Proceedings of the 2nd
International Serious Games Symposium (ISGS)
December 23-24, 2020, Tehran, Iran

Kinect-based Virtual Rehabilitation for Upper Extremity Motor Recovery in Chronic Stroke

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***Abstract*-Kinect-based virtual rehabilitation improves upper extremity motor function in stroke patients by providing intensive and repetitive exercise. This study evaluated the use of Kinect-based virtual rehabilitation in the upper extremity motor recovery of patients with chronic stroke. In this pre-post study, seven stroke patients performed physiotherapy exercises by using games three times a week for one month. The primary outcome was measuring upper extremity motor function by using the Fugl-Meyer Assessment Scale for upper extremities, and measuring shoulder and elbow range of motion by goniometry. The secondary outcome was measuring the Brunnstrom recovery stages and the Modified Modified Ashworth Scale (MMAS). The data were analyzed in SPSS via the Wilcoxon signed-rank test. The Kinect-based virtual rehabilitation led to motor improvement in terms of the Fugl-Meyer assessment scores (p = .01). The range of motion was also improved in terms of shoulder flexion (p = 0.02) and horizontal shoulder adduction (p = 0.02). All the participants believed that virtual rehabilitation was an enjoyable and motivational method and suggested that the number of games and movements be increased. Therefore, Kinect-based virtual rehabilitation led to motor recovery in the participants. Since the sample size was small, it is recommended that future studies examine larger samples and include a control group.**

***Keywords*-Stroke, rehabilitation, virtual reality, video games**

2020 International Serious Games Symposium (ISGS) | 978-1-6654-1587-3/20/$31.00 ©2020 IEEE | DOI: 10.1109/ISGS51981.2020.9375290

I. INTRODUCTION

Stroke is the second most prevalent cause of mortality and the third cause of disability worldwide [1], [2]. The prevalence of stroke will globally rise due to the increased age of the population. Also, stroke happens in the majority of young people in low- and middle-income countries [3]. Upper extremity motor disorders are the most common disorders resulting from stroke, and include muscle weakness, alterations in muscle tone, impaired motor control, limitations in the range of motion of joints, contractions, or laxity [4]. Intensive and repetitive rehabilitation, based on the performance of specific intensive tasks, is essential for upper extremity motor recovery [5]- [7]. The rehabilitation of upper extremities in stroke patients may take a long time, thereby increasing costs for the patients [8]. Moreover, if the treatment is prolonged, the active participation of the patients in performing the tasks will be reduced, and patients will lose the motivation to continue treatment [9]- [11]. The use of technology in rehabilitation is rapidly expanding. One such technology is virtual reality, which is known as an effective intervention in rehabilitation [12]. Kinect-based virtual rehabilitation is an inexpensive method that provides a simulated environment, induces a sense of active participation in patients for performing the tasks, and thus motivates them [13]. A unique feature of Kinect is providing a method for interaction with the game without using any controllable or wearable device. Users can perform the games or exercises by using natural movements and view their performance live on the monitor [14], [15]. Various studies have demonstrated that Kinect-based virtual rehabilitation leads to upper extremity motor recovery, while also keeping the patients motivated and active throughout the course of treatment by having them perform tasks with more repetitions [16], [17]. Despite the advantages of these games, some studies have reported that commercial games used in rehabilitation of stroke patients do not yield effective results in terms of upper extremity motor recovery compared to traditional rehabilitation methods [18]- [20]. As commercial games are usually designed for healthy people and involve complex and rapid tasks, stroke patients often face problems when playing these games due to their heterogeneous and limited abilities [21]. Therefore, this study aimed to design and evaluate Kinect-based games and assess their effects on upper extremity rehabilitation for patients with chronic stroke.

II. Methods

A. *Participants*

This cross-sectional study was conducted in a rehabilitation clinic affiliated with Tehran University of Medical Sciences. Seven patients with chronic stroke who visited this clinic were selected. The inclusion criteria were: 1) being in the chronic stage of stroke, 2) not having other disorders, e.g. neurological disorders, rheumatism, and orthopedic disorders, 3) being able to understand the commands for playing the games, and 4) being in Brunnstrom Stage 2, 3, 4, or 5. The exclusion criteria were: 1) delirium, severe consciousness problems, and confusion, 2) uncontrolled medical conditions, 3) inability to follow the commands due to cognitive problems, and 4) visual impairment. This study was approved by the Ethics Committee of Tehran University of Medical Sciences (IR.TUMS.SPH.REC.1396.2633).

B. *Study design*

In this pre-post study, seven patients with chronic stroke who visited the physiotherapy clinic of the School of Rehabilitation, Tehran University of Medical Sciences, were selected. This study was the second stage of evaluating virtual reality-based games for patients with chronic stroke, the first stage of which had been conducted on 10 patients with stroke [22]. The patients were first evaluated by a physiotherapist. All the patients were informed of the objectives of the study and provided written informed consent. Before the intervention, the way the games were played was first explained to the patients, and then the intervention was provided. The participants performed physiotherapy by using these games for one month (three times a week, in sessions of 45 minutes to 1 hour). During the intervention, they performed rehabilitation exercises only through games, and no therapeutic exercise using other physiotherapy methods was performed. Also, patient assessment was made by a physiotherapist who was not involved in the administration of the study intervention.

C. *Kinect-based virtual rehabilitation:*

First, the method of providing rehabilitation to stroke patients was identified by a review of specialized books and articles. Some therapeutic exercises used for the upper extremity rehabilitation of stroke patients were selected based on The Brunnstrom Approach and examined by nine physiotherapy professors for final confirmation. Then, a questionnaire was developed to identify the features of the games from the viewpoint of computer game design experts and physiotherapy professors. This questionnaire was also sent to nine physiotherapy professors and 11 game developers. The content validity ratio (CVR) was calculated to examine the validity of these two questionnaires. Based on this index, the minimum acceptable value of CVR for samples of 9 should be 78%, and values less than this do not indicate validity. Moreover, the minimum acceptable value of CVR for samples of 20 for the games' content analysis should be 42%. After designing the games and before the intervention, nine physiotherapists who had also participated in the survey part were asked to play the games once and express their opinion while playing (think-aloud method). Subsequently, their opinions were applied to the games [23]. The games were developed in Unity (v. 5.3) or in C#. Unity is a cross-platform game engine that can support programming languages and Kinect [24]. The hardware required for running the games included an XBOX 360 Kinect and a computer system (Fig. 1). The XBOX 360 Kinect is cost-effective and its main feature is that it does not need any wearable when playing the games [15], [25]. The virtual rehabilitation software included four games, each covering a specific type of rehabilitation movement (Fig. 2):

1) *Butterflies:* In this game, some butterflies are placed on different parts of the body, and the player must make them fly away by performing the intended movements.

Movements: elbow flexion/extension with supination, and horizontal shoulder abduction and adduction.

2) *Space War:* The player moves a spaceship forward by his/her hands and protects it from being hit by meteorites thrown at it. This game can be adapted based on the affected side of the body, and there is an icon for selecting the left or right hand. In this game, the score is calculated by eliminating the meteorites. This game also has audio features. Movements: shoulder flexion/extension with elbow extension, and horizontal shoulder adduction/abduction with an extended elbow
3) *Snowflakes:* The player catches snowflakes by extending his/her arms, and receives scores. The challenge is the speed, which is increased after reaching a score of 10, and the player has to adjust the speed of his/her hands to the rate of falling of the snowflakes. When the time is up, the score is calculated and displayed. Movements: shoulder flexion/adduction, elbow bending, horizontal shoulder adduction/abduction with elbow supination
4) *Tubes:* The player should direct a green object through three tubes, and the tubes disappear when the green object reaches the end of the tube. Movements: elbow flexion/extension, elbow supination, and horizontal shoulder abduction/adduction

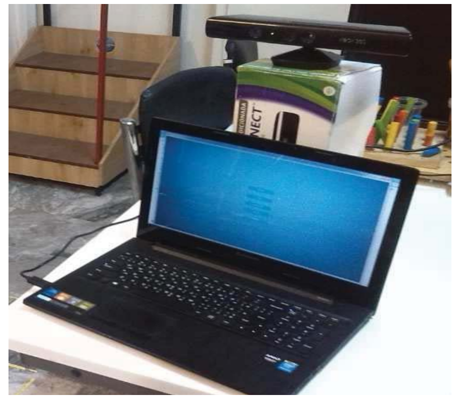

Fig. 1. Hardware used in the game design

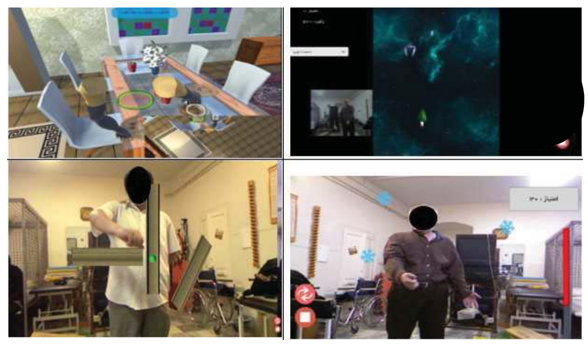

Fig. 2. VR-based game

D. Primary outcome measure

The upper extremity motor recovery level was evaluated by the Fugl-Meyer assessment scale. This test examines five domains of the upper extremity, lower extremity, balance, sensory function, and range of motion, via 155 items. For the upper extremity motor function, this scale examines shoulder, elbow, wrist, and hand reflexes, as well as coordination and speed (32 items). Each task is scored on a three-point scale: (0=cannot perform, 1=can partially perform, 2=can perform fully) [26]. The scores for motor function range from 0 to 100 (full recovery). The section belonging to upper extremity motor function (total score of 66) was employed in this study. In [27], the reliability of this section is reported to be 97-99%.

Moreover, goniometry was performed to measure the shoulder and elbow range of motion.

E. Secondary outcome measures

The secondary outcome was measuring the stages of recovery by The Brunnstrom Approach and the Modified Modified Ashworth Scale (MMAS). The Brunnstrom Approach evaluates muscle tone, stages of recovery, motor patterns, speed of motion, and prehension patterns, and has six stages of recovery: Stage 1 (flaccidity): not able to perform any movement. Stage 2 (spasticity appears): synergy appearing between limbs or some of their parts in the form of reactions. Stage 3 (increased spasticity): voluntary control of motor synergies. Stage 4 (decreased spasticity): performing motor combinations that do not follow synergies. Stage 5 (complex movement combinations): synergies not being dominant anymore. Stage 6 (spasticity disappears, except in rapid movements): performing extended isolated movements. The Brunnstrom movements focus on the upper extremity, hands, and lower extremity [28]. In this study, the part belonging to upper extremity movements was utilized. In [29], the reliability of The Brunnstrom Approach has been confirmed. The MMAS was employed for evaluating the spasticity and tone of flexor muscles in elbow and wrist joints. It is scored from 0 to 4, with a score of 0 showing normal muscle tone, and a score of 4 indicating rigid flexion or extension [30]. The high reliability of this scale for different joins of stroke patients has been demonstrated [31], [32].

F. Usability evaluation:

A researcher-made questionnaire was administered to examine the usability of the games. This questionnaire had nine items scored from 1 to 5 to assess patient satisfaction. A scoring scale of 1-5 in this questionnaire showed the minimum degree of effect (1) to the maximum degree of effect (5). The questionnaire also contained two open-ended questions to collect patients' comments on the use of the games for treatment and their suggestions for making these games usable for treatment. The answers were analyzed based on the main themes and the number of respondents.

G. Statistical analysis:

The mean and standard deviation (SD) were calculated, and the statistical analysis was performed in SPSS v.20. The Wilcoxon signed-rank test was performed to compare the variables before and after the intervention.

III. RESULTS

There were seven participants, including three women and four men (Table 1). The mean and SD of their age was 51.57 ± 18.43 years, and the mean and SD of the time elapsed since the stroke was 5.71 ± 5.64 years. Moreover, the mean Fugl-Meyer score was 31.71 ± 9.62 at the beginning of the study.

A. Primary and secondary outcomes

As for the primary outcomes, the mean Fugl-Meyer scores were improved following the intervention ($p = 0.01$) (Table 2). Furthermore, the range of motion was enhanced in terms of shoulder flexion ($p = 0.02$) and horizontal shoulder adduction ($p = 0.02$). However, the intervention did not bring about any improvement in the range of motion of horizontal shoulder abduction, elbow flexion, elbow extension, supination of the wrist, wrist flexion, extension of the wrist, or the MMAS test. As for the secondary outcome, the intervention did not improve the Brunnstrom stages of recovery (p = 0.3).

Table 1. Demographics and clinical characteristics of the participants

Participant ID	Age, years	Gender Male(M) / Female(F)	Time since Stroke, years	Affected side Right(R)/ Left(L)	Baseline FMA-UE scores
1	73	F	1	L	42
2	56	M	10	L	27
3	58	M	16	L	23
4	34	F	7	L	33
5	54	M	3	L	35
6	66	M	2	R	18
7	20	F	1	R	44

FMA-UE: Fugl-Meyer Assessment Scale of Upper Extremity

Table 2. Changes of outcomes from pre- to post-training

Outcomes		Pre-intervention, (Mean ± SD) N=7	Post-intervention, (Mean ± SD) N=7	**p-value**
FMA-UE total (scores)		31.71±9.62	37.28±10.62	.01
Measurement with Goniometer	*Flexion* shoulder	73.85±50.21	86.00±48.84	.02
	Horizontal abduction shoulder(Degrees)	67.14±13.89	74.28±18.08	.10
	Horizontal adduction shoulder(Degrees)	30.14±12.56	34.57±10.13	.02
	Flexion elbow(Degrees)	89.42±52.98	114.71±28.42	.06
	Extension *elbow*(Degrees)	102.14±43.41	106.14±42.44	.2
	Supination of wrist (Degrees)	20.71±31.14	23.57±31.05	.1
	Wrist flexion(Degrees)	10.71±12.05	20.71±22.44	.1
	Extension of wrist (Degrees)	11.28±13.09	17.14±19.11	.1
MMAS	Elbow flexors	.85±.69	.57±.53	.3
	wrist flexors	1.28±1.25	.57±.53	.1
Brunnstrom Stages	UE	3.57±1.13	3.71±1.38	.3

FMA-UE: Fugl-Meyer Assessment Scale of Upper Extremity, MMAS: Modified Ashworth Scale, UE: Upper Extremity

B. Evaluation of the virtual rehabilitation software by the patients based on the questionnaire and their suggestions

All the participants were satisfied with the feedbacks in the games and believed the games were enjoyable, motivating, and challenging. The mean score was > 4 (Table 3). However, the participants were not completely satisfied with the characters in the game, the fact that the games would help patients regain their independence, and the ease of use of the software, and gave a score of < 4. The first open-ended question was: “What do you think about the use of these games for treatment?”. The majority of the participants viewed the games as enjoyable and motivational for treatment, and most of them suggested that these games be played at home to avoid commutes. The second question was: “What do you suggest for improving the games?” All the participants suggested that the number of the games be increased, and other games be designed for other parts of the body, such as the wrist and toes. They also suggested that a reporting system be included in the games to record their performance and process of recovery. Some participants recommended that the speed of the games be increased and the feature of personalization based on the player’s abilities be added.

Table 3. *Results of system evaluation with questionnaire at post-training*

Questions	Participant ID							Mean
	1	2	3	4	5	6	7	
The feedbacks in the games are useful and easily understandable.	4	5	3	4	5	4	4	4.14
The character in the games lets me be part of the game.	4	3	5	4	3	4	4	3.85
Playing the games is enjoyable and motivates me to continue treatment.	5	5	5	5	4	5	4	4.71
After the games, I am motivated to play again.	5	4	4	4	5	5	5	4.57
Playing the games is challenging for me.	4	5	4	5	3	5	5	4.42
Exercising with these games helps me become more independent.	3	2	4	3	4	3	3	3.14
By playing these games, I try to perform new tasks with the affected side of the body.	4	5	5	4	5	4	3	4.28
I am satisfied with the increased level of challenge during the games.	5	2	4	4	5	3	5	4
It is easy to learn and use the program.	4	3	5	3	4	4	4	3.85

Notes: 1 = strongly disagree; 2 = disagree/seldom; 3 = neutral/cannot decide 4 = agree and 5 = strongly agree

Table 4. *Patient's response to the virtual reality-based game*

Questions	Comments	Frequency
What do you think about the use of these games for treatment?	The games are enjoyable and motivate me for treatment.	6
	The challenges in the games are easy.	4
	It is an interesting method of rehabilitation.	3
	Playing the games at home	5
What do you suggest for improving the games?	Increasing the number of games and including more movements in them	7
	Including patient information reporting and recording systems to display the process of recovery	5
	Personalization by the physiotherapist based on patients' level of ability	2
	Increasing the speed and precision of the games	4

IV. DISCUSSION

This study examined the effect of Kinect-based virtual rehabilitation for upper extremity rehabilitation in stroke patients. Motor recovery was observed in terms of Fugl-Meyer scores, as well as shoulder flexion and horizontal shoulder adduction, after the intervention. The participants described virtual rehabilitation as motivational and interesting and asked for more games and movements, as well as the ability to play the games at home.

Kinect-based rehabilitation is a novel technology in neural rehabilitation [33]. In a meta-analysis by Karamians et al., it has been shown that the use of virtual reality-based games is generally more effective in the treatment of stroke patients compared to traditional physiotherapy methods [34]. The findings of other studies also indicate that Kinect-based rehabilitation is a useful, interesting, safe, and motivational method for patients, and enhances their adherence to treatment [35], [36]. Different feedbacks such as scores (to demonstrate the performance), a challenge level appropriate for the players' abilities, and a simple user interface, were included in the design of the virtual rehabilitation. Based on various studies, features such as positive feedback, a challenge proportionate to the patients' level of cognitive ability, social interaction, a simple user interface, and reporting, are effective in increasing patients' motivation [37]- [39]. However, in our study, the games did not present reports on the patients' performance and did not include social interaction with other patients.

Kinect-based virtual rehabilitation led to motor recovery in terms of Fugl-Meyer assessment and shoulder movements, a result that is consistent with that of similar studies [40]. Based on our findings, the use of virtual rehabilitation for four to five weeks leads to the motor recovery of patients with chronic stroke, a result that is in line with that of similar studies [41], [42]. In [43], Kinect-based rehabilitation technology was an effective method for rehabilitation of stroke patients even in the short term (two weeks). Moreover, other studies have reported that Kinect-based rehabilitation is a complementary method for other physiotherapy methods, and an effective and beneficial method for the rehabilitation of upper extremities in stroke patients [38], [44], [45]. In these studies, Kinect-based rehabilitation was performed in addition to other physiotherapy methods, whereas in the present study, only Kinect-based rehabilitation was used. Evidence suggests that repetitive and regular exercise is beneficial to the rehabilitation of patients with chronic stroke [46]. The Kinect-based virtual rehabilitation in the present study was an enjoyable and motivational method for patients. It provided them with repetitive and regular exercise at a high dose in an acceptable duration of treatment (three times a week for a month, in sessions of 45 minutes to 1 hour), similar to other studies [47], and is thus an effective therapeutic method for the physiotherapy of stroke patients.

This study had three limitations. First, no control group was included; therefore, no claim can be made as to the superiority of virtual rehabilitation over regular physiotherapy methods. Second, the sample was small; thus, the results cannot be generalized to all stroke patients. To further confirm the findings of this study, a randomized controlled trial with a larger sample is needed. Third, the software and the games did not allow the physiotherapist to monitor the performance and recovery of the patients, and did not have a reporting feature.

V. CONCLUSION

The Kinect-based virtual rehabilitation led to motor recovery in the patients. Still, to further confirm this findings, a randomized controlled trial with a larger sample is required. Owing to appropriate feedbacks, a simple design, and challenges appropriate for the players' ability level, these games enhance patients' motivation for continuing their treatment.

Acknowledgments

The authors are grateful to the physiotherapy clinic of the School of Rehabilitation, Tehran University of

Medical Sciences, for assistance in evaluating the games.

Financial support**:** By Tehran University of Medical Sciences (TUMS)

Conflict of interest**:** none

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