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Use of real-time multimodal sensory feedback home program improved backward stride and retention for people with Parkinson Disease: A pilot study

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ABSTRACT

Introduction: Parkinson disease (PD) impairs sensory integration, contributes to motor dysfunction, loss of gait automaticity, and increased fall risk. Employing multimodal sensory feedback (MMSF) has the potential to improve proprioceptive integration and gait safety while reducing exercise burden especially for backward gait.
Methods: This single-blinded, randomized controlled pilot study used a home program with or without real-time visual, proprioceptive, and auditory feedback with stepping exercises which progressed in speed and distance. Both groups completed a six-week intervention followed by 6 weeks without exercise to assess long-term retention. Six additional weeks of exercises were completed to assess recovery of potential losses after the washout session.
Eleven people with PD exercised with real-time MMSF and 7 exercised without MMSF. Outcome measures included backward stride length, velocity, cadence, and double support time. The Dual Timed Up and Go measured automaticity. Self-perceived improvements in gait, activities of daily living, participation, and quality of life were registered by a questionnaire.
Results: Analysis was by repeated measures ANOVA. Using MMSF significantly improved backward stride length at 12 and 18 weeks, $p = .007$, $\eta^2 = 0.239$. Both groups improved in all outcome measures after the initial 6-week exercise program, supporting efficacy of stepping exercises. The MMSF + ex group's significant improvements after a 6-week washout supported automaticity development. Questionnaire items received higher agreement percentages from MMSF + ex participants.
Conclusion: Using real-time MMSF in a home program for pwPD provided significant and lasting improvements in backward stride, and potentially decreased fall risk and exercise burden compared to the same program without MMSF.

1. Introduction

Gait impairments occur frequently in Parkinson Disease (PD) with earliest losses in backward walking and stepping [1]. Poor integration of proprioceptive information with vestibular and visual input [2] is thought to underlie the early deterioration of backward gait. Lack of integration [3] as well as central deficits in timing and gain of sensory reweighting responses to changing environmental and balance threats [4,5] may also contribute to gait deficits, increased fall risk [1], and visual dependence [6]. These sensory impairments are minimally responsive to levodopa [7].

Typically, once gait in an environment is learned, it becomes automatic [8]. Hallmarks of automaticity are stereotypical movement patterns resulting in energy preservation without the demands of executive (cortical) control. Sensory input, especially proprioception, while maintaining automaticity provides adaptive responses to the environment [8].

Visual dependence may impair automaticity in people with PD (pwPD). Using Wii bowling, Kearney [9] found that pwPD performed best with 100% visual feedback while age-matched control participants performed best with 20%. Retention was absent for pwPD at 6-week follow up testing, indicating a failure to develop automaticity in

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stepping using visual feedback alone.

Development of automaticity requires high numbers of repetition and intensity [8] which is difficult to achieve since typically therapy involves treatment only 2 to 3 times weekly with each session lasting an hour or less.

When relevant real-time external sensory cues are available for pwPD, significant improvements occur to re-establish motor programs [10–13]. Real-time feedback from multimodal sensory systems leads to performance improvement [14].

Sensory input, other than auditory feedback, is often neglected during intervention but recent shifts in rehabilitative training which enhance sensory input hold promise for pwPD. Programs such as PD SAFEx [15], a sensory and attention focused rehabilitation program as well as blindfolded balance training emphasize sensory training and report positive improvements in both motor and balance deficits [16].

Shen [17] used more traditional verbal and summary feedback (percentage of correct fast stepping and perturbation responses) for pwPD and found significant differences in stride length at 3 and 12 months after completing intense training compared to a program without feedback. MMSF has been successful for pwPD [12] and for people with incomplete spinal cord injury relearning to walk [18]. Yen [18] demonstrated increased stride length through use of either visual feedback or resistance applied to the swing leg to enhance proprioception. Combining both feedback types produced significantly greater improvements with longer retention than either type alone. Real-time, multimodal sensory feedback (MMSF) during a home exercise program (HEP) offers feedback on performance often lacking in HEPs as well as providing high intensity and repetitions. Espay [12] used at-home training with visual augmented-reality walking and auditory feedback of steps in real-time which improved gait parameters. Although at-home training has the advantage of more repetitions and promotes self-efficacy, HEPs have not been effective in changing gait for pwPD longer term [19]. A major deficit of home programs is lack of feedback about performance. Developing a home program that provides sensory feedback in real-time with sufficiently rigorous intensity and repetition while fading feedback to improve motor learning and decrease visual dependence could provide clients with greater independence in self-management and reduce disability.

This study tested feasibility and efficacy of using real-time MMSF during fast stepping, striding and balance exercises in a HEP to improve gait and retention for pwPD.

2. Methods

2.1. Study design

Regis University Institutional Review Board approved this study.

This was an 18-week, 2 group, single blind repeated measures experimental pilot study. Examiners were blinded to group assignments and training therapists. Trainers were blinded to testing therapists and test results.

Thirty-seven pwPD responded to flyers in physician and physical therapy offices, Parkinson's association groups, and by word-of-mouth. Enrollment was open throughout the study. Inclusion criteria were: 1) physician diagnosis of idiopathic PD, 2) stable medication for 3 weeks minimum and maintained throughout the study, 3) ability to stand up from a chair and take 5 steps without assistance, 4) score 26 or higher on the Mini Mental Status Exam [20] and, 5) if in a current exercise program, it must have been of 3 months duration or longer and participants must be willing to continue without program change throughout the study.

On the initial call, potential participants were informed that both participant groups would perform the same basic exercises of fast stepping and balance 5 times weekly. These interventions have been effective for pwPD [21]. Groups would either perform self-evaluation of their performance, a technique used by athletes to improve performance [22] or have real-time auditory, visual, and somatosensory feedback during exercising.

Potential participants completed a phone interview with the primary investigator (PI) who explained the study and protocols, answered questions, and assessed whether inclusion criteria were met.

All participants signed a written, informed consent. Data collection and training were performed at the research lab at Regis University.

The PI used a computer-generated random numbers table to assign participants to exercise-only (Ex-only) or exercise with real-time MMSF (MMSF + ex) before their arrival on the morning of the participant's baseline testing.

Twenty-six participants began the study. Eleven participants in the MMSF + ex and 7 in the Ex-only group completed the 18-week study. Fig. 1 describes recruitment and disposition. For participant characteristics and comparison of gait parameters to typical elderly view Table 1. The study was composed of three six-week sessions. Sessions 1 and 3 were exercise sessions 5 days per week. Exercise sessions of 6 weeks achieve maximum effect size for pwPD [23]. Session 2 was a 6-week washout period of no exercise.

3. Intervention

All participants performed the same basic HEP including step initiation, rapid forward and backward stepping from midline, and full stride training. Step training has been shown to improve gait, balance, and decrease falls in the elderly [21]. Balance exercises included single leg stance with opposite leg swing, and 90° stepping turns. Sensory reweighting was promoted by stepping on and off foam, eyes closed (EC).

Those in the MMSF + ex group performed the exercises using the Balance Matters® System by Step and Connect (Denver, CO). This system employed movable footpads with clickers embedded in the heel and forefoot areas that attached to a lined floor mat and provided somatosensory and auditory (clicks) feedback for heel and forefoot contact during stepping. A laser light attached to the chest near the axilla by a Scotch Fasteners™ strap focused on the Balance Matters' lined wall mat mounted in front of the participant. The laser spot on this wall mat provided visual feedback about trunk verticality (flexion and/or extension) and trunk rotation (left or right); there was no visual feedback for lower extremity movements. Proprioceptive feedback was enhanced through one-pound weights on wrists for facilitating arm swing and on forefeet to facilitate pretibial muscles and hip flexors during stepping. Early exercise sessions took up to 45 min but were reduced with practice to 20 to 30 min. Fig. 2 is a photograph demonstrating a stepping exercise using MMSF by a pwPD. Exercises progressed by increasing speed and distance. By week 4, after 3 or 4 repetitions of each exercise, visual feedback was faded to EC and auditory feedback faded to every other day.

3.1. Training

Following baseline testing, each participant was seen 2 to 3 times within 7 days for HEP instruction, with a 3-week follow-up. The basic exercise program was developed by the 2 training physical therapists (PTs) instructing the participants. One PT trained the MMSF + ex participants and the other trained those in the Ex-only group. All participants were called by their PT during the 6-week exercise session to answer questions and were encouraged to call if they had questions.

Four goals for participants' daily performance were to: 1) increase distance and speed for all stepping exercises, 2) produce step widths that were neither abducted nor adducted, 3) step fast enough to produce errors about 30% of the time (this was practiced in training sessions) and 4) progress to EC exercises to promote proprioceptive use.

Participants in the Ex-only group completed self-evaluation forms after daily exercises, rating their performance compared to the previous session as better, the same, or worse, on distance moved, balance, and speed. Self-evaluation promotes learning through reflection and is

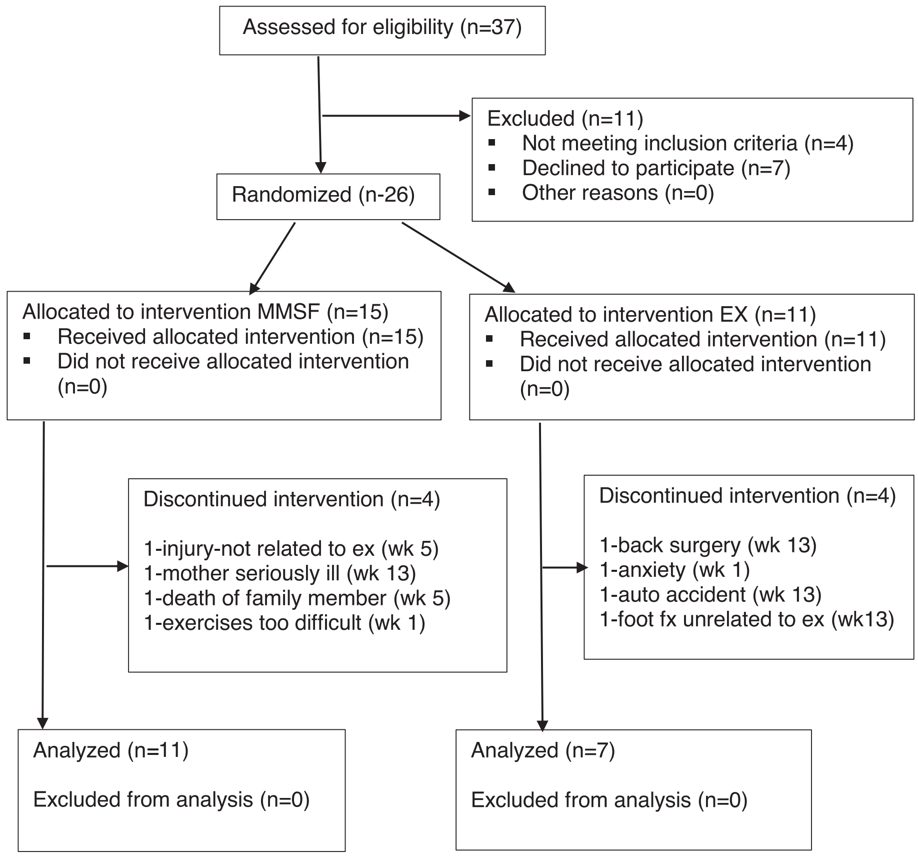

Fig. 1. Consort Diagram. Flow of participants through study.

effective for improving performance [22].

4. Outcome measures

Standing on foam, single leg stance, and Dual Timed Up and Go (DTUG), were taken from timed sub-scores on the Mini-BESTest™ to measure impairments in balance and cognitive tasks (counting backward from 100 subtracting 3 each time) during gait. After training, 2 steady-state walks, comfortable forward and backward, acquired on the GaitRite® Mat system, were averaged for cadence, double support, velocity, and stride length to measure gait. If a measurement score was missing, the remaining score was used for analysis. If no data existed, it was treated as missing.

A Likert perceived outcome scale (POS) measured participants' perception of change at the impairment, activities of daily living (ADLs), activity, and participation levels using a 5-level scale of strongly agree, agree, neutral, disagree, or strongly disagree at study's end.

Testing was scheduled in the "on" condition for participants taking medication.

5. Results

Statistical analyses used SPSS (version 27, IBM Armonk, NY) a mixed repeated measures ANOVA with significance set at $p \leq 0.05$. Post hoc pairwise comparisons used a Bonferroni adjustment. Univariate analysis was used for between-group differences. A split group repeated measures analysis determined within-group statistics.

Data were normally distributed (Shapiro-Wilk, $p > .05$) except backward velocity at 12 weeks (Ex-only participants). Velocity data were re-run with a square root variable transformation, p values results are reported from these data. Mauchly's test of sphericity was $p > .05$ for all tests; however, Greenhouse-Geisser was used to report p values due to the small sample sizes [25]. There were no outliers on any tests as assessed by examination of studentized residuals for values greater than $\pm$ 3. Baseline measures showed no significant differences between groups. Refer to Table 2 for details.

Baseline: Most participants showed few impairments in forward walking compared to results published by Hackney [24] for typical elderly (65 y/o $\pm$ 10) but had deficits with backward walking including velocity, stride length, double stance time, and cadence. Refer to Table 1 for comparison of backward gait measurements of pwPD from this study compared to older people without PD from Hackney [24].

Findings. A significant two-way intervention effect of time and group occurred for backward stride, $F= (2.6, 41.3) = 5.04$, $p = .007$, $\eta^2 = 0.239$. Univariate analysis demonstrated significant differences at 12 and 18 weeks between groups. Split file by group showed significant improvements for the MMSF + ex participants from baseline to 6,12, and 18 weeks and from 6 to 18 weeks while Ex-only participants had no significant findings. Statistically significant main effects of time (session) occurred from baseline to 18 weeks. Refer to Table 2 for details.

Initially, only 1 participant from each group had backward walking stride lengths in the range of older adults without PD (>100 $\pm$ 1 cm) [24]. Four additional participants, all receiving MMSF + ex, achieved that level by 18 weeks.

All 4 GaitRite measures and DTUG demonstrated significant findings by session.

Sensory reweighting improved across groups as all participants could stand on foam, EC, for the maximum 30 s by the 12-week testing.

The POS showed higher percentages of agree or strongly agree responses by the MMSF + ex participants on questions pertaining to balance, walking, and ADLs as well as the quality-of-life response. Ninety-two percent of MMSF + ex participants believed their walking improved. Refer to Table 2 for scores on POS.

Table 1
Participant characteristics and comparison of backward gait parameters with typical elderly from Hackney [24].

	Typical Elderly*	MMSF + ex	Ex-only
Age range (yrs.)	55–75	62–75	54–80
Age Mean (SD)	65	67.4 (6.7)	68.6 (5.6)
Gender	17F 57M	5F 6M	3F 4M
Time from DX (yrs.)		1–16	1–15
Hoehn&Yahr (number)		1.0–4 1.5–3 2.0–1 2.5–3	1.0–3 1.5–1 2.0–2 3.0–1
UPDRS Motor Scale (range)		4–36	6–26
Fall Hx (2 + falls past 12 mo.		10	7
On Levodopa or equivalent		10	6
Impaired vibration (256 Hz to great toe)		7	3
Semmes-Weinstein monofilament test1st and 4th met head		5	3

GAIT PARAMETER	Typical Elderly*Mean ± SE	MMSF + ex Baseline Mean ± SE	Ex-only Baseline Mean ± SE	MMSF + ex 18 wks Mean ± SE	Ex-only 18 wk Mean ± SE
Backward Stride (cm)	100 ± 1.0	81.8 ± 4.5	73.6 ± 5.3	99.3 ± 6.2	79.1 ± 6.1
Backward Velocity (cm/sec)	90 ± 0.2	73.5 ± 5.5	63.7 ± 7.2	95.7 ± 6.5	87.0 ± 7.5
Backward Double Support GC %)	32 ± 0.8	34.1 ± 1.5	39.1 ± 2.0	30.9 ± 1.2	32.7 ± 2.1

*Seventy-four subjects without PD 65yrs old ± 10 yrs. using GaitRite (CIR Systems, Inc., Havertown, PA) from Hackney 2009 [24].

Fig. 2. Photo of pwPD stepping forward showing 3 MMSF: laser light on wall mat, foot pads with auditory clickers, and 1-lb wrist and forefoot weights.

Table 2
Outcome measure means, standard deviations, Interaction effect of group*time and main effects of group and time.

BACKWARD STRIDE (cm)			
	p value	power	
Two-way interaction	0.007*	0.855	
Session	0.001*	0.968	
Group	0.110	0.356	
	MMSF + ex Mean (SD)	***Ex-only*** Mean (SD)	***Group*** *(univariate)* p value
Baseline (B)	81.8 (15.0)	73.6 (14.4)	0.270
6 wks	87.1 (18.7)	81.2 (18.7)	0.517
12 wks	95.5 (21.6)	75.0 (12.0)	0.037*
18 wks	99.3 (20.4)	79.1 (16.6)	0.043*
Pairwise	***Session*** p value	***Two-way interaction*** (split file) p value	***Two-way interaction*** (split file) p value
		MMSF + ex	**Ex-only**
B-6 wks	0.085	0.004*	0.476
B-12 wks	0.106	0.043*	1.00
B-18 wks	0.000*	0.001*	0.067
6–12 wks	1.00	0.147	1.00
6–18 wks	0.206	0.002*	1.00
12–18 wks	0.591	1.00	1.00
BACKWARD VELOCITY† (cm/sec)			
	p value	power	
Two-wayInteraction	0.284	0.275	
Session	0.000*	1.00	
Group	0.245	0.189	
	MMSF + ex Mean (SD)	***Ex-only*** Mean (SD)	***Group*** *(univariate)* p value
Baseline (B)	73.5 (18.3)	63.7 (19.4)	0.295
6 wks	84.3 (22.6)	77.8 (30.4)	0.579
12 wks	92.4 (25.3)	72.8 (16.7)	0.091
18 wks	95.7 (21.6)	87.0 (20.3)	0.412
Pairwise (session)	p value		
B-6 wks	0.027*		
B-12 wks	0.012*		
B-18 wks	0.000*		
6–12 wks	1.00		
6–18 wks	0.014*		
12–18 wks	0.024*		
BACKWARD CADENCE (steps/min)			
	p value	power	
Two-way interaction	0.114	0.482	
Session	0.001*	0.955	
Group	0.885	0.515	
	MMSF + ex Mean (SD)	***Ex-only*** Mean (SD)	***Group*** *(univariate)* p value
Baseline (B)	109.8 (15.7)	102.0 (14.2)	0.301
6 wks	117.6 (20.2)	115.0 (23.8)	0.570
12 wks	116.9 (14.2)	116.7 (31.1)	0.980
18 wks	118.1 (18.4)	127.7 (21.1)	0.325
Pairwise Session	p value		
B-6 wks	*0.224*		
B-12 wks	*0.062*		
B-18 wks	0.003*		
6–12 wks	1.00		
6-18wks	0.446		
12–18 wks	0.339		

(*continued on next page*)

Table 2 (*continued*)

BACKWARD DOUBLE LIMB SUPPORT (% gait cycle)			
	p value	power	
Two-way interaction	0.437	0.194	
Session	0.009*	0.816	
Group	0.123	0.189	
	MMSF + ***ex***Mean (SD)	***Ex-only***Mean (SD)	***Group*** *(univariate)* p value
Baseline (B)	34.1 (4.9)	39.1 (5.4)	0.059
6 wks	33.0 (6.1)	34.7 (3.1)	0.517
12 wks	31.2 (5.9)	35.2 (4.3)	0.139
18 wks	30.9 (4.1)	32.7 (5.6)	0.446
Pairwise (Session)	p value		
B-6 wks	*0.394*		
B-12 wks	*0.331*		
B-18 wks	0.007*		
6–12 wks	1.00		
6-18wks	0.375		
12–18 wks	1.00		
DTUG (sec)			
	p value	power	
Two-way interaction	0.399	0.226	
Session	0.000*	0.985	
Group	0.068	0.451	
	MMSF + ***ex*** Mean (SD)	***Ex-only*** Mean (SD)	***Group*** *(univariate)* p value
Baseline (B)	10.6 (2.3)	13.3 (4.1)	0.089
6 wks	9.5 (1.7)	11.2 (2.6)	0.109
12 wks	8.9 (1.8)	11.4 (4.2)	0.104
18 wks	9.2 (1.8)	12.0 (3.9)	0.046*
Pairwise	p value		
B-6 wks	0.019*		
B-12 wks	0.001*		
B-18 wks	0.003*		
6–12 wks	0.998		
6-18wks	0.986		
12–18 wks	0.796		
PATIENT OUTCOME SCALE % agree or stongly agree			
Question	***MMSF*** + ***ex***	**Ex-only**	
Balance	85%	44%	
Walking	92%	55%	
ADL	64%	44%	
Life quality	73%	67%	

*p < .05, † sq. root

6. Discussion

This pilot study tested the feasibility and efficacy of real-time MMSF in a HEP using the Balance Matters System® for visual and auditory feedback about distance and direction stepped, a chest laser light for visual feedback of trunk movements, and 1-pound weights on wrists and forefeet for proprioceptive feedback. To our knowledge, this is the first time that 3 types of real-time sensory feedback have been used by pwPD in a HEP.

MMSF in a HEP for pwPD showed acceptable feasibility as we observed positive results for training adherence, project implementation, and participant convenience. Participants in both groups adhered to a home exercise program performed 5–6 times weekly for 20–30 min shown by their completed daily exercise logs. One participant in the Ex-only group became bored with the stepping program, but the logs showed that exercises were completed 5 to 6 times weekly. None of the participants found the required exercise frequency or duration onerous.

Balance Matters® system implementation for MMSF + ex participants went smoothly. Participants were able to assemble and disassemble the sensory training feedback mat, footpad system, and chest laser without assistance. All mechanical clickers worked. Understanding and use of the Balance Matters Mat® and moveable foot pads as well as the laser for visual feedback of trunk flexion and rotation during fast stepping appeared to be fairly intuitive after initial verbal and written instructions. Only one participant required a third training session for the HEP. Two MMSF + ex participants did not use weights the first week because they felt they could not attend to more than the feedback from the footpads and laser.

Initially, backward stepping and stride exercises were uniformly difficult for all participants. During initial training, all participants were surprised to learn they had flexion on the stance leg knee and little or no hip extension in the trailing limb position during stepping. Hatzitaki [26] reported similar findings for participants with PD.

All MMSF + ex participants improved their stride length score between the 6-week and 18-week tests while no Ex-only participants maintained or improved. Participants using MMSF demonstrated significant improvements and retention of these gains which they partially attributed to the convenience of using portable equipment and being able to exercise at home. Reducing the burden by eliminating travel time and setting their own schedule offset increased frequency of the HEP. Even with an extended break between sessions (washout), improvements continued which is important both physically and psychologically, especially for people with chronic diseases.

These findings contrast with previously reported weak effects of HEP on gait and balance for pwPD [19]. Three variables may have improved the effectiveness of the exercises: real-time MMSF, intensity, and adherence. The HEP allowed participants to perform exercises 5 times weekly. Intensity of exercise is important for promoting neuroplasticity [8], and exercise using high repetitions promotes this adaptation [8]. Real-time MMSF feedback allowed immediate modifications in performance similar to those reported by Kearny [9] using 100% feedback. The autonomy of determining exercise place, practice and schedule adds flexibility and convenience. Finally, adherence to a HEP improves when participants receive phone calls during home programs, a tactic also employed in this study [27].

Efficacy of the MMSF + ex HEP was supported by the significant two-way interaction between group and time for backward stride length. Shortened backward stride length is a hallmark of PD and a fall-risk factor [1]. Typical balance corrections during standing and walking use sensory information from proprioception, vestibular and visual receptors depending on type of balance loss and surface conditions. Visual flow on the retina assists in determining head movement, such as occurs in leaning forward or falling sideways. The visual flow information is matched to body proprioceptive and vestibular information to correct movements when appropriate. When pwPD use vision as their primary input for balance and gait [6] moving visual environments become destabilizing, providing inaccurate cues about stability.

The absence of vision during backward gait requires proprioceptive information for accurate foot placement particularly from the hip where ipsilateral limb flexion is initiated by stretch of hip flexors [28]. While all participants in this study had sensory input about hip flexor lengthening through proprioceptors during stepping, only the MMSF + ex participants had additional information of backward step distance through tactile (foot pads), auditory (heel-toe clickers), and enhanced proprioceptive feedback (foot weights). Taken together with the visual laser feedback for trunk upright posture, the sensory information would permit MMSF + ex participants to re-code angles of the hip, knee, and ankle during the backward stride and stepping exercises. Although visual feedback was faded for all participants by week 3, only the MMSF + ex participants significantly improved in backward stride. Forcing use of proprioception through EC exercise may not have been effective for Ex-only participants since there was no additional sensory information to integrate with limb position.

Backward gait velocity and cadence both significantly increased by session. Velocity is dependent primarily on stride length but also increases when cadence increases (velocity = stride length × 0.5 cadence). At the 18-week test session, cadence increased for all Ex-only participants and for 2 in MMSF + ex. This is concerning since pwPD commonly have atypically increased cadence and both groups of participants had cadence means above norms at all testing sessions. Since stride length increased for only one Ex-only participant, the velocity improvements were likely achieved through increased cadence which is undesirable for pwPD. Future research should evaluate if programs using fast stepping contribute to increased cadence without increasing stride length in velocity gains even when participants are asked to step as far as possible.

The DTUG also showed a trend toward significance for the MMSF + ex participants ($p = .066$) and $p = .046$ between groups at 18 weeks, likely secondary to improved automaticity.

Both groups' means for double support time matched those for elderly without PD by 18 weeks. Double support stance is controlled through the vestibular system [29] and the decrease in time is likely due to the balance training with eyes closed stepping on and off the foam pad [16]. The finding is consistent with those of Tramontano [16] who used this exercise in pwPD.

Retention of backward stride improvements by MMSF + ex participants was confirmed by significant increases from baseline to12 weeks, after the 6-week washout period. Measures where means improved after the 6-week washout for MMSF + ex participants were: backward velocity, double support, and DTUG. Ex-only participants had no significant improvements during the wash-out period.

POS, the 5-level scale rating perceived changes in balance, walking, ADLs, and overall life impact, reflected differences between the 2 HEP. MMSF + ex participants positively rated balance, walking, and ADLs much higher. Question 4 on life impact was more evenly distributed with positive responses for MMSF + ex at 73% and Ex-only participants at 67%. Improvements in endurance were not measured but may explain the relatively positive responses about life impact by both groups. Refer to Table 2.

7. Weaknesses of the study

A larger study with increased power is needed to confirm the findings of this small pilot study. Because study participants had mild to moderate PD, the outcomes of MMSF for more advanced PD are unknown. Most participants were previously involved in exercise programs, and compliance for intense exercise programs for pwPD who do not exercise routinely could not be evaluated. Finally, speed of movement has the potential to improve neuroplastic [8] responses as well as aerobic conditioning which were not evaluated in this study.

8. Conclusion

Real-time MMSF retraining has been successful for people with vestibular dysfunctions, spinal injury, and stroke [30]. In this study, a HEP employing real-time MMSF for trunk position, amplitude, and accuracy of fast stepping and stride practice was effective in improving backward stride length in pwPD, a fall-risk indicator. Recalibration of proprioceptive information, increased use of vestibular information, and decreased visual dependence may underlie the longer term carry-over of improvements in backward gait. Automaticity may underlie improvements over the washout period for those using MMSF + ex.

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CRediT authorship contribution statement

A. Winkler Patricia: Conceptualization, Methodology, Validation, Software, Formal analysis, Writing – original draft, Investigation, Supervision, Project administration, Resources. **A. Demarch Erica:** Conceptualization, Methodology, Investigation, Writing – review & editing. **L. Campbell Heather:** Conceptualization, Validation, Investigation, Writing – review & editing, Data curation. **B. Smith Marcia:** Methodology, Investigation, Writing – review & editing, Formal analysis, Visualization, Resources.

Declaration of Competing Interest

Patricia Winkler, Heather Campbell and Marcia Smith declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Erica DeMarch is the owner/developer of the balance mat from Balance Matters®, Step and Connect. This product was in development and modified specifically for this study's needs. Erica was reimbursed at cost for the product. It is currently commercially available.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.prdoa.2022.100132.

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