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ORIGINAL RESEARCH

A Body-Driven Mind: Effects of Conventional and Non-Immersive Virtual Reality–Based Physiotherapy on Cognitive Function in Older Orthopedic Patients

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Objective: This study evaluated the effects of exercise-based rehabilitation on cognitive functions in orthopedic patients and compared conventional rehabilitation with a protocol supplemented by physical activity (PA) performed in a non-immersive virtual reality (nIVR) environment.

Materials and Methods: A three-week exercise-based intervention was conducted among 48 orthopedic patients with lower limb joint dysfunctions (mean age 69.9 ± 4.8 years) hospitalized at the AccessMedica Rehabilitation Center. Participants were randomly assigned to two groups: the control group (CG; n = 24), which completed a standard kinesiotherapy and physical therapy program, and the experimental group (EG; n = 24), which, in addition to standard therapy, participated in three 30-minute nIVR-based PA sessions per week using interactive applications. Cognitive functions were assessed using the Addenbrooke's Cognitive Examination III (ACE-III)—version A before and version B after the intervention. The intensity of nIVR-based PA was monitored by heart rate telemetry, and participants' perceived enjoyment was assessed using the Physical Activity Enjoyment Scale (PACES).

Results: A significant improvement in overall cognitive performance was observed only in the EG following the intervention ($p < 0.004$, $d = -0.643$). Significant enhancements were found in attention ($p = 0.004$) and verbal fluency ($p = 0.039$). In contrast, patients undergoing conventional rehabilitation demonstrated no statistically significant pro-cognitive effects. The intensity of nIVR-based PA corresponded to a moderate level or close to its upper limit, and participants reported high enjoyment of this form of exercise.

Conclusion: Supplementing conventional exercise-based rehabilitation with VR-supported physical activity sessions yields superior outcomes in attention and verbal fluency as well as higher overall cognitive results compared to standard rehabilitation programs. Moreover, VR-assisted exercise therapy is perceived by orthopedic patients as highly engaging, while its exercise intensity remains within the range recommended for health benefits in both physical and psychological domains.

Keywords: cognitive functions, exercise-based rehabilitation, virtual reality, orthopedic patients, physical activity

Introduction

Virtual Reality in Rehabilitation

Virtual reality (VR) has found increasingly broad applications across various fields of rehabilitation, complementing both physical (motor) and psychological recovery processes. Over the past decade, numerous studies have reported the outcomes of interventions utilizing non-immersive (nIVR) and immersive virtual reality (IVR) systems in neurological (primarily post-stroke), orthopedic (post-arthroplasty),[1–5] cardiological (cardiorespiratory fitness),[6–8] oncological (breast cancer, pediatric oncology),[9–12] and psychiatric rehabilitation (neurodegenerative diseases, schizophrenia, post-traumatic stress disorder, autism spectrum disorders).[13–19]

The findings of these studies demonstrate the effectiveness of virtual exercise therapy, cognitive training, relaxation exercises, and pain management techniques used in the restoration of psychophysical functioning.[20–22] The integration of

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modern technologies enriches traditional rehabilitation procedures, allowing exercise programs to be performed under the supervision of a virtual coach even in home environments. Some studies emphasize that supplementing standard exercise-based rehabilitation with VR-supported exercise enhances therapeutic effectiveness.[23–25] This form of training is also characterized by relatively high physical intensity, strong attractiveness, and increased satisfaction and flow experience among participants.[26–28]

In orthopedic exercise-based rehabilitation, VR is primarily applied to support exercise therapy, reduce pain, and facilitate patient relaxation. VR technology is also used in preoperative rehabilitation to provide comprehensive preparation for surgery. VR-based programs improve the range of motion, muscle strength, and motor control; visual feedback helps correct abnormal movement patterns, facilitating postoperative exercise implementation.[2,4] Additionally, interactive environments help to alleviate emotional tension and preoperative anxiety by reducing stress levels. During the perioperative period, immersive VR enables relaxation and analgesic interventions that positively influence physiological parameters and reduce the need for pharmacological sedation.[3,21,29]

The use of VR technology in postoperative exercise-based rehabilitation allows for diversification of conventional exercise therapy and for home-based supervision by a virtual coach.[1,5] Studies have confirmed the particular effectiveness of immersive environments in developing correct movement patterns among patients after anterior cruciate ligament (ACL) reconstruction.[2] Other research highlights the positive influence of VR-based exercise therapy on postural stability and gait parameters following total knee arthroplasty.[5] Recent investigations have also begun to evaluate the impact of immersive environments on gait dynamics and locomotor activity intensity.[27,30]

VR-based exercise applications also enable training personalization and objective monitoring of progress. Importantly, the gamification elements embedded in modern training applications may strengthen patients' motivation to adhere to prescribed exercise programs and to engage in the rehabilitation process, ultimately improving therapeutic outcomes. The use of VR solutions in clinical rehabilitation is widely endorsed by medical professionals.[3]

The effectiveness of the rehabilitation process largely depends on adherence to therapy protocols and accurate performance of therapeutic recommendations—factors often identified as key limitations to rehabilitation success.[31] Implementing exercise-based programs requires close cooperation between the physiotherapist and the patient, and often also the involvement of family members.[32] This process demands sufficient cognitive capacity to understand the rehabilitation program, acquire proper movement patterns, plan therapy sessions, and adjust them to environmental conditions. Thus, patients' mental capabilities, enabling comprehension of therapeutic goals and their organization, play a crucial role.[33]

Physical Activity and Cognitive Health

At the same time, an increasing number of studies confirm the preventive effects of physical activity (PA) on cognitive and emotional functioning. Neurobiological changes accompanying PA—such as enhanced neurogenesis, angiogenesis, and neurotransmitter regulation—contribute to cognitive improvement in both healthy[34–36] and clinical populations.[12,24,37–39] Evidence consistently indicates that movement-based interventions enhance overall cognitive performance and its specific domains, especially attention, memory, and executive functions.[40] The cognitive benefits can arise both from single bouts of exercise and from regular participation, with the duration of the effects depending on exercise frequency, intensity, and volume. For example, a study among young Spanish men showed that a single 10-minute high-intensity interval training session tripled the concentration of brain-derived neurotrophic factor (BDNF),[41] while Rentería et al[42] demonstrated that a four-week training intervention increased BDNF levels by 12% in young women. Regular moderate-intensity aerobic activity significantly enhances cerebral blood flow,[43,44] thereby improving cognitive function across age groups[38,45] and supporting functional capacity.[46,47]

Therefore, when designing exercise-based rehabilitation interventions, it is essential to assess patients' cognitive status and to tailor physical exercise parameters that simultaneously enhance cognitive functioning (eg, intensity, frequency), ensuring a holistic approach to recovery.[48] A representative example of the comprehensive impact of movement on psychophysical functioning is a study conducted among older adults at increased risk of falls, where a VR-based postural stability training program using Xbox Kinect Sports significantly improved both mobility and global cognitive screening results.[49] Huang et al[37] found that integrating aerobic exercise sessions with standard cognitive training in post-stroke patients with mild cognitive impairment led to significant improvements in working memory, visuospatial, and executive functions.

Study Rationale and Objectives

In summary, the effectiveness of the rehabilitation process depends largely on the quality of interaction between patients and therapists, which is moderated, among other factors, by patients' cognitive functioning. Modern technologies such as VR are increasingly integrated into exercise-based rehabilitation, offering engaging and individualized exercise modalities through diverse training applications and devices. Concurrently, numerous studies confirm that physical activity exerts neuroprotective effects and supports cognitive functions. VR-based movement interventions have been primarily applied to enhance cognitive functioning in older adults and those with mild cognitive impairment.[50–52] However, implementing PA in virtual environments may also play an important role in supporting cognitive function among orthopedic patients, thereby enhancing the overall effectiveness of rehabilitation interventions.

The objective of this study was to evaluate the effect of standard exercise-based rehabilitation on cognitive functions in patients following orthopedic procedures of the lower limbs and to compare the effectiveness of this conventional rehabilitation approach with a program supplemented by physical activity (PA) performed in a non-immersive virtual reality (nIVR) environment.

It was hypothesized that enriching the traditional rehabilitation process with interactive exercise-based entertainment using the Nintendo Switch console and the *Ring Fit Adventure* application could positively influence the overall level of patients' cognitive functioning, as assessed with the Addenbrooke's Cognitive Examination III (ACE-III) scale.

Additionally, the study aimed to assess the intensity of physical exertion occurring during nIVR-based activity with *Ring Fit Adventure* and to evaluate patients' satisfaction and enjoyment derived from participation in this form of digital physical activity.

Material and Methods

Participants

An experimental study was conducted among patients of the AccessMedica Rehabilitation Center in Olsztyn, Poland, diagnosed with orthopedic disorders of the lower limb joints in late adulthood. The predominant diagnostic categories included degenerative diseases of the hip and knee joints. Most participants presented with gait biomechanical disturbances and pain complaints. Common accompanying symptoms included edema and reduced muscle strength, while some patients also exhibited limited joint range of motion. A total of 48 patients who met all inclusion criteria were recruited for the study (mean age = 69.9 ± 4.8 years; height = 164.9 ± 8.3 cm; body mass = 79.6 ± 16.0 kg). The majority of the participants were women (n = 32; mean age = 70.7 ± 4.7 years; height = 161.8 ± 6.5 cm; body mass = 74.9 ± 14.4 kg), while men accounted for 16 participants (mean age = 68.4 ± 4.8 years; height = 171.2 ± 7.9 cm; body mass = 88.8 ± 15.6 kg). In the whole sample, 19% of participants had vocational education, 60% had secondary education, and 21% had higher education. The average length of education was 13.83 ± 3.36 years.

Participants were eligible for the study if they met all of the following conditions:

- medical qualification for inpatient or post-hospital exercise-based rehabilitation lasting a minimum of four weeks,
- age of 60 years or older,
- absence of medical contraindications to participation in physical exercise,
- self-reported ability to complete a 30-minute standing exercise program,
- no diagnosed mental disorders within the preceding year,
- provision of informed consent for participation in the study.

Patients were excluded from participation if they presented with:

- acute inflammatory or infectious conditions,
- hemodynamic instability and/or balance impairments,
- contraindications to standing exercise,
- severe comorbidities precluding participation in rehabilitation, or
- cognitive dysfunctions that could interfere with cooperation during the intervention.

Sample Size and Randomization

The minimum sample size was determined using a power analysis ($\alpha = 0.05$; $1-\beta = 0.80$), assuming a moderate effect size ($d = 0.52$), a high correlation between pre- and post-intervention measures ($r = 0.80$), and a 20% expected dropout rate. The analysis indicated a required minimum of 24 participants per group (control and experimental).

Participants were randomly assigned to the experimental group (EG) (n = 24) or the control group (CG) (n = 24) Randomization was performed using a computer-generated sequence, with group allocation automatically assigned upon participant enrollment to ensure unbiased assignment and concealment from study personnel. The gender distribution was comparable between groups: 17 women and 7 men in the EG, and 15 women and 9 men in the CG. Also, a similar distribution of educational levels was observed between the groups (EG: 21% vocational education, 58% secondary education, 21% higher education, CG: 17% vocational, 63% secondary, and 21% higher education).

The CG participants underwent a standard three-week exercise-based rehabilitation program in an inpatient setting, while the EG participants followed the same program supplemented with additional nIVR-based exercise therapy sessions using interactive applications.

Ethical Considerations

Prior to the commencement of the study, each participant was fully informed about the study procedures, objectives, and the intended use of the collected data. Participants were also advised of their right to withdraw from the study at any time, without providing justification and without any consequences, particularly if they experienced discomfort or fatigue during the intervention. All participants provided written informed consent to participate in the study.

The study was conducted in accordance with the principles outlined in the Declaration of Helsinki and was reviewed and approved by the Research Ethics Committee of the Academy of Physical Education in Katowice, Poland (protocol no. 9/2018, supplement KB/27/2022 – the signature of the Ethics Committee Approval).

Instruments and Procedure

In the healthcare system where the study was conducted, the standard duration of inpatient or post-hospital rehabilitation is approximately four weeks. To avoid potential confounding factors related to immediate post-admission changes in affective state and adjustment to a new environment, cognitive assessments and the intervention were not initiated on the first days of hospitalization; instead, a three-day adaptation period was allowed at the beginning, and testing concluded three days before patient discharge. For these reasons, the duration of the intervention was scheduled for three weeks.

Cognitive Functioning

To assess cognitive functioning, the Polish version of the Addenbrooke's Cognitive Examination III (ACE-III) was used.[53,54] This expanded screening tool is widely recognized for its usefulness in the early detection of cognitive impairments.[55–57] The ACE-III evaluates five cognitive functions: attention, memory, verbal fluency, language, and visuospatial abilities. It consists of 23 tasks designed to assess the above-mentioned processes.[58] Two equivalent versions of the test (A and B) were used to minimize the learning effect (task memorization) that could influence post-test results. Version A was administered one day before the start of the physiotherapy program, and version B one day after its completion. The cognitive assessment was conducted individually with each participant and took approximately 40 minutes to complete. For each participant, a total cognitive function score and five domain-specific scores were calculated. At the diagnostic stage, double blinding was applied: the personnel conducting the cognitive function assessment were unaware of the participants' group allocation, and the analysis of results was performed independently by psychologists who had no contact with the participants and no information about their group assignment.

Physiotherapy Intervention Protocol

The standard rehabilitation program included five therapeutic sessions per day (two physical therapy and three exercise-based rehabilitation sessions), implemented six days per week for a total of approximately 2 hours per day. Participants in the experimental group (EG), in addition to the standard rehabilitation program, performed exercise-based sessions in a non-immersive virtual reality (nIVR) environment three times per week for three weeks, with each session lasting 30 minutes.

The intervention was conducted using a Nintendo Switch console connected to a TV screen (Figure 1). The device includes two detachable motion controllers ("Joy-Cons"): the left Joy-Con was inserted into a "Leg Strap" worn on the participant's thigh, while the right Joy-Con was mounted in a flexible "Ring-Con" (Figure 2). These accessories form integral components of the "Ring Fit Adventure" software.

The "Ring-Con" is an approximately 33 cm plastic ring equipped with a holder for the Joy-Con controller. It detects pressure and stretching forces, allowing for precise monitoring of upper-body movements. The "Leg Strap" is a fabric band with a controller pocket that detects lower-limb motion and body positioning during exercise.

"Ring Fit Adventure" combines an adventure video game with an interactive fitness training system, featuring a variety of exercises targeting multiple muscle groups and motor skills, as well as mini-games that integrate physical activity (PA) with entertainment. The advanced "Custom Mode" used in this study enables the creation of personalized training sessions, allowing the composition of customized exercise sets and mini-games suited to research protocols. The system tracks users' real-time movements and provides instant visual feedback (eg, "Great!", "Excellent!"), ensuring correct performance and engagement. Exercises available in the application are categorized into arm, leg, and core workouts, yoga poses, and aerobic/rhythmic activities. In "Custom Mode," researchers can design standardized,

Figure 1 Nintendo Switch console.

Figure 2 "Ring-Con" wheel and "Leg-Strap" thigh band.

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replicable training sessions of up to 30 exercises per session, allowing adaptation to individual participant needs (eg, older adults or persons with movement limitations).

All nIVR sessions were delivered in Ring Fit Adventure using "Custom Mode" to ensure a standardized and replicable protocol: the task set and order were identical across sessions and participants (Figure 3). "Personalization" was limited to accommodating functional limitations and to the built-in Ring-Con calibration/in-game "strength" setting (ie, the squeeze-intensity input threshold/sensitivity) to ensure safe, pain-free execution with correct technique; the setting was kept stable unless a safety-related adjustment was required. Participant-level numeric values of this in-game setting were not systematically recorded (stored within the user profile and not routinely exported as research data). Sessions lasted 30 minutes, with brief between-task pauses and additional rest permitted as needed; pacing followed in-game prompts and therapist guidance. No predefined progression of the task list was applied; safety stops included pain escalation, dizziness/vertigo, excessive fatigue/discomfort, or therapist judgment of unsafe movement. Each session was supervised continuously with a 1:1 therapist-to-participant ratio.

Each 30-minute session in this study consisted of 21 physical tasks selected in consultation with orthopedic physicians and physiotherapists at AccessMedica Rehabilitation Center. Exercises were chosen to ensure safety, general conditioning benefits, and engagement, focusing on lower-limb strength and mobility. The exercise program included Basic conditioning exercises: Overhead Press (×14), Squat (×14), Overhead Side Bend (×14), Back Press (×14), Side Step (×34), Overhead Lunge Twist (×16), Knee Lift (×34), Overhead Hip Shake (×34), Bow Pull (×16), Overhead Arm Spin (×34); Skill-based mini-games: Aerochute, Crate Crasher, Gluting Gallery, Squat Goals, Squattery Wheel; Locomotor tasks: walking or running in place through virtual environments (eg, Beginnia, Transient Temple, Trotter's Grove, Monster Den, Starting-Block Bridge, Sportan Highway). The sequence of exercises is presented in Figure 3. Sessions took place in two identical, isolated rooms prepared specifically for the study (Figure 4).

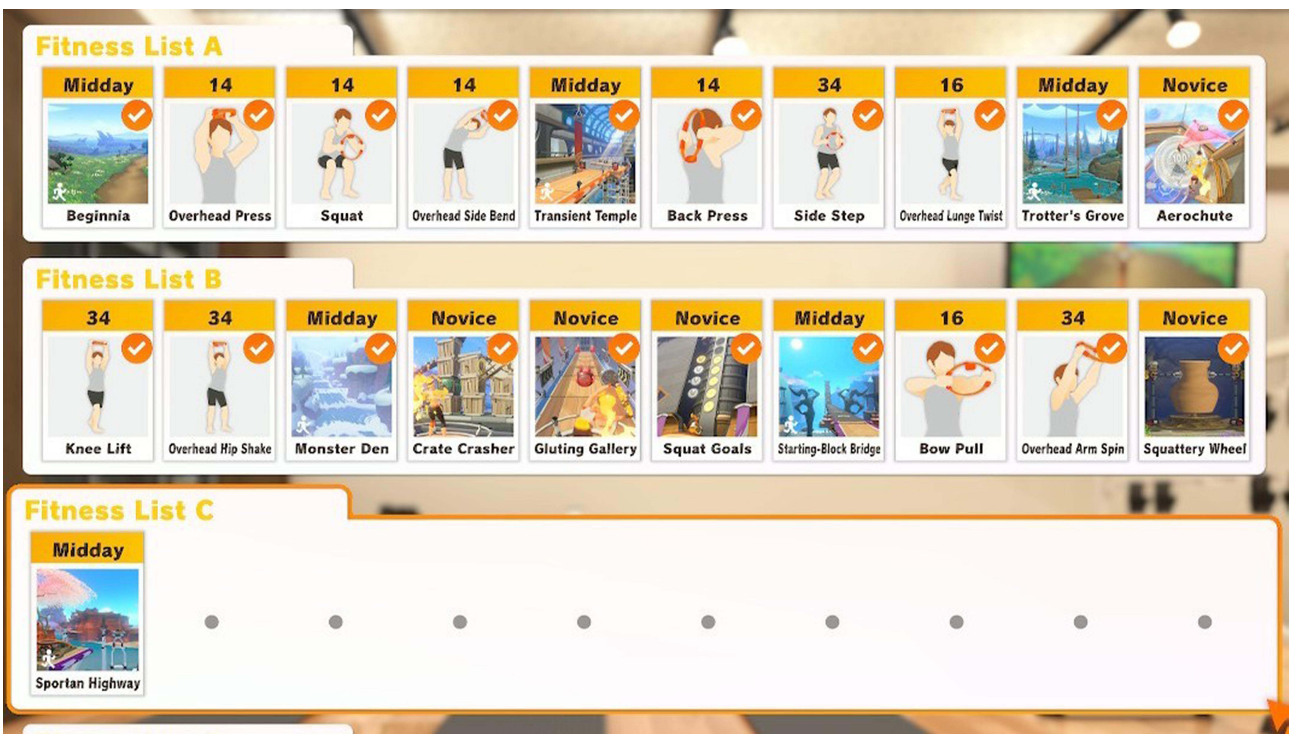

Figure 3 Set of exercises used during the intervention in the EG – "Ring Fit Adventure" application.

Figure 4 Experimental setups.

Physical Activity Intensity

To evaluate exercise intensity during "Ring Fit Adventure" sessions, both objective and subjective measurements were conducted during the 3rd and 9th training sessions. Objective intensity was measured using a Polar Vantage V heart rate monitor (Polar Electro Oy, Kempele, Finland) paired with a Polar H10 chest strap sensor. The average exercise heart rate (HR_{ave}) was calculated, and the percentage of maximum heart rate ($\%HR_{max}$) was determined based on the formula HR_{max} = 208–0.7 × age.[59] Exercise intensity was evaluated based on heart rate ($\%HR_{max}$) and interpreted according to the American Heart Association (AHA) guidelines, which define moderate intensity as 50–69% HRmax, and vigorous as ≥70% HRmax (Strath et al, 2013). This approach was chosen because it provides a standardized benchmark for assessing exercise load, taking into account the functional limitations common among orthopedic patients and current recommendations for rehabilitation in late adulthood (Groen et al, 2023). Subjective exertion was assessed using the Borg Rating of Perceived Exertion (RPE) scale (6–20).[60,61] Ratings of 10–11 indicated low intensity, 12–13 moderate intensity, and 14–16 high intensity.[62]

Assessment of Exercise Enjoyment

Following the intervention, participants evaluated the enjoyment of exercise in nIVR using the Physical Activity Enjoyment Scale (PACES) short form (8 items).[63] Responses were given on a 7-point Likert scale, and the overall score was calculated as the mean of all item responses.

Statistical Analysis

Descriptive statistics were calculated for all analyzed variables, including the arithmetic mean (M) and standard deviation (SD). The normality of data distribution was verified using the Shapiro–Wilk *W*-test. When the distribution of variables did not deviate from normality, parametric tests were applied to assess the statistical significance of differences. The paired Student's *t*-test was used for within-group comparisons, whereas the independent samples Student's *t*-test was used for between-group comparisons. In cases where the variable distributions deviated from normality, nonparametric tests were applied. The Wilcoxon signed-rank test was used for within-group comparisons, and the Mann–Whitney *U*-test was used for between-group comparisons. Effect sizes were estimated using Cohen's *d* for parametric tests and the rank-biserial correlation coefficient (r_{rb}) for nonparametric tests. All statistical inferences were conducted at a significance level of $\alpha = 0.05$. Statistical analyses were performed using *Statistica* software version 13 (TIBCO Software Inc., USA) and *Jamovi* software version 2.2.3.0 (The Jamovi Project, Australia).

Results

Before the intervention, no statistically significant differences were observed between the experimental group (EG) and the control group (CG) in the total ACE-III score or in any of its subscales (p > 005). Mean total scores were comparable between groups (EG: 8579 ± 4.92 points; CG: 84.88 ± 9.18 points). Effect sizes (Cohen's *d*, r_{rb}) indicated no significant or only very small between-group effects (Table 1).

After the intervention, the EG demonstrated a statistically significant improvement in the total ACE-III score compared to baseline (8854 ± 5.07 vs 85.79 ± 4.92 points; $p = 0.004$; $d = –0.643$). This change was also significant in the attention subscale ($p = 0.004$; $r_{rb} = –1.000$) and verbal fluency ($p = 0.039$; $d = –0.448$). No significant changes were observed in memory, language, or visuospatial abilities ($p > 0.05$) (Table 2).

In the CG, no statistically significant changes were found in the total ACE-III score after the intervention compared to baseline (86.50 ± 6.68 vs 84.88 ± 9.18 points; $p = 0.080$; $d = –0.374$). Similarly, no significant changes were observed in individual subscales ($p > 0.05$), although both the total score and most subscale means showed upward trends (Table 3).

Table 1 ACE-III Scores in the Experimental and Control Groups Before Intervention

ACE-III	EG M ± SD	CG M ± SD	Effect Size	*p*
ACE Total	85.792 ± 4.917	84.875 ± 9.181	d = 0.124	0.668
Attention	17.167 ± 1.167	17.292 ± 1.268	r_{rb} = 0.122	0.423
Memory	20.417 ± 3.374	19.208 ± 4.782	r_{rb} = −0.231	0.17
Verbal Fluency	9.250 ± 2.111	9.333 ± 3.158	d = −0.031	0.915
Language	25.125 ± 1.296	25.500 ± 1.474	r_{rb} = 0.167	0.269
Visuospatial Abilities	13.833 ± 1.435	13.542 ± 2.265	d = −0.007	0.975

Abbreviations: EG, experimental group; CG, control group; M, mean; SD, standard deviation; d, Cohen's d; r_{rb}, rank-biserial correlation coefficient; *p*, p-value.

Table 2 ACE-III Scores in the Experimental Group Before and After Intervention

ACE-III	Pre-Intervention M ± SD	Post-Intervention M ± SD	Effect Size	*p*
ACE Total	85.792 ± 4.917	88.542 ± 5.073	d = −0.643	0.004**
Attention	17.167 ± 1.167	17.792 ± 0.415	r_{rb} = −1.000	0.004**
Memory	20.417 ± 3.374	21.667 ± 3.510	r_{rb} = −0.372	0.138
Verbal Fluency	9.250 ± 2.111	10.000 ± 2.207	d = −0.448	0.039*
Language	25.125 ± 1.296	25.167 ± 2.014	r_{rb} = −0.348	0.319
Visuospatial Abilities	13.833 ± 1.435	13.917 ± 1.412	r_{rb} = −0.037	0.901

Notes: p < 0.05* significant, p < 0.01** highly significant.
Abbreviations: M, mean; SD, standard deviation; d, Cohen's d; r_{rb}, rank-biserial correlation coefficient; *p*, p-value.

Table 3 ACE-III Scores in the Control Group Before and After Intervention

ACE-III	Pre-Intervention M ± SD	Post-Intervention M ± SD	Effect Size	*p*
ACE Total	84.875 ± 9.181	86.500 ± 6.679	d = −0.374	0.080
Attention	17.292 ± 1.268	17.583 ± 0.974	r_{rb} = −0.429	0.343
Memory	19.208 ± 4.782	20.208 ± 3.336	d = −0.237	0.10
Verbal Fluency	9.333 ± 3.158	9.125 ± 2.559	d = 0.088	0.66
Language	25.500 ± 1.474	25.417 ± 0.881	r_{rb} = 0.167	0.647
Visuospatial Abilities	13.542 ± 2.265	14.167 ± 1.659	r_{rb} = −0.412	0.148

Abbreviations: M, mean; SD, standard deviation; d, Cohen's d; r_{rb}, rank-biserial correlation coefficient; *p*, p-value.

In summary, the intervention applied in the experimental group led to an improvement in the overall ACE-III score, particularly in attention/orientation and verbal fluency, while no significant changes were found in the control group.

During the intervention in the EG, additional measurements were taken to assess the intensity and enjoyment of physical activity (PA) in the non-immersive virtual reality (nIVR) environment Exercise intensity, evaluated twice (during the 3rd and 9th rehabilitation sessions), reached 62.63 ± 10.77% and 62.14 ± 10.01% HR_{max}, respectively. According to the AHA classification (Strath et al, 2013) these values fall within the moderate-intensity PA range (50–69% HR_{max}), No significant differences were observed between the two measurement points ($p = 0.512$; $d = 0.136$).

Participants also rated their perceived exertion during the 3rd and 9th sessions using the Borg Rating of Perceived Exertion (RPE) scale (6–20). After the 3rd session, perceived exertion averaged 14.17 ± 2.46 points, and after the 9th session, 13.75 ± 1.89 points. This difference was not statistically significant ($p = 0.170$; $d = 0.289$). Referring RPE values to the PA intensity classification (Piepoli et al, 2016) shows that participants perceived the nIVR activity as moderate to vigorous, ie, higher than suggested by objective HR-based assessment.

Finally, based on the Physical Activity Enjoyment Scale (PACES) questionnaire (1–7 scale), participants reported very high satisfaction with the nIVR exercise sessions, with a mean score of 6.60 ± 0.26 points, indicating excellent acceptance of this training modality.

Discussion

Cognitive Effects of Exercise-Based Rehabilitation in nIVR

The results obtained indicate that the enrichment of the standard classical physiotherapy program with a non-immersive virtual reality (nIVR) environment (experimental group, EG) contributed to a significant improvement in the overall ACE-III test score. This effect was not observed in the group of patients undergoing the standard form of kinesitherapy (control group, CG), in which only a trend toward improvement in overall cognitive function was noted.

Physical activity (PA) in the nIVR environment, in addition to engaging the motor system, requires increased activation of cognitive processes. The novel form of performing movements, the need to master the operation of a simple device (the elastic Ring-Con), and to become accustomed to the mode of performing dexterity-based minigames, all likely contribute to greater cognitive effort necessary to perform rehabilitation exercises. This may translate into a higher initial cost of integrating visual, auditory, and motor stimuli. The situation in which the participant controls the movements and speed of a virtual avatar displayed on a monitor placed in front of them through their own body movements demands high concentration, sustained attention to the successive phases and range of motion, and efficient cognitive control and executive processes.[64]

In the present study, the greatest improvement in the experimental group performing PA sessions in VR was observed in the attention domain—one of the most fundamental cognitive processes that determine the performance of other functions. Previous research indicates that training combining motor and cognitive components—so-called *dual-task training*—is more effective in improving cognitive function than training focused solely on one type of task.[51,65] The VR

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environment itself, combined with the need to operate exercise equipment, inherently creates a dual-task situation in which the participant must simultaneously engage motor (postural stabilization, movement control) and cognitive-manual systems (handling the resistance ring, making decisions regarding the range and pace of movement).

Comparison with Previous Studies and Theoretical Background

A systematic review of randomized controlled trials by Sakaki et al[66] showed that most of the 11 interventions analyzed confirmed a positive effect of VR-based physical activity on overall cognitive performance—particularly on executive functions and cognitive flexibility in older adults. Similar improvements in cognitive function following a 12-week VR exercise program were reported in a Taiwanese study by Liao et al[51] among older adults with mild cognitive impairment. The authors, as in our study, observed a greater effect of training sessions utilizing modern technologies compared with standard physical and cognitive training. Likewise, in post-stroke patients performing daily activities simulated in a VR environment, better outcomes were observed in attention, memory, visuospatial abilities, and executive functions than in those undergoing traditional exercises.[67]

In contrast, a study conducted among older adults in the United States did not show significant differences between traditional physical training and VR-based training in gait or cognitive outcomes;[52] however, that study assessed the effect of a single training session only.

Each nIVR training session was characterized by continuous effort, based primarily on aerobic activity complemented with strength exercises, which aligns with general health-oriented recommendations and rehabilitation guidelines for older adults.[68–71] Numerous studies have confirmed that regular physical exercise—particularly aerobic activity of at least moderate intensity—stimulates neurogenesis, synaptogenesis, and angiogenesis, and supports the normalization of neurotransmitter concentrations.[72,73] Positive effects on information processing speed, reaction time, verbal memory, and executive functions have also been observed following regular strength training.[74–78] Such changes contribute to the improvement of cognitive functions in both healthy[34–36,79] and clinical populations.[24,37–39,80–83] Neurobiological mechanisms associated with these changes may also explain the findings of the present study.

Exercise Intensity, Enjoyment

Our findings also demonstrated that participants rated their satisfaction with nIVR training very highly. Comparable levels of satisfaction with digital PA were found in our earlier research; however, those studies focused on young, physically fit adults training in immersive virtual reality (IVR).[84] The high attractiveness of the intervention may have promoted greater cognitive and emotional engagement in the rehabilitation program, thereby enhancing its effectiveness. At the same time, greater enjoyment of the activity may have facilitated more efficient brain stimulation, strengthening neuroplasticity processes and consequently improving global cognitive functioning.[85] It is therefore possible that the positive affective experiences associated with performing PA in the nIVR environment contributed to the significant improvement in ACE-III scores observed in the EG. The importance of exercise enjoyment has also been confirmed in a study by Chuang et al,[86] which showed that older adults who perceived VR-based physical activity as enjoyable exhibited greater improvements in global cognitive performance compared with those engaged in standard exercise programs.

The objectively measured (%HRmax) and subjectively rated (RPE) intensity of physical exertion during physiotherapy sessions using nIVR remained within, or close to, the moderate-intensity range. The mean intensity of approximately 62% HRmax corresponds, according to the American Heart Association classification,[87] to moderate physiological load. Such an intensity is recommended for achieving health benefits in both physical and psychological domains.[71]

Clinical Implications for Orthopedic Rehabilitation

In conclusion, the obtained results confirm the effectiveness of incorporating virtual reality–based motor rehabilitation sessions in improving cognitive functioning among orthopedic patients. This study highlights the potential value of complementing traditional physiotherapy with nIVR-based training as a supportive intervention that, in addition to enhancing physical performance, may also promote cognitive improvement, thereby increasing the overall effectiveness of rehabilitation programs.

Study Limitations and Future Directions

Despite the promising findings, several limitations of this study should be acknowledged, as they may affect the interpretation of the results. First, the study involved a relatively small sample size and focused exclusively on elderly orthopedic patients, which limits the generalizability of the findings to broader populations (eg, individuals with other medical conditions or from different age groups). Second, the intervention duration was limited to three weeks due to the length of stay in the rehabilitation center, and cognitive outcomes were assessed only in the short term immediately before and after the intervention; therefore, evaluation of longer-term effects would require follow-up assessments in future studies. Another limitation is the multiplicity of statistical testing across ACE-III domains. Because several subscales were examined, subscale-level p-values may be subject to inflation of Type I error. Therefore, domain-specific findings should be interpreted with caution and viewed as hypothesis-generating; future studies should prespecify key cognitive domains and/or apply multiplicity-control procedures (eg, Holm or false discovery rate approaches). Moreover, the study compared standard rehabilitation with standard rehabilitation supplemented by nIVR sessions; therefore, the observed effects should be interpreted as resulting from the addition of this specific form of physical activity rather than exclusively from the VR modality itself.

Additionally, participants' prior experience with modern digital technologies was not assessed, which might have influenced the level of task difficulty and cognitive load during the intervention. Future studies may also consider incorporating neurobiological indicators—such as brain-derived neurotrophic factor (BDNF) levels or brain activity measures (eg, fMRI)—to better elucidate the mechanisms underlying the observed cognitive improvements. Given these limitations, further research is warranted to explore the effects of nIVR-based exercise interventions within comprehensive rehabilitation programs and to confirm the observed benefits across more diverse patient populations and training protocols.

Conclusion

The addition of structured exercise sessions delivered in a non-immersive virtual reality (nIVR) environment to standard physiotherapy was associated with short-term improvements in overall ACE-III scores among orthopedic patients, particularly in the domains of attention and verbal fluency. No significant changes were observed in the control group, suggesting the superiority of nIVR-supported interventions in stimulating cognitive functions in orthopedic patients. Participants reported a high level of satisfaction with the innovative physiotherapy sessions, which may enhance cognitive and emotional engagement and, consequently, increase the overall effectiveness of the rehabilitation program. Moreover, the analysis of exercise intensity in the experimental group indicated that both objective (%HRmax) and subjective (RPE) measures fell within or close to the moderate-intensity range, which is recommended for achieving health benefits in both physical and cognitive functioning.

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Disclosure

The authors report no conflicts of interest in this work.

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