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Realisation of a Virtual Reality based Remedial Module for Cognition and Hand Function Rehabilitation

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Hand function disorders of an individual hinders them from performing activities of daily living with ease and sometimes limit their cognitive growth. As a remedial treatment, nowadays virtual reality (VR) emerged as a gaming platform that has been employed for the rehabilitation of such individuals. User motivation and engagement has risen with the development of VR technology. The developed remedial module is based on a VR platform using two games for upper limb rehabilitation with a hand motion sensing device (HMSD) to provide a solution for sensing hands and fingers movements. The movement was measured with the development of the games based on bilateral hand coordination and manual dexterity, the subset of Bruininks-Oseretsky Test (BOT2) of Motor Proficiency. However, the result of the system considered here is based on the system usability scale (SUS) for healthy individuals. Thus, the system is simple, economical, portable, user-friendly, and does not require intruding external hardware to wear. Hence, over the time these engaging VR rehabilitation games can provide an effective rehabilitation training process for upper limb hemiparesis children.

Keywords: Bruininks-Oseretsky test, Hand motion sensor device, Hemiparesis, System usability scale, User motivation, Upper limb

Introduction

The ability of the hand to accomplish certain work requires togetherness of central nervous system and this can be affected and deteriorated by multiple brain disorders.[1] Cerebral Palsy (CP) being the prevailing type of physical disorder in present times with an affecting rate of 1 out of 403 live births.[2] In addition, with this, 50% of an individual with CP[3] depicts struggle in hand movements. In daily activities, individual with unilateral spastic rarely utilise their paretic hand. Because of these factors, hand movement in an individual has received more attention in the previous decade.[4,5] Therefore, one of the most important rehabilitation goal is to help an individual to manage everyday activities so that they can live independently. In clinical settings, most conventional therapy mainly focuses on the regular, repetitive, and boring training procedure and the patient cannot immerse themselves in a 3D non-physical world.[6] For overcoming these limitations technological advances such as virtual reality (VR) are introduced in the field of hand rehabilitation process and are being used as a remedial tool. To increase the active participation of an individual during therapy sessions VR scenarios have a beneficial effect on motivation and this increases rehabilitation success.

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Related Work

Previous literature suggests that virtual reality games in the field of rehabilitation and health care centers focus on improving the motor training and motor learning through both, fine and gross movement exercises. Because rehabilitation might take a long time, these facilities are looking for novel ways to train patients. Accessibility and low-cost hardware[6] are two major areas that require attention for these facilities. Here are a few instances of VR rehabilitation systems in action. The system BioTrak[7], which is a platform for training and rehabilitation of numerous diseases because of some pathology, is one notable example. This technology contains a magnetic tracker that can detect large upper-limb gestures. The IREX (Interactive Rehabilitation and Exercise)[8] system is a technology, which offers a variety of interactive games focusing on gross motor movement for the arms. Such systems have a high efficiency, but their prices are exorbitant because of the hardware used. As a result, low-cost choices become necessary.

Thereafter, some of the new technologies that provided a clear chance to track game players' 3D positions in real time. As a result, studies on the Leap Motion[8,9], Microsoft Kinect, Nintendo Wii[10,11], and other virtual reality technologies are common. One of the study worked on a hand gesture based robot control system using leap motion device.[12] Furthermore, some studies demonstrate video game platforms for rehabilitation employing the Kinect as a rehabilitation tool.[13]

Hence, keeping this in mind some user-friendly games have been developed in VR environment. These VR games typically require training from the bio-signals, which includes optical signals, sound signals, and touch for simulating the activities of daily living[14] and environment. Virtual reality games can be used for repetitive rehabilitation exercises for an individual with their cognitive abilities in the developing stage.[15,16] These games provide a better option for the children by providing an appropriate environment with a defined duration and intensity of the activities with user-defined repeatability.[16]

The study mainly focuses on the development of VR based remedial module to regain hand movement of an individual. As the environment is virtual where the system provides real-time standard therapies for the rehabilitation of an individual, the VR-based remedial module is key in creating a comfortable environment, which helps them in the improvement of the hand function disorder. In this, the movement is performed when hands and fingers are detected by the HMSD. Unity 3D game engine is interfaced with HMSD, provides real-time data capturing of hand and finger movements. The activities performed on these games serve visual perception components, object identification, midline orientation, and muscular balance with hand pulley when initiating grasp, sensory feedback in a virtual environment. The developed remedial modules (i.e., Collision of Balls and Virtual Peg Board) are adaptable for the rehabilitation of an individual with hand disorder.

System Description

For the development of VR-based remedial module, there are mainly two components used i.e., hardware, and development platform. These are described as follows:

Hardware Used

The hardware of the system includes HMSD, a small peripheral device used for gesture detection of hand manufactured with two cameras and three infrared light-emitting diodes (LEDs). It not only detects hand but also wrist and elbow for accurate positions and movements for gestures in a three-Dimensional environment.[17] It is very easygoing as the main requirement is the installation of the software development kit (SDK) from the leap motion which could easily be downloaded from the official website. It is used for following hand movements during the play of games.

Development Platform Used

Unity is a platform used for the building of a 2D or 3D game environment. Its strength lies in the easiness of usage and documentation abundance. As in the present research, which is dedicated to make the experience of hand, wrist, elbow, and fingers rehabilitation more exciting and effective, the environment should have an increasing level of difficulties at different levels which could motivate and encourage an individual to do the exercises daily.

Materials and Methods

Some intervention and evaluative scales were involved in this study. The evaluative scale includes bilateral coordination and manual dexterity of the Bruininks-Oseretsky Test 2 (BOT2) test.[18] For testing motor proficiency BOT2 is a standardized tool.[19] The BOT2 test has been widely used to access motor proficiency for children with cognition problems. Bilateral coordination in the BOT2 test was performed by using a lawn tennis ball. To access, the manual dexterity has the following materials to be used: penny board, pegboard, strings, and cube. The development age for individual with 5 to 14 years, acts as a standardized scale.

A type of HMSD device i.e. leap motion sensor supports hand and finger tracking in VR[20] to make it easy to analyze movements in individual with hand disorder while performing game tasks. Many new applications can take assistance from the leap motion sensor as it supports many platforms including unity.[21] It is used for following hand movements[22] during the play of games. By using this device there is no need to place the sensor on the body. Different/multiple games can be developed using the leap motion sensor.

Description of Games

A collection of BOT2 based games on VR has been designed for rehabilitation of the upper limb motor.

The development process of VR-based games in which the sensor module, hardware modules, therapy, and improvements have been described are shown in Fig. 1. By using Unity3D game engine software, the leap motion sensor was used to capture the hand movements of an individual and different virtual worlds were developed. Two games based on VR were developed in total: Collision of Balls and Virtual Peg Board.

The games were developed, one which is a 3d environment game play is played with one hand while another is played with both hands. Such type of user interface helps an individual with hand disorder and psychotherapists to work through the games with ease. The system involved various functions to train different isolated movements as follows.

Fine motor activities (four levels)

Collision of Balls (hand and finger movement): An individual have to sway both hands delicately in all directions. For bilateral hand coordination move the two balls (of the same colour and same layout) using the hand gesture to make them collide based on cognitive abilities. Therefore, the initial interface described at the time if game initiation is shown in Fig. 2(a). The number (2, 4, 6, and 8) and size of balls (small, medium, and large) can be selected through settings in the main menu as shown in the GUI of Fig. 2(b). The beginning screen of the game (hence the user can begin the game via leap motion sensor) is shown in Fig. 2(c). When both same balls collide, they will be destroyed and a star is formed, and when different balls collide, no star is formed and it is not destroyed as shown in Fig. 2(d). In addition, the children have to collect three stars to complete the game. The motion of the hands is detected via the HMSD and an individual ways the balls, criss-cross hands, and accordingly, make them collide. This game helps to improve space orientation, visual

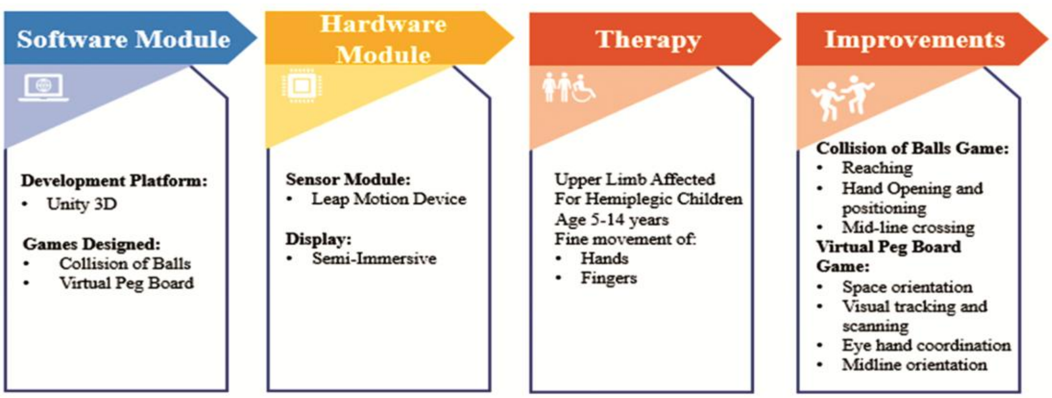

Fig. 1 — VR based games development process

Fig. 2 — Graphical user interface of collision of balls game

Fig. 3 — Graphical user interface of virtual peg board game

tracking and scanning, eye-hand coordination, and midline orientation.

Fine motor skills (four levels)

(i) Virtual Peg Board (hand and finger movements): Shoulder joint movements are performed by an individual to pick the objects from the box on the left and right side of the pegboard based on their cognitive abilities. When the hand gesture is in the range of the object it automatically attaches with the hand gesture. The object picked is mapped onto a similar shape and colour object on the virtual pegboard places towards the right. (ii) Mass grasp: in this level, the thumb is not involved, the individual has to move the hand in any plane and four objects, as shown. (iii) Grasp Object involving thumb movement: with this level six shapes have been shown in which there is an involvement of the thumb to grasp an object. (iv) Activities with tweezer: thumb and finger movement are involved in this activity to pick the balls and place them at their particular container. However, Fig. 3(a) describes the initial interface when the subject/person starts the game. In Fig. 3(b), once click on settings button from the first interface following contents are displayed (i.e., select no. of shapes to play with (2, 4, 6, 8, 10, 12)) and user can select option according to his/her preference. The beginning screen of the game, hence, the user can begin the game via Leap motion device after selecting No. of shapes as shown in Fig. 3(c) and 3(d). Therefore, the main purpose of this game is to improve reaching (i.e., shoulder girdle stabilization), hand opening and positioning, and midline crossing.

Fig. 4 — A game practicing based on collison of balls

Fig. 5 — A game practicing based on virtual peg board

Results and Discussion

In the present study, the authors have investigated the effect of VR therapy on functional development in the upper limb, affected due to hand disorder with a special focus on improving hand and finger movement and show a significant effect on cognitive ability as shown in Figs 4 and 5. As the system amalgamates VR technology with rehabilitation, increases the interest of an individual in rehabilitative training. These VR-based games help an individual with fine movements of hands and fingers. Therefore, individual fingers and hands' movements were

Table 1 — SUS scale for VR based games

No.	SUS Items	No.	SUS Items
1.	I think that I would like to play this game frequently.	6.	I think there is too much inconsistency in this game.
2.	I find this game unnecessarily complex.	7.	I would imagine that most people would learn to play this game very quickly.
3.	I think this game is easy to use.	8.	I find this game very cumbersome to use.
4.	I think that I would need the support of a technical person to be able to play this game.	9.	I feel very confident playing this game.
5.	I find various functions in this game are well integrated.	10.	I need to learn a lot of things before I could get going with this game.

restricted and made to practice these games. Moreover, different levels of training tasks are used, which makes it more effective. The collision of balls was performed to measure bilateral coordination of BOT2, and a virtual pegboard was performed to measure the manual dexterity of BOT2. Also, by performing these game activities collision of balls game helps to improve reaching (i.e. shoulder girdle stabilization), hand opening and positioning, and midline crossing as shown in Fig. 4. Virtual pegboard helps in improving space orientation, visual tracking, and scanning, eye-hand coordination, and midline orientation as shown in Fig. 5.

However, previous studies conducted have restricted capacity to control objects with their hands and fingers is one of the best indicators of ADL limits and participation constraints[23] in children with hemiplegic CP. On the other hand, a single type of treatment may not be enough to improve hand function, especially for children who require long-term care.[24]

Furthermore, from literature, there has no system developed based on BOT2 test (i.e., bilateral coordination and manual dexterity). Here, in our system both VR games are based on BOT2 test. In case of other studies that largely rely on traditional therapies under the supervision of a therapist/doctor and the use of paper and pencil, there is a lack of children's interest and participation.[25]

Additionally, standard VR-assisted therapy devices, such as Microsoft Kinect and Nintendo Wii-Fit, were widely accessible.[26] These technologies are unable to detect fine hand and finger movements, which are required for dexterity training, and existing video game-based applications do not usually correspond to specific therapeutic goals. Therefore, leap motion device is one of the effective solutions for hand and fingers movements. On the other hand, studies have shown that VR-assisted therapy is more enjoyable and preferable to traditional therapy. As VR-assisted therapy using interactive VR games can provide task-oriented practise as well as visual and auditory feedback on performance and gain, further motivating and engaging players to increase the rehabilitation intensity.[27]

Conversely, after system development, there is a need to check whether the system worked properly or not on healthy individual. For the evaluation of the system, the system usability scale (SUS) is applied after the completion of the system to healthy individuals. The main queries to be answered in the Likert Scale are an assessment of usability, learn ability, and satisfaction of the user objectives. Usability testing is generally summed up as the quality of the convenience of the system. Usability of these VR games is tested by using SUS. This requires a user to answer 10 particular items of statements as listed in Table 1. For this study, assessment by users is represented on a scale of 1 (strongly disagree) to 5 (strongly agree). The score of SUS SCALE has been calculated as: the items 1,3,5,7, and 9 i.e odd numbers were obtained by minus 1 and items 2,4,6,8, and 10 i.e. even were obtained by minus 5 with selected scale position. Then multiply that total score by 2.5 to obtain all values of SUS for one respondent. For checking the usability of the system, SUS has been used on fifteen middle-aged healthy participants. The mean score indicates that the collision of balls and virtual pegboard in VR is better in terms of SUS scores (65 and 64.166) as shown in Tables 2 and 3. This shows that both games are considered in VR to function better in terms of usability. These results stated that VR has potential benefits and positively affect the upper limb for the improvement of hand and finger movement with better motor capacity. In addition, this system is efficient with hemiplegic CP.

Our study results suggest that VR therapy is a useful treatment method that can be used in the rehabilitation of hemiplegic CP with improved motor function. The addition of this method over conventional rehabilitation techniques may have a significant impaction treatment success.

Table 2 — Collision of balls user SUS scale score table

Users	SUS Items 1	2	3	4	5	6	7	8	9	10	Total	SUS Score (Total*2.5)
1.	3	4	4	1	4	1	3	4	4	3	31	77.5
2.	3	4	4	1	4	1	3	4	4	0	28	70
3.	4	2	3	1	2	1	3	3	4	3	26	65
4.	4	4	4	1	1	2	4	1	4	1	26	65
5.	4	4	4	2	0	4	4	4	4	0	30	75
6.	3	4	3	0	4	4	2	3	2	2	27	67.5
7.	2	3	3	0	4	2	3	2	3	2	24	60
8.	2	4	2	2	3	4	0	4	3	0	24	60
9.	3	4	3	2	3	4	0	4	3	0	26	65
10.	4	2	2	4	4	3	4	1	3	0	27	67.5
11.	4	4	3	4	3	3	2	4	1	4	32	80
12.	1	1	2	0	3	2	1	1	0	0	11	27.5
13.	3	2	4	1	3	2	3	4	3	1	26	65
14.	3	2	4	1	3	2	3	4	3	1	26	65
15.	3	1	4	2	2	3	3	3	3	2	26	65
					Mean Score:							65

Table 3 — Virtual peg board user SUS scale score

Users	SUS Items 1	2	3	4	5	6	7	8	9	10	Total	SUS Score (Total*2.5)
1.	3	3	1	2	2	3	1	4	3	0	22	55
2.	4	2	2	2	4	0	2	2	4	0	22	55
3.	3	1	3	3	3	3	1	1	3	3	24	60
4.	3	3	3	3	3	2	4	3	3	1	28	70
5.	4	4	4	0	4	4	3	3	3	3	32	80
6.	4	3	4	4	4	4	3	4	3	1	34	85
7.	3	3	4	2	4	2	1	4	0	0	23	57.5
8.	4	3	4	2	3	0	0	2	0	3	21	52.5
9.	4	1	1	0	2	1	4	0	0	3	16	40
10.	4	2	4	1	2	4	3	0	3	2	25	62.5
11.	4	4	4	4	1	4	2	1	0	3	27	67.5
12.	4	4	1	2	0	4	4	4	1	4	28	70
13.	3	3	4	2	3	3	2	3	4	3	30	75
14.	0	2	2	4	2	4	4	4	2	4	28	70
15.	3	3	1	2	2	3	1	4	3	0	22	55
					Mean Score:							64.166

Conclusions

The HMSD and the games designed used in this study is to represent a rehabilitation tool that may benefit an individual having hand disorder with upper limb for the improvement of hands and finger movements. The benefits of using this system over other therapeutic VR systems are that it is simple, economical, portable, user-friendly, and does not need any wearable devices or sensors mounted to the surface of the body. For the development of an effective rehabilitation system, sole dependency lies on the HMSD and unity 3d. According to the middle-aged healthy participants, the system helps to improve fine motor skills as concluded using SUS. This system is designed with a basic, practical, and adaptable approach that makes the rehabilitation of an individual effective.

Currently, the game targets the rehabilitation of the upper limb, affected due to hand disorders with a special focus on improving hand and finger movement. It will aid in learning through fun and improving the upper limb motor functions. Virtual reality has potential benefits for an individual and this system is a prototype sample with limited trials during development on healthy participants. Now, authors are also engaged with the trails, which performed with hemiplegic CP patients, which can be used to demonstrated improvement in movement of upper limb in hemiplegic CP children using VR- based therapy. It also has a significant effect on the level of participation and cooperation.

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Conflict of Interest

The authors hereby declare no conflict of interest.

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