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Impact of a virtual reality program on post-stroke upper limb function: a randomized controlled trial

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Abstract

Introduction. Motor function after stroke may be facilitated by the application of a task-oriented approach which provides both functional and neurological recovery. Also, virtual reality training promotes the restoration of movements by immersing the patient in an entertaining trial of performance. The study aim was to compare the effect of a virtual reality training program and a task-oriented training program on the paretic upper limb function after stroke.

Methods. Overall, 20 subacute stroke survivors participated in the study. They were randomly allocated to 2 equal groups: an experimental group (A) and a control group (B). Group A performed a virtual reality program and a task-oriented program, while group B performed a task-oriented program only. Assessment was carried out for all participants by using the Upper Extremity Functional Index and grip strength test before and after 6 weeks of intervention.

Results. Paired t-test revealed that the virtual reality training group (A) presented statistically significant increases in the post-intervention mean values of both the Upper Extremity Functional Index and hand grip strength compared with the pre-intervention scores ($p < 0.05$). Furthermore, independent t-test showed a statistically significant difference in the post-intervention mean values between group A and group B.

Conclusions. Virtual reality training has a vital role in improving upper limb function and augmenting hand grip strength after stroke. It can be considered more effective than task-oriented training in such cases.

Key words: virtual reality, upper limb, stroke, task-oriented

Introduction

Stroke is a foremost reason for long-duration neurological disabilities in adults and may result in a difficulty to perform either self-care or community activities [1]. Loss of motor control of the upper limb is the major form of neurologic debility after brain stroke [2]. The paretic arm remains without function in 32–34% of stroke survivors, especially early after stroke, according to the estimates of the cohort studies [3]. Return of voluntary arm motor control and function is an important goal during stroke rehabilitation to minimize the patient's disability [4]. Although most of the recovery is obtained in the first few weeks after stroke, patients may show functional improvements many months after the accident [5].

To achieve motor recovery after stroke, passive movement is not sufficient. Motor recovery depends on the timing of intervention, as well as the repetition and intensity of exercises [6]. A concentrated training related to a specific goal is very beneficial for the development of independence and optimization of functional recovery [7]. Task-oriented training was found to induce motor control and motor learning through practising a group of selective meaningful functional tasks which made it easy to be transferred to real-life activities [8]. The task-oriented training approach has a measurable effect on motor recovery of hand function and the whole paretic arm in stroke survivors. This can be explained with the neural plasticity induced by task-specific motor training and exercising [9], which was confirmed in functional neuroimaging studies [5, 10].

Although clinical trials have suggested that task-oriented training may be superior to other current clinical practices in upper extremity rehabilitation in stroke patients [11], virtual reality (VR) training is an intervention that shows promise in stroke rehabilitation [12, 13]. VR is associated with a great advancement in the application of healthcare because it provides patients with an immersive and entertaining approach that helps accomplish performance optimization [14]. The visual reality technology used in physical therapy helps the individuals re-learn the use of their upper limbs and return to normal limb function. This occurs through a motivating practice with sufficient feedback for both the patient and the therapist concerning the performance of the trained activity [15].

The clinical application of VR in rehabilitation is relatively novel, and its effectiveness is still questionable, especially with the lack of randomized controlled studies and thus lack of clinical evidence, mainly with regard to the early period after stroke. Because of the absence of qualitative evidence for the superiority of the currently practised interventions for the upper limb motor training after stroke [5], there is a growing need to recognize the best training methods and protocols [16]. A number of training programs have been conducted to improve the upper limb functions. These have included VR training and task-oriented upper limb training [17]. Therefore, the aim of this study was to provide a direct clue to the preference of the application of VR-based training in comparison with task-oriented rehabilitation in improving upper limb function after stroke. The study was designed to investigate whether VR training as an adjunct to task-oriented training

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would produce a significant improvement in the Upper Extremity Functional Index (UEFI) score and hand grip strength in the subacute phase after stroke onset as compared with task-oriented training alone. This study attempted to offer technologically entertaining exercises that were easy to be performed and were selected to emphasize the bilateral use of both the affected and the unaffected arm while going through the virtual training experience. This, in turn, provided both repetitive and entertaining upper limb rehabilitation to patients with subacute stroke, focusing on paretic upper limb function improvement and an increase in muscle strength to obtain motor recovery [17].

Subjects and methods

Study design

The study followed a pretest-posttest control group design. It evaluated the cause-effect relationship between 2 groups, the study group and the control group, at 2 time points of testing: before and after 6 weeks of intervention.

Participants

A total of 20 subacute stroke patients (less than 6 months after stroke) of both genders participated in the study. Their age ranged from 55 to 65 years. All subjects were diagnosed with a cerebrovascular accident by a specialized neurologist and were undergoing outpatient rehabilitation. The individuals included in the study were visually intact, with normal cognitive functions. This was easily confirmed since they were able to understand the physiotherapist's instructions and respond to the sections of testing appropriately. They also exhibited mild spasticity in accordance with the Ashworth scale (1, +1) [18]. Patients who suffered from acute cerebrovascular accident with moderate to severe spasticity, impaired cognitive skills, or any musculoskeletal deficit affecting their upper limb function were excluded from the study. Those who met the inclusion criteria signed an informed consent form to participate in the study before the clinical trial commencement. Then, they were randomly divided into 2 equal groups: the experimental group (A) performed VR and task-oriented training programs and the control group (B) only performed a task-oriented training program. The simple random allocation method was applied with the use of statistical tables and both patients and examiners were blinded (double blinding randomization). The UEFI score and grip strength were assessed for all patients in both groups twice: before and after 6 weeks of intervention.

Assessment tools

Upper Extremity Functional Index test

It is a reliable and valid test that evaluates the performance of daily living activities engaging the upper limbs and household activities [19, 20]. It consists of a 20-point area-specific and patient-described index. It examines the function of the upper limb in individuals with hand and upper limb problems. Patients level the task on a 0–4 scale, with 0 denoting maximum effort and 4 meaning no effort executing the task. This is interpreted into a maximum potential mark of 80, which indicates outstanding performance. UEFI requires nearby 5 minutes for completion and is easy to be applied. The overall mark is calculated as the sum of the participant's marks.

Grip strength test

A hand-held dynamometer is a valid and reliable device used to measure the grip strength, as approved by many studies. The patient held the handle with their hand, with the arm in adduction and elbow in 90° flexion resting on an armchair or supported by the examiner's hand [21]. The examiner asked the patient to squeeze as hard as possible, then release. On the basis of the results, the strength increment could be measured.

Interventions

The virtual reality training program

The VR training session lasted for 15 minutes and was performed in a well-equipped room to give the patient the best VR training experience. The equipment included a screen to observe what the patient could see in the play as feedback for the examiner, a PlayStation console, VR goggles to immerse the patient inside the game, and controllers to play with.

At the beginning, the examiner taught the patient how to play by guiding the movement and then the subject was allowed to play alone. The game was called Super Punch; it is a boxing game, with the participant sitting on a high back chair with fisted hands holding twin packs in the starting position. The game allowed patients to bilaterally use their upper extremity with repetitive flexion-extension for elbow and shoulder to produce punching movements at different heights. The patient could reach by their hand in all directions (forward, upward, downward, left, and right) to hit the paddles with boxing gloves. The game consists of 3 levels of playing; the highest level is above the head, the middle one is at 90° shoulder horizontal flexion, and the lower one is at 45–35° shoulder flexion. During playing, the computerized system measures each punch at each level and gives the participant direct visual feedback via a written word evaluating the performance (weak, slow, okay, good, or perfect). This enhances the eye-hand coordination and upper limb function. It is a timed game so the patient is motivated each time they play to get a higher score. The time set for each game was 2 minutes and the game was repeated 5 times per session, with a rest of 1–2 minutes in between. So, the total time of a VR training session was 10–15 minutes. The sessions were performed 3 times per week for 6 successive weeks.

The task-oriented training program

The program included 5–10 repetitions of selective motor training, selective functional movements, and fine motor training. The selective motor training took a form of throwing a standard volleyball, which enabled gross upper extremity function and optical training program. The selective functional movements involved reaching and manipulative tasks by using standard rehabilitation cones and washing pegs. The fine motor training consisted in a ball grip training by squeezing balls of different shapes and sizes with the thumb and fingers, playing with clay, holding a pin with the thumb and the index finger, and handwriting. The program was first performed unilaterally and then progressed to be implemented bilaterally. The total training session lasted for 1 hour and was applied 3 times per week for 6 successive weeks.

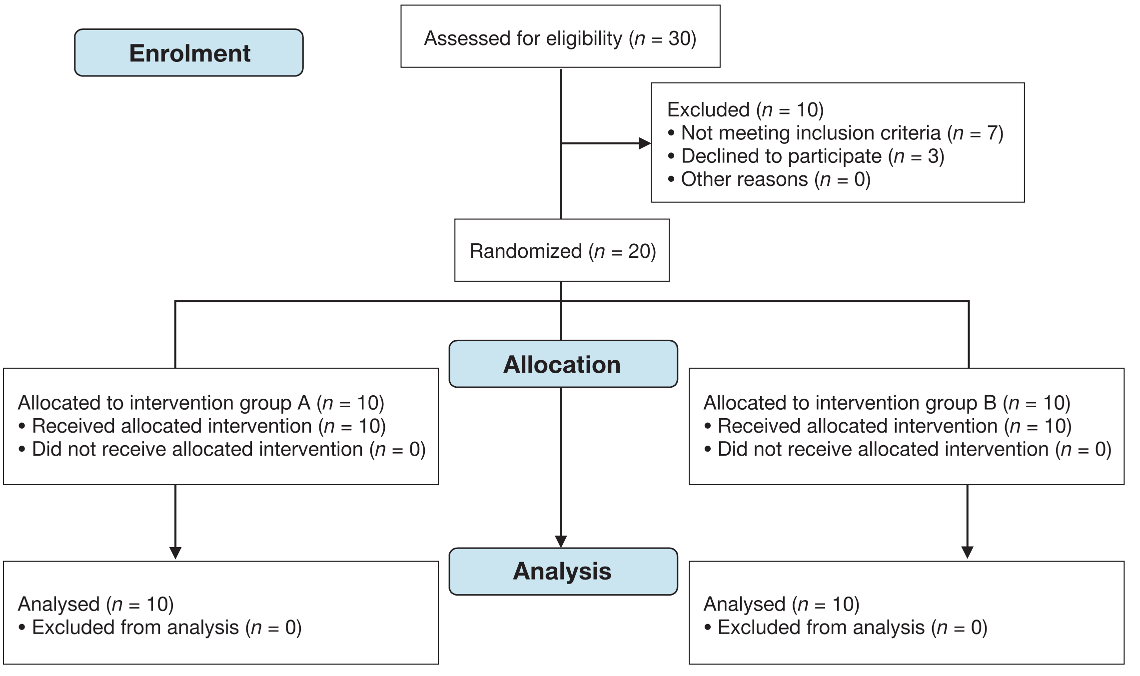

Figure 1. CONSORT 2010 flow diagram

Statistical analysis

Before initiating the clinical part of the study, a pilot study was conducted with 5 participants to determine the appropriate sample size. Power analysis was calculated via power analysis equation at a significance level of 5% and a test power of 80%. The primary outcome measure was the UEFI test value. The power analysis revealed that a minimum sample size of 20 participants were required for the study.

A total of 30 patients were assessed for eligibility to randomize dropouts; 7 were excluded from the study because they did not meet the inclusion criteria and 3 participants declined to participate. Overall, 20 individuals were then randomized for allocation and divided into 2 groups: the experimental group (A) ($n = 10$) and the control group (B) ($n = 10$), as presented in the CONSORT flow chart diagram (Figure 1).

Firstly, the patients' demographic data, including age, body weight, and height, were tested before initiating the study via independent *t*-test to assess homogeneity between the 2 groups. The mean values of age, body weight, and height were 54.20 ± 3.20 years, 88.20 ± 12.90 kg, and 162.10 ± 5.40 cm, respectively, for the experimental group (A) and 56.40 ± 3.60 years, 79.20 ± 13.50 kg, and 161 ± 7.60 cm, respectively, for the control group (B). The independent *t*-test revealed no statistically significant differences between the 2 groups in all tested variables ($p > 0.05$) (Table 1).

Table 1. Patient demographic data

Characteristics	Mean ± *SD*		*t*-test	*p*
	Experimental group (A) *n* = 10	Control group (B) *n* = 10		
Age (years)	54.20 ± 3.20	56.40 ± 3.60	0.137	0.893
Body mass (kg)	88.20 ± 12.90	79.20 ± 13.50	–1.524	0.1448
Height (cm)	162.1 ± 5.40	161 ± 7.60	0.472	0.642

Level of significance at $p < 0.05$

After completing the study, data were collected and outcome measures were coded and investigated with the Microsoft Excel software. Data were then analysed with the Statistical Package for the Social Sciences (SPSS), version 20 for Windows. Data exploration was done to assess normality. Data were normally distributed, with statistically insignificant Shapiro-Wilk test ($p > 0.05$) and normal frequency distribution curves, skewness, and kurtosis. Paired *t*-test was then conducted to compare the pre- and post-intervention results within each group. Independent samples *t*-test was used to compare the results between the 2 groups. Alpha level of significance was set at 0.05 for all the statistical tests.

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Research Ethics Committee of the Faculty of Medical Rehabilitation Sciences, King Abdulaziz University, Saudi Arabia (decision No.: FMRS-EC2020-02-004).

Informed consent

Informed consent has been obtained from all individuals included in this study.

Results

The statistical analysis using paired *t*-test demonstrated a statistically significant increase in the post-intervention mean values of UEFI and grip strength compared with the pre-intervention mean values in the experimental group (A) ($p < 0.05$). In the control group (B), no statistically significant difference was detected between pre- and post-intervention mean values of either UEFI or grip strength ($p > 0.05$). The independent *t*-test revealed no statistically significant differences in the baseline values of UEFI or grip strength between the groups ($p > 0.05$). When comparing the post-intervention mean values between the groups, a statistically significant increase was indicated in UEFI and grip strength in the experimental group (A) compared with the control group (B) ($p < 0.05$) (Table 2).

Table 2. Descriptive and inferential statistics of Upper Extremity Functional Index (UEFI) and grip strength before and after the intervention in both groups

Measured variables	Mean ± *SD*			
	Experimental group (A)		Control group (B)	
	Pre-intervention	Post-intervention	Pre-intervention	Post-intervention
UEFI	42.50 ± 15.70	55.10 ± 12.90	41.1 ± 11.50	50.4 ± 13.47
Grip strength	10.90 ± 14.11	22 ± 19.30	9 ± 3.10	12 ± 5.40

Statistical tests			*t*-test	*p*
Paired *t*-test (pre- vs. post-intervention)	UEFI	Experimental group (A)	2.698	0.024
		Control group (B)	1.254	0.241
	Grip strength	Experimental group (A)	3.757	0.005
		Control group (B)	1.50	0.241
Independent *t*-test (group A vs. group B)	UEFI	Pre-intervention	0.268	0.79
		Post-intervention	4.351	0.02
	Grip strength	Pre-intervention	1.887	0.75
		Post-intervention	3.163	0.005

Level of significance at $p < 0.05$

Discussion

The outcomes of our study proved a statistically significant change in UEFI and grip strength scores in the experimental group in comparison with the control group. This improvement confirms the positive effect of the new VR technology in neurorehabilitation to potentiate motor recovery after stroke [22, 23]. This can be explained by practising upper limb movements in an enjoying experience with instant feedback either in a visual or auditory form [24]. Moreover, the training was applied with constant motivation to complete the session with high acceptability [25]. The repeated practice in such environment enhances the motor performance and induces neural plasticity [26], as evidenced by electroencephalogram data, especially in brain areas concerned with motor planning [27]. In addition, repetitive bilateral training by using the controllers of the VR play from different levels motivates to hit the paddles strongly. The statistically significant improvement in the current study results can also be attributed to the positive effect of both symmetric and asymmetric bilateral activity of the upper limb movement while using the VR play, which helps the patients to be interactive, highly responsive, and more motivated than when performing the routine selected functional tasks of the prescribed task-oriented training program.

Although there was a post-intervention increase in the UEFI and grip strength scores in the control group, it was not statistically significant. This small variation may be due to the programmed repeated performance of meaningful and everyday familiar tasks of the task-oriented training program. One critical element of functional recovery in task-oriented training is the adaptation, which is achieved through focusing on the functional tasks and active participation to fulfil them [28, 29].

The statistically significant improvement of the UEFI and grip strength scores in the experimental group as compared with the control group in the current study remains in line with the results obtained by Lee et al. [30], who examined 18 stroke survivors to evaluate the influence of VR-based bilateral upper limb physical activity on paralyzed upper extremity function and muscular strength.

In the same context, Lee et al. [31] compared the effects of an individualized VR program vs. a group-based rehabilitation program on upper extremity function and certain daily living activities. By using the Fugl-Meyer Assessment and Manual Function Test, they revealed that a greater improvement was induced by the VR training than by the group-based rehabilitation.

However, the current study findings are in opposition to the work by Kong et al. [32], who compared the efficacy of a commercial VR gaming device Nintendo Wii and conventional therapy, both applied for 3 weeks, in facilitating upper extremity recovery among 105 patients within 6 weeks after stroke, indicating no outcome differences in the intervention and control groups. Neither does the present study support the results obtained by Afsar et al. [33], who studied 35 stroke patients (19 in the VR group, 16 in the control group) before and after 4 weeks of intervention and concluded no difference between the investigated groups in the Functional Independence Measure gain or the Fugl-Meyer Assessment gain [33].

Limitations

The current study has some limitations, including patient dropout, which was a reason for the decreased sample size. In addition, the selected VR training game (Super Punch) unfortunately emphasized only the gross motor functions of the upper limb, so we could not train patients for fine movements.

Conclusions

From our study findings, it can be concluded that the VR training program is more effective than the task-oriented training program in improving the upper extremity function after stroke.

Implications

Adding a VR training program to the physical therapy rehabilitation program for stroke patients helps them re-learn the use of their upper limbs and return to normal limb function. The VR training program enhances faster recovery and gain of upper extremity function.

Recommendations

The authors recommend to increase the sample size for future studies investigating the effect of a VR training program in such cases to be able to determine the effect size and generalize the results.

Additionally, we strongly recommended to use a VR training program in a home environment and in many other cases that seek motor control of the upper extremity.

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Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

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