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Article

Immersive Virtual Reality as Computer-Assisted Cognitive-Motor Dual Task Training in Patients with Parkinson's Disease

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Abstract: *Background and Objectives:* The purpose of the study was to investigate the effect of immersive virtual reality (IVR) as computer-assisted cognitive-motor dual task training on stability and gait in patients with Parkinson's disease. The sub-objective focused on quality of life in the study group of patients. *Materials and Methods:* Nineteen patients (64.2 ± 12.8 years) were included in the study. Inclusion criteria for the study: adult patients in Hoehn and Yahr's stage 1-3, cooperative, with stable health status, independent and mobile. IVR therapy was performed twice a week for 20 minutes for one month. Input and output measurements were taken within 14 days of starting or ending therapy. The Berg Balance Scale test (BBS) was used to assess balance with a 14-item balance scale containing specific movement tasks. In addition, the 10 Meter Walk test was used to examine and assess both comfortable and fast walking, and the Timed Up and Go (TUG) + s dual task was applied to quickly assess the highest possible level of functional mobility. The standardized Parkinson's Disease Questionnaire (PDQ-39) was used to assess quality of life. Data were processed in the PAST program using a parametric paired t-test. *Results:* A statistically significant improvement in the BBS score was found after applied therapy (p = 0.033) and a statistically significant reduction in the TUG parameter was found after therapy (p = 0.021). In the PDQ-39 questionnaire, a statistically significant improvement was found in the study group after therapy not only in the total score characterizing quality of life, but also in the domains of mobility, ADL, and emotional well-being. *Conclusions:* The results of the study indicate a positive effect of virtual reality therapy on balance and gait, which is also good in terms of reducing the risk of falls in the study group. Therapy also promoted quality of life in the study group.

Keywords: balance; clinical trials; mobility; neurodegenerative diseases; questionnaire; rehabilitation

1. Introduction

Parkinson's disease (PD) is a progressively worsening neurological disease characterised by typical motor manifestations that include impaired balance (postural instability), slowed movement (bradykinesia), resting tremor, and increased muscle rigidity. Although pharmacological interventions for PD may provide some relief from motor symptoms, managing gait and balance problems remains a significant challenge for patients throughout the course of the disease. PD is also associated with non-motor symptoms, including cognitive impairments that complicate the daily life of those affected [1]. The ability to multitask is crucial in daily life, as it often requires the simultaneous performance of cognitive and motor tasks. It allows individuals to engage in complex behaviours such as navigating the environment while remaining alert to potential hazards and obstacles while walking. The consistency between cognitive processes and motor actions is an important component of efficient and safe movement in a variety of environments. This phenomenon is referred to in the literature as cognitive-motor interference, cognitive training, or dual task [2–4]. Cognitive-motor interference requires the patient to perform motor and cognitive tasks simultaneously. This approach provides information about automation [4].

Individuals with Parkinson's disease typically have a reduced performance in cognitive motor tasks compared to healthy peers of the same age, sex, and education [5]. Therefore, a therapeutic intervention in this area is also appropriate. Cognitive-motor dual task training (CMDT) simultaneously targets not only motor skills but also cognitive abilities. This maximizes the effectiveness of functional therapy and the coherence of cognitive-motor coordination [6]. The dual task method involves the simultaneous performance of two different goal-oriented activities, such as solving simple number problems simultaneously with walking a certain distance [5]. Simultaneous activation of motor and cognitive functions can provide additional benefits in dual task training compared to single task training protocols [7].

Cognitive-motor dual task training (CMDT) can be performed with or without the support of technology systems [8]. Integrated sophisticated technologies are useful for monitoring participant therapy, providing real-time feedback, and increasing patient motivation [9,10]. In recent years, there has been a gradual increase in research using computer-assisted devices in interventions to improve the effectiveness of treatments or the precision of diagnostic assessments. One possible technology is immersive virtual reality (IVR), which creates authentic cognitive-motor challenges. The tasks simulate real-world interactions and provide multisensory experiences in a virtual environment [11,12]. When this technology enters therapy, we talk about computer-assisted cognitive-motor dual task training (CACMDT) [13]. Long-term therapy is needed for patients with PD, and we wondered if IVR would be tolerated by patients and therefore may be an appropriate therapy choice. The aim of the study was to investigate the effect of immersive virtual reality as computer-assisted cognitive-motor dual task training on stability and gait in patients with Parkinson's disease. The sub-objective focused on quality of life in the study group of patients.

2. Materials and Methods

2.1. Study Design

The study was carried out according to the principles of the Declaration of Helsinki and was approved by the Ethics Committee of the University Hospital in Ostrava (reference number 57/2024).

2.2. Participants

Participants were recruited through the outpatient clinic of the University Hospital in Ostrava. All participants provided their written informed consent.

A total of 19 patients (64.2 ± 12.8 years) participated in the study. Inclusion criteria for the study: adult patients in Hoehn and Yahr stages 1-3, cooperative, with stable health, independent and mobile, without visual, hearing, speech or cognitive impairment, without severe neurological disease (epilepsy, vertigo, etc.). The Addenbrooke's cognitive examination (ACE III) was used to classify cognition and the group of patients was within normal limits in the overall assessment (score 90). Only for visual-spatial ability were they borderline dementia (score 14) [14].

2.3. Procedures

To assess balance, the Berg Balance Scale (BBS) test, a 14-item balance scale that contains specific movement tasks, was used. The 10 Meter Walk test (10MWT) was used to examine and assess both comfortable and fast walking. The Timed Up and Go test (TUG, standing and walking test) + dual task (DT) was applied to quickly assess the highest possible level of functional mobility. The standardized Parkinson's Disease Questionnaire (PDQ-39) was used to assess quality of life, consisting of 39 questions, eight domains: mobility, daily life, emotions, stigma, communication, and physical discomfort.

2.4. Instruments Used

The Meta Quest 2 headset (Meta Platforms, New York, NY, USA) was used for the virtual reality application. The device includes 6 GB of RAM and the Qualcomm Snapdragon XR2 platform for high performance. The system includes a projection helmet with LCD displays with a resolution of 1832 x 1920 pixels per eye, which provides a visual fidelity of approximately 21 pixels per degree without visual artifacts. The helmet is equipped with adjustable straps and is compatible with dioptric glasses. The two touch controls include control buttons, joystick, and anti-slip fixation straps. The glasses are connected via Bluetooth to a mobile app on a tablet that allows the therapist to monitor, control, and analyse the patient's performance on tasks.

2.5. Intervention

The virtual reality software VITALIS Pro version 0.4.1 was used for the therapy, in which modules including exercises with dual task components were developed for Parkinson's patients.

For the upper limbs, the modules were as follows:

- hanging laundry (laundry) - range of motion support,
- watering flowers (flowers) - focus on precision,
- catching butterflies (butterflies); - developing range of motion,
- opening doors with keys (keys), - training fine motor skills,
- chopping wood (chopping) - focus on range of motion,
- folding mugs (mugs) - focus on the shape and colour of the mug.

For the lower limbs, the modules were as follows:

- stomping in puddles (puddles) - agility of movement,
- kicking the ball (kicking) - focus on control of movement,
- walking on tracks without obstacles (steps) - education of walking,
- walking on tracks with obstacles (steps - obstacles) - gait education and fall prevention.

Exercises were designed to maintain range, fluency, and accuracy of movement and to promote patient reactivity. The individual tasks were performed in three thematic environments complemented by appropriate sound sensations: in the forest by birdsong, by the sea by the sound of waves, and in space by computer music, which contributed to the overall immersive experience.

In addition to group conventional exercise of 30 minutes once a week, the group received rehabilitation in IVR 10-20 minutes twice a week according to the patient's tolerance in the constant physical presence of a physiotherapist or occupational therapist.

Baseline and outcome tests were performed up to a maximum of 14 days before therapy and up to 14 days after therapy.

2.6. Statistical Methods

The freely available statistical software PAST 4.08 (PALaeontological STatistics) was used for static processing. A parametric paired t-test was used to assess post-processing differences. Differences at the level of statistical significance $\alpha = 0.05$ were considered statistically significant.

3. Results

Table 1 shows the values of the clinical gait and stability tests. The BBS test showed a statistically significant improvement in the score after the applied therapy ($p = 0.033$), and the TUG test measured a statistically significantly lower time after therapy ($p = 0.021$).

Table 1. Clinical test values.

Monitored parameter	Before therapy (M \pm SD)	After therapy (M \pm SD)	<i>p</i>
10MWT comfortable [s]	9.2 \pm 1.7	9.0 \pm 1.7	0.419
10MWT fast [s]	7.2 \pm 1.8	6.8 \pm 1.6	0.062
TUG [s]	10.9 \pm 3.4	9.5 \pm 2.0	0.021
TUG+DT [s]	12.9 \pm 4.4	12.9 \pm 7.6	0.971
BBS [score]	52.1 \pm 6.0	54.0 \pm 3.4	0.033

Explanatory notes: BBS - Berg Balance Scale test; 10MWT - 10 Meter Walk test; TUG - Timed Up and Go test; TUG + DT - Timed Up and Go test + dual task; M - arithmetic mean; SD - standard deviation; *p* - probability value.

Table 2 shows the scores for each domain of the PDQ-39 quality of life questionnaire, as well as the total score. Statistically significant improvements were found in the domains of mobility, ADL, and emotional well-being. The overall score characterizing quality of life showed improvement after therapy in the study group but was not statistically significant.

Table 2. Scores of individual domains of the PDQ-39 quality of life questionnaire.

PDQ-39 Scales	Before therapy (M \pm SD)	After therapy (M \pm SD)	<i>p</i>
Mobility	26.4 \pm 15.9	21.8 \pm 14.0	0.031
ADL	29.2 \pm 23.1	22.4 \pm 15.8	0.045
Emotional Well-Being	22.4 \pm 16.3	17.3 \pm 14.7	0.010
Stigma	16.8 \pm 19.4	12.8 \pm 14.4	0.220
Social support	14.5 \pm 20.0	11.8 \pm 16.3	0.209
Cognition	22.4 \pm 17.6	23.7 \pm 15.5	0.654
Communication	18.4 \pm 16.6	18.4 \pm 18.1	1.000
Bodily discomfort	28.5 \pm 15.3	33.3 \pm 20.2	0.213
PDSI	22.3 \pm 13.4	20.2 \pm 12.2	0.119

Explanatory notes: ADL - activities of daily living; PDSI - summary index of PD (the lower the better the quality of life); M - arithmetic mean; SD - standard deviation; *p* - probability value.

4. Discussion

Computer-assisted cognitive-motor dual task training (CACMDT) is considered a central strategy for neurorehabilitation in Parkinson's disease (PD), which is characterized by a complex relationship between cognitive and motor dysfunction. Cognitive functions are closely related to motor abilities in PD. Therefore, in our study, we chose to use IVR therapy to promote cognitive-motor interference, as was done in studies. The main benefit of this therapy is to increase motor automaticity with minimal conscious attention or executive control [1,13,15–17], but under the simultaneous supervision of a physiotherapist. Single task training (ST) is often used in rehabilitation to improve specific motor skills and does not present the same cognitive load as CACMDT [18]. Although ST may lead to improvements in targeted motor function, it may not address the cognitive-motor interference often experienced in everyday activities. Some degree of cognitive impairment is manifested by a change in postural control prioritization, loss of rhythmicity, and a reduction in gait speed. As a result, there is a high risk of falling. [4]. In our study group of patients with PD, cognitive-motor therapy was specifically targeted at stability and gait optimization. Even though our patients were in the low fall risk region of the BBS (according to the Berg et al. [19] study, this is a score range

of 41 – 56 and before therapy, PD patients had a score of 52.1), we felt that assessment of this factor after therapy would be important in terms of postural confidence due to the effects of therapy. After therapy in the IVR, we found significant improvements in reactivity in the TUG test and stability in the BBS score in our study group of patients with PD. The results highlight the importance of incorporating CACMDT within rehabilitation programs for patients with PD, as well as in a broader range of fall prevention strategies. Improved stability had a positive impact on patients' mobility, which was also reflected in the quality of life questionnaire. There was also a significant improvement in quality of life in a study [20] that focused on cognitive-motor therapy.

Preservation of walking ability is a primary concern for patients with PD. Physicians focus primarily on cadence, stride length, and gait speed. These parameters are crucial for measuring individual independence and are possible indicators of other problems, such as stability [21]. In addition, they are closely associated with the severity of PD as assessed by various clinical scales. Responses to gait parameters reflect limitations in physical activity and overall increase in disability, and can also be used to infer response to treatment, which is essential to assess the effectiveness of interventions designed to address gait impairment in PD. In addition, they are recognized as reliable predictors of an individual's ability to walk independently within the community. In our study group of patients with PD, there was no change in walking speed in the TUG test with DT after VR treatment. The work of Raffegeau et al. [22] showed that the addition of DT during walking had a moderate to large negative effect on walking speed in individuals with PD, regardless of single task or dual task type. Dual tasks severely and meaningfully affect walking in people with Parkinson's disease, which was also evident in our TUG + DT test. However, in the TUG test without DT, significant gait acceleration occurred in the PD patients we studied. The change in walking speed is reported in a study by Tan et al. [13], where participants in the dual task (DT) therapy group showed a statistically significant increase in walking speed after the intervention, and this improvement was maintained throughout the follow-up period under different conditions. Gait acceleration indicates improved stability and motor control during normal and fast walking. Improved mobility also entailed significant improvements in ADL and emotional well-being, as self-reported by patients on the PDQ39 quality of life questionnaire. Cognitive function, particularly executive function, and attention play an important role in mobility, so rehabilitation interventions that focus on both cognitive function and motor improvement are potentially very beneficial for mobility outcomes [15,17,23].

4.1. Limits

A major limitation of the study is the small sample size of patients with PD. This is due to the low motivation to participate in the study due to PD-related discomfort. For example, medication is altered in PD, which carries a negative impact related to adaptation to medication, mood changes, impaired concentration, rapid fatigue, increased sweating may occur, and also change in weather affects the patient's perception and mood.

5. Conclusions

The study group of PD patients accepted IVR therapy. Cognitive-motor dual task training in the IVR (CACMDT) is a promising neurorehabilitation pathway for patients with PD, offering a dual approach focused on motor automaticity and improved cognitive function. The study group of patients with Parkinson's disease showed a significant increase in stability, mobility, and quality of life. Therapy in the IVR offers a comprehensive and flexible strategy to address the multifaceted challenges presented by this disease.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of the University Hospital in Ostrava, proceedings number: 57/2024.

Informed Consent Statement: Patients included in the study signed an informed consent to be included in the study and for publication of the results of the study in a peer-reviewed journal.

Data Availability Statement: All research data were securely stored in digital format and protected from loss and unauthorized access. The data presented in this study are available on request from the corresponding author due to privacy reasons.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

10MWT	10 Meter Walk Test
ACE III	Addenbrooke's Cognitive Examination
ADL	Activities of Daily Living
BBS	Berg Balance Scale
CACMDT	Computer-Assisted Cognitive-Motor Dual Task
CMDT	Cognitive-Motor Dual Task
DT	Dual Task
IVR	Immersive Virtual Reality
M	arithmetic mean
p	probability value
PD	Parkinson's Disease
PDQ	Parkinson's Disease Questionnaire
PDSI	Summary Index of Parkinson's Disease
SD	standard deviation
ST	Single Task
TUG	Timed Up and Go

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