NeuroRehabilitation 34 (2014) 557–572
DOI:10.3233/NRE-141051
IOS Press

The effects of speed-dependent treadmill training and rhythmic auditory-cued overground walking on gait function and fall risk in individuals with idiopathic Parkinson's disease: A randomized controlled trial

Cathy C. Harro*, Michael J. Shoemaker, Oksana J. Frey, April C. Gamble, Kendra B. Harring, Katherine L. Karl, Jeffrey D. McDonald, Carolyn J. Murray, Erika M. Tomassi, Jasmine M. Van Dyke and Rachel J. VanHaistma
Department of Physical Therapy, Grand Valley State University, Grand Rapids, MI, USA

Abstract.
OBJECTIVES: The purpose of this randomized controlled study was to examine and compare the immediate and retention effects of speed-dependent treadmill training (SDTT) and rhythmic auditory-cued (RAC) overground walking on gait function and fall risk in individuals with Parkinson's disease (PD).
METHODS: Twenty participants (mean age 66.1 yrs) with idiopathic PD were randomized into either SDTT ($n = 10$) or RAC ($n = 10$) progressive, interval-based locomotor training protocols. Immediate and retention training effects on gait function and fall risk were measured by comfortable and fast gait speed (CGS, FGS), 6-Minute Walk Test (6MWT), and Functional Gait Assessment (FGA).
RESULTS: Immediate within-group training effects revealed significant gains in CGS, 6MWT, and FGA for the RAC group, and in FGS, 6-MinuteWalk Test, and FGA for the SDTT group. Retention effects were found at 3-month follow-up for all gait measures in the RAC group, and for FGS and FGA in the SDTT group. No statistically significant differences in immediate or retention training effects on gait measures were found between groups.
CONCLUSIONS: Externally-cued locomotor training with progressive and interval-based speed challenges, either with RAC overground or on a treadmill, produced significant improvements in walking speed, endurance, and dynamic balance during walking.

Keywords: Parkinson's disease, locomotor training, rehabilitation

1. Introduction

Parkinson's disease (PD) is an idiopathic neurodegenerative disorder resulting in a combination of motor control, postural control, and gait impairments, which contribute to limitations in mobility skills and increased fall risk (Bloem, Grimbergen, Cramer, Willemsen, & Zwinderman, 2001; Lewis, Byblow, & Walt, 2000; Morris, 2000; Morris, Huxham, McGinley, Dodd, & Iansek, 2001; Smithson, Morris, & Iansek, 1998). Morris et al. (2001) estimated that 50 to 70 percent of individuals with PD fall within a one-year period. More than 45% of these falls occur during ambulation or functional mobility tasks (Ashburn, Stack, Ballinger, Fazakarley, & Fitton, 2008). Falls often trigger a fear of future falls, leading to self-imposed activity restriction

*Address for correspondence: Cathy C. Harro, Grand Valley State University, 301 Michigan NE, Suite 247, Grand Rapids, MI 49503, USA. Tel.: +1 616 331 5974; Fax: +1 616 331 5654; E-mail: harroc@gvsu.edu.

and reduced quality of life (QOL) (Adkin, Frank, & Jog, 2003; Bloem et al., 2001).

Characteristics of gait in PD include slowed speed, narrowed base of support, and decreased step length and foot clearance, resulting in shuffling of gait (Morris & Lansek, 1997; Morris, 2000; Morris, Martin, & Schenkman, 2010). The underlying PD-specific impairments contributing to these gait deficits are hypokinesia, akinesia, and problems with centrally-generated rhythmic movements (Morris & Lansek, 1997). Postural instability and cognitive impairment also occur with disease progression, further contributing to gait dysfunction (Morris & Lansek, 1997; Bloem, Grimbergen, van Dijk, & Munneke, 2006). Instability is evident during walking in dual task conditions and in changing environmental demands (Ashburn et al., 2008; Morris & Lansek, 1997; Bloem et al., 2006; Bloem, Hausdorff, Visser, & Giladi, 2004; Smulders et al., 2012). Akinesia, motor blocks, and arrhythmic gait in PD can cause freezing of gait, further increasing fall risk (Bloem et al., 2004). These complex gait and balance deficits result in a gradual decline in safe mobility in the home and community. Preserving walking and balance function is a priority of rehabilitation for persons with PD.

Externally-cued gait training paradigms are supported in the literature to address these gait deficits in PD. These paradigms use temporal or spatial stimuli to facilitate stepping and a rhythmic gait pattern (Morris et al., 2010; Nieuwboer et al., 2007). Treadmill training (TT) is an externally-cued intervention that utilizes somatosensory cues via movement and speed of the treadmill belt to drive the stepping pattern. Several TT protocols have been applied in previous PD research. Speed-dependent TT (SDTT) employs short intervals of fast or maximum speed (Pohl, Rockstroh, Ruckriem, Mrass, & Mehrholz, 2003), while progressive speed protocols use systematic and gradual speed increases over time (Bello, Sanchez, & Fernandez-del-Olmo, 2008; Merholz et al., 2010; Pelosin et al., 2009; Protas et al., 2005). Dosage, including training frequency and intensity, has varied across studies; therefore optimal training parameters are unclear (Bello et al., 2008; Frenkel-Toledo et al., 2005; Herman, Giladi, & Hausdorff, 2009; Merholz et al., 2010; Pelosin et al., 2009; Protas et al., 2005). Research evidence supports that these TT protocols produced short-term improvement in gait measures including gait speed, stride length, cadence, and walking distance (Bello et al., 2008; Cakit, Saracoglu, Genc, Erdem & Inan, 2007; Frazzitta et al., 2009; Frenkel-Toledo et al., 2005; Herman et al., 2009; Merholz et al., 2010; Pelosin et al., 2009; Pohl et al., 2003; Protas et al., 2005; Skidmore, Patterson, Shulman, Sorkin, & Macko, 2008). Only a few TT studies examined balance outcomes following TT and reported immediate gains in balance abilities (Cakit et al., 2007; Protas et al., 2005) and reduced falls in PD (Protas et al., 2005). The majority of TT research, however, has focused primarily on immediate temporal-distance gait outcomes, and has inadequately addressed both short and long-term effects on gait and balance function, and fall risk reduction.

Rhythmic auditory-cueing (RAC) is another type of externally-cued gait intervention employed during overground walking to improve gait function in persons with PD. RAC protocols use rhythm and musical beats to facilitate sensory motor stimulation during gait training (de Bruin et al., 2010; Ford, Malone, Nyikos, Yelisetty, & Bickel, 2010; Freeland et al., 2002; McIntosh, Brown, Rice, & Thaut, 1997; Nieuwboer, 2008; Willems et al., 2006). Previous research provides evidence that RAC training improves gait parameters in PD, including gait speed, stride length, cadence and gait rhythmicity (Bryant, Rintala, Lai, & Protas, 2009; de Bruin et al., 2010; Ford et al., 2010; Frazzitta et al., 2009; Nieuwboer et al., 2007; Thaut et al., 1996). Only Nieuwboer et al. (2007) examined retention effects at 6 and 12 weeks post-training and found that treatment effects were not maintained. Most of the studies, however, examined only short-term temporal-distance gait outcomes. There is insufficient research assessing the effects of RAC training on functional gait and balance measures, which may be more reflective of fall risk reduction. The treatment parameters of RAC training (frequency, intensity, duration, and speed of auditory cueing) are highly variable across studies; therefore optimal training parameters are unclear. Similar to SDTT training, the carryover or retention effects of RAC training are inadequately examined.

Frazzitta et al. (2009) compared TT and RAC overground training in persons with PD, utilizing combined auditory and visual cues in both protocols. Both treatment groups showed significant improvements in gait parameters and reduced freezing of gait episodes immediately post-training. These gains were greater in the TT group, which may be explained by the combined use of TT and RAC cueing. Further research is needed to examine the immediate and retention effects of these two cued paradigms on functional gait, balance and fall risk reduction in PD, and to better delineate the contributions of TT versus RAC.

The primary objective of the present study was to determine the immediate and 3-month post-training

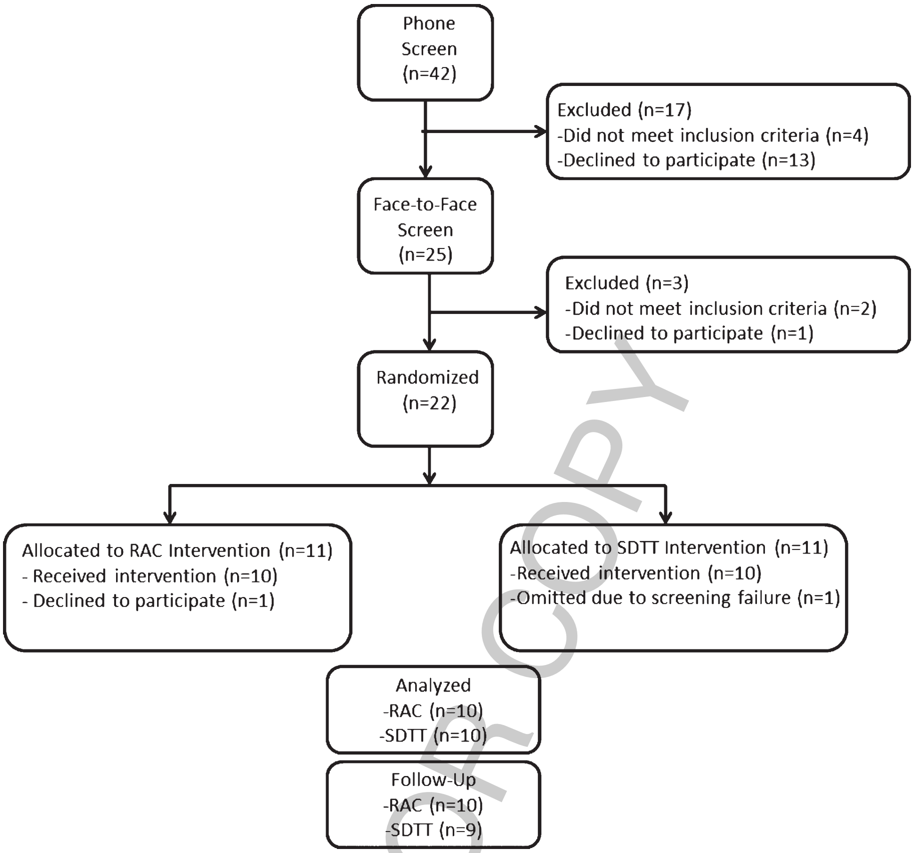

Fig. 1. Consort Diagram. Sequencing of participant screening, enrollment, randomization and allocation. The number of participants involved in each segment of the chart is represented with "n." The rhythmic auditory-cued training group is represented with RAC and the speed-dependent treadmill training group is represented with SDTT.

within-group effects of SDTT and RAC overground walking programs on gait function, dynamic balance function, and fall risk in individuals with PD. The secondary objective of the study was to compare these training effects between the RAC overground and SDTT groups. This paper will discuss the immediate and retention training effects on gait function and fall risk. A second paper addresses the immediate and retention training effects on balance function, balance confidence, quality of life and fall incidence (Harro et al., 2014, in press). This study has important clinical implications regarding identification of effective physical therapy interventions to improve walking function and reduce falls in persons with PD.

2. Methods

A single-blinded, randomized controlled trial design was utilized to examine the effects of two evidence-based locomotor training protocols. Both protocols incorporated external cueing and a progressive speed component to facilitate improved gait function. For the within-groups effect, the independent variable was time [baseline, post-training, 3-month retention follow-up]. For the between-groups effect, the independent variable was group assignment [type of locomotor training protocol (SDTT vs. RAC)].

2.1. Participants

Forty-two individuals diagnosed with PD were recruited utilizing convenience sampling. Twenty-two participants met inclusion and exclusion criteria for the study. Refer to Fig. 1 for screening and enrollment process. Recruiting sources included the local chapter of the National Parkinson Foundation, the Mercy Health Hauenstein NeuroScience Center, and local retirement communities. Inclusion criteria for the study were: (1) age of 18–89 years, (2) diagnosis of idiopathic PD, stage 1–3 on the Hoehn and Yahr (1967) scale, (3) ability to walk continuously without physical assistance for five minutes with or without an assistive device, (4) stable PD medication schedule and dosing over past month as reported by the participant's neurologist and (5) functional vision and hearing sufficient to perceive cues with or without aides/glasses. Exclusion criteria for participation in this study were: (1) impaired cognitive functioning evidenced by a score of 20 or less on the Saint Louis Mental Status Examination (SLUMS) (Tariq, Tumosa, Chibnall, Perry, & Morley, 2006), (2) history of other neurologic or vestibular disorders, (3) current orthopedic conditions that would affect the ability to walk, (4) history of PD-related deep brain stimulation, (5) inability to speak and read English, and (6) unstable medical status and inability to engage in moderate exercise based on the LEAPS clinical trial criteria (Duncan et al., 2007). Participants were deemed safe to engage in the locomotor training based on these above criteria and were cleared to participate in the study by their primary care physician. This study was approved by the Institutional Review Boards at Mercy Health Saint Mary's and Grand Valley State University. All participants who met the inclusion and exclusion criteria completed the informed consent process prior to participation.

2.2. *Intervention procedures*

Twenty-two participants who qualified enrolled in the study and were stratified based on freezing of gait attributes (classified with the Freezing of Gait Questionnaire as "freezers" vs. "non-freezers") and age (<70 vs. >70 years old), and then were randomly assigned to one of two groups: (1) SDTT or (2) RAC. One participant declined to participate due to his work schedule and another was omitted due to screening failure. Participants received three, 30-minute training sessions per week for six weeks. The SDTT group consisted of moderate intensity treadmill locomotor training with a safety harness support. The RAC group consisted of auditory-cued overground locomotor training on an indoor track while listening to a personalized music playlist set at subject-specific beats per minute (bpm). During the intervention period, participants were required to abstain from any therapeutic intervention that involved gait training or treadmill walking outside of the treatment sessions.

2.3. *Speed-dependent treadmill training*

Speed-dependent treadmill training was provided with one-on-one supervision by three researchers who followed a standardized protocol (Fig. 2). Each session started with a 5-minute warm-up period walking at the participant's comfortable gait speed (CGS) on the treadmill, followed by three 5-minute speed intervals with a 2.5-minute walking recovery between intervals at CGS. The speed of the first two intervals was at the participant's subjective maximal "fast" walking speed (V1), and the speed of the third interval was a 5% increase (V2) of V1 speed, as long as during the first two intervals there was no decline in gait pattern, balance, or excessive cardiovascular fatigue. If researchers observed any of these criteria, then the third interval was performed at V1 or slightly slower if necessary. The training session ended with a 5-minute cool down walking at CGS. Participants were allowed to use treadmill railings only during the first minute following speed interval changes if necessary to adjust their balance and gait to the speed demands, and then were encouraged to use a reciprocal arm swing. Researchers closely monitored the participant's gait pattern, safety, and cardiovascular responses (blood pressure, heart rate and perceived exertion) during the training. Training progression across sessions was individualized by utilizing the participant's fastest gait speed from the previous session as their V1 interval training speed for subsequent session.

2.4. *RAC overground training*

The RAC training was provided in small groups of five participants by two experienced physical therapists, which followed a standardized protocol (Fig. 3). Each participant was provided headphones and an iPod shuffle (Apple Inc., Cupertino, California), with a personalized music playlists. The prescribed target bpm was based on CGS and 5–10 bpm incremental speed increases. These playlists were created using PitchSwitch+software (Pitch Switch+, Inspyder Software, 3342 Mainway, Suite 200, Burlington, ON). The RAC training consisted of walking overground for 30 minutes on a level indoor track. Each training session included a 5-minute warm-up walking with the musical playlist (bpm) at the participant's CGS, followed by two 10-minute speed intervals walking at speeds 5–10 bpm faster (V1) than their CGS, and ending with a 5-minute cool down walking at CGS. Training progression was individualized and was based on quality of gait during the speed intervals. If the participant was unable to maintain a rhythmic gait pattern at prescribed V1 speed, then the selected playlist was set back to the participant's CGS for the second 10-minute interval. If no decline in gait or balance was observed at V1, then the music

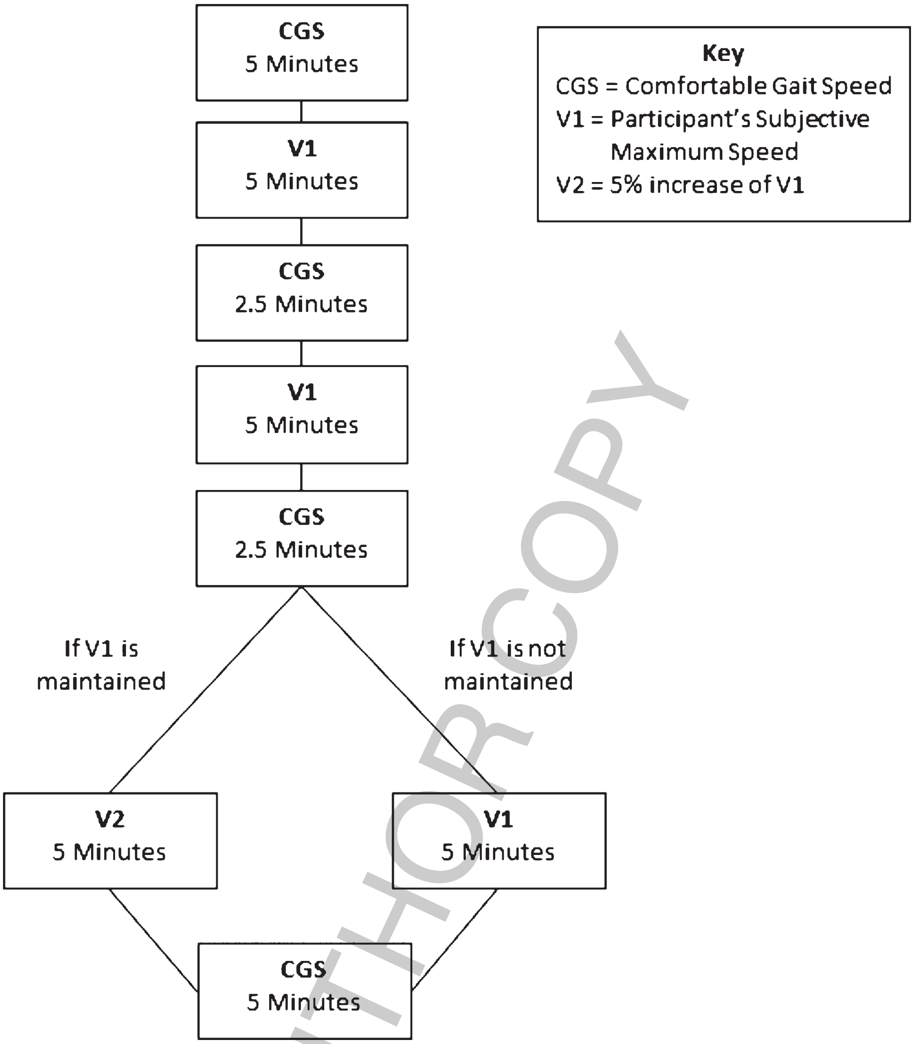

Fig. 2. Speed-dependent treadmill training protocol.

playlist was increased by 5–10 bpm (V2) for the second 10-minute interval. The researchers assisted each participant in finding the beat of the music with use of a metronome or clapping at the target bpm during the training. Consistent with the SDTT protocol, researchers closely monitored participant's gait pattern, safety, and cardiovascular responses during the training. Training progression across sessions was individualized by utilizing the participant's fastest gait speed from the previous week as the V1 training speed for subsequent session. At the end of each week, the participant's CGS was reassessed using the 10-meter walk test, and the playlist was adjusted accordingly to reflect this new baseline.

For both training groups, the researchers provided intermittent verbal cues to the participants regarding posture, stride length, and arm swing. At the end of each training session, participants were guided through a standardized stretching exercise program. Termination of a training session was based on the cardiovascular criteria as described in the LEAPS controlled clinical trial on locomotor training post-stroke (Duncan et al., 2007).

2.5. Outcomes

Assessments were completed prior to training (T0), immediately post-training (T1) and 3 months post-training (T2) to examine retention effects. All assessments were completed during the participant's on-phase of PD medication. Testing was conducted by

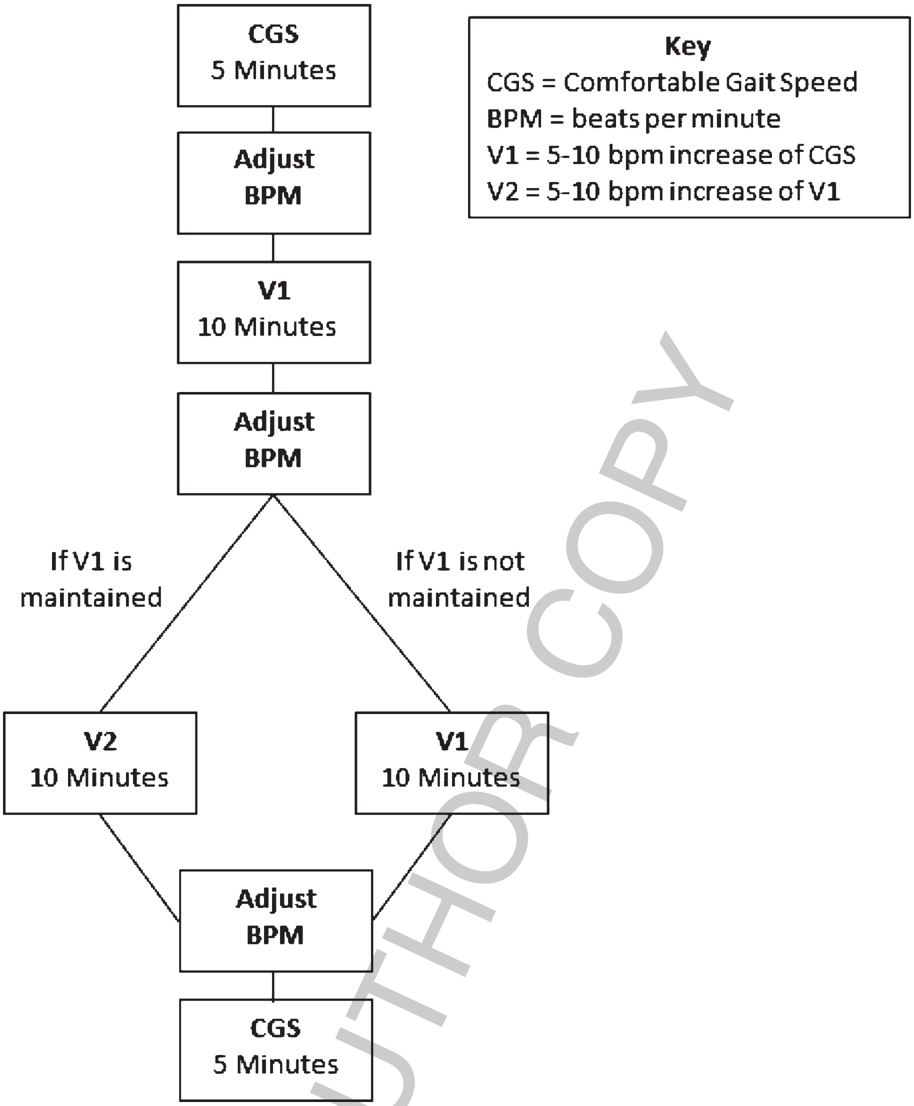

Fig. 3. Rhythmic auditory-cued training protocol.

three trained researchers who were blinded to group assignment and did not participate in the interventions.

The primary gait outcome measures addressed in this paper were comfortable gait speed (CGS) and fast gait speed (FGS) based on the 10-meter walk test, the 6 minute walk test (6MWT), and the Functional Gait Assessment (FGA). The secondary outcome measures that are described in a second paper were functional and impairment-based measures of balance, including the Rapid Step-Up Test, the Berg Balance Scale (BBS), and standardized measures on the SMART EquiTest System from NeuroCom® (Limits of Stability, Motor Control, and Sensory Organization tests). Balance confidence and quality of life measures (Parkinson's Disease Questionnaire-39), as well as 6-month prospective fall incidence were also assessed in a second paper.

The 10-meter walk test (Stokes, 2011) was used to assess CGS and FGS, with one trial completed at each speed. Comfortable and fast gait speed has excellent test retest reliability (ICC = 0.96, 0.97, respectively) in persons with PD (Steffen & Seney, 2008). Gait speed is a sensitive measure to detect change in walking function in older adults (Perera, Mody, Woodman, & Studenski, 2006). The researchers administered the 10-meter walk test recording the total time from 2 m to 12 m using a 14-meter path to allow for acceleration and deceleration.

The FGA is a 10-item clinical gait test used to assess dynamic balance during walking. The total score is 30 points, with lower scores indicating greater impairment. A cutoff score of 22 out of 30 points is the reported fall risk threshold, with excellent sensitivity (sensitivity 1.00, specificity 0.72) for detecting elderly fallers (Wrisley & Kumar, 2010). The FGA has excellent inter-rater reliability (ICC 0.93) and good concurrent validity with the BBS and Activities-Specific Balance Confidence Scale-16 in persons with PD (Leddy, Crowner, & Earhart, 2011), as well as with PDQ-39 motor score (Ellis et al., 2011). Standardized test procedures and equipment were used with administrating the FGA (Walker et al., 2007).

The 6MWT assessed walking capacity and endurance relevant to community ambulation (Butland, Pang, Gross, Woodcock, & Geddes, 1982). Participants walked up and down a 100 ft. (30.48 m) course. Excellent test-retest reliability (ICC ranging from 0.87—0.99) has been demonstrated across multiple clinical populations, including those with neurologic conditions (Steffen & Seney, 2008). The 6MWT was conducted using standard test administration according to the American Thoracic Society Guidelines (2002).

2.6. *Statistical analysis*

All statistical analyses were conducted using PASW 18.0 (SPSS Inc., Chicago, IL). Sample size was determined with a priori power analysis for within-group differences with gait speed as a primary dependent variable to be 6 participants for each group (one tailed dependent *t*-test, expected effect size = 1.2, $\alpha = 0.05$, power = 0.80). The sample distributions for the dependent gait variables met assumptions of normality; therefore parametric statistical tests were used. For dependent variables, within-groups effects were analyzed using dependent paired *t*-tests, and between-groups effects were analyzed using independent *t*-tests. Data were analyzed from Baseline (T0) to Post-Training (T1) to assess training effects, and Baseline (T0) to Follow-up (T2) to assess retention effects. The level of statistical significance was set a priori at $p < 0.05$.

3. Results

3.1. *Participant demographics*

Twenty participants with mean age of 66.1 years enrolled in this study and were randomly assigned to RAC and SDTT groups. Refer to Table 1 for participant demographics and clinical characteristics for each training group. The mean time since onset of PD for all participants was 4.12 (2.26) years with a mean Hoehn and Yahr stage of 1.93 (0.57). Symptoms for FOG were reported in 35% of participants based on the FOG-Q. Twenty percent of sample ($n = 4$) had a history of one fall and 20% ($n = 4$) were frequent fallers (≥2 falls) in past 6 months. All participants were community ambulators and only two reported the use a standard cane while walking in the community. The mean SLUMS score was 27.2 (range of 21–30), with 40% of sample ($n = 8$) classified as Mild Neurocognitive Disorder (score between 21 and 26) (Tariq et al., 2006). Independent *t*-tests and Chi Square analysis revealed no statistically significant differences in participant characteristics (age, gender, Hoehn and Yahr stage, time post-diagnosis, SLUMS, and FOG or fall risk classification) or in any dependent measures between training groups at baseline ($p < 0.05$). One subject in the SDTT group was omitted from the 3-month follow-up analysis due to an unrelated development of vertigo. The onset of this new medical condition, which was an exclusion criterion for this study, had the potential to confound the follow-up assessment data and skew the results.

3.2. *Training progression*

Participation rates were comparable in both training groups (100% in SDTT and 99% in RAC). Table 2 summarizes the training parameters for both groups, reflecting walking speeds and distances at the end of week one as compared to the end of week six of training. In regards to mean total distance walked per 30-minute training session among participants, the RAC group progressed from 1.56 to 1.72 miles and the SDTT group progressed from 1.24 to 1.65 miles. Both groups also showed progression of CGS across training sessions with a mean change from 115.7 to 124.0 bpm in the RAC group and a mean change from 2.10 to 2.98 mph in the SDTT group. The different construct of each protocol precludes meaningful quantitative comparison of training data.

Following training, participants were encouraged to engage in walking activity on their own. Activity logs were collected monthly from participants. The participants' activity logs showed that 50% of the RAC group did walking exercise for ≥30 minutes, three times per week for six months following the intervention, versus only 22% of the SDTT group. However, 70% of the RAC group and 66% of the SDTT group stayed active

Table 1
Participant characteristics

Participant	Intervention	Gender	Age (y)	Hoehn and Yahr	Time Since Onset (y)	Freezer vs. Non-freezer	Fall History (baseline)	Fall History (prospective)	SLUMS	PD Medication(s)	Medical Co-morbidities
1	RAC	M	76	2	1.75	NFr	0	0	23	Sinemet	None
2	RAC	M	67	2	7.00	NFr	0	0	25	Sinemet, Azilect	None
3	RAC	M	76	2	5.50	Fr	0	0	29	Sinemet, Mirapex	HTN, Hx of MI, Orthostatic hypotension
4	RAC	M	66	3	5.50	NFr	0	0	29	Mirapex, Stalevo	HTN, DM, OA
5	RAC	M	75	1	1.00	Fr	0	1	29	Sinemet, Mirapex	Ca, Sleep apnea
6	RAC	M	85	2	1.00	Fr	2+	0	26	Sinemet	DM, Neuropathy, Ca, Lumbar stenosis
7	RAC	F	46	2	4.00	NFr	0	0	29	None	None
8	RAC	M	67	2	3.00	NFr	0	0	26	Sinemet, Azilect	Ca
9	RAC	F	55	1	4.58	NFr	2+	0	26	Artane, Klonopin	None
10	RAC	M	60	2	6.50	Fr	1	1	29	Sinemet, Selegiline	Ankylosing spondylitis
11	SDTT	F	55	2	5.42	NFr	1	2+	30	None	Glaucoma
12	SDTT	F	62	2	6.42	NFr	1	1	29	Requip, Selegiline	Atrial fibrillation
13	SDTT	M	73	3	5.00	Fr	2+	0	21	Sinemet, Clonazepam	HTN, DM
14	SDTT	F	75	2	5.00	Fr	0	0	29	Sinemet	Osteoporosis, Glaucoma, Ca
15	SDTT	M	64	3	3.50	NFr	2+	1	29	Sinemet	Ca
16	SDTT	F	63	1	2.50	NFr	1	0	27	Sinemet	HTN, DM, Diabetic retinopathy
17	SDTT	F	45	2	1.00	NFr	0	0	30	Sinemet, Requip	None
18	SDTT	M	66	2	3.25	NFr	0	0	30	Sinemet	None
19	SDTT	M	73	1	1.50	NFr	0	1	25	Sinemet	HTN, Atrial fibrillation, Glaucoma
20	SDTT	M	73	2	9.00	Fr	0	0	23	Sinemet	None
Mean ± SD (range)			66.10 ± 10.31 (45–85)	1.93 ± 0.57 (1–3)	4.12 ± 2.26 (1–9)				27.2 ± 2.69 (21–30)		

Independent *t*-tests revealed no statistically significant differences between training groups in the following participant characteristics at baseline: age, Hoehn and Yahr stage, time since onset of PD, and SLUMS ($p < 0.05$). Abbreviations: RAC, rhythmic auditory-cued training; SDTT, speed-dependent treadmill training; F, female; M, male; Fr, freezer; NFr, non-freezer; Fall History (baseline): 0 = no falls 6 months prior to training, 1 = 1 fall 6 months prior to training, 2+ = 2 or more falls 6 months prior to training; Fall History (post): 0 = no falls 6 months after training, 1 = 1 fall 6 months after training, 2+ = 2 or more falls 6 months after training; SLUMS, St. Louis University Mental Status; PD, Parkinson's Disease; HTN, hypertension; Hx, history; MI, myocardial infarction; DM, diabetes mellitus; OA, osteoarthritis; Ca, cancer.

Table 2
Summary of training parameters

	RAC	SDTT
Mean CGS Session 3:	115.70 bpm (105–126 bpm)	2.10 mph (0.80–4.10 mph)
Mean CGS Session 18:	124.00 bpm (114–135 bpm)	2.98 mph (2.10–4.80 mph)
Mean V1 Session 3:	125.70 bpm (113–144 bpm)	2.83 mph (1.10–5.10 mph)
Mean V1 Session 18:	130.90 bpm (123–144 bpm)	3.57 mph (2.30–5.60 mph)
Mean V2 Session 3:	133.70 bpm (113–146 bpm)	3.00 mph (1.20–5.40 mph)
Mean V2 Session 18:	136.20 bpm (123–144 bpm)	3.77 mph (2.50–6.50 mph)
Mean Distance Walked Session 3 (miles):	1.56 (1.20–1.83)	1.24 (0.84–2.47)
Mean Distance Walked Session 18 (miles)	1.72 (1.33–2.09)	1.65 (1.08–2.70)
Mean % Change in Distance Walked (%):	29.39 (22.85–35.11)	26.62 (14.77–46.35)

Summary of training parameters for the rhythmic auditory-cued training group and speed-dependent treadmill training group at the end of week 1 (session 3) and the end of week 6 (session 18). Abbreviations: RAC, rhythmic auditory-cued training; SDTT, speed-dependent treadmill training; CGS, comfortable gait speed; V1, first velocity speed interval; V2, second velocity speed interval; bpm, beats per minute; mph, miles per hour.

in some form of aerobic activity (e.g., biking, playing tennis) over the six-month follow-up period.

3.3. *Within-group effects of training on gait function*

Statistically significant within-group training effects for the gait measures were found in both the SDTT and RAC groups (Table 3). Dependent *t*-tests revealed statistically significant increases in mean CGS for the RAC training group ($p = 0.013$) and in mean FGS for the SDTT group ($p = 0.012$) from baseline to post-training. The RAC group's mean CGS improved from 1.30 to 1.45 m/s (11.93%, $p = 0.02$), as compared to 1.30 to 1.36 m/s (4.53%, $p = 0.13$) improvement in the SDTT group. In contrast, the SDTT had greater gains in FGS, 1.69 to 1.82 m/s (7.45%, $p = 0.01$), as compared to 1.74 to 1.81 m/s (3.56%, $p = 0.08$) gain in the RAC group. These training effects were maintained at follow-up for CGS in the RAC group ($p = 0.003$) and for FGS in the SDTT group ($p = 0.05$). Interestingly, the RAC group's mean FGS continued to improve 3 months post-training (1.74 m/s baseline, 1.81 m/ post-training and 1.87 m/s at three months follow-up), with a statistically significant difference found between baseline and follow-up FGS ($p = 0.02$). Refer to Fig. 4 for a comparison of CGS and FGS at baseline, post-training, and 3-month follow-up for the two groups.

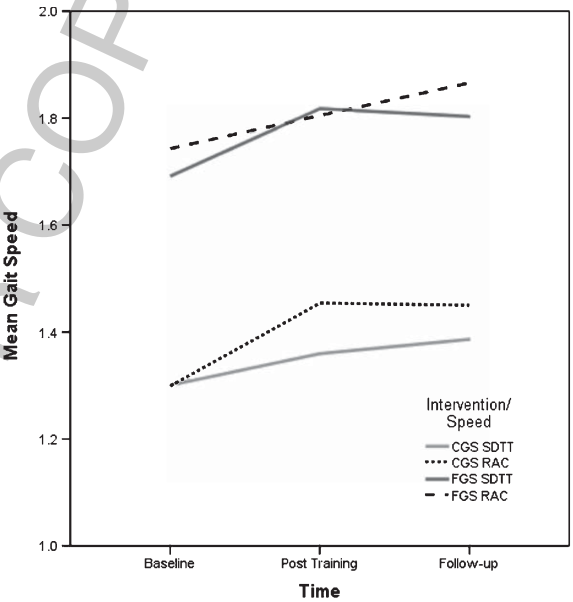

Fig. 4. Mean Comfortable and Fast Gait Speed at Baseline, Post-training, and 3-month follow up. Dependent *t*-tests showed statistically significant increases in mean Comfortable Gait Speed (m/sec) for the Rhythmic Auditory-Cued training group and in mean Fast Gait Speed (m/sec) for the Speed Dependent Treadmill Training group from baseline to post-training ($p < 0.05$). These increases were maintained at 3-month follow-up, as well as an additional statistically significant increase in mean Fast Gait Speed for the Rhythmic Auditory-Cued Training group. There was insufficient evidence to demonstrate a between-group effect for both gait speeds ($p < 0.05$). Abbreviations: SDTT: speed dependent treadmill training; RAC: rhythmic auditory-cued; CGS: comfortable gait speed; FGS: fast gait speed.

Statistically significant within-group improvements from baseline to post-training were also found in both training groups for the 6MWT (RAC, $p = 0.007$; SDTT, $p = 0.027$) and FGA (RAC, $p = 0.003$; SDTT, $p < 0.001$). The RAC and SDTT groups increased 6MWT distances by 47 m (9.41%) and 30 m (5.84%), respectively (Fig. 5). This gain in 6MWT was maintained at follow-up for the RAC group only ($p = 0.05$). Regarding the FGA (Fig. 6), based on a threshold FGA score of 22 for identifying those at fall risk, 4 participants in each training group who were classified as being at fall risk at baseline, improved scores and moved out of this fall risk category post-training. Improvements in FGA scores post-training were retained at follow-up for both groups (RAC, $p = 0.01$, SDTT, $p = 0.001$).

Table 3
Descriptive Statistics for Gait Outcome Measures for Groups at Baseline, Post-training & Follow-up

Primary Gait Outcome Measure	RAC Baseline (0)	RAC Post-training (1)	RAC Follow-Up (2)	RAC Within-group Comparison (0–1)	RAC Within-group Comparison (0–2)	SDTT Baseline (0)	SDTT Post-training (1)	SDTT Follow-Up (2)	SDTT Within-group Comparison (0–1)	SDTT Within-group Comparison (0–2)
CGS (m/s)	1.30 (0.13) 1.05–1.45	1.45 (0.19) 1.16–1.84	1.45 (0.17) 1.17–1.65	$t = 3.08$ $p = 0.02$* (0.04, 0.27)	$t = -3.97$ $p = 0.003$* (−0.24, −0.06)	1.30 (0.19) 1.08–1.62	1.36 (0.21) 1.05–1.70	1.39 (0.24) 1.05–1.73	$t = 1.65$ $p = 0.13$	$t = -1.72$ $p = 0.12$
FGS (m/s)	1.74 (0.27) 1.23–2.12	1.81 (0.26) 1.23–2.18	1.87 (0.21) 1.43–2.07	$t = 1.94$ $p = 0.08$	$t = -2.98$ $p = 0.02$* (−0.22, −0.03)	1.69 (0.27) (1.28–2.11)	1.82 (0.30) 1.38–2.35	1.80 (0.33) 1.46–2.24	$t = 3.15$ $p = 0.01$* (0.04, 0.22)	$t = -2.32$ $p = 0.05$* (−0.20, −0.00)
6MWT (m)	509.7 (81.5) 356.6–649.9	557.6 (76.5) 398.4–670.6	544.2 (76.7) 360.0–637.0	$t = 3.45$ $p = 0.01$* (16.54, 79.40)	$t = -2.29$ $p = 0.05$* (−68.57, −0.44)	509.2 (80.1) 407.9–658.4	539.0 (74.4) 445.0–712.3	531.4 (122.7) 367.9–741.0	$t = 2.64$ $p = 0.03$* (4.25, 55.23)	$t = -0.46$ $p = 0.66$
FGA (Total = 30)	21.3 (4.7) 15–28	25.5 (3.3) 21–30	26.0 (2.2) 23–29	$t = 3.99$ $p = 0.003$* (1.82, 6.58)	$t = -3.74$ $p = 0.01$* (−7.54, −1.86)	20.1 (4.3) 16.0–27.0	24.8 (3.2) 20.0–30.0	26.8 (3.1) 22–30	$t = 5.75$ $p < 0.001$* (2.85, 6.55)	$t = -5.64$ $p < 0.001$* (−8.77, −3.68)

The mean, standard deviation (SD) and range are represented above for baseline (0), post-training (1) and 3-month follow-up (2) data. The test statistic (t), p-value (p) and 95% confidence interval (CI) are represented above for the comparison data. *Denotes statistically significant differences for within group comparisons are presented, $p < 0.05$. A 95% CI was only reported if the measure was statistically significant. Abbreviations: RAC, rhythmic auditory-cued training group; SDTT, speed-dependent treadmill training group; CGS, Comfortable Gait Speed; FGS, Fast Gait Speed; 6MWT, 6 Minute Walk Test.

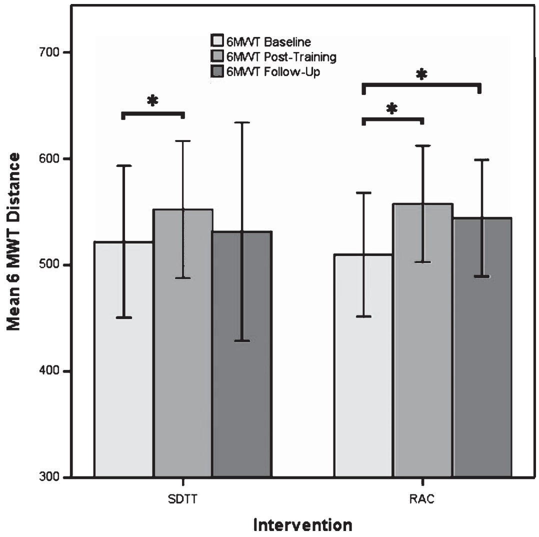

Fig. 5. Mean Six Minute Walk Test Results from Baseline, Post-training, and 3-Month Follow Up. The rhythmic auditory-cued training group and the speed-dependent treadmill training group both demonstrated significant within-group increases in the distance walked (meters) during the Six Minute Walk Test from baseline to post-training ($p < 0.05$). This gain was only maintained in the RAC group ($p = 0.05$). No between-group difference was found ($p < 0.05$). * Denotes statistically significant differences for within-group comparisons, $p < 0.05$. Abbreviations: 6MWT: 6-Minute Walk Test; SDTT: speed dependent treadmill training; RAC: rhythmic auditory-cued.

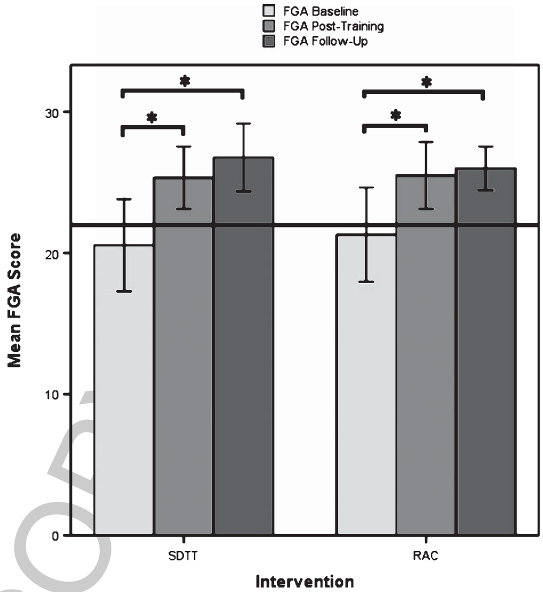

Fig. 6. Mean Functional Gait Assessment Results from Baseline, Post-Training, and 3-Month Follow-Up. The rhythmic auditory-cued training group and the speed-dependent treadmill training group both demonstrated significant within-group increases Functional Gait Assessment score from baseline to post-training ($p < 0.05$). This gain was maintained in both groups at 3-Month Follow-Up ($p = 0.05$). No between-group difference was found ($p < 0.05$). *Denotes statistically significant differences for within-group comparisons, $p < 0.05$. The horizontal line at 22 points represents fall risk threshold. Abbreviations: FGA: Functional Gait Assessment; SDTT: speed dependent treadmill training; RAC: rhythmic auditory-cued.

3.4. Between-group effects of training on gait function

There were no statistically significant differences found between training groups in any of the dependent gait measures from baseline to post-training, or from baseline to 3 month follow-up. However, for CGS and FGS, there appeared to be a trend toward a training-specific effect of group assignment on gait speed. From baseline to post-training, there was a trend of greater CGS improvement in the RAC training group as compared to the SDTT group (0.16 vs. 0.06 m/s, $p = 0.138$) and a trend of greater FGS improvement in the SDTT group as compared to the RAC training group (0.13 vs. 0.06 m/s, $p = 0.227$). It should be noted that *post hoc* power analyses revealed low statistical power for the between-group effects for gait speed and 6MWT distance (e.g., effect size = 0.70, two-tailed $\alpha = 0.05$, $1–\beta = 0.31$ for FGS). Table 3 summarizes the between-group comparison of gait dependent measures.

4. Discussion

This study applied the best evidence regarding over-ground and treadmill locomotor training paradigms to design and evaluate outcomes of training protocols that systematically applied externally-cued, individually progressive, and interval-based SDTT and RAC training. Results from this study provide support for efficacy of both interventions in persons with PD as evidenced by significant training-specific changes in CGS, FGS, 6MWT and FGA. Gains in walking speed and endurance were evident across the 6 weeks of training sessions for both groups, and the majority of gains were maintained at the three-month follow up. Although there were not any statistically significant between-group differences in gait function in this small sample, there are some potentially important implications of the present study's results for intervention selection in individuals with PD.

4.1. Effects on gait function

Both groups demonstrated clinically meaningful gains in gait capacity (e.g., speed and distance walked) immediately post-training; however, retention effects varied between training groups. Speed-specific changes were noted in the two training groups. For the RAC group, statistically significant gains were found in CGS but not FGS, immediately post-training. At follow-up, the RAC group maintained these CGS gains, and also displayed a significant improvement in FGS from baseline. In comparison, the SDTT group demonstrated significant gains in FGS post-training that were maintained at follow-up, but did not display significant changes in CGS.

Although the improvements in CGS in RAC group are consistent with previous research (Bryant et al., 2009; Ford et al., 2010; Nieuwboer et al., 2007), the speed-specific findings in the present study are inconsistent with previous research that reported improvements in both CGS and FGS following RAC locomotor training (Ford et al., 2010) and improvements in CGS in treadmill training protocols (Frazzitta et al., 2009; Herman et al., 2009; Pohl et al., 2003). The training specificity of RAC and SDTT protocols may explain the speed-specific training effects found in the present study. The Minimal Detectable Change (MDC) for CGS in individuals with PD and stroke is reported to range from 0.1 and 0.18 m/s (Adkin et al., 2003; Perera et al., 2006). The RAC group demonstrated a 0.15 m/s gain post-training, reflecting meaningful change. This effect is consistent with the RAC protocol's training demands, which required participants to complete relatively longer walking intervals at faster-than-comfortable walking speeds (V1 and V2). The MDC for FGS in individuals with PD has been reported to be 0.25 m/s (Stokes, 2011). Although neither group met the MDC, it is important to note that the SDTT group's mean FGS at baseline (1.69 m/s) fell within the age-related normative range, reflecting a potential ceiling effect in this measure in the cohort. The significant change in FGS observed in the SDTT group immediately post-training may be explained by training demands of a SDTT training paradigm. The three, 5-minute intervals of maximal walking speed employed in the protocol may have translated into task-specific changes in FGS. The moving treadmill belt provides external pacing, which may have forced participants to precisely maintain fast walking speeds. The SDTT group may also have also been able to engage in greater training speeds due to the utilization of the harness and one-on-one training, promoting feelings of safety and enhanced motivation. It is unclear why this gain in FGS did not generalize to changes in CGS for the SDTT group.

Significant gains in 6MWT distance were found in both the RAC and SDTT groups immediately post-training, which were maintained at follow-up in the RAC group only. These gains in 6MWT are consistent with results from previous studies (Frazzitta et al., 2009; Pelosin et al., 2009; Skidmore et al., 2008). Based on previous research in persons with varied neurologic conditions, the MDC for the 6MWT ranges from 36.6 to 82 m (Flansbjer et al., 2005; Perera et al., 2006; Steffen & Seney, 2008). The RAC training group's mean improvement post-training was within this MDC range (47.87 m), whereas the SDTT mean change (29.74 m) was lower than this MDC threshold and gains were not retained. The greater improvements in 6MWT findings for the RAC group may be due to the longer, sustained fast walking intervals in the protocol, which may have had a greater effect on walking endurance. Additionally, the overground walking performed by the RAC group may have training effects that better translate to ambulation in the community. These training effects may also have contributed to participants' increased adherence with maintaining an independent walking program following training.

Both training groups demonstrated statistically significant improvements in dynamic balance function during walking as measured by the FGA, which were maintained at follow-up. Although the MDC estimates for FGA have not been reported for individuals with PD, studies in the stroke population reported an MDC of 4.2 points (Lin, Hsu, Hsu, Wu, & Hsieh, 2010). Improvements in FGA scores of 4.2 and 4.7 points for the RAC and SDTT groups in the present study, respectively, likely represent a clinically meaningful change. The FGA is a sensitive tool to detect elderly fallers (Leddy et al., 2011) and has good predictive validity to assess fall risk in persons with PD (Foreman, Addison, Kim, & Dibble, 2006). Forty percent of the participants in the present study had a significant reduction in fall risk post-training based on based on cutoff score of 22 points. Four participants in each group who were identified at increased fall risk at baseline improved their FGA scores to exceed this fall risk threshold post-training and maintained this gain at follow-up. Functional Gait Assessment scores continued to improve at follow-up, as another three participants moved out of the fall risk category. Improved FGA scores support the premise that task-specific locomotor training with speed challenges may translate into improved dynamic balance for walking tasks. Only one previous study examined balance-related gait outcomes following locomotor training in PD. Consistent with our findings, Cakit et al. (2007) reported significant improvements in Dynamic Gait Index scores following SDTT. No previous RAC studies evaluated these functionally relevant gait measures. Therefore, the present study is the first to demonstrate the positive effect of RAC overground training on the ability to safely perform functional gait tasks. This finding is critical for individuals with PD who demonstrate instability while adapting their gait to a busy and changing environment, increasing their risk for falls (Ashburn et al., 2008; Bloem et al., 2004; 2006; Morris & Lansek, 1997; Smulders et al., 2012). The significant gains in FGA scores in both training groups may reflect improved dynamic balance during walking, which may translate to reduced fall risk for mobility tasks.

Although between-group differences were not observed in the gait measures utilized in the present study, it is important to note that only the RAC group retained statistically significant improvements in all gait measures at follow-up when compared to baseline. Limited research is currently available that examines retention effects in locomotor training other than the RESCUE trial (Nieuwboer et al., 2007), which did not support retention of RAC training effects. The present study provides evidence for retention effects in gait and dynamic balance function following cued locomotor training paradigms in PD.

4.2 Clinical implications.

The present study was designed to implement and evaluate two reproducible, externally-cued progressive locomotor training protocols based on application of previous research. This study's results provide evidence that a 30-minute training session three times per week for six weeks was of sufficient intensity to produce meaningful changes and retention in walking function. Given these training parameters, the clinician should be able to effectively implement these gait interventions in individuals with PD in daily practice. Due to the inherent variability of clinical symptoms in individuals with PD it is necessary to individualize training parameters and progression of each training session. Based on the present authors' experience, ongoing evaluation of participants' gait pattern, balance and cardiovascular responses was required for safe training prescription and progression. Therefore, it is recommended that these protocols initially be implemented in a therapist-directed plan of care before prescribing independent training programs in the home or community setting. Furthermore, it should be noted that this study's inclusion and exclusion criteria ensured a sample of individuals with PD who were independent community ambulators and had stable cardiovascular status, which limits generalizability to a broader population with greater impairment and/or comorbidities that might limit exercise intensity.

Regarding clinician selection of a training protocol, each protocol has unique benefits as a mode of locomotor training. The somatosensory cueing via the moving treadmill belt in SDTT may allow individuals to achieve faster gait speeds without a compensatory decrease in stride length. Additionally, the environment of SDTT allows for training speeds to be more tightly controlled and enforced. However, there was an adjustments period (3–4 sessions) required before participants felt comfortable being challenged with speed demands on the treadmill and harness support was required for safety. The RAC training utlized rhythmic music with prescribed bpm that was a genre selected by the participant; therefore this was an enjoyable mode of training. The RAC training was implemented in small groups of 5 participants, which was clinically feasible for monitoring individual performance and was motivational for the participants. This mode of training may have application to wellness-based classes for persons with PD. Some participants had difficulty maintaining the correct walking rhythm with their music, which required researchers to assist them in finding the music's bpm using a metronome. It is noteworthy that the RAC group was able to maintain their improvements in gait function at follow-up and a greater percentage of this group continued independent walking training for 6 months post-training. These findings may suggest that the RAC training may have enhanced participants' walking self efficacy, which facilitated continued walking exercise in the community setting. However, it is important to note that our findings demonstrate that both RAC and SDTT training groups had significant improvements in gait function.

4.3. Limitations

This study has several limitations. Sample size was statistically powered to detect within-group differences with gait speed as primary outcome measures. Therefore, the small sample size was under-powered to definitively assess between-group differences. Convenience sampling was utilized in participant recruitment that resulted in a sample of higher-level functioning community ambulators, thus limiting the generalizability of this study's findings. Therefore, caution should be taken regarding applying this study's findings to individuals in later stages of PD or those with great gait disability. However, the present study's implementation of stratified and randomized group allocation resulted in equivalent groups with a range of impairment, which enhances both the internal validity and the generalizability of the results. Another potential limitation of this study is that two different groups of examiners completed the baseline/post-training testing and the 3-month follow-up testing. However, both groups of examiners were trained by the same researcher and demonstrated competency in test administration and scoring, and all examiners were blinded to group allocation.

4.4. Implications for further study

This comparative locomotor pilot study lays important groundwork for further research. A larger controlled clinical trial is needed to determine if the RAC or SDTT protocol is superior in improving gait function and reducing fall risk in persons with PD. Furthermore, a broader sample with a wider range of disease severity would help to identify which individuals will be most responsive to cued locomotor training based on clinical and personal characteristics. A clinical trial targeted for individuals with freezing gait, who are at particularly high fall risk, is needed to assess if FOG episodes and fall incidence can be reduced following cued locomotor training. Future research could also examine the effect of the each training protocol on non-motor symptoms associated with PD using the Non-Motor Symptoms Scale (NMSS) (Bryant et al., 2009), as numerous participants in this study reported anecdotal improvements in sleep, mood and other non-motor symptoms of PD.

5. Conclusion

A 6-week, externally-cued, locomotor training program with progressive, interval-based speed challenges, whether overground with RAC or on a treadmill, produced significant improvements in walking speed, endurance, and dynamic balance during walking based on CGS, FGS, 6MWT and FGA. Gains in gait speed and FGA were maintained at follow-up in both groups, while only the RAC group showed retention of 6MWT gains. These changes are clinically relevant as they may translate to enhanced gait capacity, reduced fall risk, and improved safety for community mobility in persons with PD.

Acknowledgments

This study was supported by a grant from the Saint Mary's Healthcare Doran Foundation. The authors thank the clinicians and physicians at Mercy Health Hauenstein NeuroScience Center for their assistance in this endeavor.

Declaration of interest

There are no declarations by authors regarding any conflict of interest.

References

Adkin, A. L., Frank, J. S., & Jog, M. S. (2003). Fear of falling and postural control in Parkinson's disease. *Movement Disorders: Official Journal of the Movement Disorder Society*, *18*(5), 496-502. doi:10.1002/mds.10396

American Thoracic Society. (2002). ATS statement: Guidelines for the six-minute walk test. *American Journal of Respiratory Critical Care Medicine*, *166*, 111-117.

Ashburn, A., Stack, E., Ballinger, C., Fazakarley, L., & Fitton, C. (2008). The circumstances of falls among people with Parkinson's disease and the use of falls diaries to facilitate reporting. *Disability and Rehabilitation*, *30*(16), 1205-1212. doi:10.1080/09638280701828930

Bello, O., Sanchez, J. A., & Fernandez-del-Olmo, M. (2008). Treadmill walking in Parkinson's disease patients: Adaptation and generalization effect. *Movement Disorders: Official Journal of the Movement Disorder Society*, *23*(9), 1243-1249. doi:10.1002/mds.22069

Bloem, B. R., Grimbergen, Y. A., Cramer, M., Willemsen, M., & Zwinderman, A. H. (2001). Prospective assessment of falls in Parkinson's disease. *Journal of Neurology*, *248*(11), 950-958.

Bloem, B. R., Grimbergen, Y. A., van Dijk, J. G., & Munneke, M. (2006). The "posture second" strategy: A review of wrong priorities in Parkinson's disease. *Journal of the Neurological Sciences*, *248*(1-2), 196-204. doi:10.1016/j.jns.2006.05.010

Bloem, B. R., Hausdorff, J. M., Visser, J. E., & Giladi, N. (2004). Falls and freezing of gait in Parkinson's disease: A review of two interconnected, episodic phenomena. *Movement Disorders: Official Journal of the Movement Disorder Society*, *19*(8), 871-884. doi:10.1002/mds.20115

Bryant, M. S., Rintala, D. H., Lai, E. C., & Protas, E. J. (2009). An evaluation of self-administration of auditory cueing to improve gait in people with Parkinson's disease. *Clinical Rehabilitation*, *23*(12), 1078-1085. doi:10.1177/0269215509337465

Butland, R. A., Pang, J., Gross, E. R., Woodcock, A. A., & Geddes, D. M. (1982). Two-, six-, and 12-minute walking tests in respiratory disease. *British Medical Journal (Clinical Research Edition)*, *284*, 1607-1608.

Cakit, B. D., Saracoglu, M., Genc, H., Erdem, H. R., & Inan, L. (2007). The effects of incremental speed-dependent treadmill training on postural instability and fear of falling in Parkinson's disease. *Clinical Rehabilitation*, *21*(8), 698-705. doi:10.1177/0269215507077269 de Bruin, N., Doan, J. B., Turnbull, G., Suchowersky, O., Bonfield, S., Hu, B., & Brown, L. A. (2010). Walking with music is a safe and viable tool for gait training in Parkinson's disease: The effect of a 13-week feasibility study on single and dual task walking. *Parkinson's Disease*, *2010*, 483530. doi:10.4061/2010/483530

Duncan, P. W., Sullivan, K. J., Behrman, A. L., Azen, S. P., Wu, S. S., Nadeau, S. E., Tilson, J. K., et al. (2007). Protocol for the locomotor experience applied post-stroke (LEAPS) trial: A randomized controlled trial. *BMC Neurology*, *7*, 39. doi:10.1186/1471-2377-7-39

Ellis, T., Cavanaugh, J. T., Earhart, G. M., Ford, M. P., Foreman, K. B., & Dibble, L. E. (2011). Which measures of physical function and motor impairment best predict quality of life in Parkinson's disease? *Parkinsonism & Related Disorders*, *17*(9), 693-697. doi:10.1016/j.parkreldis.2011.07.004; 10.1016/j.parkreldis.2011.07.004

Flansbjer, U. B., Holmback, A. M., Downham, D., Patten, C., & Lexell, J. (2005). Reliability of gait performance tests in men and women with hemiparesis after stroke. *Journal of Rehabilitation Medicine: Official Journal of the UEMS European Board of Physical and Rehabilitation Medicine*, *37*(2), 75-82. doi:10.1080/16501970410017215

Ford, M. P., Malone, L. A., Nyikos, I., Yelisetty, R., & Bickel, C. S. (2010). Gait training with progressive external auditory cueing in persons with Parkinson's disease. *Archives of Physical Medicine and Rehabilitation*, *91*(8), 1255-1261. doi:10.1016/j.apmr.2010.04.012

Foreman, K. B., Addison, O., Kim, H. S., & Dibble, L. E. (2011). Testing balance and fall risk in persons with Parkinson disease, an argument for ecologically valid testing. *Parkinsonism & Related Disorders*, *17*(3), 166-171. doi:10.1016/j.parkreldis.2010.12.007

Frazzitta, G., Maestri, R., Uccellini, D., Bertotti, G., & Abelli, P. (2009). Rehabilitation treatment of gait in patients with Parkinson's disease with freezing: A comparison between two physical therapy protocols using visual and auditory cues with or without treadmill training. *Movement Disorders: Official Journal of the Movement Disorder Society*, *24*(8), 1139-1143. doi:10.1002/mds.22491

Freedland, R. L., Festa, C., Sealy, M., McBean, A., Elghazaly, P., Capan, A., & Rothman, J., et al. (2002). The effects of pulsed auditory stimulation on various gait measurements in persons with Parkinson's disease. *Neurorehabilitation*, *17*(1), 81-87.

Frenkel-Toledo, S., Giladi, N., Peretz, C., Herman, T., Gruendlinger, L., & Hausdorff, J. M. (2005). Treadmill walking as an external pacemaker to improve gait rhythm and stability in Parkinson's disease. *Movement Disorders: Official Journal of the Movement Disorder Society*, *20*(9), 1109-1114. doi:10.1002/mds.20507

Harro, C., Shoemaker, M. J., Frey, O., Harring, K. B., McDonald, J. D., Murray, C. J., et al. (2012). The effects of speed-dependent treadmill training and rhythmic auditory-cued overground walking on gait and balance function and fall risk in individuals with idiopathic Parkinson's disease: A randomized controlled trial. *(DPT, Grand Valley State University)*.

Harro, C. C., Shoemaker, M. J., Frey, O., Gamble, A. C., Harring, K. B., & Karl, K. L., et al. (2013). *The effects of speed-dependent treadmill training and rhythmic auditory-cued overground walking on balance function, fall incidence and quality of life in individuals with idiopathic Parkinson's disease: A randomized controlled trial*. Manuscript in Preparation, Grand Valley State University, Grand Rapids, MI.

Herman, T., Giladi, N., & Hausdorff, J. M. (2009). Treadmill training for the treatment of gait disturbances in people with Parkinson's disease: A mini-review. *Journal of Neural Transmission (Vienna, Austria : 1996)*, *116*(3), 307-318. doi:10.1007/s00702-008-0139-z

Hoehn, M. M., & Yahr, M. D. (1967). Parkinsonism: Onset, progression and mortality. *Neurology*, *17*(5), 427-442.

Leddy, A. L., Crowner, B. E., & Earhart, G. M. (2011). Functional gait assessment and balance evaluation system test: Reliability, validity, sensitivity, and specificity for identifying individuals with Parkinson disease who fall. *Physical Therapy*, *91*(1), 102-113. doi:10.2522/ptj.20100113; 10.2522/ptj.20100113

Lewis, G. N., Byblow, W. D., & Walt, S. E. (2000). Stride length regulation in Parkinson's disease: The use of extrinsic, visual cues. *Brain : A Journal of Neurology*, *123*(Pt 10), 2077-2090.

Lim, I., van Wegen, E., Jones, D., Rochester, L., Nieuwboer, A., Willems, A. M., et al. (2010). Does cueing training improve physical activity in patients with Parkinson's disease? *Neurorehabilitation and Neural Repair*, *24*(5), 469-477. doi:10.1177/1545968309356294; 10.1177/1545968309356294

Lin, J. H., Hsu, M. J., Hsu, H. W., Wu, H. C., & Hsieh, C. L. (2010). Psychometric comparisons of 3 functional ambulation measures for patients with stroke. *Stroke; a Journal of Cerebral Circulation*, *41*(9), 2021-2025. doi:10.1161/STROKEAHA.110.589739

McIntosh, G. C., Brown, S. H., Rice, R. R., & Thaut, M. H. (1997). Rhythmic auditory-motor facilitation of gait patterns in patients with Parkinson's disease. *Journal of Neurology, Neurosurgery, and Psychiatry*, *62*(1), 22-26.

Mehrholz, J., Friis, R., Kugler, J., Twork, S., Storch, A., & Pohl, M. (2010). Treadmill training for patients with Parkinson's disease. *Cochrane Database of Systematic Reviews (Online)*, *1*(1), CD007830. doi:10.1002/14651858.CD007830.pub2

Morris, M. E., & Lansek, R. (1997). Gait disorders in Parkinson's disease: A framework for physical therapy practice. *Neurology Report*, *21*, 125-131.

Morris, M. E. (2000). Movement disorders in people with Parkinson disease: A model for physical therapy. *Physical Therapy*, *80*(6), 578-597.

Morris, M. E., Huxham, F., McGinley, J., Dodd, K., & Iansek, R. (2001). The biomechanics and motor control of gait in Parkinson disease. *Clinical Biomechanics (Bristol, Avon)*, *16*(6), 459-470.

Morris, M. E., Martin, C. L., & Schenkman, M. L. (2010). Striding out with Parkinson disease: Evidence-based physical therapy for gait disorders. *Physical Therapy*, *90*(2), 280-288. doi:10.2522/ptj.20090091

Nieuwboer, A. (2008). Cueing for freezing of gait in patients with Parkinson's disease: A rehabilitation perspective. *Movement Disorders: Official Journal of the Movement Disorder Society*, *23*(Suppl 2), S475-S481. doi:10.1002/mds.21978

Nieuwboer, A., Kwakkel, G., Rochester, L., Jones, D., van Wegen, E., Willems, A. M., et al. (2007). Cueing training in the home improves gait-related mobility in Parkinson's disease: The RESCUE trial. *Journal of Neurology, Neurosurgery, and Psychiatry*, *78*(2), 134-140. doi:10.1136/jnnp.200X.097923

Pelosin, E., Faelli, E., Lofrano, F., Avanzino, L., Marinelli, L., Bove, M., et al. (2009). Effects of treadmill training on walking economy in Parkinson's disease: A pilot study. *Neurological Sciences: Official Journal of the Italian Neurological Society and of the Italian Society of Clinical Neurophysiology*, *30*(6), 499-504. doi:10.1007/s10072-009-0141-8

Perera, S., Mody, S. H., Woodman, R. C., & Studenski, S. A. (2006). Meaningful change and responsiveness in common physical performance measures in older adults. *Journal of the American Geriatrics Society*, *54*(5), 743-749. doi:10.1111/j.1532-5415.2006.00701.x

Pohl, M., Rockstroh, G., Ruckriem, S., Mrass, G., & Mehrholz, J. (2003). Immediate effects of speed-dependent treadmill training on gait parameters in early Parkinson's disease. *Archives of Physical Medicine and Rehabilitation*, *84*(12), 1760-1766.

Protas, E. J., Mitchell, K., Williams, A., Qureshy, H., Caroline, K., & Lai, E. C. (2005). Gait and step training to reduce falls in Parkinson's disease. *Neurorehabilitation*, *20*(3), 183-190.

Skidmore, F. M., Patterson, S. L., Shulman, L. M., Sorkin, J. D., & Macko, R. F. (2008). Pilot safety and feasibility study of treadmill aerobic exercise in Parkinson disease with gait impairment. *Journal of Rehabilitation Research and Development*, *45*(1), 117-124.

Smithson, F., Morris, M. E., & Iansek, R. (1998). Performance on clinical tests of balance in Parkinson's disease. *Physical Therapy*, *78*(6), 577-592.

Smulders, K., Esselink, R. A., Weiss, A., Kessels, R. P., Geurts, A. C., & Bloem, B. R. (2012). Assessment of dual tasking has no clinical value for fall prediction in Parkinson's disease. *Journal of Neurology*, *259*(9), 1840-1847. doi:10.1007/s00415-012-6419-4

Steffen, T., & Seney, M. (2008). 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. *Physical Therapy*, *88*(6), 733-746. doi:10.2522/ptj.20070214

Stokes, E. K. (2011). *Rehabilitation outcome measures*. New York, Edinburgh: Churchill Livingstone.

Tariq, S. H., Tumosa, N., Chibnall, J. T., Perry, M. H., 3rd, & Morley, J. E. (2006). Comparison of the Saint Louis university mental status examination and the Mini-mental State examination for detecting dementia and mild neurocognitive disorder–a pilot study. *The American Journal of Geriatric Psychiatry: Official Journal of the American Association for Geriatric Psychiatry*, *14*(11), 900-910. doi:10.1097/01.JGP.0000221510.33817.86

Thaut, M. H., McIntosh, G. C., Rice, R. R., Miller, R. A., Rathbun, J., & Brault, J. M. (1996). Rhythmic auditory stimulation in gait training for Parkinson's disease patients. *Movement Disorders: Official Journal of the Movement Disorder Society*, *11*(2), 193-200. doi:10.1002/mds.870110213

Walker, M. L., Austin, A. G., Banke, G. M., Foxx, S. R., Gaetano, L., Gardner, L. A., et al. (2007). Reference group data for the functional gait assessment. *Physical Therapy*, *87*(11), 1468-1477. doi:10.2522/ptj.20060344

Willems, A. M., Nieuwboer, A., Chavret, F., Desloovere, K., Dom, R., Rochester, L., VanWegen, E., et al. (2006). The use of rhythmic auditory cues to influence gait in patients with Parkinson's disease, the differential effect for freezers and non-freezers, an explorative study. *Disability and Rehabilitation*, *28*(11), 721-728. doi:10.1080/09638280500386569

Wrisley, D. M., & Kumar, N. A. (2010). Functional gait assessment: Concurrent, discriminative, and predictive validity in community-dwelling older adults. *Physical Therapy*, *90*(5), 761-773. doi:10.2522/ptj.20090069