestibular disorder (n = 1), hospital location (n = 2), and loss of contact (n = 2).

The participants underwent 12 sessions of RAGT and completed an evaluation before and after treatment. There were no adverse effects related to treatments. The average maximum training velocity was 1.50 km/h in the first session and 2.02 km/h in the last session. The average number of steps was 1259 in the first session and 1705 in the last session.

The final model of the LMM analysis showed no statistically significant changes over time in dual-task interferences. Table 2 shows the changes in the percentage of dual-task interference (%) on gait velocity. Cognitive dual-task interference significantly increased from −15.78 ± 7.78% to −21.50 ± 7.62% (P = .026) at T1, but not at T2 (−20.75 ± 6.40%, P = .203). During the cognitive dual-task gait, maximum forward digit spans were 7.09 ± 1.22 at T0, 7.45 ± 1.04 at T1, and 7.7 ± 1.06 at T2, and the error rate in recalling the strings of digits were 0.28 ± 0.24 at T0, 0.39 ± 0.23 at T1, and 0.35 ± 0.24 at T2, without significant changes. No significant changes were observed for physical dual-task interference at T1 and T2.

The single-task gait speed was significantly changed over time in the final model of the LMM analysis (P = .007). In this model, there were significant interactions in time × H&Y stage, time × disease duration, and time × H&Y stage × disease duration (P = .006, P = .008, and P = .007, respectively). The final model of the LMM analysis showed no statistically significant changes over time in dual-task gait speed and KFES. As BBS was not normally distributed according to the Shapiro–Wilk test, the LMM was not employed. The single-task gait speed of the 10MWT was significantly increased from 1.13 ± 0.23 m/s to 1.24 ± 0.28 m/s at T1 (P = .041), but not at T2 (1.17 ± 0.34 m/s, P = .445) (Table 3). In contrast, there were no significant changes in cognitive and physical dual-task gait velocities in the 10MWT. A significant improvement was noted in BBS score from 52 (IQR, 46–54) to 54 (IQR, 52–56) at T1 (P = .004), and to 54 (IQR, 49.75–55) at T2 (P = .024). There were no significant changes in KFES at both T1 and T2.

Table 4 shows the individual data for the 10MWT. In the single-task gait, 9 of 11 patients (81.8%) had an improved walking speed at T1 and 5 of 10 at T2 (50.0%). Four of 11 patients (36.4%) showed improvement in gait velocity under the cognitive dual-task condition at T1, and 5 of 10 (50.0%) at T2. Under the physical dual-task condition, 7 of 11 (63.6%) showed improvement in walking speed at T1, and 6 of 10 (60.0%) at T2.

## 4. Discussion

In the present study, cognitive dual-task interference increased significantly, while physical dual-task interference did not change after RAGT using an exoskeleton-type robot. Our results show

## Table 2

**Changes in percentage of dual-task interference (%).**

| | | T0 (n = 11) | T1 (n = 11) | T2 (n = 10) | Within-group comparisons (changes) | |
|---|---|---|---|---|---|---|
| | | | | | T1–T0 | T2–T0 |
| Gait velocity[†] | Dual-task (cognitive) | −15.78 (7.78) | −21.50 (7.62) | −20.75 (6.40) | .026[*] | .203 |
| | Dual-task (physical) | −21.23 (7.42) | −21.10 (5.79) | −23.51 (12.55) | .929 | .646 |

T0 = Before treatment, T1 = After treatment, T2 = 1-month post-treatment.
[†] Mean (Standard deviation).
[*] P < .05 by Wilcoxon signed-rank test.

### Table 3

**Changes in the outcome variables between before treatment, after treatment, and 1-month post-treatment.**

| | T0 (n=11) | T1 (n=11) | T2 (n=10) | Within-group comparisons (changes) T1–T0 | T2–T0 |
|---|---|---|---|---|---|
| 10MWT[†] (m/s) | | | | | |
| Single-task | 1.13 (0.23) | 1.24 (0.28) | 1.17 (0.34) | .041[*] | .445 |
| Dual-task (cognitive) | 0.94 (0.25) | 0.98 (0.24) | 0.92 (0.26) | 1.000 | .721 |
| Dual-task (physical) | 0.89 (0.22) | 0.98 (0.23) | 0.90 (0.29) | .075 | .721 |
| BBS[††] | 52.00 (8.00) | 54.00 (4.00) | 54.00 (5.25) | .004[*] | .024[*] |
| KFES[††] | 28.00 (9.00) | 30.00 (13.00) | 32.50 (15.75) | .235 | .086 |

10MWT = 10-Meter Walk Test, BBS = Berg Balance Scale, KFES = Korean version of the Falls Efficacy Scale-International, T0 = Before treatment, T1 = After treatment, T2 = 1-month post-treatment.
[†] Mean (Standard deviation).
[††] Median (Interquartile range).
[*] P<.05 by Wilcoxon signed-rank test.

that RAGT might improve single-task gait performance, but not dual-task gait performance in patients with PD.

Walking ability is an important factor that affects quality of life and participation in daily life in patients with PD.[14] The gait speed in a single-task shows a significant increase after treatment, which is consistent with previous results that showed RAGT improved gait velocity.[9,14,16–21] In this study, the change in walking speed was 0.11 m/s at the end of the intervention phase. This result was similar the 0.13 m/s change reported by Picelli et al[16]. This change was greater than the 0.04 m/s change in the study by Carda et al,[18] but less than the 0.28 m/s change reported by Picelli et al.[19] The minimal detectable change in the comfort gait speed is 0.18 m/s in patients with PD.[34] Although the change in this study was smaller than 0.18 m/s, 95% confidence interval ranged from .00 to .23 at T1 included the minimal detectable change of 0.18m/s. Therefore, further studies including a larger population are warranted to elucidate the clinical efficacy of RAGT on walking speed in patients with PD.

There have been only 2 studies that investigated the effect of RAGT using an exoskeleton-type robot on gait function in patients with PD.[9,18] They showed that gait speed improvement was sustained for 3 and 6 months. However, the effect of our study was significant only at the end of intervention phase. Compared with our study, the previous studies reported the increase in maximum training speed of up to 3.0 km/h. Therefore,

the intensity of training in our study may not be sufficient to ensure that the effect of RAGT on gait speed persists beyond the end of the intervention phase.

Improved balance in patients receiving RAGT was noted up to 1-month after treatment. This finding is in line with those reported by Picelli et al.[16,20] and Furnari et al.[9] Repetitive high intensity gait-like movements of the robot activated leg muscles and increased the patient's tolerance and weight shift functions.[16,17] Moreover, the rhythmic proprioceptive cue of gait-like movements could compensate for the defective internal rhythm of the basal ganglia and improve balance function.[16,35] In this study, the median BBS score increased from 52 to 54 points. This change was less than those reported in previous studies that reported a the change of 5 in BBS score at the end of the intervention phase and around 3 to 4 at the end of study follow-up.[16,20] However, in our study, the median BBS score was 52 on baseline evaluation, which is higher than that reported in the previous studies. The ceiling effect may mask the effect of intervention because the maximum score for BBS is 56.

There was no significant change in fall efficacy at all points of assessment despite improvement in the gait speed and balance function. Fall efficacy is the result of complex interactions of motor impairment, cognitive impairment, functional ability, disease severity, and psychological factors.[36] In addition, fall efficacy is not always associated with clinical observation.

### Table 4

**Participants' individual data of 10-Meter Walk Test gait velocity.**

| | | | | | Single-task | | | Dual-task (cognitive) | | | Dual-task (physical) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No | Age | Sex | DD | H&Y | T0 | T1 | T2 | T0 | T1 | T2 | T0 | T1 | T2 |
| 1 | 69 | M | 71 | 2.5 | 1.06 | 1.24 | 1.21 | 0.89 | 1.07 | 1.01 | 0.82 | 1.01 | 0.99 |
| 2 | 64 | F | 152 | 2.5 | 1.34 | 1.38 | loss | 1.28 | 1.07 | loss | 0.99 | 1.13 | loss |
| 3 | 64 | M | 125 | 3 | 1.50 | 1.62 | 1.64 | 1.35 | 1.32 | 1.36 | 1.28 | 1.21 | 1.20 |
| 4 | 60 | F | 129 | 3 | 1.00 | 0.82 | 1.00 | 0.85 | 0.66 | 0.80 | 0.82 | 0.66 | 0.88 |
| 5 | 61 | F | 168 | 2.5 | 1.04 | 1.28 | 1.00 | 0.78 | 0.96 | 0.79 | 0.81 | 1.03 | 0.49 |
| 6 | 70 | F | 172 | 2.5 | 1.14 | 1.30 | 1.17 | 0.93 | 0.80 | 0.78 | 0.87 | 1.07 | 0.94 |
| 7 | 68 | F | 144 | 2.5 | 1.16 | 1.18 | 1.15 | 1.14 | 1.08 | 0.96 | 1.09 | 1.05 | 0.95 |
| 8 | 78 | M | 36 | 2.5 | 0.65 | 0.81 | 0.53 | 0.47 | 0.63 | 0.43 | 0.43 | 0.60 | 0.37 |
| 9 | 62 | F | 24 | 2.5 | 1.02 | 1.00 | 0.97 | 0.80 | 0.74 | 0.84 | 0.72 | 0.67 | 0.77 |
| 10 | 73 | M | 120 | 3 | 1.15 | 1.65 | 1.71 | 0.96 | 1.28 | 1.19 | 0.95 | 1.26 | 1.14 |
| 11 | 62 | M | 101 | 2.5 | 1.27 | 1.38 | 1.36 | 1.12 | 1.12 | 1.07 | 1.07 | 1.12 | 1.27 |

DD = Disease duration, H&Y = Hoehn and Yahr stage, T0 = Before treatment, T1 = After treatment, T2 = 1-month post-treatment.

Therefore, more diverse approaches must be attempted to increase fall efficacy.[37]

The improvement in gait speed may not seem to be directly related to the dual-task performance based on the result of this study. Gait training under dual-task conditions may improve gait automaticity.[4] Since RAGT using exoskeletal robotic devices has no risk of fall, RAGT with concurrent tasks may reduce dual-task interferences and improve gait automaticity in patients with PD. Recently, stepping in position training with a wearable sensor or integrated dual-task training were attempted to enhance dual-task function.[38] Auditory feedback using a sensor system, which measures step height during training, improved step automaticity.[38,39] Integrated dual-task training led to sustained improvement in dual-task walking speed, similar to consecutive dual-task training.[39]

Also, some researchers have suggested that high intensity repetitive gait could improve gait automaticity.[7–9,40] In this study, the number of sessions, time per session, and training intensity of the session may not be sufficient to reinforce the functions of neural circuits. Additional therapeutic cues, such as visual and auditory cues, as well as proprioceptive cues may be needed for improving gait automaticity in patients with PD.[10,41] These external cues stimulate the pre-motor control system which bypasses the basal ganglia and supplementary motor area circuit.[42]

This study investigated the effect of RAGT on the dual-task gait performance in patients of PD for the first time. Because a decline in gait automaticity causes difficulties in daily participation, which further decreases quality of life, it is necessary to figure out how to improve the dual-task performance in PD patients. Although this study was the first to examine the effect of RAGT on gait automaticity in patients with PD, the sample size was too small to confirm the results. In addition, this study had no control intervention such as treadmill training or conventional physical therapy. The training protocol of RAGT, such as intensity, number of sessions, and external cues during training, may be modified to achieve optimal therapeutic effects. Therefore, a randomized controlled trial, based on the results of this pilot study, will be needed to confirm the effect of RAGT using an exoskeleton-type robot and its therapeutic mechanism on gait function in patients with PD.

This pilot study suggests that RAGT using an exoskeleton-type robot may not improve gait automaticity despite improvement in walking speed and balance in patients with PD. Additional therapeutic components may be needed to improve gait automaticity in tandem with RAGT in this population. A randomized controlled trial with a larger population is warranted to elucidate the effect and therapeutic mechanism of RAGT in patients with PD.

## Author contributions

## References

[1] Redgrave P, Rodriguez M, Smith Y, et al. Goal-directed and habitual control in the basal ganglia: implications for Parkinson's diease. Nat Rev Neurosci 2010;11:760–72.

[2] Gilat M, Bell PT, Ehgoetz Martens KA, et al. Dopamine depletion impairs gait automaticity by altering cortico-striatal and cerebellar processing in Parkinson's disease. Neuroimage 2017;152:207–20.

[3] Baker K, Rochester L, Nieuwboer A. The immediate effect of attentional, auditory, and a combined cue strategy on gait during single and dual tasks in Parkinson's disease. Arch Phys Med Rehabil 2007;88:1593–600.

[4] Canning CG. The effect of directing attention during walking under dual-task conditions in Parkinson's disease. Parkinsonism Relat Disord 2005;11:95–9.

[5] Rochester L, Hetherington V, Jones D, et al. The effect of external rhythmic cues (auditory and visual) on walking during a functional task in homes of people with Parkinson's disease. Arch Phys Med Rehab 2005;86:999–1006.

[6] Rochester L, Baker K, Hetherington V, et al. Evidence for motor learning in Parkinson's disease: acquisition, automaticity and retention of cued gait performance after training with external rhythmical cues. Brain Res 2010;1319:103–11.

[7] Canning CG, Ada L, Johnson JJ, et al. Walking capacity in mild to moderate Parkinson's disease. Arch Phys Med Rehabil 2006;87:371–5.

[8] Frenkel-Toledo S, Giladi N, Peretz C, et al. Treadmill walking as an external pacemaker to improve gait rhythm and stability in Parkinson's disease. Mov Disord 2005;20:1109–14.

[9] Furnari A, Calabro RS, De Cola MC, et al. Robotic-assisted gait training in Parkinson's disease: a three-month follow-up randomized clinical trial. Int J Neurosci 2017;127:996–1004.

[10] Kelly VE, Eusterbrock AJ, Shumway-Cook A. A review of dual-task walking deficits in people with Parkinson's disease: motor and cognitive contributions, mechanisms, and clinical implications. Parkinsons Dis 2012;2012:918719. https://www.hindawi.com/journals/pd/2012/918719/.

[11] Esquenazi A, Packel A. Robotic-assisted gait training and restoration. Am J Phys Med Rehabil 2012;91(Suppl 3):S217–27.

[12] Díaz I, Gil JJ, Sánchez E. Lower-limb robotic rehabilitation: literature review and challenges. J Robot 2011;2011:759764. https://www.hindawi.com/journals/jr/2011/759764/.

[13] Lo AC, Chang VC, Gianfrancesco MA, et al. Reduction of freezing of gait in Parkinson's disease by repetitive robot-assisted treadmill training: a pilot study. J Neuroeng Rehabil 2010;7:51.

[14] Sale P, De Pandis MF, Domenica L, et al. Robot-assisted walking training for individuals with Parkinson's disease: a pilot randomized controlled trial. BMC Neurol 2013;13:1–7.

[15] Mehrholz J, Thomas S, Werner C, et al. Electromechanical-assisted training for walking after stroke. Cochrane Database Syst Rev 2017;5:CD006185.

[16] Picelli A, Melotti C, Origano F, et al. Does robotic gait training improve balance in Parkinson's disease? A randomized controlled trial. Parkinsonism Relat Disord 2012;18:990–3.

[17] Picelli A, Melotti C, Origano F, et al. Robot-assisted gait training in patients with Parkinson disease: a randomized controlled trial. Neurorehabil Neural Repair 2012;26:353–61.

[18] Carda S, Invernizzi M, Baricich A, et al. Robotic gait training is not superior to conventional treadmill training in parkinson disease: a single-blind randomized controlled trial. Neurorehabil Neural Repair 2012;26:1027–34.

[19] Picelli A, Melotti C, Origano F, et al. Robot-assisted gait training versus equal intensity treadmill training in patients with mild to moderate Parkinson's disease: a randomized controlled trial. Parkinsonism Relat Disord 2013;19:605–10.

[20] Picelli A, Melotti C, Origano F, et al. Robot-assisted gait training is not superior to balance training for improving postural instability in patients with mild to moderate Parkinson's disease: a single-blind randomized controlled trial. Clin Rehabil 2015;29:339–47.

[21] Galli M, Cimolin V, De Pandis MF, et al. Robot-assisted gait training versus treadmill training in patients with Parkinson's disease: a kinematic evaluation with gait profile score. Funct Neurol 2016;31:163–70.

[22] Julious SA. Sample size of 12 per group rule of thumb for a pilot study. Pharm Stat 2005;4:287–91.

[23] Rochester L, Galna B, Lord S, et al. The nature of dual-task interference during gait in incident Parkinson's disease. Neuroscience 2014;265:83–94.

[24] Duncan RP, Combs-Miller SA, McNeely ME, et al. Are the average gait speeds during the 10meter and 6minute walk tests redundant in Parkinson disease? Gait Posture 2017;52:178–82.

[25] Wechsler D. WAIS-III, Wechsler Adult Intelligence Scale: Administration and Scoring Manual. San Antonio, TX: Psychological Corporation; 1997.

[26] Logie RH, Cocchini G, Della Sala S, et al. Is there a specific executive capacity for dual task coordination? Evidence from Alzheimer's disease. Neuropsychology 2004;18:504–13.

[27] Hamilton F, Rochester L, Paul L, et al. Walking and talking: an investigation of cognitive-motor dual tasking in multiple sclerosis. Mult Scler 2009;15:1215–27.

[28] Lord S, Baker K, Nieuwboer A, et al. Gait variability in Parkinson's disease: an indicator of non-dopaminergic contributors to gait dysfunction? J Neurol 2011;258:566–72.

[29] Rochester L, Hetherington V, Jones D, et al. Attending to the task: Interference effects of functional tasks on walking in Parkinson's disease and the roles of cognition, depression, fatigue, and balance. Arch Phys Med Rehab 2004;85:1578–85.

[30] Rochester L, Nieuwboer A, Baker K, et al. Walking speed during single and dual tasks in Parkinson's disease: which characteristics are important? Mov Disord 2008;23:2312–8.

[31] Berg KO, Wood-Dauphinee SL, Williams JI, et al. Measuring balance in the elderly: validation of an instrument. Can J Public Health 1992;83 (Suppl 2):S7–11.

[32] Delbaere K, Close JC, Mikolaizak AS, et al. The Falls Efficacy Scale International (FES-I). A comprehensive longitudinal validation study. Age Ageing 2010;39:210–6.

[33] Park G, Cho B, Kwon IS, et al. Reliability and validity of Korean version of falls efficacy scale-international (KFES-I). J Korean Acad Rehabil Med 2010;34:554–9.

[34] Steffen T, Seney M. Test-retest reliability and minimal detectable change on balance and ambulation tests, the 36-item short-form health survey, and the unified Parkinson disease rating scale in people with parkinsonism. Phys Ther 2008;88:733–46.

[35] Nieuwboer A, Kwakkel G, Rochester L, et al. Cueing training in the home improves gait-related mobility in Parkinson's disease: the RESCUE trial. J Neurol Neurosurg Psychiatry 2007;78:134–40.

[36] Franchignoni F, Martignoni E, Ferriero G, et al. Balance and fear of falling in Parkinson's disease. Parkinsonism Relat Disord 2005;11:427–33.

[37] Thomas AA, Rogers JM, Amick MM, et al. Falls and the falls efficacy scale in Parkinson's disease. J Neurol 2010;257:1124–8.

[38] Chomiak T, Watts A, Meyer N, et al. A training approach to improve stepping automaticity while dual-tasking in Parkinson's disease: a prospective pilot study. Medicine (Baltimore) 2017;96:e5934.

[39] Strouwen C, Molenaar EA, Münks L, et al. Training dual tasks together or apart in Parkinson's disease: results from the DUALITY trial. Mov Disord 2017;32:1201–10.

[40] Picelli A, Camin M, Tinazzi M, et al. Three-dimensional motion analysis of the effects of auditory cueing on gait pattern in patients with Parkinson's disease: a preliminary investigation. Neurol Sci 2010;31:423–30.

[41] Suteerawattananon M, Morris GS, Etnyre BR, et al. Effects of visual and auditory cues on gait in individuals with Parkinson's disease. J Neurol Sci 2004;219:63–9.

[42] Rocha P, Porfirio G, Aguiar L, et al. Effects of external cues on gait parameters of Parkinson's disease patients: a systematic review. Mov Disord 2014;29:S14–14.