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Virtual Reality Games for Rehabilitation of Upper Extremities in Stroke Patients

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Virtual Reality Games for Rehabilitation of Upper Extremities in Stroke Patients

Abstract

Introduction: Stroke is one of the main causes of physical disability in which doing frequent and early exercise is imperative for rehabilitation. Virtual reality gaming has a high potential in rehabilitation leading to increased performance of patients. This study aimed to develop, validate and examine virtual reality games in chronic stroke patients.

Methods: This was a single before-after study. To determine the movements and content of games, 9 physiotherapists and 11 game designers were asked to participate in a questionnaire-based survey. Then, to evaluate the impact of games on rehabilitation, patients (N = 10; mean age = 52 ± 4.38) with chronic stroke were asked to play the games three times a week for four weeks. Outcomes included measurement of the ability to perform shoulder, elbow and wrist movements was performed using goniometric instrument, Modified Motor Assessment Scale (MMAS) was used to assess the functional ability of patients and muscle spasticity, and brunnstrom's stages of recovery test was also used to assess spastic and involuntary muscle movement

Results: Games have positive effects on the horizontal abduction of shoulder (16.26±23.94, P= 0.02), horizontal adduction of shoulder (59.24±74.76, P= 0.00), supination of wrist (10.68±53.52, P = 0.02), elbow flexion (0.1±1.5, P= 0.00), and wrist flexion (0.06±1.34, P = 0.03). However, they had no effects on the flexion of shoulder, flexion of elbow, extension of elbow, and extension of wrist (p-value> 0.05).

Conclusions: The results showed that games improve the range of motion of the participants in terms of horizontal abduction and abduction of the shoulder, elbow flexion, and supination and flexion of the wrist. Due to the small sample size in this study, we recommend more studies with larger samples and a control group.

Key words: Virtual Reality, Games, Stroke, Rehabilitation, Upper Extremities

1. Introduction

Stroke is one of the main causes of disability (Samuel et al 2015), and the third leading cause of death in the world. According to World Health Organization's 2015 report, stroke accounts for 11% of all deaths in the world (Global Health Estimates. Geneva:World Health Organization 2016). Its annual incidence in Iran is estimated to be between 23-103 per 100,000 persons that will be increased over the years with aging. About 30-40% of people who survive stroke, suffer from severe disabilities (Firoozabadi et al 2013; Hosseini et al 2010). Stroke-induced disorders include disturbances in consciousness, physical disorders (power, great range of movements, and coordination), cognitive impairment (memory, language, and perception), visual disturbances, emotional problems, and urinary disorders (Riddoch et al 1995) which affects the quality of life and the level of individuals' autonomy (Turolla et al 2013).

Hemiparalysis is the most common post-stroke disorder. Survivors of the stroke refer to Hemiparalysis of upper limbs as the most common problem that they experience (Adey-Wakeling and Crotty 2013). After stroke, paralysis remains an important clinical problem among the stroke patients in which only less than 50% of people show varying degrees of functional or motor improvement (Crosbie et al 2012). The rehabilitation program for stroke patients involves performing specific, repetitive, intense and meaningful tasks for the promotion and improvement of nerves and movements. A post-stroke intensive rehabilitation is needed to maximize the results, improve hospitalization and reduce long-term costs (Lang et al 2015; Rensink et al 2009). In addition, studies conducted on the intensity of rehabilitation programs (i.e. number of movements per session), have shown a direct relationship between the number of movements and the levels of patients' recovery (Peiris et al 2011).

Studies have shown that patient motivation for rehabilitation is one of the important factors for continuation of the treatment and improving the patients' outcome (Maclean et al 2002). On the other hand, use of technology in the healthcare industry is increasing (Safdari et al 2012; Shahmoradi et al 2007). In recent years, use of technology based on neural rehabilitation approach is growing due to the increase in demand and stroke prevalence (da Silva Cameirão et al 2011). Neuroscience studies have shown that virtual reality games provide feedback on movement features and improves the ability to learn and perform tasks in the right way in comparison with traditional approaches. Virtual reality gaming provides various virtual environments to be applied in rehabilitation of interaction between virtual objects and movements using motion tracking (Bashiri et al 2017; Cho et al 2014). Games based on virtual reality for stroke rehabilitation are mainly focused on motor rehabilitation. Nevertheless, interest in the integration of cognitive and motor rehabilitation has grown. Research shows that the use of virtual reality-based games improves the range of motion as well as the memory and attention of stroke patients (Faria et al 2018; Clay et al 2020; Micarelli et al 2019).

Benefits of virtual reality games include diverse and intensive exercises, designing exercises tailored to patients' abilities, monitoring patients' progress, and boosting patients' motivation (Lehmann et al 2017). Game-based virtual reality is an emerging technology in healthcare allowing users to interact with a dynamic 3D environment. Studies show that this technology is an effective, feasible and safe solution which makes rehabilitation more convenient (Saposnik et al 2010; Torabi et al 2010). In addition, computer games increase motivation, satisfaction and involvement of patients (Chen et al 2015).

Virtual reality games are promising tools today as they provide repeatable task-based, reward-based, and interactive situations required for rehabilitation of patients after brain injury (Tatla et al 2015). Thus, the purpose of this study was to develop, validate and examine virtual reality games in chronic stroke patients.

Methods

2.1. Subjects

This was a cross-sectional study conducted at a rehabilitation clinic affiliated with Tehran University of Medical Sciences. Ten chronic stroke patients who were admitted to rehabilitation facility were included in this study. Inclusion criteria were as follows: 1) to be in the chronic phase of the disease (more than one year after stroke), 2) not to have other disorders including neurological, orthopedic or rheumatologic disorders in the upper limb, 3) ability to understand the instructions for responding to sensory tests and exercises, and 4) to have a score of 2, 3, 4 or 5 according to Brunnstrom's scale. Exclusion criteria were also defined as follows: 1) delusions, severe problems of consciousness and confusion, 2) uncontrolled medical conditions, 3) inability to follow orders due to cognitive problems, and 4) visual impairments.

This study was approved by Tehran University of Medical Sciences Ethics Committee (IR.TUMS.SPH.REC.1396.2633) and carried out according to the institutional guideline and principles of the Declaration of Helsinki (World Medical Association 2018). The study was supported by the University Research Fund. All subjects understood the purpose of this study and provided their written informed consent prior to their participation in the study.

1.2.Determining rehabilitation exercises

The rehabilitation process of patients with stroke was identified through reviewing pertinent document and literature. A number of therapeutic exercises used in the upper limb rehabilitation of patients with stroke were selected based on one of the common therapies, Brunnstrom's method. Brunnstrom's method is one of the important therapeutic methods in physiotherapy and rehabilitation of stroke patients, in which the treatment is based on the use of patient's existing motor patterns during the recovery process (Brunnstrom 1966). Subsequently, these exercises were sent to the 9 physiotherapists via email to be reviewed and examined in terms of clinical effectiveness (Supplementary data). In order to evaluate the validity of the questions, Content Validity Ratio of the questionnaire (CVR) was calculated for each question in the questionnaire. The numeric value of content validity ratio is determined by Lawshe Table. Content validity ratio varies between 1 and -1. The higher score indicates further agreement of members of panel on the necessity of an item in an instrument. The formula of content validity ratio is CVR=(Ne - N/2)/(N/2), in which the Ne is the number of panelists indicating "essential" and N is the total number of panelists. For example, in this phase of our study that the number of panelists is 9, if CVR is bigger than 0.78, the item in the instrument with an acceptable level of significance will be accepted (Lawshe 1975).

The feedbacks of the experts were collected. Considering the fact that some of the experts criticized the privilege or lack of priority of some of the selected exercises, the exercises were re-evaluated based on the motor recovery stages of adult hemiplegia patients and the suggestions of some experts and the modified questionnaire was sent back to physiotherapist for approval (Supplementary data).

1.3.Designing game content

In the next step, to create the content of the games, a questionnaire (Supplementary data) was developed and was sent to the same 9 physiotherapists participated in determining rehabilitation exercises phase and 11 game designers. Content of computer game exercises were designed based on three stages of patient recovery of Brunnstrom's method i.e. stage 3, 4 and 5 (Brunnstrom 1966). In addition, specialized articles in this field were reviewed to determine the content of the games. In order to evaluate the validity of the questions, Content Validity Ratio (CVR) was calculated. Items with a CVR less than 0.42 were removed and items above the threshold were accepted (Lawshe 1975). Table 1 shows the characteristics of the designed games and the type of movements employed in each of them (see Table 1).

Game designing was performed using the unity environment (version 5.3). Unity is a multi-platform gaming engine, which can be used to create games for many platforms. This engine supports C#, Javascript and boo programming languages and is capable of running on Windows, Mac, Linux, iOS, Android, Web and Flash. It also supports multi-player and network-based games. Unity also has the ability to support Kinect (Pedraza-Hueso et al 2015) and it uses C-sharp language to write codes in monolingual compiler environment. To track patients' movements, Kinect sensor (Xbox 360) was used. The sensor has an RGB camera, a deep sensor, and a multi-layer microphone capable of tracking the body's three-dimensional movements, and the ability to detect faces and sounds. These features allow Kinect to define and recognize patients' body movements. Kinect's most important feature is that it does not need to use any wearable devices (Ebert et al 2015). Various studies have proven the usefulness of this sensor in the rehabilitation of patients with stroke (Acosta 2012; Webster and Celik 2014). In this study, a Lenovo's laptop (G50, Windows 7, 4GB RAM) was used to design the games. The features and contents of the games are shown (see Table 2).

1.4.Intervention

Patients underwent a virtual reality game- based rehabilitation program 3 days for a total of 4 weeks. The Xbox Kinect and laptop were set up in a quiet room so that external factors would not influence the results. Patients could either sit on a chair or stand up to play the games.

Patients were 1.5-2 m away from the Kinect sensor. Instructions on how to play each game were given to patients before the session was started and they were shown how to play during the session as well. The following games from the game design phase of this study were used; Butterfly, Space War, Snow, Tubes and Virtual Home (see Table 1). The sessions required active movements of the upper extremity. The patients actively performed bilateral flection/extension of elbow and flection/extension of shoulder in all games. In total 12 sessions were held with a duration of 45 minutes per session. In this study, the movements induced by the games were designed based on Brunnstrom's 3, 4 and 5 stages of recovery. For example, "Butterfly" game was designed based on stage 2, 3, 4 and 5, "Space War" was designed based on stage 2, 3, 4 and 5, "Snow" game was based on stage 2, 3, 4 and 5, "Tubes" game was based on stage 4 and 5 and "Virtual Home" game was based on stage 4 and 5. Each patient practiced for 45 minutes based on their capabilities and interests. For instance, the patients in stage 3 could play Butterfly Snow and Space War, and the patients in stages 4 and 5 could play all the games. During the 4 weeks of the intervention, patients succeeded to complete all their 12 sessions and use all the designed games.

1.5.Evaluation

Patient assessment was made by a physiotherapist who was not involved in the administration of the study intervention. Measurement of the ability to perform shoulder, elbow and wrist movements was performed using goniometric instrument (see Fig. 1). Modified Motor Assessment Scale (MMAS) was used before and after the intervention to assess the functional ability of patients and muscle spasticity. Brunnstrom’s stages of recovery test was also used before and after the intervention to assess spastic and involuntary muscle movement.

1.6.Statistical Analysis

The SPPS 20 statistical software program was used for data analysis and evaluation. Mean ± standard deviation values of the variables were calculated. Considering the limited number of samples (n=10) Wilcoxon's non-parametric test was used to examine the variables before and after the intervention.

1.7.Game usability evaluation

Before proceeding with patient intervention, through application of loud thinking method and use of a questionnaire (Supplementary data), the usability of the designed games was evaluated by the 9 physiotherapists and amendments were made where necessary based on physiotherapists comments. Later, after the intervention, a questionnaire was also used to evaluate patients' satisfaction (Supplementary data). This questionnaire was comprised of nine questions. The rating score ranged from 0 to10, with zero indicating the lowest impact and 10 indicating the highest impact. This questionnaire was given to patients and their opinions and comments were collected. All ten patients completed the questionnaire. Collected data were analyzed using SPSS software.

Fig. 1. Measuring shoulder movement by goniometric instrument

Table 1

Characteristics of the designed games and applied movement types

Table 2

Features and contents of the games based on virtual reality

2. Results

3.1. Demographics

The average work experience of physiotherapists who completed the questionnaires was 20 years and their average age was 43 years. The average work experience of game designers was 4 years and their average age was 25 years.

10 patients (4 women and 6 men with an average age of 52 ± 4.38 years) with chronic stroke participated in this study to play with the designed games. The demographic characteristics of patients are shown (see Table 3).

Table 3

Demographic information of stroke patients

2.2.Determining the rehabilitation exercises

The results of the motivation analysis related to determining the rehabilitation exercises showed that among the selected movements only movements such as touching the chin, mouth, ear, and opposite shoulder, regardless of forearm position (Pronation/ Supination) of healthy side, lifting the affected hand up from the front to horizontal level, moving out and in the upper limb to the side of the body (abduction and adduction of shoulder), raising the shoulder from the front or sides more than 90 degrees, extending hands forward to get objects by both hands, holding a ball or box with two hands and lifting it up and taking it down, holding a ball or box with two hands and pushing it out or in towards the body had the necessary validity from experts' point of view. The results of CVR analysis related to the rehabilitation movements are shown (see Table 4).

Table 4

The results of CVR analysis related to the rehabilitation movements

2.3.Determining the game content

To determine the reliability of the questionnaire related to game content, 9 physiotherapists and 11 games makers (CVR> 0.42)(Lawshe 1975) were asked to evaluate the content of the games. The results have been shown (see Table 5).

Table 5

Results of CVR analysis related to the game content

In order to create entertainment in the game, use of avatars, picking objects and scores were considered necessary and to motivate use of games, avatars and scoring were considered necessary. Moreover, experts who participated in the questionnaire-based survey related to content of games believed that using incentive elements and bonuses during the game help to create motivation. Repeatability of the games was another essential item. Considering the fact that in patients with stroke, right or left side of body can be affected, the possibility of creating an icon for choosing the right or left hand was considered necessary. To create feedback in the game, voice and rating throughout the game was considered important. The use of game, ease of learning it and the closeness of the games' content to daily activities of patients were identified as essentials. In order to create a challenge throughout the game, speed, time and barriers were also considered as essentials. Physiotherapists and game designers' comments on the movements and content of the games were recorded separately (see Table 6).

Table 6

Physiotherapists and game designers' comments

2.4.Intervention outcome

The intervention was implemented on chronic stroke patients. Ten patients (4 women and 6 men) with chronic stroke were selected based on inclusion and exclusion criteria and their performance were evaluated using a goniometer, Modified Ashworth Scale *(*MMAS) and Brunnstrom's steps of recovery before and after intervention, playing the games. The results of the analysis of goniometer and MMAS variables are shown (see Table 7). The intervention results indicated that the games have positive effects on the horizontal abduction of shoulder (16.26±23.94, P= 0.02), horizontal adduction of shoulder (59.24±74.76, P= 0.00), supination of wrist (10.68±53.52, P = 0.02), elbow flexion (0.1±1.5, P= 0.00), and wrist flexion (0.06±1.34, P = 0.03). However, they had no effect on other variables including shoulder flexion, elbow flexion, elbow extension, and wrist extension, (p-value > 0.05).

Brunnstrom's stages of recovery test was used before and after the intervention, and patients' progress was not measured from one stage to the next. However, improvement in some of the patients' movements related to the same stage was seen. For instance, one of the patients at the third stage of the Brunnstrom's, had improved shoulder flexion from zero to 60 degrees and another patient had limited improvement in the elbow supination.

Table 7

The functional outcomes at before and after intervention

2.5.Evaluating usability of the designed games

In this stage, in order to evaluate the usability of the designed games by using active thinking method, nine physiotherapists, who had also participated at the first stage in the survey, were asked to play the game once and comment on the game during the play. Physiotherapist comments were applied to the prototype of the games and then were evaluated on the patients (see Table 8). The first column in this table includes the comments, and the second and third columns contain applicable and non-applicable items respectively. The applicable items were applied to the primary version of the game.

Table 8

Physiotherapist comments at the game evaluation stage

Nine physiotherapists were then asked to complete a questionnaire related to the game content whose validity was confirmed in the previous stage. The score ranged from 1 (the lowest) to 10 (the highest) and the mean scores for each question were separately calculated (see Table 9).

Table 9

The questionnaire related to the game content

As a final point, a questionnaire was used to assess patients' satisfaction regarding the designed games (see Table 10).

Table 10

Average scores given to the games by patients

3. Discussion

The present research was aimed to examine the application of virtual reality games in stroke rehabilitation. Overall results indicate that there is a beneficial role of application of this approach in on the horizontal abduction and abduction of shoulder, elbow flexion, supination and flexion of wrist. Since rehabilitation exercises are often long and tedious, patients have no incentives to continue treatment (Rand et al 2014). Studies also show that there is a direct relationship between the number of movements and recovery (Cooke et al 2010; Lang et al 2015). Use of video games leads to repetition of movements and motivates patients to continue with their treatment (Rand et al 2014). Similar to different studies (jaume-i-Capó et al 2014; Shah et al 2014), entertainment elements, motivation factors, feedback mechanisms and different levels of challenges were applied to design the games as follows. To make the games more fun, avatars, collecting objects and giving feedback as points were used as well.

- To motivate patients, avatars, score and matching content of the games to daily activities were used.
- The ability to repeat the game was considered and also an icon to change the left or right hand was designed on the screen.
- Points and sounds were used to give feedback throughout the game.
- To create challenge levels in the games, time, speed and escape were used for simple learning and the games were designed as simple as possible. Simple graphics were also used to avoid distraction.

In the study of Pham et al, avatars, collecting objects, rating for motivation, and also the ability to repeat the game and time constraints for challenge were used (Pham et al 2015). In the Antonio Jam et al study, the items that were considered for the design of a game include the creation of a pre-template, the mechanism of interaction, the elements of interaction in the game, the feedback, adoptability and monitoring of patient’s progress (Jaume-i-Capo et al 2014).

The results of this study are similar to other studies indicating that motivation of patients is higher when using virtual reality games than conventional methods (Chang et al 2011; Ma et al 2011). One explanation is that using virtual reality games distorts one's attention from reality, and improves performance and efficacy of patients. Moreover, patients do not have motivation in routine rehabilitation exercises because they do not have the option to choose (Shah et al 2014). Studies also show that use of game design parameters encourage patients to actively participate by making the games more enjoyable and encourage patient to play longer (Shah et al 2014). Creating positive feedback in the game would motivate patients to continue with their rehabilitation sessions (Lewthwaite and Wulf 2010). Feedback is any information about the patient's condition. In this study, feedback was created through application of points and sounds while playing.

In this study, games have been designed using the Unity engine and the C# language, and Kinect sensor was used to track the movements. These games can be used to rehabilitate stroke patients from the early to chronic stages of stroke. Unlike studies conducted on the design of games for the upper limb rehabilitation of stroke patients, in which participants had to wear wearable equipment such as gloves or a device (Cameirão et al 2010; Saposnik et al 2010), in this study, Kinect sensors in the games were used to track movements which makes it more feasible economically in settings with resource limitations. One of the benefits of Kinect sensor is that, the user is placed in front of it in both sitting and standing position, it is able to track movements, and also it does not need any wearable devices to control the game (Ebert et al 2015).

The results of this study (Liao et al 2018) showed that the use of games improves the range of motion in horizontal abduction and abduction of the shoulder, elbow flexion, and supination and flexion of the wrist. In a similar pre-post study that used Kinect-based rehabilitation for 10 stroke patients, the treatment improved the range of motion in the upper limbs of the patients. In the similar study (Yavuzer et al 2008), together with the conventional methods of physiotherapy, video games were used and the results showed that recovery was not achieved in the Brunnstrom's steps. Moreover, after intervention in some patients, the games reduced the score of Modified Motor Assessment Scale (MMAS) which is consistent with the similar study (Piron et al. 2009).

In our study, we used games to help patients recover from stroke at chronic stage of the stroke. Various studies have shown the efficacy of this method on chronic stroke patients' rehabilitation progress (Colomer et al. 2016; Laver et al. 2012; Shin et al. 2015; Shin et al. 2014). The regular and intensive use of games can improve the function of the upper extremity in stroke patients at each stage of the stroke (from the acute phase to the chronic phase), which has been proven in different studies (Wolf et al. 2010; Wolf et al. 2006).

4. Conclusions

To conclude, the results of this research support the effectiveness of virtual reality games for upper extremity rehabilitation in chronic stroke patients. Our results showed that this method could be used along with other therapeutic methods of physiotherapy to improve patients' upper limb movements. Virtual reality games are of great potential to motivate patients to continue their treatment exercises through feedback, scoring, repetition-based tasks and different levels of challenges that are tailored to the patient's ability. There are many advantages to application of virtual reality games in rehabilitation of stroke patients as examined in this research and other similar researches; however, further investigation is needed to examine if it performs more effectively than the conventional rehabilitation methods. Moreover, despite the hypothesis of more adherence to game-based rehabilitation due to unique features of virtual reality games, further research is required to put this assumption into test. The novelty of our research is the particularly designed virtual reality games for stroke patients based on Brunnstrom's stages of recovery, making the games fit to upper limb rehabilitation purposes.

Strengths and limitations

One of the strengths of this study is designing diverse games appropriate for the patients' abilities, using effective feedbacks and a simple design, and presenting challenges in proportion to the patients' abilities. Also, a Kinect version 1 sensor that was inexpensive and did not need any wearables during the game was employed. A limitation of this study was related to tracking finger movements by the Kinect sensor, as a result of which the game could not be designed for the wrist and fingers. Another limitation was the small sample recruited due to time restrictions, and not having a control group to compare the two methods (virtual reality and regular physiotherapy methods). Moreover, there were few patients at the rehabilitation center of the university, and thus there was a limitation on patient selection. A software limitation of the games designed in this study was the lack of recording patients' activities and reporting at the end of treatment sessions. With respect to the effects of stroke on patients' memory and cognition, it is recommended that games be designed for their cognitive, as well as motor functioning, rehabilitation.

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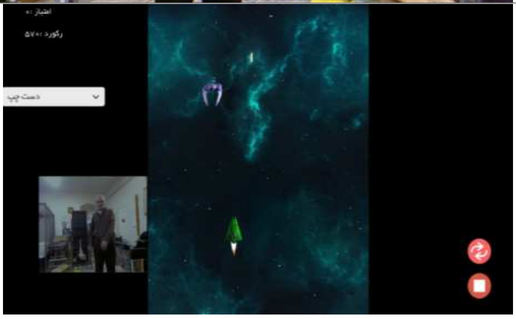
Figure:

Fig. **1.** Measuring shoulder movement by goniometric instrument

Tables:

Table 1

Characteristics of the designed games and applied movement types

Name of the game	Description	Type of movement	Patient while playing the game
Butter fly	In this game, patient is required to scare off the butterflies with his own hands.	- Flexion / Extension of elbow with elbow supination- Turning and bending of shoulder horizontally	
Space War	In this game, patient is required to guide the spacecraft with his own hand and prevents the collision with meteorites. By shooting meteorites, the score is calculated for the patient.	- Shoulder flexion / extension with elbow extension - Horizontal adduction / abduction of shoulder with open elbow	
Snow	In this game, patient is required to get the snowflakes by reaching out his hand and the amount of snow taken within the specified time	- Flection/adduction of shoulder - Bering and stretching elbow - Starching and bending of shoulder horizontally along with supination of elbow	

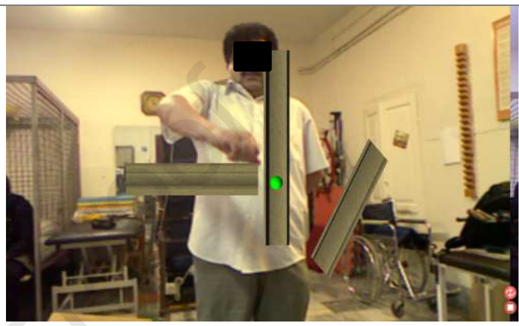
	calculates the score.		
Tubes	In this game, patient must direct a green object through three tubes, and when the green object reaches the end of the tube, the tubes disappear.	- Flection/extension of elbow - Supination of elbow - Flection/extension of shoulder horizontally	
Virtual Home	In this game, patient performs house sorting activities such as moving pillows, making coffee, closing drawer, and setting up the dishes.	- Upper limb elevation or arm elevation with internal and external rotation - Adduction and abduction shoulder - Shoulder flexion	

Table 2

Features and contents of the games based on virtual reality

Items	Features
Place of application	Upper extremity (arm and shoulder) stroke patients
Type of game	Applicable
Number of players	One player
User interface	2D dimensional
The mechanism of interaction	Kinect sensor
Software	Unity
Type of feedback	Sound, score, text

Adaptability	Based on the affected side and also based on Brunnstrom's 3, 4 and 5 steps
Portability of the system	Capability of the system to be used in the clinic and home
Challenge	Time, diversity of activities
Easy to use	Yes
Close to daily activities	Yes

Table 3

Demographic information of stroke patients

Variables	**Number**
Male	6
Female	4
Age	(32 to 69)
Time passed from the stroke (year)	(1 to 15 years)
Affected side of the body	4 patients (right side) and 6 patients (left side)

Table 4

The results of CVR analysis related to the rehabilitation movements

Brunnstrom's stage	Rehabilitation exercises	CVR index
Brunnstrom's stage 3 movements	Touch of chin, mouth, ear and opposite shoulder regardless of forearm position (Pronation/ Supination) of healthy side	77%
	Touch of the ear and the shoulder of the affected side	1%
	Open and close drawer or cabinet	33%
	Scrolling movement	11%
Brunnstrom's stage 4 movements	Taking the hand to the back	55%.
	Raising hand from the front to the horizontal level	77%
	Forearm pronation/ supination (open and next to body)	55%
Brunnstrom's stage 5 movements	Pushing away and close the upper extremity to the body from the side (abduction and adduction of the shoulder)	77%
	Raising the shoulder from the front or sides more than 90 degrees	77%
	Raising the upper limb to 90 degrees and perform internal and external rotation	77%
	Extending hands forward to get objects with two hands	100%
	Holding a ball or box with two hands and moving it up and down	77%
	Holding a ball or box with two hands and pushing it away and pulling it close the body	100%
	Raising the shoulder	33%
	Raising the hand over the head and bending the elbows (touch the head)	55%
	Abduction and adduction of arm (horizontally)	11%

Table 5

Results of CVR analysis related to the game content

Game's requirements	Components	CVR index
Game content should be amusing.	Avatar (game character)	0.6
	Escape (not being shot)	0.2
	Picking up (collecting objects)	0.5
	To penalize (when a mistake happens)	0
	Score	0.9
Game should give patient the motivation to complete the treatment sessions.	Status Indicator (Information about the Avatar status)	0.1
	Avatar (game character)	0.5
	Escape (not being shot)	0
	Picking up (collecting objects)	0.2
	To penalize (when a mistake happens)	0.2
	Score (considering the maximum points)	0.9
Being possible to repeat the game.	Replay ability	0.8
Choosing right or left hand (lifting the hand during the game).	Creating an icon to choose left or right hand	0.7
Make the feedback possible.	Sound	1
	Score	0.8
	Text	0
	Vision	0.3
Game should be easy to play.		1
Game content should be close to users' daily activities.	Eating, drinking, dressing…	0.5
Game should have an appropriate level of challenge (easy, medium, hard).	Adjust the speed of game	0.7
	Obstacles	0.6
	Escape	0.3
	Time	0.5

Table 6

Physiotherapists and game designers' comments

Physiotherapist	Game designer

1. Categorization of movements based on Brunnstrom's steps 2. Specify inclusion and exclusion criteria for study 3. Use more functional movements along with activity 4. Use of two-way and reaching movements 5. Use of movements associated with daily activities (eating, drinking, etc.) such as raising hands to reach mouth, chin and ear. 6. Generality of sentences and unclear parts of sentences related to the content of the game 7. Adjust the speed of the games based on the ability of patients so that they are slow in the early stages. 8. Making the content of the game as close as the daily activities of individuals to motivate more 9. Create a challenge in the game	1.Useing different content of the game to avoid duplication 2. If possible, use Kinect new version for better tracking of movements 3. Adjust the game speed 4. Create challenge in the game 5. Not using the obstacles in the game

Table 7

The functional outcomes at before and after intervention

Variables statistics **Measurement tool**	**Variables**	**Mean (CI 95%) before**	**Mean (CI 95%) after**	**P-Value**
Measurement with Goniometer	Shoulder flexion	60 (24.61±95.39)	73.1 (45.8±100.4)	0.06
	Horizontal abduction of shoulder	17.7 (13.47±21.93)	20.1 (16.26±23.94)	0.02
	Horizontal adduction of shoulder	54.2 (41.5±66.9)	67 (59.24±74.76)	0.00
	Flexion of elbow	131.9 (122.05±141.75)	132 (122.09±141.91)	0.78
	Extension of elbow	129.1 (118.25±139.95)	129.9 (119.61±140.19)	0.13
	Supination of wrist	24.3 (4.78±43.82)	32.1 (10.68±53.52)	0.02
	Wrist flexion	18.1 (6.03±30.17)	19.9 (6.44±33.36)	0.2
	Extension of wrist	12.6 (2.37±22.83)	17.4 (4.27±30.53)	0.08
Measurement with MMAS test	Elbow flexors	1.5 (0.75±2.25)	0.8 (0.1±1.5)	0.00
	wrist flexors	1.4 (0.74±2.06)	0.7 (0.06±1.34)	0.03

Table 8

Physiotherapist comments at the game evaluation stage

Row	Suggestions	Applicable	Non-applicable
1	Avatars have a good shape, but they may have to be more varied in terms of color and size. In fact, they should have different sizes and sharper colors to stimulate vision.	*	
2	Encouragement or punishment is considered with a score of hearing and vision aid	*	
3	Visual rating is more specific.	*	
4	Getting closer to real-life activities.	*	
5	Penalties: It is useful to punish or show a fault, but there should not be a percentage to make patients desperate, because a high repetition is not required in learning of these patients.	*	
6	It is possible for the patient to repeat easily and conveniently without complexity.	*	
7	Voice feedback or any other feedback during the game is helpful, given the possibility of visual impairment in these patients.	*	
8	Status Indicator: Patient comparison is not possible due to the condition of injury in their brain, and it may decrease motivation. The possibility to compare the patient with himself in different sessions seems to be more useful, or it is more appropriate to motivate places the group play.		*
9	The colors of the background and the game are not very different (contrast is low).	*	
10	The games should be arranged to prevent fake movements by patients.	*	

Table 9

The questionnaire related to the game content

Game's requirements	Components	1	2	3	4	5	6	7	8	9	Mean score
The content of game should be amusing	Avatar (game characters)	10	10	8	8	8	8	8	10	10	8.8
	Picking up (game characters)	10	10	7	4	8	7	7	10	5	7.5
	Feedback	9	10	8	9	9	10	9	9	8	9
The game should motivate patient to complete treatment sessions	Avatar (game character)	10	10	9	7	10	8	5	10	8	8.5
	Feedback	7	10	6	7	10	10	9	10	6	8.3
It should be possible to repeat the games	Possibility of replay (with changes in game's events and challenges)	6	10	10	10	6	10	10	10	10	9
Choosing left or right hand (upwards during the play)		7	10	10	9	10	10	10	10	10	9.5
Possibility of feedback	Sound	4	10	10	8	8	7	9	6	9	7.8
	Score	9	10	10	8	9	8	9	10	8	8.6
Games should be easy to play.		9	10	10	8	10	9	9	9	8	9.1
Game contents should be close to daily activities.	Eating, drinking, dressing….	4	1	6	1	3	3	8	5	6	4.1
Games should have various degree of challenges (easy, medium, hard).	Game speed	5	10	10	9	7	9	10	5	9	8.2
	Escape	5	10	9	7	7	10	10	8	8	8.2
	Time	4	7	5	7	7	3	5	6	5	5.4

Table 10

Average scores given to the games by patients

Row	Question	Participants										Mean
		1	2	3	4	5	6	7	8	9	10	
1	When I play I feel u have been challenged (facing new event)	7	10	8	9	7	7	7	7	8	7	7.7
2	Play game motivated me to complete the treatment	10	10	10	10	8	10	7	9	10	10	9.4
3	I enjoy playing game	10	10	10	10	9	10	10	9	10	10	9.8
4	The character in the game makes me to be part of the game	10	9	9	9	8	9	9	8	9	8	8.8
5	The alarms in the game make me more careful not to make mistake	7	8	8	8	6	7	6	7	8	7	7.2
6	Speed of the game makes me to play faster	8	9	9	10	9	9	10	8	9	9	9
7	I am satisfied to increase the level of the game	9	8	10	9	9	9	10	9	8	9	9
8	It is easy to lean and work with the program	6	5	10	9	9	9	10	9	10	9	8.6
9	I am generally satisfied with the game	7	10	10	10	9	10	10	10	10	10	9.6

Conflict of interest: none

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