Augmented reality rehabilitation at home for adults with Parkinson's disease: a feasibility study

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Abstract

Background

Parkinson's is a neurodegenerative condition causing movement impairments and increasing peoples' risk of falls. People with Parkinson's (PwP) are advised to exercise regularly to maintain their mobility and balance, specifically using sensory cueing, which is beneficial for freezing of gait, one of the most difficult apsects of living with Parkinson's. Maintaining an exercise programme to achieve the effective dose of rehabilitation can be challenging and becomes more difficult over time, leading to reduced function and deteriorating quality of life.

Objective

This study aimed to investigate the use of Strolll, a novel cueing-based rehabilitation programme for PwP, delivered through augmented reality headsets at home.

Methods

Thirty PwP were recruited. Each participant had baseline and follow-up assessments in clinic. Individual game-based rehabilitation was prescribed for home use for 6 weeks with remote monitoring and weekly telephone appointments. The primary outcome measure was the Timed-Up-and-Go (TUG). Secondary outcome measures included the Lindop Parkinson's Assessment Scale (LPAS). Statistical analysis comprised parametric and non-parametric methods appropriate to the data.

Results

Twenty-eight participants completed 6 weeks' rehabilitation; two participants withdrew. Mean TUG improved from 13.2s to10.3s ($p < 0.001$) and LPAS improved from 27 to 29 ($p < 0.01$). No falls, near falls or other adverse events were reported.

Conclusion

Novel game-based exercises through augmented reality were successfully used to deliver rehabilitation for PwP in their homes with participants' mobility improved and no adverse effects reported. A multi-site randomised controlled trial (NIHR206530) based on the results of this feasibility trial has started, which will investigate the clinical- and cost-effectiveness of this technology.

Trial Registration:

ClinicalTrials.gov No.: NCT05794542 Registered 29-10-2023

Background

Parkinson's disease is a progressive neurological condition that profoundly affects a person's functioning.[1] It is the most rapidly growing neurological condition globally and affects more than 153,000 people in the UK.[2] There is a rising prevalence with age, and projections indicate that the number of people living with Parkinson's will double in the next two decades, escalating the demands on health and social care services.[3] Each year in the UK, over 17,300 people are newly diagnosed with Parkinson's. Men are 1.5 times more likely to develop Parkinson's than women.[4]

There are three main characteristic clinical features of Parkinson's – tremor, bradykinesia and rigidity. These motor impairments affect balance and gait, particularly walking speed, and frequently lead to falls.[1] Many people with Parkinson's experience cognitive impairment, sleep disturbance, anxiety or depression, further complicating people's experience with the condition.

The UK's Department of Health and Social Care guidelines for the adult population recommend 150 minutes of moderate intensity physical activity, equivalent to 30 minutes per day for 5 days a week, or 75 minutes of vigorous intensity physical activity for everyone each week.[5] Exercise can improve physical health as well as improve sleep quality, mental health and well-being. This is no different for people living with Parkinson's. Indeed, people living with Parkinson's are encouraged to engage in a daily exercise programme to maintain their mobility, independence, and quality of life. Studies have shown that exercise can be a neuroprotective mechanism in Parkinson's and improve symptoms.[6,7]

However, it can be difficult for people with Parkinson's to perform exercises because of their motor impairments. In addition, as their gait and balance deteriorate, their fear of falls can increase, and participating in exercise groups outside the home or maintaining engagement in a generic home exercise programme becomes more difficult. All of these factors can lead to reduced function, independence and quality of life.[8]

The National Institute for Health and Care Excellence (NICE) in the UK recommends offering Parkinson's-specific therapy to people who are experiencing balance or motor impairments.[9] These therapies are most frequently delivered in specialised clinics, usually in hospital outpatient departments. Attending hospital appointments can be difficult and inconvenient for many people, particularly for those whose mobility is already impaired.[10] Home-based community services are costly, often stretched and not always available when needed. Importantly, therapy, whether during a clinic or a home appointment, will not be accessible to a person with Parkinson's experiencing an "off" period, when the effect of medication has worn off. As Parkinson's disease continues to rise in prevalence, it is imperative that therapy services adapt to meet the increasing and evolving demands.

As Parkinson's progresses, people may experience episodes of 'freezing of gait'. These are untimely interruptions in walking. The individual's feet may become immobile despite the intention to walk. These episodes may last several seconds, which can be frustrating and lead to falls. One of the most effective treatments for freezing of gait for people with Parkinson's is sensory cueing.[11] Cueing is where an external prompt is provided to the individual to help them to take a step and start walking again. Cues may be visual, auditory or vibrotactile. Various methods of visual cueing are simple and effective, such as having parallel lines drawn on the floor for the person to step over. More sophisticated solutions include a laser pointer incorporated in a walking stick that projects a dot on the floor ahead to walk towards. Other solutions include auditory cueing using a rhythmical beat to walk to such as a metronome, counting or music, and wearable vibrating devices.[12]

There are several challenges in the delivery of cueing. The strategy often relies heavily on a therapist providing cueing in person with the individual being able to replicate this at home, which is not always feasible given it can require specific knowledge or equipment. Cueing is difficult to target, as there are different types of "cues" across visual, audio and vibrotactile modalities, where for each modality the positive effects on gait and balance vary widely between people due to the heterogeneity of their Parkinson's. This means that a "one size fits all" solution is not possible, and cueing strategies must be personalised to the user.[13] The positive benefits on gait and balance from cueing can also wear off over time as the individual becomes accustomed to them. This is often referred to as habituation and means that any therapeutic input must be able to be easily adapted as the condition progresses in each individual. Many devices currently available deploy single modality sensory cueing methods and do not have the flexibility to adapt to changing needs. Therefore provision of effective and efficient sensory cueing treatments at scale to all people living with Parkinson's who are experiencing freezing of gait poses a significant challenge.

Augmented reality presents an opportunity to overcome the challenges of providing cueing to people living with Parkinson's. Augmented reality involves wearing a headset that allows the user to see their real-life surroundings through a transparent screen on which is overlaid computer-generated interactive simulations. This allows users to engage with their environment with additional information. This study aims to investigate the feasibility of delivering gait and balance rehabilitation in people's homes using augmented reality glasses.

Methods

Study design

This was a prospective, single site, phase II, open label, uncontrolled feasibility study. The study was performed in accordance with the spirit and the letter of the declaration of Helsinki, the Principles of Good Clinical Practice, the protocol, and applicable local regulatory requirements and laws. This study received national and institutional review board approvals (IRAS Project Identification Number: 321744;

Yorkshire and Humber Health Research Authority Committee 23/YH/0106) and was registered on ClinicalTrials.gov (NCT05794542).

Setting

This study was carried out predominantly in participant's homes, where a home-based rehabilitation programme was delivered through augmented reality glasses. Baseline assessments, training in the use of the technology and follow-up assessments were carried out in the outpatient department at Chapel Allerton Hospital, Leeds, UK, which is part of Leeds Teaching Hospitals NHS Trust, a regional neurosciences rehabilitation unit.

Participants

We planned to recruit 30 participants whose walking and balance is affected by their Parkinson's. Participants in the study were aged 18 years or older with a confirmed diagnosis of Parkinson's and an ability to walk indoors with or without a walking aid (Hoehn and Yahr stages 2–4). For this feasibility study, participants were required to be under the care of a consultant physician or Parkinson's specialist nurse within Leeds Teaching Hospitals NHS Trust.

People with Parkinson's were unable to participate if they had a skin condition on their head or face that prevented wearing the headset, had cognitive impairment meaning that they were unable to consent to take part, were unable to walk at any time, or had visual impairment meaning that they were unable to see the augmented reality information. People who had epilepsy that was not controlled by medication or who were experiencing hallucinations that affected their ability to interact with the augmented reality software were also unable to participate.

Potential participants were identified by specialist doctors, nurses and physiotherapists. They were either known to these healthcare professionals or identified when they attended outpatient appointments and were provided with an information sheet containing a brief overview of the study. All participants were screened by the research physiotherapist to ensure that they met the eligibility criteria and were provided with a comprehensive information pack about the study.

Study procedure

Where possible, appointments were scheduled to try to make sure participants were assessed when they were experiencing their best functional ability (ON state). The ON state is used by people living with Parkinson's to refer to a time when their medication is effective and their motor function is at its optimum. The OFF state refers to when their medication is wearing off and their motor symptoms may worsen. This time of day varies from person to person.

Baseline assessment including informed consent procedure

The initial appointments took place in the rehabilitation outpatient department at Chapel Allerton Hospital or in a participant's home if required. Written, informed consent was given by all participants at this face-to-face appointment. Participation in the study was recorded in the participants' electronic patient record.

During the baseline assessment, participants' demographic information, relevant medical history and medications were recorded, and patient-reported and clinician-scored outcome measures were collected. The Hoehn and Yahr stage was recorded for each participant.[14] This standardised staging scale is used to document the severity of Parkinson's.

Following training in the use of the technology and the prescription of an individualised augmented reality programme, each participant was provided with augmented reality glasses and a Wi-Fi router to use at home. Between baseline and follow-up assessments, participants received a telephone call from the research physiotherapist each week to check if there were any difficulties in carrying out their rehabilitation.

Follow-up assessment

On completion of 6 weeks of rehabilitation, each participant returned to the rehabilitation outpatient department and the follow-up outcome measures were completed. On conclusion of their involvement in the study, participants also completed a user satisfaction questionnaire comprising 16 questions; participants were also encouraged to provide free comments and suggestions for improvement. The Strolll technology was returned and prepared for the next participant.

Outcome measures

Participants were assessed using two clinician-scored measures and two self-reported measures:

Timed-up-and-go (TUG)

This is a clinician-scored test of gait and balance that is commonly used to examine functional mobility. The test measures the time in seconds that it takes a person to stand up from a chair, walk 3 metres, turn around, walk back to the chair and sit back down.[15] The TUG has been used extensively to measure gait and balance in people living with Parkinson's with lower scores indicating improved walking speed.[16]

Lindop Parkinson's Assessment Scale (LPAS)

This is a standardised physical assessment of a person living with Parkinson's ability to move in bed, sit, stand and walk.[17] Higher scores indicate greater physical ability.

EuroQol-5D-5L (EQ-5D-5L)

This is a well-established generic self-reported health-related quality of life measure validated for use with people with Parkinson's. It provides a simple descriptive profile across the 5 dimensions of mobility, self-care, usual activities, pain and anxiety/depression, and a single index value for health status with higher scores indicating greater health-related quality of life.[18]

Parkinson's Disease Questionnaire-39 (PDQ-39)

The PDQ-39 is the most widely used condition-specific health-related quality of life rating scale for Parkinson's. It is a 39-item self-report questionnaire, which assesses Parkinson's-specific health-related quality of life across the 8 dimensions of mobility, activities of daily living, emotional well-being, stigma, social support, cognition, communication and bodily discomfort with lower scores indicating greater quality of life.[19] The overall PDQ-39 is summated in a single index, which is the sum of the dimensions divided by eight.

Intervention

This study used Strolll software on Magic Leap and Microsoft Hololens augmented reality glasses. Strolll supports independent rehabilitation, delivered in augmented reality by providing visual and audio cues though games in a single wearable device. The cue-assisted gait and balance exercises that underpin the games have been designed with people with Parkinson's, physiotherapists and occupational therapists. The games are selected to form an exercise programme personalised to each user, aiming to maximise and maintain the positive effect of cueing on gait and balance over time. Strolll is software as a service, is CE marked and is a class 1 medical device with an ISO 13485 compliant QMS system. The hardware, Magic Leap and Microsoft Hololens augmented reality glasses, have the necessary electrical safety certificates and CE marks for consumer use.

Following baseline assessment, participants were provided with an introduction to the glasses and the games including instructions, demonstrations and a trial of the device. Participants were shown how to charge and store the glasses between use. An individualised exercise programme was prescribed for each participant and seated, standing or walking games were selected based on each participant's abilities. Programme selection considered participant safety as well as ensuring the tasks were sufficiently engaging and challenging to maintain participants' motivation. Participants were taught how to select an appropriate area to do the games at home and how to set up the gaming area through the glasses. Participants were given advice regarding safety when using the glasses at home.

Participants were asked to carry out daily games on the glasses. There were five games with the length of each game prescribed to last between 1 and 10 minutes. The prescribed daily activity time was between 5 and 50 minutes (most were prescribed between 10–15 minutes). Participants were asked to complete their programme as frequently as they felt able. Games were prescribed once a day, every day for 6 weeks but participants were advised that there were no expectations about how many times a

week they completed the games. There was an option to repeat the games more than once in a day if the participant desired.

Statistical Analysis

Statistical analysis comprised parametric and non-parametric methods appropriate to the data. Analyses included descriptive statistics (frequencies, mean, median, SD and inter-quartile ranges) and paired *t*-tests to compare scores from baseline to follow-up. Statistical analyses were carried out in Microsoft Excel and IBM SPSS version 31.0.0.0 software packages with significance levels set at $p < 0.05$.

The clinical significance of rehabilitation was evaluated using the effect size statistic, calculated as the mean change from baseline to follow-up divided by the standard deviation of the baseline score.[20] Larger effect sizes indicate greater impact of an intervention. The effect sizes were interpreted using Cohen's criteria, where 0.20 is a small effect, 0.50 is moderate and 0.80 is large.[21]

Results

We recruited 30 participants to this feasibility study as planned in the protocol (Table 1). Twenty-eight participants completed the study and two withdrew. One person withdrew due to a change in home circumstances resulting in reduced time to participate in the study and one person with a medical diagnosis unrelated to Parkinson's experienced a deterioration in that condition. There were no falls and no adverse events reported during the trial period for any participants. Data were available for 28 participants who completed 6 weeks of daily activities.

Table 1
Participant characteristics

Baseline characteristics		Participants (n = 30)
Age group of participants	46–55 years	1
	56–65 years	9
	66–75	12
	76–85	7
	86–95	1
Sex	Male	23
	Female	7
Ethnicity	White English, Welsh, Scottish, Northern Irish or British	24
	Other White background	2
	Prefer not to say	4
Hoehn and Yahr stage	II	18
	III	8
	IV	4

The clinician scored measures statistically significantly improved when compared to baseline (Table 2). The EQ-5D-5L (Table 2) and PDQ-39 (Table 3) did not show statistically significant changes. The TUG demonstrated a large effect size with the LPAS demonstrating a moderate effect size (Table 4). Of the self-report measures, the mobility scale of the PDQ-39 demonstrated a moderate effect size (Table 4).

Table 2
Outcome measures

Outcome Measure	Initial Score Mean (SD)	Follow up Score Mean (SD)	t-test *p*-value (95% CI)
Timed Up and Go	13.2 (12.1)	10.3 (9.5)	< 0.001 (0.82–2.46)
Lindop Assessment	27.5 (3.9)	28.6 (2.5)	0.004 (-1.58 – -0.268)
EQ-5D-VAS	72.1 (16.0)	75.5 (15.6)	0.188 (-0.04–0.06)
EQ-5D-5L	0.716 (0.188)	0.707 (0.235)	0.359 (-8.81–3.45)

Table 3
Parkinson's Disease Questionaire-39 outcomes

PDQ-39 Domain	Initial Score Mean (SD)	Follow up Score Mean (SD)	t-test *p*-value (95% CI)
Mobility	13.2 (12.1)	10.3 (9.5)	0.793 (-5.41–7.02)
Activities of daily living	27.5 (3.9)	28.6 (2.5)	0.939 (-4.62–4.29)
Emotional well-being	24.1 (17.5)	19.3 (13.8)	0.547 (-4.38–2.38)
Stigma	72.1 (16.0)	75.5 (15.6)	0.463 (-2.80–5.96)
Social support	11.3 (16.8)	5.4 (10.0)	0.201 (-1.60–7.10)
Cognition	28.2 (18.6)	25.0 (19.1)	0.552 (-3.03–5.53)
Communication	23.0 (25.3)	18.6 (20.6)	0.777 (-3.98–5.32)
Bodily discomfort	32.8 (21.0)	28.5 (19.5)	0.454 (-3.99–8.65)
Single index	24.1 (17.5)	19.3 (13.8)	0.261 (-1.81–6.38)

Table 4
Effect sizes of outcome measures

Outcome Measure	Effect size	95% Confidence interval	
		Lower	Upper
Timed Up and Go	0.845	0.371	1.307
Lindop Assessment	-0.557	-0.959	-0.146
EQ-5D-VAS	-0.180	-0.574	0.217
EQ-5D-5L	0.073	-0.320	0.465
PDQ-39 Domains			
Mobility	0.530	-0.340	0.445
Activities of daily living	-0.015	-0.407	0.377
Emotional well-being	-0.122	-0.514	0.273
Stigma	0.149	-0.247	0.542
Social support	0.263	-0.139	0.659
Cognition	0.121	-0.274	0.513
Communication	0.059	-0.334	0.451
Bodily discomfort	0.152	-0.244	0.545
Single index	0.226	-0.166	0.613

Twenty-five participants completed a feedback questionnaire and 21 provided free text feedback (Table 5). Three participants did not complete a questionnaire. Most participants found the glasses satisfactory and would recommend them to another person living with Parkinson's. We identified five themes from the written feedback (Box).

Table 5
Patient Feedback Questionnaire

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. The glasses were easy to put on	20	4		1	
2. I felt comfortable wearing the glasses	17	5	2	1	
3. I felt safe while using the glasses	21	4			
4. I felt the games encouraged me to exercise	19	5	1		
5. The instructions on the glasses were understandable	19	2	4		
6. The exercises were fun	19	5	1		
7. The exercises were motivating	17	7	1		
8. The exercises were varied	15	6	3		
9. The exercises were boring	12	6	3	3	1
10. The exercises were frustrating	7	6	8	1	3
11. The glasses took too long to set up once I was home	6	8	6	4	1
12. I felt excited about using the glasses	8	11	5		1
13. I felt scared about using the glasses	19	4	1	1	
14. I would consider using CUE X on the glasses for my future rehabilitation	17	6	2		
15. I would be willing to take part in future research about CUE X	22	1	1		
16. I would recommend using CUE X exercises for other people with Parkinson’s disease	18	5		1	

Therapeutic recognition and physical benefits

The feedback we received was largely positive regarding the physical benefits of the games as exercise. Participants felt that the games were challenging as a form of exercise with cardiovascular and balance elements.

System performance and usability issues

There was substantial feedback about the technical aspects of using a new piece of technology. There were reports of glitches when using the game and difficulty with setting up the games at home which required external support from family members, the research team or Strolll technical support. The feedback suggested that once set up was complete the usability improved. The set up difficulties and glitches during game play led to frustration amongst participants. As the study progresses, and glitches were resolved through software updates, feedback on these issues improved. Participants also mentioned issues using the technology in their home environment. Some participants noted that a substantial space was required, with others reporting they were unable to play certain games due to space limitations.

Engagement evolution and motivation

The feedback indicated that participants expressed initial interest and excitement in using the technology. For some participants this initial excitement wore off and the games became repetitive, with some participants suggesting that there needed to be more variety of games. Participants commented that the games were ‘fun’ and overall, the feedback conveyed enjoyment despite occasional frustrations with the technology.

Motivation was mentioned frequently in comments, with some participants highlighting that they felt the games themselves to be motivating. Others noted that the involvement of the research physiotherapist was a motivating factor.

Individual Needs and Personalisation

The games were tailored to individuals in terms of length of time played and game play difficulty. Feedback included participants expressing they would have liked even further personalisation, for example, different playing heights for some games, and more access to their game data. One participant suggested a voice recording in the game to include their name for further motivational support.

Support infrastructure and implementation

There were a lot of comments regarding the amount of support from others that was required, especially in the initial set up. This relates back to the initial difficulties experienced in set up and game play. There were frequent, positive references made to the physiotherapist and the support given during set-up, over the phone and through home visits.

Discussion

This was the first use of augmented reality-delivered rehabilitation in the UK’s National Health Service and demonstrated that Strolll software can be deployed for independent use to deliver rehabilitation at home to people living with Parkinson’s. Through face-to-face training, and a six-week programme of remote intervention, we were able to show that the use of augmented reality to deliver rehabilitation in people with Parkinson’s is feasible with an early signal suggesting that participants’ mobility improved through the use of the technology.

Participants noted that the technology was generally acceptable to use and provided motivation to engage in rehabilitation exercise. Comments relating to difficulties in setting up the technology at home were fed back to Strolll who instituted a series of improvements in the set up process which resulted in improved feedback from later participants.

There are a number of limitations to this study. This was a non-randomised study carried out in a single centre. Funding has now been obtained from the UK's National Institute for Health and Care Research to recruit participants to a multi-centre randomised controlled trial. There were more male than female participants in the study than would be expected from the population of people living with Parkinson's and most participants were white. The randomised controlled trial will be designed to more accurately reflect the sex and ethnicity of people living in the UK with Parkinson's.

An important objective of this study was to monitor the safety of the participants and ensure that risk was minimised through appropriate game selection, advice and education. A systematic review has reported technology-enhanced physiotherapy for gait and balance training to be safe for use at home in people with Parkinson's.[22] Our study had no adverse events reported for the entirety of the participants' involvement with the intervention.

Conclusion

We have identified that augmented reality-delivered rehabilitation is a feasible, safe and potentially effective treatment for the symptoms associated with Parkinson's. Augmented reality provides a convenient, flexible option for some people and may increase accessibility to rehabilitation which may reduce the burden of attending appointments due to no travel time and cost. Further research is underway to determine the therapeutic benefits as well as assessing the health economics of using this technology compared with usual rehabilitation in the NHS.

Declarations

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Availability of data

The anonymised data supporting the conclusions of this study are available from the corresponding author upon reasonable request.

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Competing interests

The authors declare that they have no conflicts of interest.

Author contributions

CG and RJOC contributed to study design. AW and CB assisted with participant recruitment. AW, CB and AS assisted with data collection. CW, AS and RJOC conducted the data analysis and interpretation. CW and RJOC prepared the manuscript. All authors reviewed, provided comments and approved the final version of the manuscript.

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Box

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