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Original Article

Augmented reality-based dance intervention for individuals with Parkinson's disease: A pilot study

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ABSTRACT

Background: The effects of dance on improving the symptoms of individuals with Parkinson's disease (PD) is well documented. Augmented reality devices, such as Google Glass, may be used to implement dance interventions to improve mobility and balance.

Objective: To evaluate the feasibility, safety, and acceptability of a mobile dance intervention and obtain preliminary efficacy estimates for assessment of the research protocol.

Methods: Seven participants with PD were asked to use Google Glass preloaded with Moving Through Dance modules for three weeks. Changes in motor functions (balance, mobility) and non-motor functions (mood, quality of life) were evaluated before and after completion of the intervention.

Results: Recruitment rate was 50%, retention rate was 100%, and adherence to usage was 95%. The intervention was safe and accepted by participants. Use of Moving Through Glass improved mobility with a cognitive load ($F(1, 5) = 10.76$; $p < 0.05$). However, there were no significant changes to the participants' balance scores, quality of life or mood.

Conclusions: The outcomes of this pilot study suggest that Moving Through Glass, as a mobile dance intervention, may be a safe way to increase physical activity through dance in individuals with PD. Its efficacy should be investigated in a properly powered randomized controlled trial.

Introduction

Common motor symptoms of Parkinson's disease (PD) include but are not limited to resting tremor, muscular rigidity, akinesia, and freezing. These motor impairments can negatively influence the fluidity and the amplitude of movement, and contribute to increased risk of falls, reduced physical activity, and loss of independence.[1] Additionally, non-motor symptoms, such as apathy and depression, can often lead to isolation, potentially compounding problems associated with further inactivity in individuals with PD.[2]

There is growing body of evidence suggesting that individuals with PD may benefit from a wide range of physical activity interventions, including aerobic exercise, resistance training, yoga, and dance.[3–5] In particular, dance improves standing balance, motor function, and the overall quality of life of in this population.[5] The enjoyable nature of dance also creates positive emotional responses, provides an outlet for communication and expression, and motivates regular participation in dance classes.[6]

Despite the positive evidence of dance programs for individuals with PD, this population remain excessively sedentary compared to similarly aged healthy adults.[7] Lack of time and scheduling issues are often reported as a barrier to participation in physical activity and exercise classes among individuals with PD.[8] Therefore, individuals with PD are desperately in need of physical activity interventions that can be implemented and accessed conveniently from their home.[9] A plausible solution may incorporate the use of a mobile physical activity intervention that allows participants to utilize on-demand dance classes via wearable technologies, for instance augmented reality devices.[10]

Augmented reality headsets, such as Google Glass, are conveniently worn in place of, or over conventional glasses.[11] Google

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Glass offers abundant possibilities for on-demand activity applications as well as auditory and visual cueing to assist individuals with PD, to improve their daily living.[12] Moreover, hands-free interfaces, such as voice and gesture control, increase the usability of these applications for individuals with PD in comparison to use of tablets or smartphones.[13] One example of these applications is Moving Through Glass (MTG).[14] The MTG application was designed for Google Glass as a portable, round-the-clock extension of the dance classes that are taught through Dance for PD®, a program of the Mark Morris Dance Group based in Brooklyn, NY.[15] The Google Glass superimposes the MTG videos of a variety of different exercises over the wearer's natural environment.[14]

It is possible that augmented reality-based interventions, such as MTG, will increase the accessibility and adherence to dance for individuals with PD. However, the current literature investigating the benefits of augmented reality-based interventions on motor and non-motor functions in individuals with PD is limited.[16–18] Thus, the purpose of this pilot study was to evaluate the feasibility, acceptability, and safety of using MTG for individuals with PD as determined by participant feedback, participation, and retention. In addition, this research protocol was assessed for practicability and potential efficacy to inform the design of a larger randomized clinical trial.

Methods

Participants

For this single-group feasibility pilot study, all procedures were approved by the Syracuse University's Institutional Review Board. Fourteen individuals, who were 18 years old and over with self-reported diagnosis of idiopathic PD, were recruited by contacting local neurology clinics and community-led PD support groups in Upstate New York . The severity of PD was assessed by using the Hoehn and Yahr (H&Y) scale and the Movement Disorder Society Unified Parkinson's Disease Rating Scale motor examination (MDS-UPDRS Part III). Participants with scores H&Y > 3 and MDS-UPDRS Part III >57, were excluded from the study due to severity of motor impairments.[19] The Montreal Cognitive Assessment (MoCA) was used to detect cognitive impairment, score < 21 suggesting PD-dementia.[20] Participants who did not meet the above-mentioned cut off criteria and/or were unable to wear or operate Google Glass were excluded from the study. All participants provided written informed consent to participate. No participants had prior experience using Google Glass and only one participant had prior experience with a formal dance program for PD, or otherwise. Additionally, none of the participants were actively engaged in rehabilitation services during the intervention although one was actively exercising by subjective report. Participants self-reported their fall history and were categorized as non-fallers if they had not experienced any falls within the past 6 months.

Moving Through Glass application

All applications and features normally found in Google Glass were removed for this study to prevent personal information from being collected. The Google Glass were defaulted to an offline environment that only contained the MTG modules.[14] The MTG was voice-activated using the prompt "*OK Glass*" followed by choosing the preferred MTG module from the list of four MTG modules: *Warm Me Up, Balance Me, Unfreeze Me, Walk with Me*. The participants could use voice-activated commands, or swipe and tap the control bar to navigate through the menu. Each of the first three modules have three or four different movement variations, averaging approximately 45 s per video. The last module, "*Walk with Me,*" contained four different tempo options. The video displayed during this module disappeared after 15 s, while the music continued indefinitely until stopped, to minimize distraction and ensure the safety of the users while they walked. The MTG application could be stopped at any time.

Although the MTG was created as an "extension" of Dance for PD® dance classes, its straightforward operation is also of use to those who have not engaged in Dance for PD® or had any prior dance experience.[15]

Trial design and intervention

This was a single-group feasibility pilot study (ClinicalTrials.gov registry number: NCT03214926). Following eligibility assessments (Fig. 1), a semi-structured entry interview was conducted with the consented and eligible participants. After the interview, participants received a set of questionnaires (see supplemental material 1) to complete prior to their next visit. The questionnaires were returned on the baseline assessment day, demographic and clinical information was collected (Table 1), and baseline motor assessments were completed. Participants were given a 20-min demonstration on how to use the Google Glass and the MTG modules, followed by safe completion of all four MTG modules supervised by the researchers. Immediately after the completion of the modules, motor assessments were repeated using the same protocol as baseline to collect their acute scores (post-test). At the end of the session, participants received a pair of Google Glass, a calendar-style log sheet, a safety guideline booklet, and the Google Glass user-guide developed by our team. Participants were encouraged to use the MTG modules as much as they could for a period of three weeks in their homes and/or community, with a minimum of three modules a day, every day. Additionally, the participants were requested to log the times and duration of MTG usage throughout the three weeks. At the end of the intervention, participants completed a second set of the questionnaires, repeated the motor assessments (follow-up), and an exit interview was conducted. Details of the data collection are provided in the Outcome Measures section.

Feasibility and acceptability

Indicators of feasibility included recruitment, retention, intervention adherence, MTG module usage, practicability of inclusion/exclusion criteria, and the correlations of baseline assessment scores to MTG usage. Recruitment rate was calculated as the number of participants who started the intervention divided by the number of participants who were assessed for eligibility. The study was considered feasible if recruitment rate >15% due to low recruitment rates for physical activity interventions in this population.[21,22] Retention rate was defined as the number of individuals who remained in the study at the last wave of data collection as a proportion of the total number of participants recruited at the baseline assessment. The study was considered feasible if retention rate >75%. Participants completed a calendar-style log sheet daily for three weeks detailing their usage of the MTG modules, including information such as which modules were used at what time of the day and how many times a day they were used. Adherence was defined as once a day use of MTG modules for three weeks (100% adherence = 21 uses of MTG). A semi-structured interview was conducted with participants on their first and last day of the study to determine whether the intervention was acceptable. In addition, at the culmination of the intervention, the participants completed an MTG questionnaire regarding their experience using the modules (see supplemental material 2). Furthermore, the questionnaire included a feedback section that

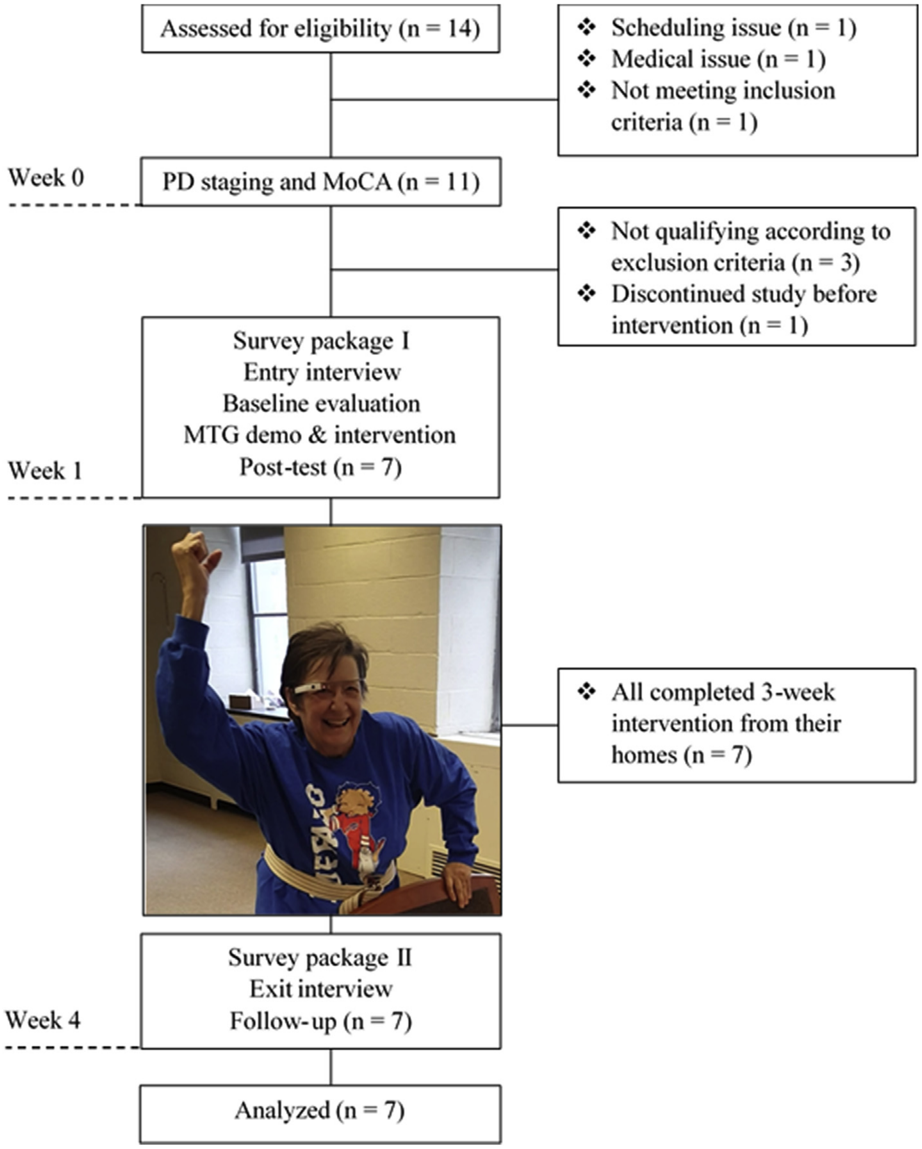

Fig. 1. Study design and timeline.

Table 1
Demographics and study test characteristics of participants.

	Participants n = 7
Sex	4 F; 3 M
Age (years)[a]	69 (5.5)
Education (years)[a]	17.1 (2.7)
Years with PD[a]	6.9 (6.9)
Fallers (F); Non Fallers (NF)	3 F; 4 NF
Hoehn and Yahr stage (/5)	2–3
MDS-UPDRS III score[a] (/132)	42.0 (9.2)
MoCA score[a] (/30)	23.4 (3.2)
MTG modules/day[a, b] (week 1)	4 (1.2)
MTG modules/day[a, b] (week 2)	4 (1.0)
MTG modules/day[a, b] (week 3)	3 (1.3)
Total MTG modules used[a, b]	78 (58)

Parkinson's Disease, PD; MDS – UPDRS III, motor section of Unified Parkinson's disease rating scale as defined by the Movement Disorders Society; MoCA, Montreal Cognitive Assessment; MTG, Moving Through Glass.
Higher scores for the MDS-UPDRS and Hoehn and Yahr reflect worsening disability while low scores for Montreal Cognitive Assessment correspond to poorer cognitive performance.
[a] Values are presented as mean (standard deviation).
[b] Participant-reported (n = 6) use of MTG modules.

allowed for open-ended and checklist responses regarding participants' experiences with the MTG modules (Table 2).

Safety

Strategies regarding safe usage of the MTG modules in both home and community environments were reviewed with participants. One week into the intervention, participants were given a phone call to answer any potential questions, address concerns regarding use of the Google Glass, and monitor any adverse events. At the end of the three-week intervention period, standardized questions were asked about any new falls, illnesses, injuries, and use of any health care services.

Secondary outcome measures

The motor assessments, Mini-BESTest, one-leg stance, 'Timed Up and Go' (TUG) and dual-task, were performed while the participants were in an "ON" state of their medication. The medication "ON" state was defined as a time period of 30 min to 3 h after the

Table 2
Participant feedback.
Number of participants who checked each item is shown in superscript for the checklist questions.

Open Ended Questions	Participant Open Ended Responses
What was the best part of using MTG?	-Self-contained, easy to do at home
	-Gives you an incentive to exercise
	- Ability to follow an instructor
	-Walking and work through the website (seating exercise class)
Do you have any suggestions for improving MTG?	- It would be helpful to meet with someone after 2–3 days to check your doing the exercises correctly
	-Include using exercises from the head and neck down during warm up.
	-Longer modules as you progress
Any positive/negative effect on your symptoms?	-None noted
	-Not sure, liked the big movements
	-Positive- made exercise more fun to do. Not so stiff after using
	-Yes, I feel more graceful
	-I feel this made a VERY positive effect on my symptoms AND my attitude towards exercising!!
	-Better coordination
	-More tired
Would you be interested in acquiring GG if they were available?	Yes^{6}
	Not answered^{1}
Would you recommend MTG to other people?	Yes^{6}
	No^{1}
Checklist Questions	***Checklist Response Options***
Controls or features most desired to add to MTG	Pause videos during exercise^{2}
	Longer exercise routines^{6}
	More exercise routines^{6}
	Control by voice when exercises are running^{2}
	More Google Glass features^{1}
Any complaints you had with MTG?	Tap controls difficult to use^{2}
	Volume commands difficult to use^{1}
	Volume is not loud enough^{3}
	Screen is too small^{2}
	Menu/Instructions confusing ^{0}
	Battery life poor^{1}
	Distracting to use in public^{0}
	Motion sickness or eye strain^{2}
	Uncomfortable to wear^{2}

MTG, Moving Through Glass; GG, Google Glass.

intake of the usual dose of dopaminergic medication prescribed by their neurologist as part of their pharmacological treatment.[23] To confirm the accuracy of the assessments, a video recorder was used throughout the assessment for offline video scoring by blinded raters from the research team. All evaluators received training from two physical therapists (AD, EYH).

Mini-BESTest

Balance and functional mobility were assessed using the Mini-Balance Evaluation Systems Test (Mini-BESTest), which is a sensitive measure of balance in the PD population.[24] This clinical tool aims at targeting different balance control systems including anticipatory postural adjustments, postural responses, sensory orientation, and dynamic gait.[25]

One-leg stance

One-leg stance test is reliable in assessing balance in individuals with PD.[26] In accordance with the general guidelines for the one-leg stance test, only the best score from the most affected side from each participant was included in the analysis.

'Timed Up and Go' and dual-task

Functional mobility under cognitive load, such as being able to perform two things at once (i.e. walking and talking), was measured incorporating a dual-task condition (counting backwards by threes from a given number) during the TUG. The time needed to complete the TUG with or without this dual-task component was measured using a stopwatch. For further analysis, dual-task cost was calculated by dividing the difference between the TUG time and dual-task time by the TUG time, expressed as a percentage.[27] A larger dual-task cost indicated poorer performance.

Questionnaires and scales

In addition to motor assessments, participants' perceived confidence in their balance was assessed by using the Activities-specific Balance Confidence scale, which is a 16-item self-report questionnaire.[28] Re-test reliability and validity within the older adult population and with individuals with PD has been reported.[28] To assess non-motor functions such as mood and quality of life, participants were asked to complete Beck Depression Inventory (Visser et al., 2006) and Parkinson Disease Quality of Life scale (De Boer et al., 1996) before they arrived for their initial motor assessment and at the end of the 3-week intervention.

Statistical analysis

Descriptive statistics were used to profile the study participants and report recruitment, safety, adherence, MTG usage, and survey outcomes. Baseline measures were compared to post-test score and to follow-up score. Paired-sample t-tests and Wilcoxon tests were used to examine differences in outcome variables listed in Table 3, as appropriate. Cohen's *d* was calculated to determine effect sizes for outcome of these variables: $d = \frac{|m1 - m2|}{\sqrt{s_1^2 + s_2^2 - (2rs_1s_2)}}$; medium 0.5, large 0.8. One-sample *t*-test was used to compare the dual-task cost to balance impairment cut off score (10%). Two-way ANOVA, with Tukey's multiple comparison as a post-hoc test, was used to compare dual-task cost and MTG usage across weeks in fallers and non-fallers. Spearman's ρ and Pearson's r correlations were used to

Table 3
Motor assessment and self-reported survey scores.

Mean Motor Assessment and Survey Scores and Mean Differences						
Variables	Baseline	Post-test		Follow-up		
	Mean (SD)	*Mean (SD)*	*Mean Difference (95% CI)*	*Mean (SD)*	*Mean Difference (95% CI)*	*Effect Size Cohen's d*
Mini-BESTest Total Score (/28)	18.0 (4.0)	20.6 (3.4)	2.6 (0.7, 4.5) *	19.71 (3.2)	1.7 (0, 3.5)	**0.50**
Mini-BESTest Anticipatory Subscore[a] (/6)	3.7 (1.3)	3.7 (1.3)	0.7 (0.3, 1.2)	4.1 (0.9)	0.4 (0.5, 1.3)	0.32
Mini-BESTest Reactive Postural Control Subscore (/6)	2.9 (1.1)	3.7 (1.3)	0.9 (0.4, 2.1)	3.1 (0.9)	0.3 (1.7, 1.3)	0.24
Mini-BESTest Sensory Orientation Subscore (/6)	4.7 (1.3)	7.9 (1.1)	0.1 (0.8, 1.1)	4.7 (1.3)	0 (0.9, 0.9)	0
Mini-BESTest Dynamic Gait Subscore[b] (/10)	6.7 (1.8)	7.6 (1.6)	0.9 (0.3, 1.7)	8.1 (1.5)	1.4 (1.2, 3.0)	0.85
One-Leg Stance (s;/30)	1.8 (0.7)	3.3 (1.8)	1.5 (0.3, 2.7) *	2.7 (1.9)	0.9 (1.0, 2.9)	**0.67**
Times Up and Go (TUG; s)	10.9 (3.0)	11.4 (3.4)	0.5 (0.6, 1.6)	11.5 (3.0)	0.6 (0.8, 2.0)	0.38
Dual-Task (DT; s)	16.5 (8.3)	15.9 (8.2)	0.5 (1.5, 0.4)	14.0 (5.1)	2.5 (5.9, 1.0)	**0.58**
Dual-Task Cost (%)	50.5 (30.2)	35.9 (30.3)	14.6 (19.1, 7.2)	18.5 (21.8)	31.9 (53.4, 10.5) *	**1.38**
ABC (/100)	74.5 (22.2)	N/A	N/A	76.1 (17.8)	1.6 (11.6, 14.7)	0.11
Beck's Depression Inventory	7.9 (4.7)	N/A	N/A	5.7 (4.2)	2.1 (5.8, 1.5)	**0.53**
PDQL	143.6 (26.2)	N/A	N/A	140.4 (19.6)	3.1 (17.0, 10.7)	0.23

ABC: Activities-specific Balance Confidence scale.
PDQL: Parkinson's Disease Quality of Life.

Table shows raw scores except for Dual-Task Cost = $\frac{DT \quad TUG}{TUG}$ 100

Mean differences are calculated as the difference between the baseline and the subsequent test.

Cohen's d is calculated as: $d = \frac{|m1 - m2|}{\sqrt{s_1^2 + s_2^2 - (2rs_1s_2)}}$; medium **0.5**, large **0.8**.

*Indicates p < 0.05.
[b]Dynamic Gait Subscore included Timed Up and Go and dual-task.
[a] Anticipatory Subscore included one-leg stance test.

determine a relationship between device usage and outcome variables as appropriate. One participant failed to complete the MTG log during the 3-week intervention, and without verification, his MTG usage data were therefore removed from the correlational analysis.

Significance level was set at $\alpha = 0.05$. Outliers were determined by the Grubbs test. All analyses were conducted using GraphPad Prism 7 (GraphPad Software Inc., USA).

Results

Feasibility and acceptability

Recruitment and retention

We aimed to recruit minimum of 20 individuals with PD. The sample size was a pragmatic decision based largely on scheduling and resources. However, we were only able to obtain 14 individuals who initially enrolled for the study (Fig. 1). Six of these individuals did not meet the inclusion/exclusion criteria or were unavailable for participation. One individual withdrew from the study prior to the intervention. Therefore, the recruitment rate was 50%. All seven individuals who started the intervention completed the requirements of the study (100% retention rate) between October 2016 and May 2017.

Module use and adherence

Demographic and clinical characteristics of the seven participants and mean daily use of MTG modules during the intervention are listed in Table 1. One participant failed to report the quantity of MTG use during intervention and, therefore, was excluded from the data analysis based on MTG usage. The remaining six participants reported safely and independently using a mean of 78 MTG modules (SD = ± 86.92), with a median module duration 3 min 25 s, across for an average of 20 days (SD = ± 15.86, 95% adherence). It is important to mention that the total number of times the MTG application was used varied widely among participants (Range: 18–47 sessions). None of the participants dropped out of the study or stop using the MTG modules during the intervention. However, there was a negative trend in MTG module usage in the third week compared to the first two weeks in non-fallers (Fig. 2). The two fallers remained consistent in their MTG module usage (Tukey's multiple comparisons test; week 1 vs week 3, $p > 0.05$). The drop in MTG module usage across weeks was mainly driven by the four non-fallers (week 1 vs week 3, $p < 0.05$) and was confirmed by a two-way ANOVA, which produced a significant interaction of faller categorization and time ($F(2, 8) = 5.412$; $p < 0.05$), with main effects of on time ($F(2, 8) = 4.506$; $p < 0.05$) and subjects matching ($F(4, 8) = 22.15$; $p < 0.0002$).

Assessment of inclusion/exclusion criteria

Correlations between the MTG module usage and baseline assessments for cognition, balance, mobility, mood, and quality of life were evaluated to ensure that baseline characteristics were not associated with MTG usage. Correlations were used to ensure that participants were able to use the technology and follow the modules safely throughout the intervention period. The statistical

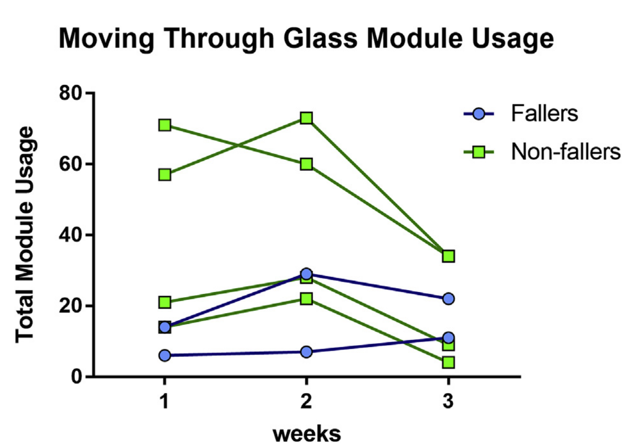

Fig. 2. Moving Through Glass usage.

analysis revealed no correlation of the severity of the PD (UPDRS Part III Spearman $\rho = 0.2899$, $p = 0.5778$) or baseline balance measurements to device usage (ABC Spearman $\rho = 0.6571$, $p = 0.1750$; Mini-BESTest Spearman $\rho = 0.6667$, $p = 0.1556$; DT Pearson $R^2 = -0.3545$, $p = 0.4905$). Additionally, no correlation was found between device usage and cognition (MoCA Spearman $\rho = -0.02899$, $p = 0.9833$), the quality of life (PDQL Spearman $\rho = 0.6571$, $p = 0.1750$), or depression levels (BDI Spearman $\rho = -0.7537$, $p = 0.1056$; data not shown).

Acceptability

During the entry interviews all seven participants reported that despite their interest in increasing their physical activity levels, they often were not able to due to a variety of barriers. One participant (MTG4) commented: *"The timing for that boxing class has been hard for me. I even went out and bought the boxing gloves because I wanted to try to get there, and I just haven't gotten there."* Another participant (MTG8) added: *"I would probably swim, but I don't drive now."*

Upon completion of the 3-week intervention, participants reported using the MTG as an enjoyable experience. All participants reported that the modules were enjoyable and they would be interested in obtaining MTG modules in the future if it becomes available to general public. Participants also did not have issues sharing with family or friends that they were using the Google Glass as way to manage their PD symptoms and increase physical activity. A quote from a participant's (MTG4) exit interview included: "*I posted a picture of the Google Glasses the day I got it and I said, 'Who knew Parkinson's could be so much fun?' Everybody thought that was very cool.*" Furthermore, another participant (MTG8) stated:

> I made everybody look at the [Google Glass] and made them go through the menu, and they loved it… and said, 'We want one because I could do this! This is good for me.' They were [really] excited about it. I recommend it to everybody; heart patients, more neurological patients, people losing weight, or just people wanting to do exercise to move. I loved it, give me some more!

Participants' enjoyment and self-efficacy were reported via MTG questionnaires regarding the overall functionality of MTG pertaining to the best qualities of MTG, suggestions for improvements, and effects, if any, on PD symptoms (Table 2). Most notably six out of seven participants would recommend MTG to other people and would be interested in acquiring Google Glass loaded with MTG modules if it became available to the general public. Four participants noted positive effects on how they felt such as "*not so stiff,*" "*feel more graceful,*" and "*better coordination*". None of the participants found the MTG distracting to use in public nor did they find the menu/instructions confusing. However, some of the participants found the Google Glass uncomfortable to wear ($n = 2$), its screen size too small ($n = 2$), or the volume not loud enough ($n = 3$).

Safety

During the intervention, there were no reported falls or adverse effects such as dizziness, anxiety or confusion while using the MTG modules or during the three-week intervention period. Two participants mentioned they had occasional eyestrain or minor motion sickness after extended use.

Assessment of the research protocol

Assessment of research protocol included 1) practicability of the study design and 2) selection of outcome measures with potential effectiveness.

Practicability of study design

On the baseline assessment day, motor assessments were repeated upon use of all MTG modules to investigate if the length of our protocol had any adverse effects on the participants' motor functions. No impairments in any balance or mobility scores were observed to indicate fatigue as a result of the length of our research protocol. On the contrary, significant improvements were seen in Mini-BESTest overall score and one-leg stance score compared to baseline (Table 3).

Selection of outcome measures with potential effectiveness

There was a significant improvement in the dual-task cost following 3-weeks use of MTG (Fig. 3; ($F(1, 5) = 10.76$; $p < 0.05$), regardless of the participants' fall history (fall category, $F(1,5) = 1.134$, $p = 0.33$; interaction, $F(1,5) = 0.022$, $p = 0.09$). Furthermore, dual-task cost was significantly higher than the balance impairment cut off value of 10% (according to Mini-BESTest) at baseline (Fig. 3; $t(3.214)$, $df = 6$; $p = 0.02$), but not after the 3-week intervention ($t(1.107, df = 6; p = 0.31)$. No significant improvements were observed in the other motor outcome measures, however, medium to large effect sizes in Mini-BESTest (overall and dynamic gait subscores), one-leg stance, and dual-task were notable (Table 3).

Lastly, there were no differences in the participants' perceived activities-specific balance confidence, depression level or the quality of life as a result of the intervention.

Discussion

The results from this pilot feasibility study are significant in that, to our knowledge, this is the first time that augmented reality-based dance application has been used in the home environment specific to individuals with PD, or otherwise. In the current study, we intended to: 1) evaluate the feasibility, acceptability, and safety of using Moving Through Glass (MTG) for individuals with PD as determined by participant feedback, participation, and retention and 2) assess the research protocol to inform the selection of outcome measures for a larger randomized clinical trial.

The results of this pilot study demonstrated that home use of augmented reality devices such as Google Glass for mobile dance classes is feasible for individuals with PD. Although we experienced some issues with recruitment, mainly due to geographical location, weather, and the time of the year, our recruitment rate is higher than many other feasibility studies in PD.[21,22] Furthermore, all participants completed the intervention and required assessments.

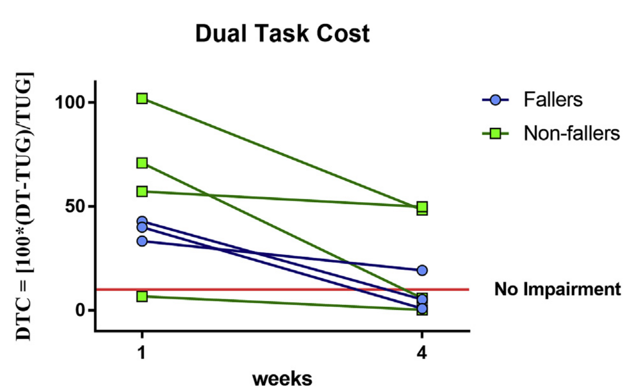

Fig. 3. Dual-task cost following 3-week intervention.

The MTG modules used in this study were designed to promote adherence to dance-centered physical activity in individuals with PD from their home environment. All participants used the device continuously for three weeks, which may not have been feasible if the individuals had to rely on transportation to a community dance program. In addition, all participants were able to use their devices and follow through the dance modules on their own, regardless of their initial cognitive, balance, and mobility scores, depression levels, or the severity of the disease. This supports that the screening and inclusion/exclusion processes applied were effective and appropriate. Moreover, participants reported high satisfaction rates with the MTG modules as indicated by the MTG questionairre and reported a desire to continue using the MTG application if it was made available, highlighting the acceptability of the intervention.

This pilot study has demonstrated that using MTG modules unsupervised can be performed safely in the home environment. Notably, six out of seven participants had one-leg stance scores of less than 10 s. These scores fell below the normative values for age and gender matched comparison.[29] Therefore, these scores may correlate with decreased postural stability, consequently putting the participants at high risk of falls.[26] However, in this study, the additional cognitive demand required by participants to use the interactive device did not cause any safety issues, falls, or adverse events which could be a concern in by health care providers recommending physical activity with individuals with PD who are at risk for falls. Improvements on the Mini-BESTest and one-leg stance after single use of MTG modules on the assessment day suggests that performing these modules increased participants' stability and, thus, potentially reduced risk of falls for these individuals.

Home-based exercise interventions have so far been ineffective for individuals for PD[30]. Nonetheless, home exercise programs remain standard-of-care for mobility deficits in PD. Contrary to the literature, findings of the current study revealed positive outcomes of a home-based exercise intervention. It is possible that the novelty of this technology combined with the ability use of the MTG at home, in the community, or during exercise classes motivated participants to be physically active. Although we did not see any improvements in raw balance and mobility scores, the amplitude of improvement in Mini-BESTest scores were comparable to those who found significant changes across a larger sample size.[31] Furthermore, dual-task cost was improved in all the participants following the intervention compared to baseline, regardless of their fall history. This may be due to improved automaticity of gait performance or enhanced cognitive function with the use of auditory and visual cues.[32] It is also noteworthy that in two individuals where Timed Up and Go time increased due to self-reported onset of orthopedic pain during the intervention period, which was not reported to be linked to the use of MTG, the overall dual-task cost still improved. In addition, although the baseline dual-task cost values were far from the balance impairment cut off point, the long-term dual-task cost values were within, or close to, the no impairment zone after the intervention. This finding also suggests that the risk of falls of the participants decreased upon completion of the intervention.

From the information and experience gained in this pilot trial, we have formulated a number of recommendations about the study protocol to guide implementation of a larger definitive trial. First, improvements to recruitment efforts is required to obtain a large sample size. For future studies, researchers should consider weather permissiveness in order to maximize the number of subjects who are staying in the area for the duration of the study.

Second, improvements to study design to maintain adherence is required. It has been demonstrated that an unsupervised, home exercise program is the least effective way to deliver exercise to people with PD.[30] However, even though most home exercise programs have low compliance rates, specifically in individuals with PD,[33] our study design confirmed that, even without supervision or a required regime, participants adhered to using the MTG. Nevertheless, the negative trend in MTG usage toward the end of the intervention suggests that future studies should evaluate the need for regular check-ins or home visits from a physical therapist in order to keep the participants motivated for the duration of the intervention and to remind the participants of safe practices. Additionally, recording the MTG use by the application itself (i.e. such as time of the day, number and duration of the modules used, etc.) would not only reduce participant burden, but also would increase the accuracy and consistency of the data collection.

Third, the secondary outcome measures applied in this pilot were comprehensive and reflective of the different components of balance, mobility, and non-motor functions. Although we did not see any impairments on mobility or balance scores, when re-tested at the end of the baseline assessment day, that indicates a burdensome protocol, future clinical trials should be conscious of the length of the protocol on participant burden.[34] We recommend such trials to limit the outcomes to those identified with highest potential effectiveness of this intervention, such as dual-task cost and one-leg stance.

The current pilot study had some limitations. This study lacked a randomized control group. Further studies related to dance application for PD and augmented reality devices need to include a randomized control group, preferably with a larger sample size, to assess the safety and effectiveness of this intervention with an improved statistical power. Inclusion of comparator interventions (i.e. traditional dance classes or use of augmented reality for exercise reminder, without the dance instruction) in a three-arm non-inferiority trial design would also reduce participant biased responses and performances. Another limitation was that a lack of designed regime of MTG use, which led to inconsistent use of the modules. Dosing parameters, such as number of times used or number of minutes per module, should be investigated with further research. Finally, individual access to the Google Glass is limited to the public due to halted production and the cost of the device. However, new and alternative augmentative reality technologies are entering the market and may be more affordable and accessible to the general population over time.

In summary, there is a scarcity of research on the implementation of augmented and virtual reality-based physical activity interventions for individuals with PD.[16,17] The current intervention provided participants with an opportunity to experience some of the benefits of a dance class in the comfort of their homes by using Google Glass. Our results revealed the potential promise of using Moving Through Glass as a mobile dance intervention for individuals with PD to improve balance and mobility. Therefore, home-based augmented reality interventions for individuals with PD should be further investigated. The process and management information obtained from this trial can be used to guide the design of a future definitive randomized clinical trial.

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Presentations

Findings from this pilot study, in part, were presented at these conferences: National Adapted Physical Activity Conference, San

Diego, 2017; American Physical Therapy Association, New Orleans, 2018, 2018; Movement Disorders Society, Hong Kong, 2018.

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Appendix A. Supplementary data

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