The Effects of Augmented Reality as a Therapeutic Tool on People with Parkinson's Disease: A Brief Review

Review

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Abstract

This narrative review investigates the effects of augmented reality on the rehabilitation of people with Parkinson's Disease. Augmented reality technology can overlay digital information in a natural environment allowing a clinician to integrate therapeutic games and tasks using visual information. Nine pertinent articles explore the impact of augmented reality as a therapeutic tool to improve gait function, freezing of gait, postural control, executive function, balance, and fall-risk outcomes. The findings support the use of augmented reality in the rehabilitation of people with Parkinson's Disease as it may improve Mini-BESTest scores, gait speed, and dual-task training in this population. However, the limited knowledge regarding the feasibility and therapeutic effect emphasizes the need for further research on this topic. The current literature requires additional high-level evidence, such as randomized control trials and increased sample size. This will help determine whether augmented reality holds promise as a primary therapy or an adjunct to therapy in people with Parkinson's disease.

Key Words: Augmented Reality, Parkinson's Disease, Physical Therapy

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Introduction

Parkinson's Disease (PD) is a neurodegenerative disease that can have the cardinal clinical features of resting tremors, cogwheel rigidity, bradykinesia, and postural reflex impairment.[1] Other observable motor symptoms include akinesia and gait disturbances.[2] Alongside these motor signs, people with Parkinson's Disease (PwPD) may experience other non-motor impairments that can negatively impact their daily function. Three of the most common non-motor symptoms include gastrointestinal dysfunction, olfactory dysfunction, and sleep disorders.[3] Sleep disorders have been associated with increased severity of PD symptoms and can increase the burden of PwPD.[4] Other non-motor symptoms may include depressive disorders, anxiety, and cognitive impairments which, when combined with other motor and non-motor symptoms, could deteriorate the quality of life in PwPD.[3,5]

The signs and symptoms of PD may increase the risk of falling and may be a cause of a fall. A fall is an event that results in a person coming to rest inadvertently on the ground, floor, or other lower level.[6] At the time of diagnosis, PwPD have a risk of falling twice as high as the general population which may result in several injuries including fractures, contusions, wounds, and sprains.[7,8] PwPD may have a fall rate of 35% in a 12-month follow-up.[9] This increase in the risk of falling has been correlated to an individual's fear of falling, hallucinations, polypharmacy, low levels of vitamin B12, and walking with assistance.[10-12] North America has an estimated 60 to 95 thousand new cases of PD among adults ages 45 and older per year.[13] Incidence rates are estimated to be higher in males and increase with age.[13] The average nine-year cumulative cost ranges from approximately 109 thousand to 118 thousand dollars. In 2017, an estimated 1.04 million individuals in the United States were diagnosed with PD with an associated 51.9 billion dollars in total economic costs. The prevalence is expected to surpass 1.6 million with a projected total economic burden greater than 79 billion dollars by 2037.[14] Fall prevention has become a focus throughout the medical field and may be emphasized in PwPD due to the increased risk of falling.

Physical therapists have a myriad of tools and interventions they can utilize to treat PwPD. Recommended therapeutic interventions include aerobic exercise, resistance training, balance training, external cueing, gait training, and task-specific training.[15] The emergence of virtual reality (VR) and augmented reality (AR) in physical therapy has provided patients and physical therapists with a new option to treat some of the deficits associated with PD. VR has been defined as a three-dimensional computer-generated simulated environment, which attempts to replicate real world or imaginary environments and interactions.[16] In PwPD, VR, whether immersive or non-immersive, has demonstrated improvements in balance function and adherence to treatment protocols.[17-20] Additional evidence has shown that VR may be an effective alternative treatment to treat motor impairments in people with multiple sclerosis.[21]

In contrast to VR, AR is defined as a system that combines real and virtual objects in a real environment, running them interactively and in real-time, and aligning real and virtual objects with each other.[22] Therapeutically, this contemporary technology is commonly implemented through the use of AR glasses which will overlay digital information in the individual's natural environment. Although limited, the use of AR in PD has been shown to be effective in improving gait speed, balance as a function of Berg Balance Scale scores, and dual-task cost.[23-25] Dual-task cost is the performance deficits for the combination of two tasks that are disproportionally greater than performing the two tasks independently.[26] Initial studies do not support its use in improving the freezing of gait.[27,28] Freezing of gait is a brief episodic reduction or halt of the forward progression of the feet, despite the intention to walk.[29] However, studies performed in other populations with neurological conditions demonstrate how this technology may be an efficacious intervention. The use of AR after a stroke has shown to be effective in increasing upper limb and lower limb function and can be a viable option for increasing treatment intensity.[30]

Although VR may be efficacious in improving balance and gait in PwPD, there is limited evidence exploring the effect of physical therapy interventions utilizing AR in PwPD.[18,31] With advancements in technology and technological access in a clinical and home setting, it is important to explore the impact this novel rehabilitation approach may have. This review explores whether the utilization of AR is supported in improving gait, balance, dual-task training, and freezing of gait in PwPD.

Scientific Methods

Searches were performed using PubMed CINAHL, Medline, and Google Scholar. Results were limited to studies published in the English language from 2020 to November 8th, 2024 due to the advancements in technology in the past five years. Searches of these databases were performed using the keywords: Parkinson's Disease, augmented reality, augmented virtual reality, physical therapy, balance, and gait. Related synonyms were taken into consideration and Medical Subject Headings (MeSH) were utilized when appropriate. All articles were screened by the primary investigator and, if the article was deemed appropriate for this study, was included in this review.

Studies included participants who were clinically diagnosed with PD without restrictions on PD subtype, gender, disease severity, age, and disease duration. No limitations were placed on the type of AR technology utilized, the frequency of AR interventions, or the duration of AR rehabilitation training. Inclusion criteria for the articles included studies that were original research studies conducted on PwPD regardless of the study design or subset of PD, utilized AR as a treatment intervention, and were published in peer-reviewed journals. Exclusion criteria comprised publications before 2020, non-English language publications, abstracts, reviews, study designs, protocols, and studies utilizing a population other than PD. A total of 13 studies were identified through the literature search. After excluding four articles, nine articles met all of the inclusion criteria and were analyzed for this study. For this review, three publications detailing study design, protocols, and rationales, concurrent validity, and test-retest reliability were not included though they may serve as a foundation for future studies.[32-35]

Included articles investigated the effect of AR on balance, gait, postural control, executive function, and dual-task training. Executive function is the abilities that enable an individual to perform purposeful behaviors, actions, planning, and performance.[36] These areas have been divided into three primary categories: 1) Gait and Balance; and 2) Dual-Task Training and Freezing of Gait.

Results

Nine articles were identified to be relevant to the scope of this review. Of the nine included, three utilized Motek's C-Mill, a treadmill with the capability to incorporate AR and VR as well as a fall safety system or bodyweight support system.[37] An additional five studies utilized variations of AR glasses in which the participant dons the AR glasses where digital information is overlayed in the field of vision. One study utilized a computer screen that captured, processed, and returned the images of the interaction with participants and projected them on a surface that faces the patient.[38] The studies included in this review were comprised of four randomized control trials, two pilot studies, two two-group designs, and one single-group design.

Although not included in the overall analysis, concurrent validity and test-retest reliability of the Five Times Sit-To-Stand (FTSTS) test and the Timed Up and Go (TUG) test have been explored in PwPD utilizing AR glasses. Participants in this study performed the FTSTS test with the researcher utilizing a stopwatch, AR glasses, and the Microsoft Kinect v2 Sensor. The TUG test was performed with a stopwatch, AR glasses, and an Inertial Measurement Unit (IMU) worn on the lower back. An excellent concurrent validity was observed between the AR and Kinect completion duration of FTSTS ($ICC_{(a,1)}$=0.999) and between AR and IMU Turn 1 subduration ($ICC_{(a,1)}$=0.913). No significant difference in consistency agreement scores was noted between the HoloLens 2 and Magic Leap AR glasses. Additionally, it was found that the within-system test-retest variation in completion times was greater than the between-systems variations which may limit the sensitivity for detecting longitudinal changes.[35]

A multitude of outcome measures were utilized to quantify changes in the participants included in this review. Of the nine studies included, the most commonly utilized outcome measures included; the Timed Up-and-Go (33.3%), dual-tasking (33.3%), gait speed(33.3%), a version of the Parkinson's Disease Questionnaire (33.3%), gait parameters (33.3%), and the Mini-BESTest (22.2%).

Parkinson's Disease Motor Severity and Staging

Eight of the nine studies included in this review utilized the Movement Disorder Society-Unified Parkinson's Disease Rating Scale (MDS-UPDRS) subsections to quantify participant motor severity and the Hoehn-Yahr scale to stage the severity of the symptoms of PD. Seven of the eight who utilized the Hoehn-Yahr scale or Modified Hoehn-Yahr scale had participants between stages 2-3, the remaining article had participants in stages 1-3.

Gait and Balance

The examination of the three studies that utilized the C-Mill demonstrated an improvement in functional outcome measures and, in one of the studies, an improvement in gait parameters after the implementation of the intervention.[23,24] Wang et al examined the effect of C-Mill training on PwPD subtypes Postural Instability/Gait Disability (PIGD) and Non-PIGD. C-Mill training was performed for seven days with AR and a duration of approximately 30 minutes. Statistically significant increases were noted in 10 Meter-Walk Test (10MWT) times at a comfortable(1.09m/s to 1.20m/s, 1.21m/s to 1.34m/s) and maximum speed (1.48m/s to 1.56m/s, 1.56m/s to 1.70m/s) for PIGD and Non-PIGD respectively.[23] There was a significant difference in TUG times (9.97 seconds to 8.74 seconds, and 8.95 seconds to 7.96 seconds for PIGD and Non-PIGD groups respectively), Berg Balance Scale (BBS) scores (53 to 54, and 55 to 55 for PIGD and Non-PIGD groups respectively). Increases in tandem walking (0.12 and 0.16), obstacle avoidance (0.40 and 0.56), and the overall score of C-gait assessment (0.29 and 0.23) were noted in PIGD and Non-PIGD groups respectively. Scoring for walking parameters was performed by the C-Mill as a percentage of correct steps relative to the projected objects.[23] However, with a lack of a control group, it may be unclear whether the use of AR is superior to conventional therapy.

Participants in a study by Gulcan et al.[24] were divided into a control group, which received therapy three days per week for 6 weeks lasting approximately one hour, while the experimental group received therapy augmented by AR/VR for the same frequency but with a duration of 1.5 hours. When discussing balance, both groups demonstrated improvements in median interquartile range BBS scores (50 to 52, and 53 to 54 for the experimental and control groups respectively) and Activities-Specific Balance Confidence Scale Scores (58 to 62, and 85.30 to 94.37 for the experimental and control groups respectively). The AR/VR training group exhibited further improvements in open and closed eyes double-leg stability tests, the single-leg stability test, and the limits of stability test.[24] Regarding gait, both groups improved in right-left step length and stride length. The AR/VR group further improved in right-left swing phase duration, step width, right-left stance phase duration, and a decrease in total double support phase duration.[24] Araujo et al demonstrated that AR, VR, and neurofunctional physical therapy improved postural control with AR and VR producing similar effects to neurofunctional therapy. With AR, anteroposterior displacement velocity (tandem eyes closed 2.3 to 2.1) decreased and one-legged stance (20.71 to 24.75 seconds) increased from following training indicating that AR may serve as an alternate treatment to increase postural control.[38]

The ability of AR to alter gait parameters is further supported by a study performed by Hoogendoorn et al.[39] This study evaluated the gait-modifying effects of AR in PwPD and whether these effects are equivalent to what was imposed with cues. An interactive walkway was utilized to impose real-world effects and was compared to the effects of cueing with AR glasses. Through multiple trials of AR and real-world effects, the authors determined that gait speed, step length, and crossing step length were able to be modified by AR and real-world cues. In clinical cases where an interactive walkway is not present, physical therapists may set up hurdles or visual markers on the floor to provide visual cues to patients whereas AR superimposes visual data on a real-world background to perform visual cueing.

However, mixed results were noted in a pilot study performed by Lee et al. depending on which AR program was utilized.[40] This study demonstrated that AR training can improve gait tasks or worsen gait tasks based on which Google Glass program was utilized. The "Walk With Me" program improved 25 feet straight walk time, average dual task serial 7's, and average walking through a door however, the average 180-degree turn after the 25 feet walk time worsened. The "Unfreeze Me" program worsened gait tasks except for dual-task serial 7 straight walking.

Dual-Task Training and Freezing of Gait

The use of AR has been shown to improve dual-task performance in PwPD and executive function.[38,41] The improvements noted in dual-task training resulted from a 45-minute session of simultaneous gait and cognitive training with and without the use of AR. In all conditions, the researchers observed improvements in gait speed, cadence, and step length during single and dual-task conditions.[41] Pilot data regarding improvements in dual-task cost through the use of AR is supported by a study using an AR module to deliver a dance-based intervention to PwPD.[25] Improvements in executive function, as noted with the Trail Making Test, were noted after a 50-minute of either neurofunctional physical therapy, AR, or VR.[38] The use of AR visual cues on turning in place demonstrated no benefits to PwPD. The experiment was divided into a training session and two experimental sessions. Each experimental session was further subdivided into 3 blocks of 15 trials performing a 180° circle with no cues, auditory cues, and AR visual cues.

However, AR has not been demonstrated to be an effective intervention in reducing the freezing of gait (FoG).[27,28] A study performed by Janssen et al. demonstrated that FoG was not reduced with AR and was found to worsen some axial kinematics.[27] Similarly, Pisano et al. determined that AR and transcranial direct current stimulation did not have a significant effect on the FoG questionnaire in PwPD although an improving trend has been observed.[28] This study also demonstrated an improvement in postural stability in eyes-opened and eyes-closed conditions. Although there may be many underlying mechanisms of FoG, a lack of improvement may be due to the loss of automatic updating of motor programs by dysfunctional basal ganglia.[42] Additionally, PwPD may decrease step length and step time when arriving at a narrow doorway which may indicate that an exaggerated response to visual information is present.[43,44] A summary of the studies regarding AR can be found in Table 1.

Table 1. Study Summary

Author	Title	Type of AR	Year	Study Design	Theme	Outcomes
Janssen, Sabine et al.[27]	The Effects of Augmented Reality Visual Cues on Turning in Place in Parkinson's Disease Patients with Freezing of Gait[27]	HoloLens	2020	Single-group, three conditions per participant; AR visual cues, metronome, and no cues	AR utilization for turns did not reduce freezing of gait and worsened some axial kinematics	AR visual cues did not significantly change the percent time frozen (p = 0.73) or the mean number (p = 0.73) and duration (p = 0.78) of FOG episodes compared to the control condition without cues.
Tunur, Tumay[25]	Augmented reality-based dance intervention for	Google Glass	2020	Single-group feasibility pilot study	AR dance-based mobile interventions may	Mean difference of dual-task cost at week 4 follow up:

	individuals with Parkinson's disease: A pilot study				improve dual-task cost and be a safe method for increasing physical activity in PwPD	95% CI: -31.9 (-53.4, -10.5), Effect Size: 1.38
Wang, Yongshi et al.[23]	Efficacy of C-Mill gait training for improving walking adaptability in early and middle stages of Parkinson's disease	C-Mill	2022	Two-group comparison	C-Mill gait training may improve walking adaptability among different motor sub-types of PD	PIGD and Non-PIGD groups improved in 10MWT-comfortable speed, 10MWT-max speed, TUG time, and BBS scores ($p < .05$)
Hayslenne Andressa Goncalves de Oliveira Arau´jo et al.[38]	Immediate Effect of Augmented Reality, Virtual Reality, and Neurofunctional Physiotherapy on Postural Control and Executive Function of Individuals with Parkinson's Disease	WebCam Mania	2023	Randomized, blinded crossover clinical trial	Neurofunctional physical therapy, AR, and VR all demonstrated improvements in executive function and postural control in PwPD	TMT part A time decreased after AR (-9.3 [-15.7 to 1.9]), permanence time in one-legged position increased in AR (Change: 2.5 [-0.2 to 6.9])
Kubilay Gulcan et al.[24]	The Effects of Augmented and Virtual Reality gait training on balance and gait in patients with Parkinson's disease	C-Mill	2023	Randomized control trial	A combination of AR and VR improved improves gait and balance in PwPD	The use of AR and VR improved open-closed eyes double-leg stability tests, single-leg stability test, limits of stability test, BBS, and ABC tests ($p < 0.05$)
Alberts, Jay et al.[41]	A Randomized Clinical Trial to Evaluate a Digital Therapeutic to Enhance Gait Function in Individuals with Parkinson's Disease	HoloLens 2	2023	Single-blind Randomized control trial	PwPD performing dual-task training with and without AR improved in gait parameters during single and multiple dual-task conditions	Among many parameters, AR training increased gait speed (1.22 to 1.33m/s), gait speed with dual task serial 7 (1.07 to 1.22 m/s), single task step length (0.65 to 0.69m) and dual-task serial 7 gait speed (0.58 to 0.64m)
Lee, Andrea et al.[40]	Can google glass technology improve freezing of gait in parkinsonism? A pilot study	Google Glass	2023	Single-group pilot Study	Mixed results were noted on gait tasks based on which AR Google Glass program was utilized	Average 25 feet straight walk by 0.32 seconds; average dual task of serial 7's and 25 feet straight walk by 1.79 seconds; and average walk through doorway by 0.59 seconds. Average 180 degree turn after 25 feet walk worsened by 1.89 seconds
Hoogendoorn, Eva et al. [39]	Gait-modifying effects of	HoloLens 2 and	2024	Two-group comparison	PwPD can increase their gait speed,	Main effects of modulation for gait

	augmented-reality cueing in people with Parkinson's Disease	Magic Leap 2			step length and crossing step length to real-world and AR cues with step length being equivalent in both groups	speed [$F(1.55,27.86) = 115.509, p < 0.001$, step length [$F(2.00,31.26) = 14285.076, p < 0.001$, and crossing step length [$F(1.29,24.53) = 63.860, p < 0.001$
Pisano, Fabrizio et al.[28]	Cerebellar tDCS combined with augmented reality treadmill training for freezing of gait in Parkinson's disease: a randomized controlled trial	C-Mill	2024	Randomized Control Trial	PwPD who received cerebellar tDCS combined with AR showed improved postural stability and may enhance motor control	After ten sessions of AR and cerebellar tDCS, right lower limb sway with eyes opened and closed improved as compared to the sham group $p < 0.05$

PD, Parkinson's Disease
PwPD, People with Parkinson's Disease
AR, Augmented Reality
VR, Virtual Reality
PIGD, Postural Instability/Gait Disability
10MWT, Ten-meter walk test
TUG, Timed Up and Go
BBS, Berg Balance Scale
TMT, Trail Making Test
tDCS, Transcranial Direct Current Stimulation

Discussion

The current body of literature, although limited, supports AR as an efficacious therapeutic intervention for PwPD to improve gait, balance, and dual-task training. This is underscored by improvements in outcome measures validated in PD including gait speed, the Berg Balance Scale, Activities-Specific Balance Confidence Scale scores, and the Trail-making test. Clinically, the aforementioned outcome measures can be used to predict fall risk and functional status of PwPD. The use of AR is however not supported to treat and improve FoG and has mixed results in improving axial kinematics and postural control.

Although the literature explored in this review generally supports the use of AR in PwPD, there may be a need to further explore AR as a therapeutic intervention to decrease the risk of falls in PwPD. Most studies utilized the MDS-UPDRS part III to measure motor severity and the Hoehn-Yahr scale to stage the diagnosis of PD. In all future studies, measuring motor severity and stage of PD would allow the intervention to be applied to the correct subset of the investigated population. To determine whether AR should be a primary or adjunct intervention in PwPD, an emphasis on high-level evidence, such as randomized control trials, is required. A limited number of studies utilized a sample size estimation. Future studies may consider performing a sample size estimation and increase their sample size to allow the results to be generalizable to a larger population or a subset of PwPD. The clinical practice guideline for physical therapist management of PD support balance training is being implemented two to three times per week for a total of 16 to 30 hours over five to ten weeks.[15] Further research on balance interventions is recommended to compare different types, doses, and methods of balance interventions.[15] Future studies may compare AR with other therapeutic interventions and explore AR's long-term efficacy in PwPD.

Practical Application of AR in PwPD

PwPD can present with a variety of signs and symptoms which may increase their risk factors and risk of falling. With access to contemporary technology, it is important to explore whether the findings discussed in this review regarding the use of AR in PwPD are generalizable. The use of AR may have the capacity to be utilized in a clinical setting as an assessment tool or to supplement balance and gait interventions. AR may be used to place visual cues to patients to provide a visual marker for the TUG assessment or to provide visual cues for gait and balance training.

The portability of this device may allow clinicians in the home health setting to leverage this technology in a home setting where space and access to hurdles or other therapeutic tools are limited. If utilized in home-based therapy, clinicians may need to train their patients on the use of AR which may be difficult in PwPD due to the cognitive effects that can occur with PD. If the patients perceive there to be complexity in using AR, there may be limited patient acceptance of interventions or assessments utilizing this technology. As accessibility increases in the future, clinicians may recommend the use of AR glasses to increase patient compliance and adherence to interventions established in the physical therapist's plan of care.

To date, the use of AR in PwPD has barriers and limitations regarding its clinical application. Financially, AR glasses can cost up to $3,500 which may be a barrier to the purchase of this equipment. Organizations or clinicians may be hesitant to purchase this equipment since AR has yet to be proven to be superior to conventional therapy. Additionally, familiarity with AR glasses is limited due to it being a novel technology that may require training and the development of AR software to meet the specific needs of patients with PD.

Limitations

It is important to note the limitations of this review. First, the inclusion criteria allowed for articles published exclusively in the English language. Second, the limited number of studies and randomized control trials on this topic did not allow the author to perform a meta-analysis or systematic review. The heterogeneity of the study designs and, in some cases, small sample sizes may make it difficult for clinicians to generalize findings to PwPD. Among the studies included, there were approximately five different AR technologies utilized, each with varying treatment interventions and parameters. As a result, clinicians may find it difficult to generalize the findings to the population they are treating. Finally, due to variability in definitions of VR and AR, it may be possible that some studies were labeled as VR but may fall under some definitions of AR.

Conclusion

The studies examined in Table 1 generally support the use of AR to improve Berg Balance Scale scores, Activities-Specific Balance Confidence Scale scores, and gait parameters such as gait speed, step length, and dual-task cost. While AR has the potential to improve gait speed, balance scores, and dual-task training, current research does not support its use in the treatment of FoG. Further research is required to determine whether AR should be utilized as a stand-alone treatment or incorporated into a multimodal therapy approach in PwPD. This novel tool in rehabilitation may be utilized by the broader population as a treatment in a physical therapy clinic, home health setting, or to supplement a home exercise program. Future clinical trials or randomized control trials are required to confirm the utility of AR in PwPD.

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