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# The Benefits of Combining Mixed Virtual Reality Exergaming with Occupational Therapy for Upper Extremity Dexterity

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**Abstract:** Virtual Reality (VR) is expanding worldwide in education, training, gaming, and healthcare to achieve distinct outcomes. This paper aimed to identify to what extent physiotherapy based on mixed VR technology and occupational therapy serves the functionality of healthy subjects' upper extremities; it also analyzed the benefits of this protocol for therapy guidelines in hand dexterity re-habilitation. Fifteen VR exergames and occupational therapy sessions were performed for 60 min in three weeks with a sample of sixteen people. The Jebsen Taylor Hand Function Test Scale (JTHFTS), Nine-Hole Peg test (9 Hole), Box and Blocks Test (BBT), and Timed Functional Test for the Arm and Shoulder (TFAST) were used for pre and post-therapy assessment. Linear regression was used to identify healthy subjects' main tasks, predicting upper extremity dexterity. The results of pre- and post-exercise assessments suggested significant improvements for both upper extremities, dominant and non-dominant. BBT, the nine-hole peg test, and FAST showed significant differences in pre- and post-therapy, favoring prophylactical exercises. Hence, in the linear regression results for the dominant hand, five models emerged as potential predictors for upper extremity agility. The capacity to pick up large light objects seemed to bring the most critical influence on hand dexterity. However, regarding the non-dominant hand, the results suggested that writing ability was the most potent predictor of dexterity. In this respect, the protocol used in this research can be used as a guideline for further upper extremity dexterity training since VR exergames combined with occupational therapy can bring essential contributions to upper limb proprioception and dexterity functioning.

**Keywords:** virtual reality; exergaming; protocol; training; upper extremity



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## 1. Introduction

Prophylaxis is the science aimed at optimizing the state of health and hindering any illness in the human body so as to prevent or delay the development of diseases with known risk factors [1]. With such aims, it needs a specific pluri-disciplinary approach with physical exercise and/or physical therapy playing a central role.

Physical therapy is the application of physical exercises that respect the basic principles of medical practice. The following forms are used: (1) primary or first-degree prophylaxis applied to healthy people to reduce the risk of developing a condition or a physical deconditioning syndrome; (2) secondary or second-degree prophylaxis for elderly people, as physical deconditioning has already occurred, aiming to prevent the aggravation of the conditions; (3) tertiary or third-degree prophylaxis for patients suffering from chronic diseases that aims to prevent the worsening of already existing diseases and their complications [2–5].

Occupational therapy is based on the fact that the voluntary activity or its occupation with specific interpersonal and environmental components can be carried out in an effective way to prevent the occurrence of ailments or dysfunctions of the human body or to improve them after the moment of occurrence; thus, it increases the patients' ability to better integrate into society [6,7]. Combined with occupational therapy, physiotherapy shares many commonalities, and they work together to help individuals achieve their rehabilitation goals.

In order to receive more rapid and better outcomes of physical and occupational therapies, Virtual Reality (VR) has become a resourceful technology developed by interdisciplinary teams made up from specialists in fields such as medicine (biomechanics, physical rehabilitation, mental rehabilitation, cognitive neuroscience), engineering, and Internet technology. The main field with extensive applicability, below the educational one, is the medical one [8–10].

The VR basic principle involves an interaction between a subject and a computer-generated environment with the help of special software. The subject and the environment interaction generated by the computer is real-time and based on proprioception, sensorial, visual, and auditive analyzers. This interaction is multisensory, multidimensional, and central to VR regarding immersive technology [11,12]. Regardless of whether this computer-generated environment contains elements from real life or is an environment generated from an imaginary world, it helps the subject believe that he/she is performing the presented tasks through his/her capabilities [13,14]. Generally, the selected exercises for the prophylaxis program are designed to improve the individual's health. Regarding VR, the exercises should simulate various activities that subjects perform during everyday tasks [15].

A study [16] identified the effect of VR training in two directions: the effects of motor learning, and postural control. The results proved that virtual-reality-based exercise programs could improve postural control better than conventional exercise. This evidence can be explained by the fact that the center of pressure of the human body in virtual-reality-based training is constantly changing and adapting according to the environmental exposure, and also that the human body's center of gravity is centeredbetter than in conventional exercise [16].

Moreover, a pilot study [17] on 30 older adults who voluntarily participated in preventive activities using VR showed its usefulness. Participants were asked to use one app of their choice out of the nine provided, for 15 min twice a week for six weeks. VR technology showed that the risk of falling decreased, and the subjects realized the ease with which they could perform specific exercises and noticed the social and psychological benefits that virtual reality technology brought to their lives [17]. In addition, VR could also be used to increase the ability to learn new skills or retain those that have previously been learned [18].

Since many VR technologies are constantly arising and are being used in many fields, the usability, applicability, and process of VR exergaming training are heterogenous; this resulted in the primary aim of this research being the identification of a potential working protocol for the use of non-immersive VR training with occupational therapy exercises for hand dexterity improvement. Furthermore, it aimed to identify to what extent physiotherapy based on VR technology and occupational therapy acted on the functionality of healthy subjects' upper extremities (UEs) and what specific tasks could influence the hand agility performance for both dominant and non-dominant extremities.

The contributions and novelty of this research are focused on two main outcomes. This research presents the development of a prophylactic therapy protocol suitable for healthy subjects, providing important results for future research on disabled people. The study's main contributions are the highlighting of: (1) the usability of a mixed VR technology that enhances upper extremity ability; (2) occupational therapy exercises as a way to fill out the therapy and integrate all of the functions of the hand; (3) how subjects may complete prophylactic tasks and motions in a mixed VR environment. In this respect, Section 2 depicts the concept and the design of the research protocol, describing the technology used in the study, the types of exergames used, and the protocol of occupational therapy exercises. Methods of assessments are also described in this section, along with the participants recruitment and statistical analysis methodology. In Section 3, the main results of the research are presented, performed on both the dominant and non-dominant hand. In Section 4, the evaluation of the results and a discussion are depicted. The conclusion is presented in Section 5.

## 2. Materials and Methods

### *2.1. Concept and Design*

A prophylaxis program was designed to be performed daily for 60 min, in a total of 15 sessions (three weeks). It consisted of: (a) exergames made with the help of the Medical Interactive Recovery Assistant (MIRA) [19] computer platform and (b) specific occupational therapy exercises aimed at increasing the ability and functionality of the upper extremity and the hand. Whereas, for the immersive VR, special devices accepting the human–computer interface are needed, such as smart goggles, sensors, or different handling devices, the non-immersive VR combines the digital world with essential elements, as a technology that is equally suitable for mobile devices and desktops, offering the possibility to reflect digital components in the real world. We considered the use of MIRA as a mixed VR technology since it allows for human–computer interactions through a sensor that detects human body motions, but also gives essential features on the individual performance and real-time human consciousness on the proprioception and body motion.

MIRA manages to transform traditional physical therapy exercises into video games designed to train subjects and thus, through their attractive and entertaining character, increase the interest and motivation of people who use this application. The subject is automatically monitored by the application with the help of the kinetic sensor throughout the session that he/she performs, and this provides the physiotherapist with feedback on the speed of the execution of the movements, the acceleration of the movements performed, and data on the joint mobility that the subject reaches at the time of executing the movement.

For the VR therapy, four types of exergames (each lasting 3 min, 24 min in total for both UEs) were used for the UE proprioception, coordination, speed, and agility increase, such as Follow, Catch, Grab, and Move (Supplementary File). Analytical and complex motions were used within MIRA exercises.

To carry out the occupational therapy part, the subjects used: the Canadian board (pliers, buttons, clamps, tap, switch, door lock) for 10 min; scissors to cut different shapes on cardboard for 5 min; drawing and writing (10 min); different merging objects of different shapes (Supplementary File) for 8 min; and also knitting or plasteline modeling in different exercises adapted to develop hand dexterity for 8 min.

### *2.2. Outcomes*

The assessment scales used in this study were the Jebsen Taylor Hand Function Test Scale (JTHFTS), Nine-Hole Peg test (9 Hole), Box and Blocks Test (BBT), and Timed Functional Test for the Arm and Shoulder (TFAST) [20].

The JTHFT scale was developed by Jebsen et al. in 1969 to allow for an objective and standardized assessment of the manual dexterity required for Activities of Daily Living (ADLs). Subjects take 15 min on average to complete the test, which includes 7 subsets: (1) writing a sentence; (2) turning 5 cards of 3 × 5 inches (7.6 × 12.7 cm) to simulate turning the page; (3) lifting small and everyday objects; (4) eating simulation; (5) placing checkers on top of each other; (6) lifting large and light objects; and (7) lifting large and heavy objects. All of the tasks on this rating scale should be performed with the non-dominant hand first and then with the dominant hand. The time required to perform these tasks is measured using a stopwatch [21]. The test has proven good psychometric qualities and a valid assessment tool [22,23].

The 9-hole peg test is a short, standardized, quantitative test of EU functionality. This is performed with both the dominant and non-dominant hand. The subject must move 9 wooden buttons from a container into 9 holes-, the activity being timed from the beginning until removing and re-inserting the buttons in the initial place [24]. Moreover, the 9-hole test offers high inter-rater reliability and increased confidence in the test–retest situation.

There is evidence for concurrent and convergent validity and sensitivity for detecting minor hand function impairments. Performance in the 9-hole test may be sensitive to practice effects; that is, patients often perform worse when tested for the first time due to unfamiliarity with the task. It is recommended that three or four repetitions be conducted before a baseline assessment if precise (rather than comparative) assessments of change over time are required [25].

The BBT is a test that can be used to measure a person's manual dexterity. The BBT is composed of a wooden box divided into two compartments with the help of a dividing wall also made of wood and 150 wooden blocks of 2.5 cm. Administration of the BBT consists of asking the subject to move the maximum number of blocks from one compartment of a box to the other within 60 s [26]. Subjects are scored based on the number of blocks transferred from one compartment to the other in 60 s. The score is recorded for each senior member separately. Higher scores indicate better manual dexterity [27].

TFAST test includes internal and external rotations of the upper limb, timed for 30 s, and circumduction of the upper limb. For rotations, the subjects put their palms on the back of their necks, and, for circumduction, they mimic washing the wall outwards and inwards, being timed for 30 s in each direction [28]. The test has proven good reliability and validity psychometric properties [29].

### 2.3. Participants

The sample consisted of participants recruited from the physiotherapists of the Clinical Hospital of Psychiatry and Neurology of Brasov and from the students of Transilvania University of Brasov, Faculty of Medicine, Physiotherapy program of study. Informed consent was obtained from each participant, and the study was approved by the local Ethics Committee under registration number 2/18.07.2019. The study included a total of 16 subjects ($n = 16$). The inclusion criteria were set for: (a) healthy clinical subjects with no pathology in the UE and mobility within normal limits; (b) subjects aged between 20 and 30 years. The exclusion criteria limited participants with: (a) pain in the UE; (b) age over 30 years; (c) people who suffer from specific ailments that affect mobility and functionality at the level of the UE; (d) cognitive disorders of any nature.

The final evaluation is an essential tool for quantifying the program's efficiency performed by the physiotherapist. After completing the exercise and exergames sessions, the final assessment was carried out using the same scales and by the same therapist. The results obtained after the final evaluations were compared to those obtained initially, and differences were identified after the prophylaxis program. This prospective study was carried out between 1 March 2022 and 31 May 2022 within the Virtual Reality Research Laboratory of Transilvania University of Brasov.

### 2.4. Statistical Analysis

The Shapiro–Wilk test was used to confirm that all outcome variables were normally distributed. One-way repeated-measure analysis of variance (ANOVA) was used to compare dependent variables within groups, and two-way repeated-measure analysis of variance was used to assess and compare the changes in upper limb function over time between the groups.

Data were analyzed using IBM SPSS statistics (version 26.0). The significance level was set to 0.05. Descriptive analysis was used, and all data are presented as mean and standard deviation (SD). Repeated-measure analysis of variance (ANOVA) with time as a within-participant factor was performed for the Jebsen Taylor Hand Function Test Scale (JTHFTS), Nine-Hole Peg test (9 Hole), Box and Blocks Test (BBT), and Timed Functional Test for the Arm and Shoulder (TFAST) outcome measures. The Bonferroni post hoc test was used to investigate differences within group at the two time points.

For the ANOVA analysis, the sphericity assumption was verified, and since the Mauchly's test of sphericity indicated that the assumption of sphericity had been violated, the results were calculated according to Greenhouse and Geisser [30], it being used to correct the one-way repeated measures ANOVA. All of the data are reported for 95% Confidence Interval (CI) and alpha value of $p < 0.05$. The sample effect size based on within-subjects factor variability is reported as partial eta squared (partial η2 or ηp2), with lower and upper bounds for CI, and considered as having a large effect size for a value >0.14 [31].

The stepwise method was used for linear regression, with iterative construction adding or removing potential variables in succession and tests for statistical significance after each iteration. The reasoning for choosing the regression analysis was to manage all of the potential predictor variables, identify and fine-tune the model, and choose the best predictor variables from the available options [32]. Standardized beta coefficients with lower and upper bound CIs were reported, with a statistical significance when $p < 0.05$.

Pearson correlation was applied to demarcate the power and tendency of a linear relationship between the assessment methods used in the research, considered as a low correlation between 0.1 and 0.3, a medium correlation between 0.3 and 0.5, and a strong correlation effect >0.5 [33].

For the sample size calculation and effect size, for the studied group, G*Power software 3.1.9.7 version was used, and a priori calculation for 0.5 effect size, with alpha < 0.05, power of 0.95, and a sample size of 16 participants, was computed [34].

## 3. Results

The mean age of the participants was 22.6 years; nine women and seven males participated in the research, of which three had their left hand as the dominant extremity.

During the prophylaxis program that the subjects completed, data were observed and collected, aimed at comparing them with those obtained when the study began. After the final evaluation, the differences arising from the program based on virtual reality and occupational therapy can be seen.

Table 1 shows the differences in the timing performance in the JTHFT test before and after prophylaxis training on the dominant limb. One-way repeated-measure ANOVA was used to identify the significant statistical differences between the initial and final assessments. Additionally, Table 2 presents the results in the JTHFT test for the non-dominant hand.

**Table 1.** Differences in the JTHFT test for the dominant hand before and after the program.

| JTHFT Item | Mean ± SD | Mean ± SD | Time Effect (Pre vs. Post Therapy) | | | Pairwise Comparison | | |
|---|---|---|---|---|---|---|---|---|
| | Pre-Therapy | Post-Therapy | F | *p* | Partial Eta Square | Mean Difference /Std. Er. | Lower Bound CI | Upper Bound CI |
| Writing | 14.68 ± 1.2 | 14.48 ± 1.2 | 115.33 | <0.001 | 0.885 | 0.20/0.01 | 0.16 | 0.24 |
| Page turning simulation | 4.95 ± 0.33 | 4.71 ± 0.32 | 28.78 | <0.001 | 0.657 | 0.24/0.04 | 0.14 | 0.33 |
| Collecting objects | 6.72 ± 0.57 | 6.55 ± 0.57 | 124.30 | <0.001 | 0.892 | 0.17/0.01 | 0.13 | 0.20 |
| Eating simulation | 8.63 ± 0.49 | 8.49 ± 0.48 | 33.17 | <0.001 | 0.689 | 0.13/0.02 | 0.08 | 0.18 |
| Stacking checkers | 4.98 ± 0.38 | 4.71 ± 0.37 | 67.81 | <0.001 | 0.819 | 0.26/0.03 | 0.19 | 0.33 |
| Picking up large light objects | 3.98 ± 0.46 | 3.84 ± 0.44 | 16.73 | 0.001 | 0.527 | 0.14/0.03 | 0.07 | 0.22 |
| Picking up large heavy objects | 4.37 ± 0.51 | 4.24 ± 0.46 | 20.98 | <0.001 | 0.583 | 0.12/0.02 | 0.06 | 0.18 |

For the mean values of the dominant hand, the ANOVA results suggested significant differences between pre- and post-therapy values, with a mean difference of 1.30, 0.10 SE (1.07 to 1.52 CI), $p < 0.001$, and partial eta square of 0.998. As can be seen from Tables 1 and 2 (mean and SD), the results show significant improvements for both extremities, but the differences between the dominant and non-dominant hand are substantial regarding the time taken to perform the tasks, especially for the writing and eating simulation, which are activities that require fine skill motions acquired through intense and repetitive fineness tasks.

**Table 2.** ANOVA results of the non-dominant hand.

| JTHFT Item | Mean ± SD | Mean ± SD | Time Effect (Pre vs. Post Therapy) | | | Pairwise Comparison | | |
|---|---|---|---|---|---|---|---|---|
| | Pre-Therapy | Post-Therapy | F | *p* | Partial Eta Square | Mean Difference /Std. Er. | Lower Bound CI | Upper Bound CI |
| Writing | 43.17 ± 7.73 | 41.98 ± 8.04 | 75.43 | <0.001 | 0.834 | 1.19/013 | 0.89 | 1.47 |
| Page turning simulation | 5.52 ± 0.72 | 5.30 ± 0.73 | 271.60 | <0.001 | 0.948 | 0.22/0.02 | 0.19 | 0.25 |
| Collecting objects | 6.88 ± 0.72 | 6.59 ± 0.71 | 80.19 | <0.001 | 0.842 | 0.29/0.03 | 0.22 | 0.36 |
| Eating simulation | 10.47 ± 0.77 | 9.85 ± 0.62 | 43.80 | <0.001 | 0.745 | 0.62/0.09 | 0.42 | 0.82 |
| Stacking checkers | 5.76 ± 1.45 | 5.53 ± 1.34 | 12.63 | 0.003 | 0.457 | 0.23/0.06 | 0.09 | 0.37 |
| Picking up large light objects | 4.10 ± 0.32 | 4.03 ± 0.50 | 1.089 | 0.313 | 0.068 | 0.07/0.07 | 0.07 | 0.21 |
| Picking up large heavy objects | 4.64 ± 0.30 | 4.41 ± 0.29 | 84.32 | <0.001 | 0.849 | 0.23/0.02 | 0.18 | 0.28 |

The most significant difference for the dominant hand in the time obtained at the end of the program compared to its beginning was achieved by the subject recorded under no. 2, namely 2.32 s.

The most negligible difference between the time obtained initially and the time obtained at the end of the program was 0.77 s, in the case of subject no. 4, whereas the average obtained in terms of the decrease in test completion time was 1.3 s in favor of the final evaluation.

For the mean values of the non-dominant hand, the ANOVA results suggest significant differences between pre- and post-therapy values, with a mean difference of 2.85, 0.24 SE (2.34 to 3.35 CI), $p < 0.001$, and partial eta square of 0.906. The most considerable difference recorded between the two ratings for the non-dominant upper limb was achieved by subject no 3. It was represented by a decrease of 5.18 s in the case of the final assessment compared to the initial one.

A minor difference recorded between initial and final ratings for the non-dominant upper limb was achieved by subject no. 9 and was qualified at 1.5 s in favor of the final evaluation. The mean difference across subjects for the non-dominant limb was 2.84 s in favor of the final rating.

In Table 3, the results of the comparison between the dominant and non-dominant limb suggest that the exposure to the designed therapy program improved both hand dexterity motions and the upper extremity functionality as well.

For BBT, the score was based on counting the blocks transferred from one box to another, so the higher this score, the more the subject's improvement may be observed.

The most considerable difference obtained between the final and initial evaluation was in the case of the fifth subject, namely 14 blocks. In the case of the initial assessment, it managed to transfer 44 blocks instead; in the final assessment, it managed to transfer 58 blocks. The subject that achieved the slightest difference between the final and initial evaluation was no. 4., namely, four blocks, increasing from the original score of 64 to a score of 68. Subjects had an average score increase of 7.3 blocks.

**Table 3.** ANOVA results of both dominant and non-dominant extremity in the 9-Hole Peg Test, BBT, and FAST assessment.

| Item | | Mean ± SD | Mean ± SD | Time Effect (Pre vs. Post Therapy) | | | Pairwise Comparison | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Pre-Therapy | Post-Therapy | F | *p* | Partial Eta Square | Mean Difference /Std. Er. | Lower Bound CI | Upper Bound CI |
| 9-Hole Test | Dom | 17.64 ± 1.24 | 17.16 ± 1.21 | 135.79 | <0.001 | 0.901 | 0.48/0.04 | 0.39 | 0.57 |
| | Non-Dom | 20.64 ± 1.30 | 19.50 ± 1.10 | 106.17 | <0.001 | 0.876 | 1.14/0.11 | 0.90 | 1.37 |
| BBT | Dom | 54.80 ± 4.69 | 62.10 ± 3.34 | 187.80 | <0.001 | 0.926 | 7.30/0.53 | 6.16 | 8.44 |
| | Non-Dom | 50.10 ± 4.52 | 56.00 ± 4.23 | 117.83 | <0.001 | 0.887 | 5.90/0.54 | 4.74 | 7.06 |
| FAST | | | | | | | | | |
| Rotation | Dom | 19.10 ± 2.08 | 21.70 ± 2.25 | 253.50 | <0.001 | 0.944 | 2.60/0.16 | 2.25 | 2.95 |
| | Non-Dom | 18.80 ± 1.96 | 20 ± 1.59 | 61.71 | <0.001 | 0.804 | 1.20/0.15 | 0.87 | 1.53 |
| Circumduction | Dom | 77.00± 6.02 | 80.40 ± 5.68 | 266.76 | <0.001 | 0.947 | 3.40/0.21 | 2.96 | 3.84 |
| | Non-Dom | 72.90 ± 5.93 | 75.40 ± 6.13 | 41.09 | <0.001 | 0.773 | 2.50/0.39 | 1.67 | 3.33 |

Regarding the assessment of the non-dominant member, the most significant difference obtained between the final and the initial assessment was 11 blocks. Two subjects, namely two blocks, achieved the slightest difference between the final and initial assessments. The increase in the average score was 5.9 blocks regarding the assessment of the non-dominant member.

With regard to the predictors for the hand ability and functioning, in healthy subjects, the results from Table 4 suggest that the capacity to manipulate large light objects by hand, along with writing and functional grasping, are indicators of the potential achievement of a superior ability through exercising for the dominant hand, whereas, for the non-dominant hand (Table 5), the capacity of writing is a good predictor of hand dexterity.

**Table 4.** Linear regression results in the JTHFT test for the dominant hand.

| Model | R Square | SE | Change Statistics | | | | 95% CI | |
|---|---|---|---|---|---|---|---|---|
| | | | R Square Change | F | *p* | B | Lower Bound | Upper Bound |
| 1 | 0.832 [a] | 0.93 | 0.832 | 69.563 | <0.001 | 0.912 | 2.90 | 4.90 |
| 2 | 0.916 [b] | 0.68 | 0.084 | 12.968 | 0.003 | 0.794 | 2.59 | 4.19 |
| 3 | 0.983 [c] | 0.32 | 0.067 | 46.392 | <0.001 | 0.725 | 2.71 | 3.49 |
| 4 | 0.989 [d] | 0.27 | 0.006 | 6.224 | 0.030 | 0.790 | 2.96 | 3.79 |
| 5 | 0.994 [e] | 0.21 | 0.005 | 7.595 | 0.020 | 1.112 | 3.59 | 5.91 |

[a]. Predictors: picking up large light objects. [b]. Predictors: picking up large light objects, writing. [c]. Predictors: picking up large light objects, writing, simulated feeding. [d]. Predictors: picking up large light objects, writing, simulated feeding, simulated page turning. [e]. Predictors: picking up large light objects, writing, simulated feeding, simulated page turning, picking up large heavy objects.

With regard to the Pearson correlation, the JTHFT test for the non-dominant hand was correlated with FAST dominant and non-dominant circumduction of 0.565 and $p = 0.023$, and0.523 and $p = 0.038$, respectively. BBT correlated the dominant UE with the non-dominant UE, with a value of 0.837, suggesting a strong correlation and $p < 0.001$. The nine-hole peg test also correlated the values of the dominant extremity with the values of the non-dominant extremity, with Pearson = 0.777 and $p < 0.001$.

**Table 5.** Linear regression results in the JTHFT test for the non-dominant hand.

| Model | R Square | SE | Change Statistics | | | | 95% CI | |
|---|---|---|---|---|---|---|---|---|
| | | | R Square Change | F | *p* | B | Lower Bound | Upper Bound |
| 1 | 0.982 [a] | 1.47 | 0.982 | 763.77 | <0.001 | 0.991 | 1.25 | 1.46 |
| 2 | 0.993 [b] | 0.97 | 0.011 | 19.57 | 0.001 | 0.892 | 1.13 | 1.32 |
| 3 | 0.982 [c] | 1.47 | 0.982 | 763.77 | <0.001 | 0.850 | 1.07 | 1.26 |

[a]. Predictors: writing. [b]. Predictors: writing, collecting objects. [c]. Predictors: writing, collecting objects, stacking checkers.

## 4. Discussion

### *4.1. The Benefits of the VR Program Designed*

The study included 16 subjects selected based on the inclusion and exclusion criteria who formed a single sample. At the beginning of the study, they were assessed using the scales presented hereinbefore: JTHFT, BBT, 9-hole test, and TFAST.

Regarding the JTHFT, a decrease in the maximum execution time of the presented tasks can be observed. In the case of the initial assessment for the dominant UE, after calculating the average time obtained by all of the subjects, the time was reached at 48.32 s. In the case of the final evaluations, the subjects performed the same tasks with an average time of 47.02 s. The decrease in the execution time is caused by a dexterity, ability, and proprioception improvement of the dominant upper limb. Regarding the non-dominant UE evaluation, most patients obtained a lower time in all of the tasks compared to the dominant upper limb; thus, the average time in which this test was initially performed was 80.53 s. In the case of the final evaluation, this average decreased to the threshold of 77.68 s, representing a beneficial evolution of the functional capacity of the non-dominant upper limb.

The nine-hole test was also performed for both the dominant and non-dominant upper limbs. The average time initially obtained by the subjects with the help of the non-dominant upper limb was 20.64 s, and, regarding the final evaluation, it decreased to a value of 19.50 s, showing a difference of 1.14 s. Regarding the dominant upper limb, the average time that resulted from the initial testing was 17.638 s, and, from the final testing, a time of 17.158 resulted in a difference of 0.48 s.

In the BBT, subjects transferred cubes (blocks) from one side of a box to the other with both the dominant and non-dominant upper limb. For the initial rating, the average number of blocks transferred was 54.8 cubes for the dominant hand and 50.1 cubes for the non-dominant hand. During the final evaluations, an increase in the number of cubes transferred was observed for all of the subjects, where the final average for the dominant upper limb increased to 62.1 blocks, registering an increase of 7.3 cubes, and, for the UE, the non-dominant average increased to 56 cubes, registering an increase of 5.9 cubes.

Within the TFAST results, after the final evaluation, differences were observed in the internal and external rotations and circumduction in both the dominant and non-dominant UE.

The results of ANOVA suggested significant improvements for both the dominant and non-dominant upper extremities, with a large effect size. With regard to the BBT, the nine-hole test and FAST, the results also suggested noteworthy differences in pre- and post-therapy scores, with a large effect size. In the linear regression results of the dominant hand, five models emerged as potential predictors for upper extremity agility, but the capacity to pick up large light objects seemed to have the most critical influence on hand dexterity, followed by the writing task. However, regarding the non-dominant hand, the results suggested that the writing ability is the most potent predictor of dexterity.

To sum up, the designed program could help medical practitioners in rehabilitation and practice. The results show that VR used in combination with occupational therapy is beneficial to UE functioning and dexterity.

*4.2. The Potential Beneficiaries of the VR Program Designed*

Previous research was mainly performed on patients with an injured central nervous system and compared different types of VR therapy with mirror therapy or conventional physiotherapy for the UE dexterity and ADL practice, proving that VR therapy as an adjunct or single therapy improves UE functioning and dexterity [35–38].

Walino-Paniagua et al. studied the effects of occupational therapy combined with VR therapy on multiple sclerosis patients [39]. Although the results of the used tests, such as JTHFT, did not show significant differences between groups, the results found improvements in the precision efficiency of task performing for the VR group [39]. Furthermore, one of the reasons for why our research used and analyzed the correlation between the assessments performed was the heterogeneity of the scales used for human body functioning and evaluation since there are many resources in the scientific literature and clinical practice.

Our protocol combining exergaming with occupational therapy tasks can be used by elderly people or patients with CNS sensory-motor disorder. Benoit et al. [40] proved that healthy elderly participants tolerate this technology and that VR stimulates the brain regarding memory issues, suggesting that it is a feasible tool during reminiscence therapy. Furthermore, new therapy strategies for VR implementation as therapeutical intervention in psychiatric and cognitive diseases are approached in the present literature [41,42]

A previous study [43] found that VR exercise games increased physical activity levels and improved cardiovascular health in adults with obesity. Participants who played VR exercise games for 30 min, three times per week for eight weeks, showed significant improvements in their heart rate, blood pressure, and body mass index compared to a control group [43]. A review published in 2020 concluded that VR is a promising tool for promoting physical activity in older adults. The review found that VR exercise programs improved balance, mobility, and physical activity levels in older adults, and were well-tolerated by participants [44]. In addition, recent research results suggest that VR exergaming is more engaging and that the physical performance in children increases compared to standard physical exercises [45]. These studies demonstrate the potential of VR for promoting physical activity in a variety of populations, and the results of our research also display significant improvements in hand dexterity and upper extremity functioning.

Recent Cochrane reviews (2011 and 2017) on VR efficiency in neurorehabilitation sought to demarcate the usefulness of VR on the UE functioning and agility of adults after stroke. The results identify low-quality evidence regarding VR efficiency in improving UE functioning and activity when used as an adjunct therapy in care or when compared to conventional intervention. The results suggest that patient's VR benefits of VR therapy enhanced the motor function when used in the subacute stage of post-stroke, especially within the first three months (up to six months). Nonetheless, the authors stated that there was incomplete evidence for reaching judgments regarding the effect of VR on other processes, such as grasping, motion finesse and flow, gait speed, or proprioception improvement, which remain unclear [46,47]. Nonetheless, the results might be biased because of the length of therapy and the therapeutic interval of treatment, since it is already known that the brain neuroplasticity is favored within the first 3 to six months following stroke [48,49]. However, evidence is provided that VR positively influences the lower extremity functioning even in chronic post-stroke patients [50].

The use of VR therapy is still a challenge for most medical personnel, and its applicability and usability are often deepened and correctly identified in time; this is because most VR devices were created for training healthy people in terms of sports performance or military training, and now they end up being used for neurorehabilitation in particular [51]. For these reasons, it is essential to have a multidisciplinary collaboration between the developers of VR therapies and those who put these types of therapies into clinical practice [52,53]. Fortunately, MIRA was developed for children's neurorehabilitation [24]. Like other VR therapies used for children, they engage with the therapy, and the motivation increases; therefore, the applicability and usability of MIRA and other non-immersive VR technologies could be extended to elderly or CNS sequelae patients. Pearson correlation results on the outcomes assessed suggest that JTHFT was correlated with FAST, whereas BBT was better correlated with the nine-hole peg test, which is confirmed by previous results [54,55].

Previous research on manual dexterity and task prediction suggested that grip strength becomes a significant factor regarding hand dexterity, while the arm curl strength contributes to hand function, suggesting that the power of the hand extrinsic muscles is essential for hand function [56,57]. Therefore, related to the previous studies and the results obtained, especially regarding the dominant hand, the fact that lifting large and light objects is suggested as being a good predictor of the dexterity of the dominant hand is precisely explained by the use of the described neuro-activation sequences motor, with the need for wrist extension and grasping.

While many studies have shown that VR can increase physical activity levels in the short term, there is less research on the long-term effects of VR on physical activity and health outcomes; therefore, we aim to further identify the long-term effect of exergaming. Future studies should also explore the sustainability of VR exercise programs over time and their impact on long-term health outcomes, but also compared to standard physical activity. As VR technology continues to advance, VR systems could incorporate haptic feedback to simulate the feeling of resistance or force during exercise. While some studies have explored the potential of VR for promoting physical activity in clinical populations, future research should focus on exergaming protocols and the effectiveness of this approach in a clinical setting. Future studies could explore the feasibility of incorporating VR exercise programs into existing clinical interventions.

## 5. Conclusions

Following the use of exergames and occupational therapy combined in a sole program, an increase in the functionality, dexterity, speed of performing specific movements, and ability of the upper limbs of healthy subjects is observed.

The results obtained from the final evaluations were compared to those initially made. Regarding the JTHFT, a decrease in the maximum execution time of the tasks presented was shown. The reduction in the execution time of the test is explained by the motion performance and function of the upper limb improvement. The results of the nine-hole test evaluation also showed a decrease in the time of execution for both limbs. In the case of the BBT, within the final evaluations, an increase in the number of cubes transferred was observed in all of the subjects. The measurement differences made by the initial and final TFAST suggest an increase in the number of repetitions in internal and external rotations and in the case of circumduction. All of the subjects registered an improvement in motions, presented for both dominant and non-dominant hands.

There has been an increase in the interest in prophylaxis and in achieving movement with augmented reality technology. Virtual reality provides subjects with a safer and more enjoyableenvironment for performing exercises that bring physical benefits; therefore, future directions regarding the usability of the existing exercise and exergaming protocol are needed.

However, the major limitation of this research is related to the fact that there was no control group in order to be able to identify the true contribution of the use of augmented virtual reality for improving proprioception and upper extremity dexterity. Additionally, no technologies were used to perform the objective measurement of movement speed or the order of neuro-muscular recruitment in task performance regarding occupational therapy exercises or exergames. Although the research was performed on a small sample size, the statistical results regarding the effect size suggest an efficient improvement in hand dexterity motions. Still, the results cannot be extrapolated to subjects suffering from peripheral or central nervous system injuries that require neurorehabilitation, and this specific type of therapy requires tailored intervention.

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