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Original Article

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Effects of Immersive Virtual Reality-Based Movement Therapy on Upper Extremity Functions and Cognitive Functions in Stroke Patients

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Abstract

Background: *This controlled experimental study aimed to investigate the effect of immersive virtual reality-based movement therapy (IVR-MT) on upper extremity functions (UEF), activities of daily living (ADL), and cognitive functions (CF) in chronic stroke patients.*

Methods: *Patients who met the inclusion criteria, were randomly assigned to the study (IVR) or control groups. Both of the groups received 60 minutes/day of conventional rehabilitation program and occupational therapy and the IVR group received 30 minutes/day of additional IVR-MT for six weeks. UEF was evaluated by the Jebsen Taylor Hand Function Test (JTHFT), and the Box and Block Test (BBT), ADL was evaluated by the Barthel Index (BI), and 36-Item Short Form Survey (SF-36), and CF was evaluated with the Mini Mental Test (MMT).*

Results: *There were no differences between the IVR (n=15), and control (n=10) groups for demographic and clinical characteristics or baseline results of JTHFT, BBT, BI, SF-36, and MMT. At six weeks post-treatment there were significant improvements in the IVR group in scores for moving large light cans (Pvalue=0.001) and moving large heavy cans (Pvalue=0.003) in the JTHFT, in BBT scores (Pvalue=0.004), in MMT (Pvalue=0.033) and for physical functioning (Pvalue=0.008) in the SF-36. In addition, the change in score in the IVR group for moving large light cans (Pvalue=0.008) and moving large heavy cans (Pvalue=0.002) at week 6 was significantly larger than in the control group.*

Conclusions: *These results suggest that additional IVR-MT, in combination with conventional physiotherapy and occupational therapy might improve outcomes in UEF and CF in chronic stroke patients.*

Keywords: Cognition, Rehabilitation, Stroke, Upper extremity, Virtual reality.

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Introduction

Post-stroke neurological symptoms vary according to the location and grade of the brain lesion, and motor and cognitive disorders are the most common symptoms.[1] Epidemiological studies of stroke have found the rate of motor disorders, such as paresis/paralysis, to be 80-90%, while 55-75% of stroke survivors have permanent upper extremity functional limitations, resulting in dependence for activities of daily living (ADL).[2] The aim of stroke rehabilitation is to ensure the highest level of functional independence and to increase the quality of life (QOL) of the individual, despite existing disabilities. Stroke rehabilitation basically consists of three approaches; conventional physical therapy, neurophysiologic approaches, and activity-based training. In addition, specific interventions for stroke rehabilitation have also been shown to promote functional recovery and reduce disability.[3,4] In an effort to assist these individuals with motor recovery, systems employing virtual reality (VR) have gradually been adopted. Virtual reality is defined as a “computer-based technology that lets users interact with a multisensory, simulated environment and have ‘real-time’ feedback on performance”.[5] The interactive "games" used for patients are designed to provide them with real-life scenarios and activities relevant to daily living.[6] The software is able to provide concepts required for motor learning, including frequency, intensity, repetition, motivation, and task-oriented training, while enabling the user to feel involved in their rehabilitation.[5] For users to experience virtual environments as real, immersion and presence conditions are required. Immersion describes a state of consciousness in which the user’s awareness of the physical self declines due to an upgrading involvement in a virtual environment. A sensation of immersion can be achieved by creating realistic tactile, auditory, or visual stimulation. An immersive VR (IVR) system projects the visual scene onto a head-mounted device filling the user’s vision or a large projection surface that completely fills the user's field of view, effectively surrounding the user. Recent studies have indicated that VR applications are low-risk and can be useful in motor relearning when applied as part of a physiotherapy program, but the quality of the available evidence is low and more comparative studies are required.[7] In the present study, we aimed to investigate the effects of IVR-based movement therapy applied in addition to conventional therapy in stroke patients on upper extremity (UE) function, ADL, and cognitive function.

Materials and Methods

In this controlled experimental study, patients with stroke who attended the outpatient clinic between March 2018 and September 2018 were assessed against study inclusion criteria. The inclusion criteria were: aged between 18 and 75 years; having hemiplegic due to stroke; disease duration of ≥6 months; a Brainstorm stage (BS) of ≥3; and having no additional pain. Exclusion criteria were patients who had: cognitive behavioral disorders that would affect participation in the study; suffered neglect; marked visual and/or hearing loss; severe UE contracture or bone and joint instability; complex regional pain syndrome in the UE and uncontrolled comorbidities. Eligible patients were assigned to the study (IVR) group or the control groups after baseline assessments were performed by using a random number program created by the computer. A randomization program was used by a physiotherapist who was blinded to the study. Patients were evaluated using the Jebsen Taylor Hand Function Test (JTHFT) and the Box and Block Test (BBT) for UE functions. The Short Form 36 (SF-36) questionnaire was used to assess QOL. The Barthel Index (BI) was used to investigate ADL and the Mini-Mental Test (MMT) was used as a measure of cognitive function (CF) assessment. All these tools were applied at baseline and six weeks post-treatment. The test within JTHFT which involves writing a sentence was not evaluated because two patients couldn’t read or write.

Both of the groups received 60 minutes of a conventional rehabilitation program (range of motion, stretching and strengthening exercises, proprioception, weight-bearing, balance, and coordination training) and 60 minutes of occupational Therapy (OT) for three weeks during weekdays, followed by 60 minutes of occupational therapy for three weeks (6 weeks total). IVR group received an additional 30 minutes of IVR-based movement therapy during this 6-week treatment time. Thus, the IVR group received a total of 15 hours of IVR-based movement therapy over a period of six weeks which the control group did not. An immersive Oculus Rift VR system (Climb game) was used for IVR-based movement therapy. Before the start of therapy, the patients were informed about the game by the therapist and they were shown how to use the bundles. The patients performed active shoulder elevation, adduction, active elbow flexion, and extension, supination, and pronation movements of both upper extremities in the game. Patients who could not perform plegic side finger flexion and could not fully grasp the bundle were assisted by the physiotherapist, who was able to see the patient’s avatar on the television screen at the same time. Patients planned which points to reach and hold by themselves.

Statistical analysis was performed by using SPSS, version 20.0 (IBM Inc., Armonk, NY, USA). Kolmogorov-Smirnov tests were used to test the normality of data distribution. Continuous variables are expressed as mean±standard deviation, median (25th-75th percentiles, the interquartile range), and categorical variables were expressed as percentages (counts). Non-normally distributed continuous variables between the groups were compared using the Mann-Whitney U Test, Wilcox on test was used for comparison of the baseline and week six evaluations for both groups. Categorical variables between the groups were compared using the Fisher’s Exact test. A two-sided Pvalue <0.05 was considered statistically significant. The post-hoc power was calculated as 0.76 in the power analysis using the BBT score measure for groups.

Results

A total of 40 stroke patients attended the center during the study period and 28 patients who fulfilled the inclusion criteria and agreed to participate in the study were included. The 28 eligible patients were randomly assigned to the IVR (n=15) and control groups (n=13). All patients included in the study completed their planned treatment, except for three patients in the control group who were lost to follow-up (Figure 1) because of familial problems. The demographic and clinical characteristics of all patients are shown in table 1.

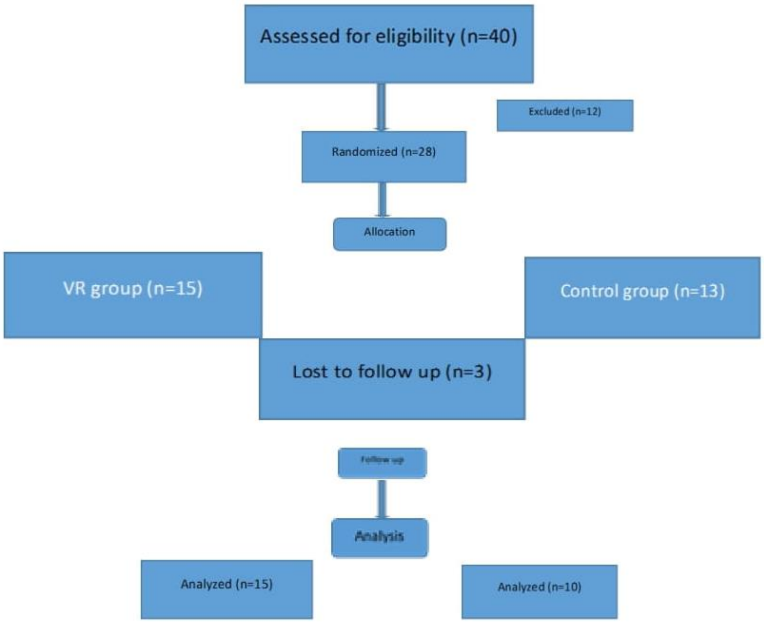

Figure1. Flowchart of the study

The results of JTHFT and BBT of the IVR and control groups are given in table 2. At baseline, there were no statistically significant differences in the baseline JTHFT and BBT scores. However, six weeks after treatment significant improvements were recorded in scores for moving large light cans (Pvalue =0.001) and large heavy cans (Pvalue =0.003) of the JTHFT, and in scores for BBT (Pvalue =0.004) in the IVR group, while improvements were present in the control group only for moving large heavy cans (Pvalue =0.021) and for BBT (Pvalue =0.011). The degree of change between baseline and six-week-post-treatment scores for the IVR group for moving large light cans (Pvalue =0.008) and moving large heavy cans (Pvalue =0.002) was significantly larger in the IVR group than in the control group.

The results of the IVR group and control groups, BI and MMT scores are given in table 3, and SF-36 scores are given in table 4. There were no significant differences in the baseline results or for the degree of change in scores for BI, MMT, and all SF-36 parameters when the IVR and control groups were compared. However, a significant improvement was found in the MMT score (Pvalue =0.033) and the results of the SF-36 physical functioning parameters (Pvalue =0.008) in the IVR group, six weeks after treatment.

Table 1. Demographic and clinical data of the IVR group and the control group*

	IVR group (n=15)	Control group (n=10)	Pvalue**
Age (year)	51 (23-61)	51 (28-63)	0.824
Sex (%)			
Female	7 (46.7%)	5 (50%)	0.873
Male	8 (53.3%)	5 (50%)	
Plegic side (%)			
Right	11 (73.3%)	6 (60%)	0.493
Left	4 (26.7%)	4 (40%)	
Etiology (%)			
Infarct	14 (93.3%)	9 (90%)	0.768
Hemorrhagia	1 (6.7%)	1 (10%)	
Disease duration (months)	20 (12-36)	25 (16.5-48)	0.428
Brunnstrom stage			
Upper extremity	6 (5-6)	5.5 (5-6)	0.683
Hand	5 (5-6)	5 (4-5)	0.397
Lower extremity	5 (5-6)	6 (5-6)	0.683
MAS			
Shoulder	1 (0-1)	0.5 (0-1)	0.892
Elbow Flexor	1 (1-1)	1 (1-1)	0.428
Wrist Flexor	1 (1-1)	1 (1-1)	0.605

Table 2. Results of JTHFT and BBT for the IVR group and the control group*.*Data shown for both groups are given as median (25-75%)

	Baseline	Change from Baseline (Week 6)	Pvalue**
JTHFT			
Turning over cards			
IVR group	19.99 (12.34-45.61)	-5.54 (-31.05-8.90)	0.125
Control group	17.24 (9.09-22.42)	-2.95 (-23.12-11.49)	0.508
Pvalue ***	0.285	0.495	
Picking up small objects			
IVR group	28.05 (21.07-107.79)	-8.85 (-33.01-3.86)	0.069
Control group	22.99 (13.38-38.15)	2.91 (-5.52-12.42)	0.541
Pvalue ***	0.338	0.103	
Simulated feeding			
IVR group	36.56 (20.75-112.18)	-10.14 (-37.53-6.97)	0.311
Control group	29.73 (15.77-63.33)	-0.23 (-4.08-4.81)	0.906
Pvalue ***	0.311	0.196	
Stacking checkers			
IVR group	22.45 (7.46-87.65)	0.00 (-21.04-29.87)	0.638
Control group	16.31 (10.52-34.18)	-8.27 (-14.89-0.79)	0.221
Pvalue ***	0.428	0.495	
Moving large light cans			
IVR group	11.84 (7.23-29.16)	-21.62 (-30.65-(-)15.54)	0.001
Control group	10.75 (8.78-27.03)	-4.26 (-25.34-0.47)	0.086
Pvalue ***	0.935	0.008	
Moving large heavy cans			
IVR group	15.14 (7.35-28.07)	-20.89 (-40.61-(-)14.99)	0.003
Control group	11.18 (9.41-23.07)	-5.01 (-11.59-(-)0.08)	0.021
Pvalue ***	1.000	0.002	
BBT			
IVR Group	28.00 (11.00–36.00)	4.00 (2.00-6.00)	0.004
Control Group	26.00 (15.75–31.75)	1.50 (1.00-4.25)	0.011
Pvalue ***	0.868	0.180	

Pvalue ** Wilcoxon, Pvalue *** Mann-Whitney-U

Table 3. Results of BI and MMT for the IVR group and the control group*

	Baseline	Change from Baseline (Week 6)	Pvalue **
BI			
IVR Group	100.00 (90.00-100.00)	0.00 (0.00-0.00)	0.102
Control Group	100.00 (85.00-100.00)	0.00 (0.00-0.00)	0.317
Pvalue ***	0.531	0.602	
MMT			
IVR Group	28.00 (27.00 – 29.00)	0.00 (0.00-1.00)	0.033
Control Group	29.00 (21.50 – 30.00)	0.00 (0.00-1.00)	0.059
Pvalue ***	0.631	0.927	

*Data shown for both groups are given as median (25-75%)
Pvalue ** Wilcoxon, Pvalue *** Mann-Whitney-U

Table 4. Results of SF-36 scores for the IVR group and the control group*

SF-36	Baseline	Change from Baseline (Week 6)	Pvalue **
Physical functioning			
IVR Group	65.0 (30.0 - 85.0)	5.0 (0.0 - 5.0)	0.008
Control Group	75.0 (41.25 - 86.25)	0.0 (0.0 - 5.0)	0.157
Pvalue ***	0.605	0.264	
Physical role functioning			
IVR Group	25.0 (0.0 - 75.0)	0.0 (0.0 - 0.0)	1.0
Control Group	75.0 (0.0 - 75.0)	0.0 (0.0 - 0.0)	0.317
Pvalue ***	0.765	1.000	
Emotional role functioning			
IVR Group	33.0 (0.0 - 100)	0.0 (0.0 - 0.0)	1.0
Control Group	33.0 (0.0 - 75.25)	0.0 (0.0 - 0.0)	0.317
Pvalue ***	0.892	0.221	
Vitality			
IVR Group	66.0 (50.0 - 85.0)	0.0 (0.0 - 0.0)	0.109
Control Group	82.5 (45.0 - 91.25)	0.0 (0.0 - 6.25)	0.109
Pvalue ***	0.461	0.711	
Mental health			
IVR Group	72.0 (60.0 - 84.0)	0.0 (0.0 - 1.0)	0.066
Control Group	78.0 (63.0 - 90.0)	0.0 (0.0 - 0.0)	0.317
Pvalue ***	0.428	0.361	
Social role functioning			
IVR Group	63.0 (25.0 - 100)	0.0 (0.0 - 0.0)	0.180
Control Group	62.5 (43.75 - 100)	0.0 (0.0 - 0.0)	0.317
Pvalue ***	0.935	0.806	
Body pain			
IVR Group	78.0 (68.0 - 90.0)	0.0 (0.0 - 0.0)	0.317
Control Group	83.5 (59.75 - 100)	0.0 (0.0 - 0.0)	0.317
Pvalue ***	0.723	0.724	
General health perceptions			
IVR Group	70.0 (45.0 - 80.0)	0.0 (0.0 - 0.0)	0.317
Control Group	77.5 (47.5 - 85.0)	0.0 (0.0 - 0.0)	1.000
Pvalue ***	0.567	0.414	

*Data shown for both groups are given as median (25-75%)
Pvalue ** Wilcoxon, Pvalue *** Mann-Whitney-U

Discussion

In this study, it was demonstrated that combining IVR-based movement therapy with conventional physical therapy and occupational therapy might provide additional benefits on UE motor recovery in stroke patients. We observed a significant improvement in the physical dysfunction data of the SF-36 test and in the MMT scores.

Improving functional performance after stroke continues to be a big challenge for rehabilitation professionals,[8] but with increased use of new technologies, such as VR, functional performance can be improved further.[9,10] There is evidence that VR-based interventions that include repetitive and task-specific activities can improve the restoration of UE function after stroke,[11,12] and an immersive design can produce greater improvement6. In our study, we used an immersive VR system to study patients in addition to their conventional rehabilitation program. Non-immersive VR systems have been widely used in stroke rehabilitation for some time to improve motor functions[13] and non-immersive VR-based rehabilitation is effective in UE functional recovery in stroke patients compared to standard physiotherapy.[12] A study that investigated the effects of VR games improving UE function and general health among stroke survivors found that replacing a section of physiotherapy program time with VR games was equally effective in improving UE function and general health compared to receiving only conventional physiotherapy among stroke survivors.[14]

Previous studies used different VR systems for UE rehabilitation. In a randomized controlled study conducted by Laffont et al., video games and conventional rehabilitation effectiveness for UE rehabilitation in patients with sub-acute stroke were compared.[15] These authors compared the effects of a 45-minute additional session of conventional OT or a VR-based OT session as additional therapy to a normal rehabilitation program, 5 days/week for six weeks. The authors found that VR-based exercises were more efficient than conventional rehabilitation on both gross grasping function and sensorimotor recovery. In another study, the effect of VR-based therapy on improving upper limb functions in individuals with stroke was investigated.[16] In this study in which 40 patients with chronic stroke were evaluated, participants were randomly assigned into two groups study and control. The study group received a conventional 1-h functional training program, followed by another hour of VR-based therapy using Armeo Spring equipment and the control group had 2 h of a conventional functional training program for three months. Both groups showed significant differences in all variables after the treatment. Individuals with stroke in the study group had a better improvement in the Action Research Arm Test (ARAT), Wolf Motor Function Test (WMFT), and WMFT-Time scores after the treatment compared to the control group. No significant difference in Hand Grip Strength (HGS) scores was detected between groups after completion of the treatment.

In our study, when comparing the study group before and after treatment, a significant improvement in the capability to lift large light objects and lifting large objects was found. In contrast, in the control group, a significant improvement was only found in the ability to lift large objects. The degree of change in capacity to lift large and light objects was greater in the IVR group compared to controls. We found a significant improvement between the pre-treatment and post-treatment BBT data of the study group and the control group. This improvement can be because of the fact that during BBT evaluation, proximal muscles of upper extremity movement are required for the patient as in the game we chose for the study patients. Afsar et al. evaluated the effect of the Microsoft Xbox 360 Kinect VR system on upper limb motor functions in subacute stroke patients.[17] The Brunnstrom stages and the Fugl-Meyer Assessment for upper extremity (FMA-UE) scores, BBT, and Functional independence measure (FIM) improved significantly during the study in both the study and the control groups. The results were similar to our study. In another systematic review and meta-analysis, Fang et al. stated that traditional plus VR rehabilitation therapy is an effective method to improve the upper limb motor function and manual dexterity of patients with limb disorders after stroke, and VR rehabilitation treatment may become a new option for rehabilitation after stroke.[18]

Although the evaluation of the effects of VR-based treatment is still in its infancy, recent systematic reviews and meta-analyses have shown that VR may increase upper extremity motor function in stroke,[14] and provide medium to large positive treatment effects in ADL.[19] Jin et al.[6] examined 40 studies including 2,018 patients and showed that VR exhibited higher beneficial effects on arm function, motor impairment, and ADL compared with the control group. In a similar study, Mekbib et al.[20] randomly divided patients with stroke into two groups and applied additional IVR-based exercises to the first group for eight hours for two weeks and time-matched OT alone to the second group. Treatment effects on cortical organization and motor recovery were investigated using the Barthel Index, FMA-UE, and resting-state fMRI. Their results suggested that using an IVR system might offer additional benefits for upper extremity rehabilitation in patients receiving OT.

In our study, we didn’t observe any significant difference in BI scores, we found a significant difference between only IVR and the control group’s SF-36 physical function data, in addition to their ADL scores. The fact that the positive results we obtained in upper extremity motor functions did not also result in improvement of ADL of the patients may be associated with the relatively short duration of our study and the game played by the patients wasn’t created for rehabilitation. Similar results to our study were found in a study that evaluated the upper extremity motor function in stroke patients. Ahmadi et al. reported significant improvements in upper limb motor function, muscle tone, and the range of motion in the study group, compared to the control group; however, no significant changes in none of the group’s ADLs.[21]

Until recently, most VR systems were designed to improve motor function in stroke patients. In studies conducted, improving and evaluating CFs are often regarded as secondary objectives.[12] Nevertheless, studies targeting improvement in both motor and CFs have revealed evidence that cognitive and motor systems work together at a structural and functional level.[8] Leng et al.[22] explored the impact of cognitive function on functional outcomes in people with subacute stroke after VR intervention. In their study, in a session VR group had a 30-minute conventional therapy program and a 30-minute nonimmersive VR training using Kinect 360. The control group received the same amount of time conventional rehabilitation program. They stated that VR intervention is as effective as conventional rehabilitation in improving upper limb function independent of the cognitive functional level.

Recent studies show that after VR applications focused on motor recovery, stroke patient’s attention and memory also developed, which had a small to moderate effect on CF. When we compared the pre-treatment and post-treatment in-group data of the patients by MMT, the IVR group had significantly better change in scores compared to controls. Better CF results may be because, the game played included a Cognitive stage (the individual learns what to do and then subsequent mental practice), the Relation stage (the individual learns the skill required for the game), and the Independent stage (the need for attention is reduced and the movement becomes automatic). In the literature, there is quality I, A grade evidence on the effectiveness of the VR practice in the enriched environment to increase participation in cognitive activities, and quality IIb, A grade evidence on the effectiveness of external memory assist technology (computer and game technologies).[2] The main limitation of our study was the small number of patients. Another limitation was that the duration of treatment in the IVR group was longer than the control group. The final limitation was that we did not follow up with the patients for more than six weeks after treatment.

Virtual reality applications, which are easy to apply and safe, appear to bring additional benefits to the treatment programs used with stroke patients. VR-based exercises are enjoyable and can be used by patients themselves at home to increase the intensity of exercise and reduce rehabilitation center dependency. Although the results of the studies conducted so far are encouraging in terms of improving UE functions in patients with stroke, larger, well-designed studies should be conducted to demonstrate the benefits and possible drawbacks of different forms of IVR-MT in stroke recovery treatment.

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Conflict of Interest

The authors declare that they have no conflict of interest.

References

1. Balami JS, Chen RL, Buchan AM. Stroke syndromes and clinical management. QJM 2013;106:607-15. doi:10.1093/qjmed/hct057
2. Nichols-Larsen DS, Clark PC, Zeringue A, Greenspan A, Blanton S. Factors influencing stroke survivors' quality of life during subacute recovery. Stroke 2005;36:1480-4. doi:10.1161/01.STR.0000170706.13595.4f
3. Mehrholz J, Pohl M, Platz T, Kugler J, Elsner B. Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke. Cochrane Database Syst Rev 2018;9:CD006876. doi:10.1002/14651858.CD006876.pub5
4. Thieme H, Mehrholz J, Pohl M, Behrens J, Dohle C. Mirror therapy for improving motor function after stroke. Stroke 2013;44:e1-2. doi:10.1161/strokeaha.112.673087
5. Saposnik G, Levin M; Outcome Research Canada (SORCan) Working Group. Virtual reality in stroke rehabilitation: a meta-analysis and implications for clinicians. Stroke 2011;42:1380-6. doi:10.1161/STROKEAHA.110.605451
6. Jin M, Pei J, Bai Z, Zhang J, He T, Xu X, Zhu F, et al. Effects of virtual reality in improving upper extremity function after stroke: A systematic review and meta-analysis of randomized controlled trials. Clin Rehabil 2022;36:573-596. doi:10.1177/02692155211066534
7. Laver KE, Lange B, George S, Deutsch JE, Saposnik G, Crotty M. Virtual reality for stroke rehabilitation. Cochrane Database Syst Rev 2017;11:CD008349. doi:10.1002/14651858.CD008349.pub4
8. Cumming TB, Marshall RS, Lazar RM. Stroke, cognitive deficits, and rehabilitation: still an incomplete picture. Int J Stroke 2013;8:38-45. doi:10.1111/j.1747-4949.2012.00972.x
9. Maier M, Rubio Ballester B, Duff A, Duarte Oller E, Verschure PFMJ. Effect of specific over nonspecific VR-based rehabilitation on poststroke motor recovery: A systematic meta-analysis. Neurorehabil Neural Repair 2019;33:112-129. doi:10.1177/1545968318820169
10. Aminov A, Rogers JM, Middleton S, Caeyenberghs K, Wilson PH. What do randomized controlled trials say about virtual rehabilitation in stroke? A systematic literature review and meta-analysis of upper-limb and cognitive outcomes. J Neuroeng Rehabil 2018;15:29. doi:10.1186/s12984-018-0370-2
11. Pollock A, Farmer SE, Brady MC, Langhorne P, Mead GE, Mehrholz J, et al. Interventions for improving upper limb function after stroke. Cochrane Database Syst Rev 2014;2014:CD010820. doi:10.1002/14651858.CD010820.pub2
12. Wu J, Zeng A, Chen Z, Wei Y, Huang K, Chen J, Ren Z. Effects of virtual reality training on upper limb function and balance in stroke patients: Systematic review and meta-meta-analysis. J Med Internet Res 2021;23:e31051. doi:10.2196/31051
13. Park DS, Lee DG, Lee K, Lee G. Effects of Virtual reality training using xbox kinect on motor function in stroke survivors: A preliminary study. J Stroke Cerebrovasc Dis 2017;26:2313-9. doi:10.1016/j.jstrokecerebrovasdis.2017.05.019
14. Ahmad MA, Singh DKA, Mohd Nordin NA, Hooi Nee K, Ibrahim N. Virtual reality games as an adjunct in ımproving upper limb function and general health among stroke survivors. Int J Environ Res Public Health 2019;16:5144. doi:10.3390/ijerph16245144
15. Laffont I, Froger J, Jourdan C, Bakhti K, van Dokkum LEH, Gouaich A, et al. Rehabilitation of the upper arm early after stroke: Video games versus conventional rehabilitation. A randomized controlled trial. Ann Phys Rehabil Med 2020;63:173-80. doi:10.1016/j.rehab.2019.10.009
16. El-Kafy EMA, Alshehri MA, El-Fiky AA, Guermazi MA. The effect of virtual reality-based therapy on ımproving upper limb functions in ındividuals with stroke: A randomized control trial. Front Aging Neurosci 2021;13:731343. doi:10.3389/fnagi.2021.731343
17. Ikbali Afsar S, Mirzayev I, Umit Yemisci O, Cosar Saracgil SN. Virtual reality in upper extremity rehabilitation of stroke patients: A randomized controlled trial. J Stroke Cerebrovasc Dis 2018;27:3473-8. doi:10.1016/j.jstrokecerebrovasdis.2018.08.007
18. Fang Z, Wu T, Lv M, Chen M, Zeng Z, Qian J, et al. Effect of traditional plus virtual reality rehabilitation on prognosis of stroke survivors: A Systematic review and meta-analysis of randomized controlled trials. Am J Phys Med Rehabil 2022;101:217-28. doi:10.1097/PHM.0000000000001775
19. Chen J, Or CK, Chen T. Effectiveness of using virtual reality-supported exercise therapy for upper extremity motor rehabilitation in patients with stroke: Systematic review and meta-analysis of randomized controlled trials. J Med Internet Res 2022;24:e24111. doi:10.2196/24111
20. Mekbib DB, Debeli DK, Zhang L, Fang S, Shao Y, Yang W, et al. A novel fully immersive virtual reality environment for upper extremity rehabilitation in patients with stroke. Ann N Y Acad Sci 2021;1493:75-89. doi:10.1111/nyas.14554
21. Soufi Ahmadi H, Hassani Mehraban A, Amini M, Sheikhi M. The effects of virtual reality on upper limb function in chronic stroke patients: A clinical trial. Iranian Rehabilitation Journal 2019;17:81-9.
22. Leng Y, Lo WLA, Mao YR, Bian R, Zhao JL, Xu Z, et al. The impact of cognitive function on virtual reality ıntervention for upper extremity rehabilitation of patients with subacute stroke: Prospective randomized controlled trial with 6-month follow-up. JMIR Serious Games 2022;10:e33755. doi:10.2196/33755
23. Winstein CJ, Stein J, Arena R, Bates B, Cherney LR, Cramer SC, et al; American heart association stroke council, council on cardiovascular and stroke nursing, council on clinical cardiology, and council on quality of care and outcomes research. Guidelines for adult stroke rehabilitation and recovery: A guideline for healthcare professionals from the American heart association/American stroke association. Stroke 2016;47:e98-e169. doi:10.1161/STR.0000000000000098