Physical and functional effects after an Immersive Virtual Reality based exercise program: experience in a Spanish Association of Parkinson's patients

Efectos físicos y funcionales tras un programa de ejercicios basado en realidad virtual inmersiva: experiencia en una Asociación Española de Pacientes con Parkinson

Authors

Pablo Campo-Prieto [1,2]
Diego Santos-García [3,4]
José María Cancela-Carral [2,5]
Gustavo Rodríguez-Fuentes [1,2]

[1] Facultade de Fisioterapia, Universidade de Vigo, 36005 Pontevedra, Spain
[2] HealthyFit Research Group, Galicia Sur Health Research Institute (IIS Galicia Sur), SERGAS-UVIGO 36002 Vigo, Spain
[3]Complejo Hospitalario Universitario de A Coruña (CHUAC), 15006 A Coruña, Spain
[4]Grupo de Investigación en Enfermedad de Parkinson y otros Trastornos del Movimiento, Biomedical Research Institute A Coruña (INIBIC) 15006 A Coruña, Spain
[5] Facultade de Ciencias da Educación e do Deporte, Universidade de Vigo, 36005 Pontevedra, Spain

Corresponding author:
Pablo Campo-Prieto
pcampo@uvigo.gal

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Abstract

Introduction: Physical exercise is an emerging approach in Parkinson's disease (PD) and new technologies such as immersive virtual reality (IVR) could contribute towards the development of specific programs targeting prevalent symptoms.
Objective: To explore the feasibility of an IVR-based exercise program and its effect on physical and functional abilities and quality of life in a population with PD.
Methodology: A sample of 20 volunteers from an association of patients diagnosed with early-stage PD (H&Y I-II) were divided into experimental ([EG] n=14; 68.50 ± 7.70 years) and control ([CG] (n=6; 65.00 ± 12.81 years) groups. Both groups continued with their usual therapeutic programs designed by the association for eight weeks, whilst the EG also completed and IVR-based intervention (two sessions/week).
Results: The program was feasible (91% attendance, 98% usability, zero dropouts or adverse events). Significant pre-post intragroup improvements were observed in the EG regarding Tinetti scores for balance (p = 0.004), gait (p = 0.013) and overall (p = 0.002), and Timed Up and Go (TUG)-dual motor-cognitive task time (p = 0.000), which evaluates functionality and coordination between two tasks with independent and unrelated purposes. Some improvements were found in strength, certain aspects of quality of life and exergaming although these were not statistically significant.
Conclusions: The proposed IVR-based exercise program is safe and appears to provide a feasible and valid approach to the maintenance and/or improvement of physical abilities such as balance and gait, in addition to functionality and coordination in patients with early-stage PD.

Keywords

Exercise; exergames; Parkinson's disease; physiotherapy; virtual reality; virtual reality exposure therapy.

Resumen

Introducción: El ejercicio físico es un abordaje emergente en la enfermedad de Parkinson (EP) y, nuevas tecnologías como la realidad virtual inmersiva (RVI), podrían contribuir al desarrollo de programas específicos dirigidos a la sintomatología prevalente.
Objetivo: explorar la factibilidad y los efectos de un programa de ejercicio implementado con RVI sobre las capacidades físicas, funcionales y la calidad de vida de población parkinsoniana.
Metodología: una muestra de 20 voluntarios de una Asociación de pacientes con diagnóstico de EP con poca evolución (H&Y I-II) fueron divididos en experimental ([GE] n=14; 68,50 ± 7,70 años) y control ([GC] n=6; 65,00 ± 12,81 años). Ambos grupos mantuvieron el programa terapéutico habitual diseñado por la Asociación durante 8 semanas y el GE sumó una intervención con RVI (2 sesiones/semana).
Resultados: El programa fue factible (asistencia 91%, usabilidad 98%, ningún abandono ni evento adverso). El GE obtuvo mejoras significativas pre-post intragrupo: puntuación en Tinetti para equilibrio (p = 0.004), marcha (p = 0.013) y marcador total (p = 0.002), y tiempos en *Timed Up and Go* (TUG)-doble tarea motora-cognitiva (p = 0.000), que evalúa funcionalidad y coordinación entre dos tareas con fines independientes y no relacionadas. Hubo mejoras en la fuerza, aspectos de calidad de vida o marcador del *exergame* aunque no fueron estadísticamente significativas.
Conclusiones: La aplicación del programa de ejercicio con RVI seleccionado es segura y parece ser una intervención factible y válida para el mantenimiento y/o mejora de capacidades físicas como el equilibrio, la marcha o funcionalidad y coordinación en pacientes con EP de poca evolución.

Palabras clave

Ejercicio; enfermedad de Parkinson; exergames; fisioterapia; realidad virtual; terapia de exposición con realidad virtual.

Introduction

Parkinson's disease (PD) is a neurodegenerative disorder that has a chronic and progressive impact on the nervous system, which occurs through the destruction of dopaminergic neurons in the substantia nigra of the basal ganglia (Braak & Braak, 2000). This leads to the emergence of a number of motor: sluggish movement or bradykinesia, tremoring in a rested state, muscular stiffness and postural instability and non-motor symptoms: neuropsychiatric disorders, disturbed sleep and cognitive impairment, amongst others (De Oliveira et al., 2021; Muentes Solorzano et al., 2020; Politis et al., 2010).

Motor symptoms of PD lead to deterioration in functional capacity, especially when associated with a sedentary lifestyle (De Oliveira et al., 2021). It is well-known that physical activity levels decrease with increasing age and that this contributes to functional deterioration. It has also been demonstrated that people with PD exhibit more rapidly decreasing levels of physical activity than their healthy peers and have lower levels of strength and functional capacity (Goodwin et al., 2008). Further, the substantial loss of type IIA muscle fibers can cause muscular atrophy and reduced physical fitness, which progressively leads to uncoordinated movement, trips, falls and gait-related disorders (Bonjorni et al., 2012). For this reason, for a number of years, exercise has been proposed as a positive intervention in the treatment of PD for modifying long-term clinical outcomes in patients with PD (Ahlskog, 2018). Currently, evidence exists to support the therapeutic use of physical exercise in PD as a means of improving functional capacities and/or attenuating the deterioration caused by the disease (Keus et al., 2007; Mak et al., 2017). All of this leads to the conclusion that, in order to prevent functional disability and improve quality of life, physical exercise may represent an excellent non-pharmacological treatment option for individuals with PD (De Oliveira et al., 2021).

One option for implementing an exercise program in people with PD is using virtual reality (VR). This tool has been seen to be more effective when compared with traditional rehabilitation (Erhardsson et al., 2020), whilst also potentially improving adherence and long-term engagement (Campo-Prieto, Cancela-Carral, & Rodríguez-Fuentes, 2022b). Whilst evidence is very recent, improvements have already been demonstrated in some capacities such as balance and quality of life in individuals with PD (Warland et al., 2019).

Within the branch of VR, different limits are defined as a function of the degree of immersion (Saeed et al., 2017). Specifically, immersive virtual reality (IVR) refers to VR in which participants are fully immersed. Devices are employed, such as head-mounted display (HMD) or virtual reality glasses, through which individuals receive multi-sensory feedback that allows them to be integrated into a virtual world in a similar way to in the real world (Campo Prieto et al., 2021). In this reality, exergames or active video games can be used, which may promote improved functional capacity or quality of life in participants. Such claims are supported by evidence produced by preliminary studies on PD (Campo-Prieto et al., 2023), as well that pertaining to other populations such as older individuals (Campo-Prieto, Cancela-Carral, & Rodríguez-Fuentes, 2022b), individuals following a stroke (Winter et al., 2021) and individuals with multiple sclerosis (Ozkul et al., 2020). IVR represents an innovative approach for engaging and motivating patients during treatment sessions (Bergmann et al., 2018), making its use potentially viable in populations diagnosed with PD. This gives it the potential to contribute towards improving the symptomology of these individuals and/or slowing their disease progression. Nonetheless, a recent review concluded that, whilst IVR appears to be a promising tool for promoting exercise therapy in populations with PD, it still finds itself at a pre-clinical stage of development and current evidence to support it is scarce (Campo Prieto et al., 2021).

Thus, the main aim of the present study was to examine the feasibility of implementing an IVR based exercise program and identify its effects on physical and function capacities and quality of life in a population with PD.

Method

Study design and participants

A meeting was held to discuss the study with members of the Vigo Parkinson's Association, addressing all issues to arise and encouraging members to participate. After signing up to the study, the health team at the association selected participants based on selection criteria established by researchers. Criteria required participants to be diagnosed with early-stage PD (I-II Hoehn & Yahr), undergoing regular dopaminergic medication, and able to maintain a standing position and walk by themselves, and not present be faced with any impediment to engaging in a physical exercise program. Individuals were excluded who presented with a cognitive deficit that impaired their ability to understand or follow instructions required for their participation in the IVR program and /or assessment protocol. This included serious visual or auditory impairments, dyskinesias and dizziness, vertigo, epilepsy and uncontrolled psychiatric disorders. Finally, a non-randomised clinical study was conducted which comprised experimental (EG) and control groups (CG) assigned using simple blinding (the association assigned to the EG all volunteers who were able to attend the intervention two times a week, but researchers were unaware of the group to which participants under evaluation belonged). The present research was conducted in adherence with the Declaration of Helsinki. All participants signed a written informed consent form, and the study was approved by the Ethics Committee of the Faculty of Physiotherapy at the University of Vigo with the reference number 205-2021-8.

Procedure

The present study comprised 20 individuals diagnosed with PD (EG: 14; CG: 6).

The EG completed a physical exercise program based on IVR that was conducted using the facilities of the Vigo Parkinson's Association. All participants performed the intervention in the on state. This consisted of two non-consecutive IVR sessions a week over a period of eight weeks (16 sessions). Each session consisted of a dual session of individualised training for three minutes, with a 90 second rest break between training. IVR *Meta Quest 2* HMD (see Figure 1) were worn during sessions and sessions were monitored via *iPad* so that research professionals could observe what each individual participant was seeing. In order to complete intervention exercises, the exergame *FitXR* was used. This is an active game based on boxing, which places participants in a virtual gym or in other settings in which boxing is practiced (see Figure 2). According to Combs et al. (2011), boxing is a promising physical work tool in relation to PD, with potential benefits regarding balance, mobility and quality of life, in addition to gait, speed and resistance. In consideration of the present proposal, exergaming demands that participants make quick decisions in relation to stimuli appearing before them and move their upper and lower limbs, torso, head and extremities in coordination. In addition, different stimuli appear on one side or the other, requiring individuals to change their posture (through lateral inclinations, squats and shifting weight between both lower limbs). These aforementioned stimuli appear at different speeds and frequencies but they are all initiated from a static position in relation to the participant, so as to avoid sudden accelerations or shifts that could cause any of the adverse symptoms associated with IVR (so-called cybersickness or simulator sickness, which is a type of motion sickness that can emerge in individuals who use IVR devices and can give rise to nausea, sweating, dizziness, headaches and/or visual fatigue) (Mazloumi Gavgani et al., 2018). Finally, the motor and cognitive task is accompanied by music which helps a suitable rhythm to be established. The present research team has already examined this issue in previous studies, in both healthy individuals (Campo-Prieto, Cancela-Carral, Alsina-Rey, et al., 2022; Campo-Prieto, Cancela-Carral, & Rodríguez-Fuentes, 2022a) and in patients with PD (Campo-Prieto, Cancela-Carral, & Rodríguez-Fuentes, 2022b; Campo-Prieto et al., 2020, 2023), confirming that no adverse symptoms occurred.

Figure 1. Immersive virtual reality Meta Quest 2 HMD (left) and their controllers (right).

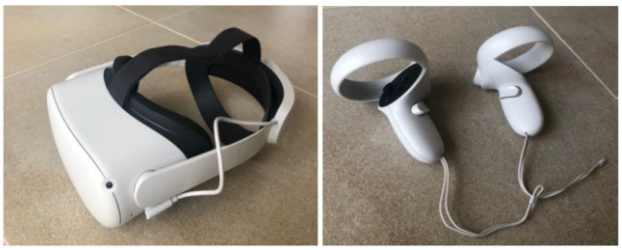
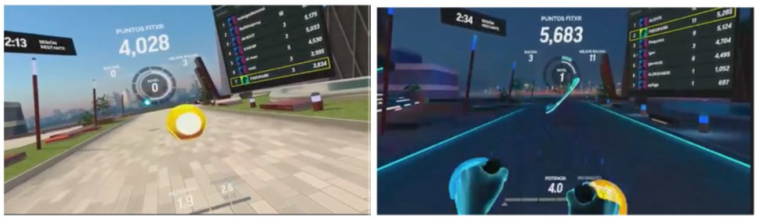


Figure 2. Screenshots of different virtual spaces in which the participants can be situated (left, objects to hit; right, objects to dodge).



At the end of each three-minute session, participants receive a score based on the output of their upper (average hitting accuracy and speed calculated from all hits, differentiated based on side) and lower limbs (avoidance of interspersed obstacles). In addition to the physical effort required, this exergame demands constant decision making so that participants can respond to the stimuli that appear before them on the screen (presented stimuli demand different hitting gestures), which implies the combination of physical and cognitive stimulation.

Finally, in-game settings can be personalised, making it possible to choose, amongst other settings, a study on the seafront, a gym or an urban landscape (see Figure 2). All settings have broad depths and can be established in a daytime or night-time environment.

Both groups continued with the habitual therapeutic program designed for them by the Vigo Parkinson's Association during the eight weeks of the study. This consisted of physiotherapy, psychology, occupational therapy, speech therapy, social education, dog-assisted intervention, music therapy and art therapy sessions.

Instruments

The following tests were administered at both the beginning and end of the intervention:

Five times sit-to-stand test (FTSST). This test assesses functional strength of the lower extremities. It is also related with balance and bradykinesia, despite not being strongly associated with disease severity (Duncan et al., 2011). The test was performed in a chair without armrests that was pushed back against the wall to minimise the risk of falling during the test. Each participant had two attempts at the test with a one-minute rest break between attempts. Participants were instructed to keep their arms crossed over their chest throughout. Final scores were formed from the average of both attempts. Shorter times indicated better functionality.

Tinetti test. This scale is used to assess gait and balance, whilst also providing an early indicator of the risk of falling in individuals with early and intermediate stage PD (Kegelmeyer et al., 2007). The highest possible score on this scale is 28 points (16 for balance and 12 for gait), with lower scores indicating greater risk of suffering from a fall.

Hand grip strength test. This test measures grip strength using a hydraulic hand dynamometer. The test was performed with participants in a seated position, with their shoulder adducted, elbow bent at 90º, and the forearm and wrist in a neutral position (Villafañe et al., 2016). Each participant has two attempts at the test, with average scores being recorded in kilograms.

Timed up and go test (TUG). This test is used to assess the risk of falling associated with PD, with a longer test time being associated with a higher risk of falling (Vance et al., 2015). This test was evaluated based on three variants: conventional (time taken to get up from a chair, roll a cone a distance of three metres, come back and sit back down), dual-motor task (perform the task carrying a glass of water) and dual

motor-cognitive task (perform the task whilst performing a mathematic calculation consisting of subtracting three at a time away from the starting number of 56) (Theill et al., 2011).

39-item Parkinson's disease questionnaire (PDQ-39). This test assesses physical, emotional and psychosocial aspects of quality of life in individuals with PD (Martínez-Martín et al., 1998). This outcome was expressed as a summary statistic (%).

Additional measures were also taken, namely, heart rate measured with a *Polar M430* wrist-worn heart rate monitor, perceived exertion according to a modified version of the Borg rating of perceived exertion scale (0-10) (Bray et al., 2016) and presence of negative symptoms related to IVR exposure (cybersickness). Finally, attendance was recorded, as were scores achieved for each game.

Alongside the aforementioned tests, in the final assessment, the EG was asked about aspects inherent to IVR exposure through the following questionnaires:

Simulator sickness questionnaire (SSQ) (Kennedy et al., 1993). This questionnaire assesses safety of exposure to IVR. It comprises 16 items that are grouped according to three sub-scales: 1) Oculomotor symptoms; 2) Disorientation; 3) Nausea. A translated version adapted to the Spanish context was employed (Campo-Prieto, Rodríguez-Fuentes, & Cancela Carral, 2021).

System usability scale (SUS) (Brooke, 1995; Hedlefs Aguilar & Garza Villegas, 2016). This survey is used to assess usability of a device, in the present case, IVR glasses.

Game experience questionnaire (GEQ-post game) (Ijsselsteijn & de Kort, 2013). This module of the GEQ is used to identify experiences following the use of IVR. No validated Spanish version of the questionnaire is available. In order to enable understanding in the present sample, the present research team translated this scale, which has already been employed in other previously conducted research studies (Campo-Prieto, Rodríguez-Fuentes, & Cancela-Carral, 2021b; Campo-Prieto, Cancela-Carral, & Rodríguez-Fuentes, 2022a).

Data analysis

Descriptive analysis was performed of the main variables used to characterise participants, differentiating this analysis as a function of group assignment (CG, EG). With the aim of analysing the influence of the intervention program on physical and functional variables, intra-group statistical inferences through the Student t test for related samples were performed. Prior to this, was examined in all test variables through the Kolmogorov-Smirnov test ($p>0.05$). The statistical package IMB SPSS Statistics for MAC, version 25.0 (Armonk, NY: IBM Corp) was used to perform all the different analyses. Statistical significance was set at $p<0.05$.

Results

The study comprised an overall sample of 20 individuals (females: 4/14 in the EG and 1/6 in the CG) whose demographic characteristics are presented in Table 1. Both groups, EG and CG, were homogenous, with no significant demographic differences being revealed. With regards to pharmacological treatment, the most commonly used was levodopa (100%), followed by monoamine oxidase B inhibitors (IMAO-B) (75%), agonist dopaminergic therapy (40%), catechol-O-methyl transferase inhibitors (ICOMT) (20%) and Amantadine (10%). The levodopa daily dose was 227.54 ± 213.00 mg/day, with the levodopa equivalent daily dose (LEDD) (Schade et al., 2020), being 1037.86 mg/day.

Table 1. Demographic characteristics of the sample.

	Experimental group (n=14)	Control group (n=6)
	Mean ± SD	Mean ± SD
Age (years)	68.50 ± 7.70	65.00 ± 12.81
Height (cm)	168.29 ± 8.64	166.50 ± 6.06
Weight (kg)	80.00 ± 11.59	76.00 ± 4.34
BMI (m/Kg^2)	28.39 ± 4.79	27.5 ± 2.45

BMI: body mass index; cm: centimeters; kg: kilograms; m: meters; SD: standard deviation;

Findings support the feasibility of the proposed program, with 91% of assistance to programmed sessions. In addition, no dropouts or adverse events were recorded.

Table 2 presents absolute values for physical and functional tests in both groups at the beginning and the end of the study. Most notable outcomes pertained to the handgrip strength test, with a slight improvement emerging in the EG (+ 0.80kg) compared to a worse outcome in the CG (- 4.89kg).

Table 2. Absolute physical and functional values for participants in both groups (pre-post intervention).

		Experimental group		Control group	
		Mean	SD	Mean	SD
Tinetti balance	Pre	13.79	1.25	14.33	1.03
	Post	14.71	0.91	14.50	1.38
Tinetti gait	Pre	10.64	0.93	11.17	0.41
	Post	11.29	0.47	11.33	0.52
Tinetti overall	Pre	24.43	1.70	25.50	1.38
	Post	26.00	1.18	25.83	1.72
Handgrip (kg)	Pre	34.74	10.53	42.49	13.53
	Post	35.54	10.41	37.60	9.21
FTSST (s)	Pre	13.96	4.71	11.05	2.03
	Post	13.20	4.04	11.97	2.95
TUG (s)	Pre	10.15	3.51	9.41	2.98
	Post	10.18	3.52	10.30	3.13
TUG 2TM (s)	Pre	10.56	3.92	9.58	3.00
	Post	10.46	3.84	10.32	2.69
TUG 2TMC (s)	Pre	14.65	4.78	13.35	5.08
	Post	13.17	4.50	12.97	4.44

FTSST: five times sit to stand; kg: kilograms; s: seconds; SD: standard deviation; TUG: Timed up and go test; TUG 2TM: TUG with dual motor task; TUG 2TMC: TUG with dual motor-cognitive task.

In Table 3, intra-group physical and functional test outcomes are presented comparing data collected at the start of the intervention with those collected at the end. It serves to highlight that the EG exhibited significant improvements in relation to the Tinetti scale for balance (p = 0.004), gait (p = 0.013) and overall (p = 0.002), in addition to in performance times for the TUG-dual motor-cognitive task (p = 0.000), which assesses the coordination exhibited by participants between two independent and unrelated tasks. In the case of all other examined variables, no statistically significant differences emerged, not even with regards to between-group comparisons.

Table 3. Intra-group analysis of physical and functional test outcomes (pre-post intervention).

	Test		Mean	SD	95% confidence interval			t	df	Sig. (two-tailed)
					Standard error	Lower	Upper			
Experimental group	Tinetti balance	Pre Post	-0.92857	0.99725	0.26653	-1.50437	-0.35278	-3.484	13	0.004*
	Tinetti gait	Pre Post	-0.64286	0.84190	0.22501	-1.12895	-0.15676	-2.857	13	0.013*
	Tinetti overall	Pre Post	-1.57143	1.55486	0.41555	-2.46918	-0.67368	-3.782	13	0.002*
	Handgrip	Pre Post	-0.80000	2.70249	0.72227	-2.36037	0.76037	-1.108	13	0.288
	TUG	Pre Post	-0.02929	1.17125	0.31303	-0.70555	0.64698	-0.094	13	0.927
	TUG 2TM	Pre Post	0.09643	1.39816	0.37367	-0.71084	0.90370	0.258	13	0.800
	TUG 2TMC	Pre Post	1.47857	1.19888	0.32042	0.78636	2.17079	4.615	13	0.000*
Control group	Tinetti balance	Pre Post	-0.16667	0.75277	0.30732	-0.95665	0.62332	-0.542	5	0.611
	Tinetti gait	Pre Post	-0.16667	0.40825	0.16667	-0.59510	0.26176	-1.000	5	0.383
	Tinetti overall	Pre Post	-0.33333	0.81650	0.33333	-1.19019	0.52353	-1.000	5	0.383
	Handgrip	Pre Post	4.89167	5.25418	2.14501	-0.62226	10.40559	2.280	5	0.071
	TUG	Pre Post	-0.89500	2.00082	0.81683	-2.99473	1.20473	-1.096	5	0.323
	TUG 2TM	Pre Post	-0.73833	2.19308	0.89532	-3.03983	1.56317	-0.825	5	0.447
	TUG 2TMC	Pre Post	0.37667	3.52220	1.43793	-3.31966	4.07299	0.262	5	0.804

* Indicates a statistically significant difference; df: difference; SD: standard deviation; TUG: Timed up and go test; TUG 2TM: TUG with dual motor task; TUG 2TMC: TUG with dual motor-cognitive task.

Outcomes from the intra-group analysis pertaining to quality of life measured using the PDQ-39 are shown in table 4. It is observed that, in the EG, significant improvements were achieved in the domains

of emotional wellbeing, stigmatisation and cognitive status, whilst, in the CG, improvements were produced in relation to pain and total score. No differences between groups were found.

Table 4. Intra-group analysis comparing quality of life (PDQ-39), pre-post the intervention.

					95% confidence interval				
	Domain	Mean	SD	Standard error	Lower	Upper	t	df	Sig (two-tailed)
Experimental group	Mobility	6.42857	15.24525	4.07446	-2.37377	15.23092	1.578	13	0.139
	Daily activities	5.64786	22.92023	6.12569	-7.58589	18.88160	0.922	13	0.373
	Emotional wellbeing	9.22429	14.72253	3.93476	0.72375	17.72482	2.344	13	0.036*
	Stigmatisation	9.08071	14.10312	3.76922	0.93781	17.22362	2.409	13	0.032*
	Social support	-3.56143	15.23362	4.07136	-12.35706	5.23420	-0.875	13	0.398
	Cognitive status	15.65071	19.51789	5.21638	4.38142	26.92001	3.000	13	0.010*
	Communication	5.37000	34.37434	9.18693	-14.47715	25.21715	0.585	13	0.569
	Pain	1.20571	30.28821	8.09486	-16.28218	18.69360	0.149	13	0.884
	Summary score	6.57821	12.81105	3.42390	-0.81867	13.97510	1.921	13	0.077
Control group	Mobility	-5.00000	18.09696	7.38805	-23.99160	13.99160	-0.677	5	0.529
	Daily activities	8.31667	14.66081	5.98525	-7.06891	23.70224	1.390	5	0.223
	Emotional wellbeing	2.77667	10.40721	4.24873	-8.14503	13.69837	0.654	5	0.542
	Stigmatisation	-2.77667	4.30159	1.75612	-7.29091	1.73758	-1.581	5	0.175
	Social support	4.15500	13.69003	5.58893	-10.21181	18.52181	0.743	5	0.491
	Cognitive status	10.07167	11.83525	4.83172	-2.34867	22.49200	2.084	5	0.092
	Communication	15.29000	37.04432	15.12328	-23.58563	54.16563	1.011	5	0.358
	Pain	18.06833	15.28211	6.23890	2.03074	34.10593	2.896	5	0.034*
	Summary score	4.78917	3.90158	1.59281	.69471	8.88363	3.007	5	0.030*

* Indicates a statistically significant difference; df: difference; SD: standard deviation.

In Table 5, average session scores and average hitting speeds (AHS) are presented, alongside the highest recorded score, for the first and last sessions of the training program. A notable difference can be observed between the highest scores achieved in the two parts of the training session, as well as between the scores achieved in the first and last sessions of the program.

Table 5. Outcomes from different parts of the training session (session 1 and session 16).

		Mean	Standard deviation	Minimum	Maximum
1st session score	session 1	8522.50	11986.73	161.00	37286.00
	session 2	25185.5	24818.94	1110.00	87176.00
	highest score	31380.07	24400.93	5296.00	87176.00
1st session AHS(m/s)	session 1	1.33	0.89	0.60	3.50
	session 2	2.38	1.70	0.70	6.50
	highest score	2.82	1.74	0.90	6.50
16th session score	session 1	13678.57	14028.91	205.00	49139.00
	session 2	30029.15	26586.07	875.00	98855.00
	highest score	33422.50	26154.62	5064.00	98855.00
16th session AHS(m/s)	session 1	1.69	1.02	0.70	4.30
	session 2	2.51	1.85	0.70	7.20
	highest score	2.99	1.84	0.90	7.20

AHS: average hitting speed; m/s: meters for second

Finally, Table 6 shows outcomes pertaining to heart rate and perceived exertion recorded for participants after finishing the first and last sessions of the program.

Table 6. Perceived exertion outcomes measured using the modified Borg scale (0-10) and heart rates at first and last training sessions.

		Mean	Standard deviation	Minimum	Maximum
Borg	session 1	4.96	1.76	2.50	7.00
	session 16	5.11	2.16	2.00	9.00
HRavg (beat/min)	session 1	94.29	11.63	76.00	112.00
	session 16	95.14	11.64	71.00	114.00
HRmax (beat/min)	session 1	108.29	14.32	81.00	129.00
	session 16	110.29	13.06	91.00	129.00

HRmax: maximum heart rate; HRavg: average heart rate; beat/min: beats/minute.

Finally, with regards to intrinsic aspects inherent to IVR exposure, post-game GEQ scores describing experiences following the IVR experience indicated encouraging outcomes in relation to positive (3.24/4) and negative experiences (0/4), alongside low scores pertaining to tiredness (0.32/4) and affectation due to the return to reality (0.07/4). Further, SUS outcomes indicated high usability (98/100), whilst SSQ outcomes did not reveal any cybersickness symptoms in any of the sessions.

Discussion

Findings from the intervention examined in the present study are encouraging. It was hypothesized that the use of IVR would be feasible in a population diagnosed with PD and that this could, potentially, contribute towards improved symptomology and/or maintenance with regards to disease progression.

Amongst the main findings, it can be surmised that the IVR tool used was useful and feasible, given that it supported the safe delivery of an eight-week exercise program, with no adverse effects or dropouts and with good program adherence. Thus, it is possible to confirm that development of a protocol within an entirely immersive setting using software based on a commercially available exergame is feasible for improving symptomology in individuals affected by PD. This is in line with that suggested in previous research conducted by the present research team (Campo-Prieto, Cancela-Carral, & Rodríguez-Fuentes, 2022b; Campo-Prieto, Rodríguez-Fuentes, & Cancela-Carral, 2021a). These studies also correspond with the present research since it was observed that engagement and usability were even further supported by the wearable nature of equipment, which removed barriers to transporting and setting up the device. Up until the time of writing, research studies conducted by the present research group had all used IVR devices (HTC ViveTM Pro) that required additional equipment (desktop, PC and workstations), which presented a logistical challenge and limited the completion of tests to certain determined physical locations. The present study used equipment that was less cost-prohibitive and, additionally, more manageable, as it could be transported in a small backpack and implemented with patients in a small room at the Vigo Parkinson's Association.

In another sense, significant improvements were demonstrated in participants' balance and gait. This invites us to consider the existence of a potential relationship between the IVR protocol followed and the maintenance/slowing of disease progression, although the baseline stage of participants may have an impact on this. Nonetheless, progressing from Hoehn and Yahr stage II to stage III implies a clear deterioration in postural stability and, therefore, the maintenance or improvement of balance could slow down disease progression.

The work presented here was also designed to examine the impact of the intervention on physical and functional capacities, whilst also assessing quality of life perceptions. With regards to the effects achieved by the program, outcomes indicate substantial short-term improvements in both balance and gait and/or in the capacity to coordinate two independent and unrelated tasks. These findings are similar to those reported in a systematic review conducted by Gao & Lee (2019), in which improvements in balance were highlighted and attributed to the use of VR. This is particularly relevant, given that exercises targeting improvements in balance are essential for reducing the risk of falling in individuals with PD (Campo-Prieto, Cancela-Carral, & Rodríguez-Fuentes, 2022b). Furthermore, if this argument is combined with present outcomes pertaining to the Tinetti scale, it can be concluded that the risk of falling was significantly reduced in the intervention participants.

In relation to other examined aspects, such as handgrip strength, slight improvements were achieved in the EG, which, despite not reaching statistical significance, are somewhat meaningful when compared with the losses in handgrip strength seen in the CG. The same could be said of findings pertaining to the FTSST, although, in this case, scores were more similar between groups. In any sense, values indicating the sustained maintenance of physical and functional capacities should be considered positively when considering a degenerative condition such as PD.

Another relevant finding is that improvements appear to have been detected in certain domains of quality of life in intervention participants, ranging from emotional wellbeing to stigmatisation and including, even, cognitive status (potentially linked to the positive outcomes found in the assessment of complex physical-cognitive tasks). These findings are in line with those reported by other studies based on non-immersive VR, which indicate improvements in balance and quality of life in patients with PD (Warland et al., 2019). This being said, it is also important to highlight that the CG reported significant improvements in overall quality of life and in the pain domain. This could indicate that other therapies provided by the Vigo Parkinson's Association are also proving to be beneficial.

Present findings fit in with those reported in systematic reviews (Campo Prieto et al., 2021; Munar Rodríguez & Pérez Gómez, 2024), in which the most up-to-date published evidence in the field of physical and functional rehabilitation of PD in fully and semi-immersive settings was examined. Based on its findings, this review recommends that prospective work focuses on balance, gait and functional capacities, suggesting potential benefits of employing IVR for the improvement of physical and functional capacities in populations with PD.

Despite not forming part of the set of main study objectives, the systematic recording of data from training sessions enabled further analysis of other gathered parameters, such as the scores obtained by participants in relation to hitting speed, percentage accuracy, etc. All these aforementioned variables progressively increased and improved over the course of the intervention, probably due to factors related with learning, better performance and the motivation to perform better each day. Further, surprisingly, perceived exertion and heart rate outcomes remained stable over the course of the intervention. From this, it could be inferred that participants achieved improvements in physical fitness, given that they achieved better performances with the same degree of exertion (stable perceptions of exertion between the first and last session, with scores close to 5/10 on the modified Borg score). Whilst this finding must be confirmed through future research addressing aims with a greater focus on physical condition, nevertheless, that discussed above reinforces calls to introduce IVR into the treatment and rehabilitation of PD, as has been done lately in other neurodegenerative conditions (Ozkul et al., 2020; Rodríguez-Fuentes et al., 2024).

Limitations

Even though the present work reports some highly promising findings, evidence must be considered in light of a number of limitations:1) a small sample size was used that was also relatively unbalanced in terms of participant sex and disease stage. The study is, therefore, hampered by a lack of ecological validity that prevents findings from being extrapolated. This aspect must be kept in mind when interpreting outcomes; 2) lack of double blinding could call into question the impartiality of findings and interpretation of findings; 3) unavailability of measures of global disease progression, such as the Unified Parkinson's Disease Rating Scale (UPDRS), or cognitive scales, such as the Montreal Cognitive Assessment (MoCa), which could have contributed more specific outcomes regarding disease progression; 4) a short intervention timeframe (eight weeks) with a small overall number of sessions (16 sessions) was examined. Whilst this can provide valid findings and conclusions in relation to the short-term, a greater timeframe and higher number of sessions is needed to be able to optimise findings. Medium- and long-term follow ups required to confirm the existence and duration of the effects. It is possible that this conditioned the improvements discovered in other parameters.

Conclusions

It can be concluded that an IVR-based exercise program is safe and appears to offer a feasible and valid intervention for the maintenance or, even, improvement of physical capacities such as balance and gait and the ability to coordinate two independent and unrelated tasks in patients with early-stage PD. Despite this, further research in the field is required to confirm findings regarding the utility of IVR-based exercise program as a non-pharmacological treatment of PD and address the limitations outlined in the present work.

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Authors' and translators' details:

Pablo Campo-Prieto	pcampo@uvigo.gal	Author
Diego Santos-García	diegosangar@yahoo.es	Author
José María Cancela-Carral	chemacc@ uvigo.gal	Author
Gustavo Rodríguez-Fuentes	gfuentes@ uvigo.gal	Author