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Designing and Developing Four Games for Rehabilitation of the Wrist Complex and Forearm Complex: An Action Research

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Original Article

Abstract

Introduction: Virtual reality (VR) games are among the rehabilitation strategies that, while effective, are attractive to the individual and facilitate and encourage proper movement. In this study, four VR games were designed and assessed to encourage the movements of the forearm and wrist complexes.

Materials and Methods: The games were designed using the leap motion device, a small non-tactile device with good spatial resolution. Cameras were responsible for detecting the depth and distance of the hand from the device, and the infrared sensors were responsible for detecting hand movements. In order to determine the level of attractiveness of the game for people with upper motor neuron disorders, three individuals aged 18 to 41 were randomly selected from among the people referred to the physiotherapy department of Al-Zahra Educational and Medical Center, Tehran, Iran.

Results: The effectiveness of the games was confirmed by board members of department of physical therapy. Three games were applicable in the early stages of rehabilitation for all three participants. One game could not be used in the early stages of rehabilitation due to the complexity of the required movement.

Conclusion: The four designed games required the basic movements required for daily and self-care activities and seemed to appeal the younger users.

Keywords: Leap motion; Motor defect; Filial therapy; Virtual reality

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Introduction

The motor system is divided into two parts: peripheral part including muscles, joints, and sensory and motor nerves, and the central part, which includes a part of the cerebral cortex and movement control centers. The central part is possible for the strategy including the goal and plan to perform the movement in the best way, tactics (sequence of muscle contraction in space and time to perform natural and precise movement to achieve the strategic goal), execution (activation of motor neurons and the pool of interstitial neurons and the creation of the necessary movement to achieve the goal), and the issuance of the necessary commands to perform movement to the motor-peripheral system (1,2). Upper motor neuron syndrome (UMNS) is a condition that results from damage to the motor cortex of the brain and, depending on the location and severity of the injury, may lead to a range of movement control or execution disorders such as muscle weakness, motor disability, and spasticity (2,3).

Muscle weakness limits independence and interferes with important activities such as personal

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hygiene and self-care.

Disability affects an individual's mobility in daily activities and his role in society and can lead to a decrease in his quality of life (QOL) (4). Cerebrovascular accident (CVA), cerebral palsy (CP), and Parkinson's disease (PD) are some of the brain injuries that cause symptoms of UMNS.

According to the World Health Organization (WHO), the prevalence of CVA is 15 million people a year, of whom about 5 million suffer from mobility disabilities for the rest of their lives. As a result of this disability, the person is deprived of the ability to perform separate movements due to improper restraint, overactivity, weakness, and lack of coordination among muscles (1); CP is the most common cause of motor impairment in childhood. The cost of caring for these people for life is estimated at about $ 1 million (5,6). The main individual clinical features of PD include movement abnormalities such as bradykinesia and rigidity (7-8). Rigidity means an increase in speed-independent muscle tone and can play an important role in the individual's dysfunction (9).

Spasticity causes a person to lose mobility and may cause pain by increasing muscle tone (10). This complication in the upper extremities usually engages the flexor muscles of the elbow, wrist, fingers, and forearm pronators, making it difficult to control these movements on the one hand, and reciprocal inhibition and weakness on the antagonist muscles on the other (extensors of elbows, wrists, and fingers, and forearm supinators), imposing several restrictions on the individual (1).

CVA is one of the most common acquired disorders of upper motor neurons, which accounts for a significant share of disability in people over 50 in developed countries (11). In Iran, stroke (CVA) is one of the most important non-communicable diseases (NCDs) that in the last decade, its prevention and, if it occurs, its effective rehabilitation has become one of the clinical-research priorities of the Ministry of Health and Medical Education. Acute stroke is associated with flaccid paralysis of one side of the body. Thereafter, during the subacute and chronic stages, the tone of the affected side muscles increases, which may interfere with the individual and social independence of the person by turning into spasticity (12). The reduced age of incidence and movement of society towards modern lifestyle with the use of computer technology make one to think of computer use and virtual reality (VR)-based games in these people. Performing therapeutic movements while playing creates an entertaining environment that increases the individual's motivation and reduces treatment costs on an overall scale (13).

Games can provide information about the type of movement to the treating physician and, taking into account the person's level of ability, allow the adaptation to the dynamic difficulty of the game. This article presents some examples of VR-based games with the aim of improving the movements and motion control of the wrist and hand complex.

This study is a design study with the main purpose to report how to design four VR-based games that cover all the movements of the forearm and wrist and have the ability to progress the difficulty of the game in proportion to the ability progress of the person examined.

Materials and Methods

The study population included people with subacute and chronic stroke. Four mini games were designed using a leap motion device to increase the desire of individuals with stroke to perform movements. These games were created using the Unity Game Engine (Unity Software: Unity® 2018.4.3, Unity Technologies, 2018, San Francisco, California, U.S.) coded in C-Sharp.

The unity game engine is a cross-platform game engine developed by Unity Technologies (Unity Technologies, San Francisco, California, US) and can support popular programming languages such as C-Sharp, JavaScript, and Python. This software is applied to make video games for personal computers, game consoles, mobile devices, and websites (14).

The leap motion device (Figure 1) is a small non-touch device with suitable spatial resolution and measuring 1.27 cm in height and 8 cm in width, has two cameras and three infrared light-emitting diodes (LEDs). The cameras are responsible for detecting the depth and distance of the hand from the device and the infrared sensors are responsible for detecting hand movements (15). Leap Motion Controller software was used to connect the device to the computer.

Figure 1. Leap motion device

Designed games: The idea of designing the games was developed in consultation with the physiotherapy specialists in the Department of Physical Therapy, School of Rehabilitation Sciences, Isfahan University of Medical Sciences, Isfahan, Iran. During the design, the main movements used in the self-care activities were discussed, and the process of advancing the physiotherapy interventions with the aim of achieving the best performance of the wrist and hand complex was explained to the game developers. The initial design of the game was used and analyzed twice by the physiotherapists in the presence of the game developers and the weaknesses of the games were investigated and the necessary corrections were implemented to the extent possible for the existing system.

The experts believed that in order to participate in this treatment, it is better for the participant to have an active movement ability of at least 10% of the functional range of motion (ROM) of the joint in the directions required for playing, equivalent to Grade 2 (Poor) on the manual muscle testing scale (MMT). This level of mobility means that a person can complete at least 10% of the functional ROM of the target joint without the intervention of gravity (16). In the absence of this ability and also in the stages of development, active-assisted movements can be used to retrieve motor memories. After the final approval, the games were given to several subjects with UMNS to measure their usefulness and attractiveness and to record their limitations in a realistic way.

Balloon game: Given figure 2, the design of this game is such that there is a balloon above the city and by opening and closing the hand, the height of the balloon increases and decreases, respectively. During the game, obstacles move in the form of clouds and points move in the shape of stars in the sky; the health of the balloon decreases when the person encounters obstacles, and his score increases by receiving a star. In addition, in case of the balloon hitting the city, its excessive height, or running out of health, the balloon is destroyed and the game ends. The participant is forced to perform opening and closing movements to advance the game and earn points.

Figure 2. View of the balloon game

Aircraft game: In this game, the person, as a pilot, passes the plane through the gray clouds, which in case of collision, will be electrocuted and its health will be reduced. Moreover, receiving rewards and hearts in the sky will lead to earning points and increase health, respectively (Figure 3). To pilot an aircraft, the player must perform supination and pronation movements.

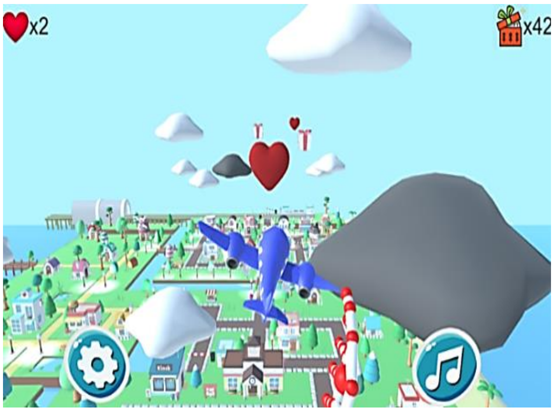

Figure 3. View of the Aircraft game

Boating game: This game includes a boat, watercraft, diamonds, and hearts, in which the boat is controlled by wrist flexion and extension. The boat is damaged when it hits the watercraft, and the person must receive hearts to repair. Diamonds are as points (Figure 4).

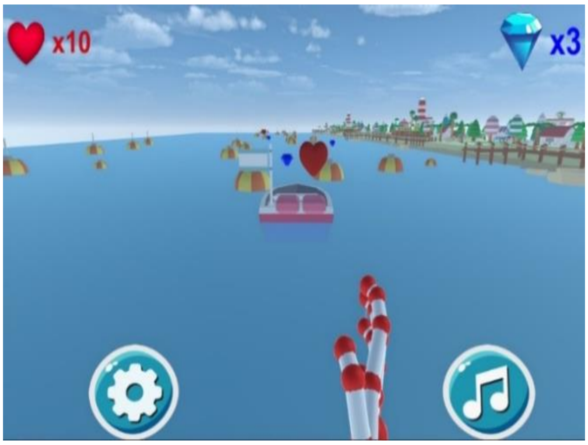

Figure 4. View of the boating game

Gardening game: The purpose of this game is to pick tree products including apples, lemons, and oranges, which is performed by moving the finger extension and forearm supination. The number of fruits picked and also the time of picking all the fruits of the trees are calculated and can be seen in the game as figure 5. Performing the movements used in each game helps the treatment.

Assessing the game attractiveness: In order to determine the attractiveness of the game for patients with UMNS, three people aged 18-41 were randomly selected from those who referred to the physiotherapy department of Al-Zahra Educational and Medical Center, Tehran, Iran.

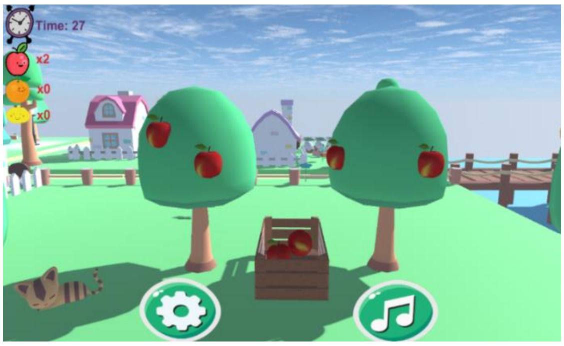

Figure 5. View of the Gardening game

The details of the games were explained to the participants and an informed consent form was signed by all of them to participate in this primary study. Two participants had a stroke (an average of 6 months after the stroke) and one had a traumatic brain injury 15 years ago. Depending on the level of ability of the recovered individuals, a usable game was selected for each. Each person spent 15 minutes playing games that could be used for their specific conditions. Then, the individuals' opinions about the game were measured in a researcher-made questionnaire with 6 items. In this questionnaire, the person's opinion about the attractiveness and variety of the games, as well as the person's motivation to continue this type of treatment were recorded on the Likert scale with very good, moderate, and poor answers.

Results

The demographic characteristics of the 10 physiotherapists participating in the study included a mean age of 49.90 ± 11.80 years and work experience of 18.70 ± 12.85 years. Among the physiotherapists, 3 (30%) and 7 (70%) were female and male, respectively. In addition, 3 (30%) had a master's degree and 7 (70%) had a doctorate. Moreover, the university rank of 3 (30%), 6 (60%), and 1 (10%) of the physiotherapists were instructor, assistant professor, associate professor, respectively.

According to the physiotherapists, the above set of games had the main functional movements for daily activities, and given the studies conducted in this field, the use of this type of treatment accelerates the rehabilitation process. The demographic characteristics of the three participants in the study are as shown in table 1.

The answers of the subjects to the game attractiveness questionnaire are given in table 2.

It was difficult for all participants to play the gardening game, and it seems that this game can be prescribed in the advanced stages of rehabilitation when performing combined movement patterns of the hands, wrists, and forearms is the goal of the exercise. The game of the boating and aircraft games was interesting and acceptable for all three people. However, the Balloon game was not examined in any of the subjects due to the lack of finger extensions.

Based on the evaluation results, two younger participants (with an average age of 21.5 years) while increasing motivation, found playing to continue the treatment process attractive. The 41-year-old patient with stroke, despite expressing satisfaction with the games, told his main therapist (outside the research team) that participating in this type of treatment program was unattractive and useless. Furthermore, this participant refused to complete the game attractiveness questionnaire.

Discussion

VR-based video games are a young approach to rehabilitating people with mobility problems. The findings of the present study indicated that experts consider the four designed games to have the potential to be implemented in medical centers and evaluated the results of their use as positive. These games are more likely to be accepted by younger people who have lost part of their mobility due to a stroke or brain injury. It seems that playing the suggested games will be attractive for younger people and will enhance the motivation to attend the treatment environment and cooperate with the specialists.

Table 1. Characteristics of the three participants in the evaluation of the games

Row	Occupation	Age (year)	Gender	Duration of injury (year)	Type of injury	Duration of receiving physiotherapy services
1	Unemployed	23	Man	15 years	TBI	3 months
2	Unemployed	18	Man	3 months	CVA	3 months
3	Unemployed	41	Man	1 year	CVA	Unknown

TBI: Traumatic brain injury; CVA: Cerebrovascular accident

Table 2. Game attractiveness questionnaire and the number of participants' answers to it

Row	Item	Good	Moderate	Weak
1	How do you evaluate the attractiveness of the game?	1 (50)	1 (50)	-
2	How do you evaluate the variety of games?	2 (100)	-	-
3	How do you evaluate the environment of each game?	1 (50)	1 (50)	-
4	How do you evaluate the quality of using this method to recover motion compared to conventional methods?	1 (50)	1 (50)	-
5	How do you evaluate your positive feeling when using this game?	1 (50)	1 (50)	-
6	How do you assess your motivation to continue treatment using this method?	1 (50)	1 (50)	-

Data are reported by number (%).

Rehabilitation is a process aimed at preventing the reduction of limb function, and/or restoring it to the highest possible level. Rehabilitation assessments are performed to examine the person's body structure and function, activities and participation, and environmental factors. In rehabilitation, it is tried to make the person maintain his normal function in the face of the environment. In this regard, strategies such as maintaining the individual's current performance, preventing performance decline, slowing down the performance decline process, restoring performance, and using compensatory ways to replace lost performance (17) may be planned by the rehabilitation team.

Upper limb health has a significant effect on individual independence due to its wide application in self-care (such as nutrition, personal hygiene or protection of the body against injury), manipulation with the environment and objects, and transmission of emotional information, through specific gestures as an important part of body language (18). One of the complications and outcomes of UMNS is the occurrence of various disorders in the performance or control of upper limb motor activities, especially the wrist complex and the forearm complex (19); However, due to the delicacy and complexity of the movements of these sections, their rehabilitation is often time consuming and its success depends to a large extent on the therapist's skill in restoring the person's motor memories and cooperation in the continuation of the treatment sessions (20). Accordingly, the use of rehabilitation strategies that, while effective, are attractive for the person and facilitate and reinforce the movements correctly, will be valuable.

Progressive strengthening exercises improve muscle strength and increase the speed of recovery if combined with functional activities. Additionally, periodic use (circuit training) of workstations increases the efficiency of these exercises by involving different muscles (1). Nowadays, in order to perform functional exercises in physiotherapy centers, the subjects are required to perform movements in the form of daily activities. For example, it is recommended to pick up objects for the movements of opening and closing the fingers, and to rotate objects for the supination and pronation movements. One of the problems of this treatment is its monotony and dullness, and thus, the person's reduced motivation to continue the treatment.

The rehabilitation process is improved by items such as task-specific training, biofeedback, stimulus rich environment, and active participation (21).

The results of a study carried out on the motivation of subjects with stroke showed that the use of VR in rehabilitation despite low cost, by providing a fun and relaxing environment, increases an individual's motivation (13). This type of treatment makes it possible to practice by repeating functional and task-based activities that improve limb control, increase muscle strength, and facilitate the neural plasticity process (22). VR and video games are new technologies that can be applied in conjunction with conventional therapies for upper extremity motor recovery (7,23,24).

In a study on the effectiveness of leap motion therapy on the upper extremities of patients with mild to moderate PD, the participants were randomly divided into the case and control groups, both of who received conventional physiotherapy treatment and the experimental group experienced leap motion-based therapy at the same time. The variables of effective muscle strength in grip, coordination, speed, and skill of performing fine and gross movements and acceptability of treatment in both groups before and after treatment were evaluated. The intergroup statistical analysis indicated that compared to the control group, the case group obtained a significant improvement in the studied variables in the more involved side (7).

The most difficult part of rehabilitating people with UMNS is the functional recovery of the affected hand. In a study of 26 subjects with sub-acute stroke, the subjects in the case and control groups received leap-motion therapy and conventional physiotherapy for 4 weeks, respectively, and the wolf motor function test (WMFT) was utilized to evaluate motor performance. The results suggested a significant improvement in the case group compared to the control group and the WMFT time was reduced in the case group. As a result, VR exercises in the form of leap motion proved to be a promising and feasible complementary intervention and could facilitate functional movement improvement (24).

A definite opinion on the addition of these games to the specialized rehabilitation program for patients with UMNS requires the design of standard clinical trials. To determine the clinical value of these games, studies with sufficient sample size of patients with different types of UMNS, along with the development or localization of standard questionnaires seem necessary. Comparing the effectiveness of complementary programs with VR compared to conventional methods of exercise therapy and measuring their immediate, short-term, and long-term effects after cessation of treatment will help clinicians to identify the optimal conditions for using these tools to achieve the best therapeutic results.

Limitations

Due to the type of sensor used and its limitations, it was not possible to program the available hardware to understand the delicate and complex movements performed during games. For example, the sensor could not distinguish the movements of the lateral fingers from each other. Therefore, these games can be used only in some parts of the treatment, and as the individual's performance status improves, more advanced and accurate systems should be used to simulate therapeutic movements in the form of games. Furthermore, taking into account the research ethics, three participants with UMNS were entertained with games for only a few minutes. Commenting on the clinical value of the games requires its use in the form of clinical trials with scientific and principled design.

Recommendations

It is suggested that in further studies, more sensitive and accurate sensors be applied and the games be designed using dynamic difficulty algorithms requiring the use of full ROM and in various combinations to respond to the development of motor skills of the participant during treatment. Besides, it would be desirable to design and conduct a clinical trial study with a sufficient sample size, taking into account a control group and comparing it with various standard and routine therapeutic interventions, and follow up of the results at longer intervals.

Conclusion

The four designed games have the basic movements needed for daily self-care activities and seem to appeal to younger users. Determining the clinical value of these games and the possibility of replacing conventional exercise therapy methods with designed games requires further studies.

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Authors' Contribution

Zahra Sadat Rezaeian: Study design and ideation, attracting financial resources for the study, support, executive, and scientific study services, analysis and interpretation of results, specialized statistical services, manuscript preparation, specialized evaluation of the manuscript in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, the responsibility of maintaining the integrity of the study process from

the beginning to the publication, and responding to the referees' comments; Zahra Nasr-Esfahani: game design and development, data collection, analysis and interpretation of results, manuscript preparation, specialized evaluation of manuscript in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, the responsibility of maintaining the integrity of the study process from the beginning to the publication, and responding to the referees' comments; Zahra Moradi-Shahrbabak: game design and development, data collection, analysis and interpretation of results, manuscript preparation, specialized evaluation of manuscript in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, the responsibility of maintaining the integrity of the study process from the beginning to the publication, and responding to the referees' comments; Hamed Garousi: game design and development, data collection, analysis and interpretation of results, manuscript preparation, specialized evaluation of manuscript in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, the responsibility of maintaining the integrity of the study process from the beginning to the publication, and responding to the referees' comments.

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Conflict of Interest

The authors declare no conflict of interest.

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