A Usability Evaluation of Neuromender’s Upper Limb Game-based Rehabilitation System for Stroke Survivors

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Abstract—Game-based technologies have been widely used as part of stroke rehabilitation. The Neuromender system utilises game-based technologies and consists of serious games that are designed and developed for the purpose of rehabilitation of stroke survivors. In this paper, one of the modules in the Neuromender system which is the “upper limb” module is described and tested for its usability. The upper limb module primarily focuses on the rehabilitation of the upper body extremities of stroke survivors. An experimental study is designed to test the usability of the upper limb module. Various metrics including the optimal distance between the 3D depth sensor device and the survivor, the optimal position of the 3D depth sensor with respect to the survivor, and the response time of the gestures made by the survivors based on their distance to the sensor are evaluated. At the end of the experiments, the optimal distance and optimal position for the survivors to utilise the upper limb module is determined.

Keywords—game, Neuromender, stroke, rehabilitation, upper limb

I. INTRODUCTION TO STROKE

The human brain is a very complex organ of the human body and according to the US National Stroke Association, “A stroke is a “brain attack”. It can happen to anyone at any time. It occurs when blood flow to an area of the brain is cut off. When this happens, brain cells are deprived of oxygen and begin to die. When brain cells die during a stroke, abilities controlled by that area of the brain such as memory and muscle control are lost” [1].

Stroke is one of the leading causes of long-term disabilities both globally [2] and in Australia [3]. Moreover, studies found that nearly 80% of stroke survivors experience upper limb dysfunctions [4, 5]. Persistent loss of upper limb functions was found in 45% of stroke survivors, which further contribute to stroke-related disabilities [2]. Nearly 50% of the stroke survivors with limitations in upper extremities are susceptible to problems in performing their daily activities [6, 7] such as bathing, eating. Furthermore, [8] mentions that stroke-related impairments can lead to mental and physical difficulties. These difficulties have a significant impact on stroke survivors’ quality of life as it leads to complications in the upper limb functions [9, 10]. Limitations in the upper limb i.e. lack arm movements have a direct negative impact on independence in the “activities of daily living” [6, 11].

Neuroscientists believe that rehabilitation involving one-on-one supervised intense therapies [12-14] can bring clinical improvement to the upper limb functions of stroke survivors. Most of the current rehabilitation techniques focus on the functional restoration of the lower limb rather than restoration of upper limb motor and sensory functions [15].

As the population ages, there will be an increase in the number of stroke survivors resulting increased demand for rehabilitation services [16, 17], which will increase incomplete upper limb recovery and insufficient therapies. Insufficient therapies are caused due to the increased number of stroke survivors, lack of time, funds and therapists [18]. Furthermore, a limited number of stroke rehabilitation care is also one of the reasons for incomplete recovery [9]. Due to the increased population of stroke survivors and increased demands for therapists, rehabilitation providers are forced to reduce the duration of therapy sessions i.e. the reduction in run time of each session in order to meet the increasing demands, which in turn reduces the number of tasks to-be-performed by stroke survivors. One way of tackling this issue is to use low-cost game-and-home-PC-based rehabilitation system such as the Neuromender system.

This paper describes the third module of the Neuromender system which is the “upper limb” rehabilitation module. This paper also presents an experimental study designed to evaluate the usability of this upper limb module. Various metrics including the optimal distance between the 3D depth sensor device and the survivor, the optimal position of the 3D depth sensor with respect to the survivor, and the response time of the gestures made by the survivors based on their distance to the sensor are evaluated. At the end of the experiments, the optimal distance and optimal position for the survivors to utilise the upper limb module are concluded.
II. STROKE REHABILITATION

A systematic review by Kelly et al. [8] demonstrates physical therapy as an aid for stroke recovery. Animal studies [5, 17, 19] suggest that between 400 and 600 repetitions per session may be necessary to stimulate neuroplasticity needed to initiate functional recovery of upper limb extremities. A report by [17] shows that improved motor rehabilitation is feasible through physical therapy. Likewise, [12, 20, 21] suggest that a high repetition of task-oriented exercise can improve motor functions. Rehabilitation techniques such as constraint-induced movement therapy (CIMT), robotic-assisted therapy and bilateral training are employed in improving upper limb dysfunctions [9, 15]. Restoration of the limb functions is possible by providing high-dose therapy under one-on-one supervision [15, 17].

Robotic rehabilitation has been widely used to provide intense therapy [22]. Studies find that robotic therapies are more effective than the traditional standard therapy [17]. Robotic therapies are expensive and complex to use in domestic settings [2]. [10] state that repetitive and task-specific exercise are crucial for rehabilitation therapy. Likewise, in 2008, a study reveals that a standard therapy includes 39 repetitions of active movements, 34 repetitions of passive movements and 12 repetitions of purposeful movements [23]. Stroke survivors may find such repetitive tasks as dull and start losing motivation [10]. Incomplete recovery occurs due to the lack of adherence, cognitive factors, lack of motivation [6, 7].

III. WHY USE GAMES FOR STROKE REHABILITATION?

Recent studies reveal that computer games have been making progress into therapeutic rehabilitation with the objective of making rehabilitation fun and contextual [8, 12]. Simulation and game developers working alongside health professionals created game-based technologies to increase motivation amongst survivors [22]. Game platforms like Sony’s PlayStation and EyeToy, Nintendo’s Wii and Microsoft’s Xbox 360, and PCs have increased the opportunities for low-cost, off-the-shelf rehabilitation methods [17, 22, 23]. Ref. [6] argues game-based rehabilitation techniques creates interventions which are both effective and engaging for survivors. Moreover, computer and video games have the capabilities to incorporate a high number of repetition and to motivate the player [6].

In 2011, Saposnik reviewed 12 studies, which used game-based rehabilitation techniques and reported that game-based technologies could be used alongside with traditional rehabilitation for upper arm movements [22]. Virtual Reality (VR) and game-based technologies allow users to engage in a different sensory environment, which helps them to retain their motivation and interest [7]. [23] reports that using EyeToy for intervention resulted in significant development of the upper limb functions. Likewise, [24] in her case study report mentions that the use of EyeToy has improved the neural reorganisation and decreased the general deficits found after stroke. Furthermore, in 2013, a research study involving Kinect-based games was conducted and reported a high level of user satisfaction and improvements in upper body movements [22].

Motion controlled games made for PlayStation Move, Nintendo’s Wii and Xbox 360 uses gesture-based elbow movements [10, 11]. Several studies on the effectiveness of the off-the-shelf computer games report that game-based techniques improve the upper body extremities [9-11]. The research results reveal that game based approach enable functional tasks at a higher dosage comparing to traditional approach [6]. A review of occupational therapy also indicates that game-based intervention increases therapeutic effect and participation [10].

Recent studies also reveal that increased use of robots and game-based technology in stroke rehabilitation has reduced the physical demands for therapist and provides a high-dosage therapy to the victims [17]. Robot therapies like the robotic arm, which assists patients in their upper limb movements, is more effective compared to the standard therapy given by the therapist and the intensive therapies [21]. However, existing therapy robots like the robotic arm is prohibitively expensive for clinical use where each rehabilitation centre may only have one installed. Furthermore, the robotic arm cannot be afforded by survivors for daily home use. A typical schedule for a centre that provides a robotic arm therapy session is a stroke survivor can only participate between 1-3 hours per week for a duration of 6 to 9 weeks, and it will cost a survivor $1500. Due to the high demand for upper body limb rehabilitation, easy access to these robotic therapies by all stroke survivors is practically impossible. An affordable home-based solution is required where continuous therapy sessions involving repetitive tasks and activities in the affected limb using PC games will be more effective than the current standard rehabilitations [14, 17, 20].

In order to bridge this gap, the Neuromender system has been designed and developed in close collaboration and with the active involvement of computer scientists, neuroscientists, neurologists, clinical exercise physiologists and psychologists as well as stroke survivors [25]. The hypothesis behind the system is that with regular rehabilitation at home, clinical recovery can be achieved faster.

IV. PROJECT NEUROMENDER AND THE NEUROMENDER SYSTEM

The Neuromender system is part of Project Neuromender. This project is an ongoing research which incorporates the design and development of a game-and-home-PC-based end-to-end stroke rehabilitation system. Neuromender addresses the challenge of providing accessible, affordability, consistency, convenience and reliable post-stroke rehabilitation for stroke survivors. This system provides a low-cost, highly personalised rehabilitation in the comfort of the survivors’ homes using virtual autonomous clinicians that dynamically adapt to survivors’ needs within parameter ranges set by expert human clinicians.

Project Neuromender has been running for the past three years where a fully functional prototype system with various modules has been designed and developed to cater for the rehabilitation needs of stroke survivors. This project involves collaboration with various stakeholders. The Neuromender system has been initially tested with 5 stroke survivors and current undergoing a pilot trial in a larger population.
Neuromender has two main components: the front-end game-based applications, and the backend online data storage and data analytics server. The front-end components of Neuromender use game-and-home-PC-based and Virtual Reality (VR)/Augmented Reality (AR) technologies to assist stroke survivors in their rehabilitation. The back-end component is a server, and the data storage and data analytics performed on this server are developed using HTML5, CSS3, JavaScript, PHP and MySQL frameworks.

Unlike current rehabilitation solutions, the Neuromender system has non-invasive articulated human body tracking with remote monitoring, playback, control, alert and data analytics functions that enable all treatment parameter ranges to be remotely overridden, adjusted and controlled by human clinicians. This includes restricting or disabling if necessary, the amount of rehabilitation to prevent overuse and the consequent side-effects.

In catering for a game-and-home-PC-based end-to-end stroke rehabilitation solution, the Neuromender system includes the following modules:

1) FlexiBrains – a module that is focusing on cognitive retraining and currently under investigation and piloting a small scale prototype.
2) Vision restoration therapy – an interactive visuo-tactile module that focuses on the rehabilitation of sensorimotor and recovery of visuomotor function. This module has been proposed in [26].
3) Upper limb rehabilitation – a module that is currently undergoing a trial pilot and forms the subject of this paper.
4) Lower limb rehabilitation – a module which is still under development.
5) Translation to real-life experiences – a module using fully immersive 3D VR/AR technologies to replicate activities of daily living such as cooking, eating, putting on clothes, showering, etc.
6) Transition to independence – a module that focuses on tasks that lead to independence such as driving a car. A driving simulator has been developed for this purpose and currently undergoing trial.

The success of a product can be determined by the readiness of users to accept the product i.e. “ease of use” [27]. Success can also be determined in terms of their performance, aesthetic features, contents, user interfaces and user interactions, etc.

The Neuromender system, with the inclusion of interactive simulations and 3D motion sensor, captures movements of the upper body stroke survivors in real time as they play games available in the modules. In respect to the upper limb module, three games have been developed, and each game is targeting a specific area of rehabilitation; one for lifting the arm, one for extending the arm, and one for rotating the arm in a circular motion. Each game has a different level of difficulties so that each survivor’s rehabilitation can be personalised and tailored by their clinician. The rehabilitation parameters can only be set up by approved clinicians via the Neuromender system’s online portal. This is to ensure expert control over the prescribed rehabilitation sessions for stroke survivors. The games were developed in consultation with exercise physiologists, neuroscientists, clinicians and also a number of stroke survivors who were helping with the project.

Elements of game design were employed to make the rehabilitation tasks entertaining to encourage adherence to clinician set rehabilitation regimes.

In the arm lifting rehabilitation game component of the Neuromender system, a survivor assumes the role of a person in a winged suit in a 3D environment gliding through a specified number of rings (waypoints) down a mountainous path [28] (Fig. 1). A survivor has to control the winged game character by lifting one’s affected arm up and down in a prescribed and repetitive manner to enable a controlled glide through the rings. A survivor has to focus and adjust the arm movement carefully to glide through the centre of each ring to receive the maximum score. User interaction is one of the critical aspects of Neuromender since it does not employ traditional inputs and uses a 3D depth sensor device connected to a PC [22]. In using this 3D depth sensor, the motions of the survivor’s arm is captured and translated into the respective movements to guide the winged game character. This 3D depth sensor is used to avoid the need for lengthy preparation on the survivor’s behalf to do rehabilitation (Fig. 2). A survivor can simply turn on the PC, launch and log in into the Neuromender system and perform rehabilitation; no body markers and no complex setup are needed. Once a survivor completes a rehabilitation session, all scores and movement data are sent to a secured backend server. As mentioned earlier, this server host and performs the data-analytics functions of the rehabilitation sessions undergone by the survivors. This backend server component of the Neuromender system also presents easy-to-understand graphs and tables of the rehabilitation progress where survivors and clinicians can monitor and discuss their progress over time (Fig. 3).

![Fig. 1. A screenshot showing the winged game character in Neuromender](image)

As the data being captured and stored on the system was essential to tracking rehabilitation progress, the capturing and recording process had to be verified. This required a series of experiments to be conducted to ensure that once the system was deployed in a survivor’s home, the system would function correctly. As the primary data capture device was the 3D sensor, it was necessary to ensure the placement of the sensor would not introduce data anomalies including failure to capture
data. It was also necessary to check that the data being recorded in the database was correct.

The arm lift component of Neuromender was built as a game, so it was also necessary to check that the game was playable in a number of situations, so a number of usability studies had to be carried out.

**Fig. 2.** A survivor playing the winged game for his upper limb rehabilitation

**Fig. 3.** A screenshot showing one of the rehabilitation progress graphs of a survivor that is recorded over a period of time

### V. METHODOLOGY

As part of the usability evaluation, an experimental study was conducted on the Neuromender system’s upper limb module. The user experience from the viewpoint of a stroke survivor about the module’s interface was evaluated and reported. In order to perform the usability evaluation, heuristics was established based on the “heuristics evaluation of user interface” developed by [27]. This approach has been widely used in the previous literature [29, 30].

Several experiments were conducted in the IVES (Intelligent Virtual Environments & Simulations) laboratory at a public university in Western Australia. The Neuromender system records all the data and stores them in a database on a secured online server. This server is accessible by both the survivor and clinician. Two accounts were created; 1) a survivor account and 2) a clinician account. In using the survivors’ account, the winged game was played, and by using the clinician’s account, the data was accessed for data analysis. During rehabilitation, the system instructs the survivor to lift one’s arm up or down as needed. The survivor has to raise one’s arm to a particular angle to get the winged character through the rings. This angle was measured and recorded by the 3D depth sensor, and stored on the online server.

### VI. EXPERIMENTAL SET-UP

The experiment started with a usability evaluation to measure the functionalities of the upper limb module. In the experiment, a laptop with Windows 10 operating system and the Neuromender system upper limb module installed and connected to the 3D depth sensor via the USB 3.0 port, was used. The entire setup was stationed on a table measuring 105×50×75cm (L×W×H). Then the upper limb module was executed, and the winged game was played. The table was divided into four different quadrants of equal distances (Fig. 4). Four different distances 0.5m, 1.0m, 1.5m, 2.0m, were measured from the table and marked. Experiments were conducted in all of the four marked distances. This experiment focused primarily on testing the functionalities of the affected elbow movement when using the upper limb module.

**Fig. 4.** Representation of the four quadrants

A. **Determining the Optimal Position of the 3D Depth Sensor**

As mentioned earlier, to determine the optimal position of the sensor, the table was divided into four different quadrants of equal distances. By placing the sensor in all four quadrants, four tests were performed in the experiment. The user played the winged game at 1.5m from the edge of the table.

Initially, the 3D depth sensor was placed in the first quadrant, and the laptop was stationed in between the second and the third quadrants. In the first test, the beach mode (low-detail) of the winged game was played, and the results were recorded. Secondly, the 3D depth sensor was placed in the second quadrant, and the laptop was placed in between the first and fourth quadrant. In the second test, the beach mode (low-detail) of the winged game was played again. Thirdly, the 3D sensor was placed in the third quadrant of the table, and the laptop was placed in between first and fourth quadrants, and the experiment was performed by playing the winged game in beach mode (medium-detail). Finally, the 3D depth sensor device was placed in the fourth quadrant, and the winged game was played again in the beach mode (medium-detail), with the laptop been stationed in the second and the third quadrant. The results and the optimal position were determined based on these four tests, and the results are discussed in the discussion section.
B. Determining the Optimal Distance when using the Neuromender System

Four different distances of 0.5m, 1.0m, 1.5m, and 2.0m were measured from the edge of the table and marked. The tester sat at each of the marked distances in turn. Tests were conducted in each range to determine the optimal distance when using the system. For those tests, the 3D depth sensor was placed in the first quadrant, and the laptop was placed in between the second and third quadrant. The test began by putting the chair at 0.5m, and the winged game was played. At 0.5m, all three modes of the winged game i.e. beach (low detail), temple (medium detail) and forest (high detail) were played. Each mode also has three levels of difficulties as in flying speed i.e. slow, medium and fast, and all of these levels were played as well. Similarly, the tester’s chair was placed at all distances of 1.0m, 1.5m, and 2.0m respectively. All levels of the winged games were played at all four distances to determine the optimal distance when using the Neuromender system, and a total of 27 tests were performed. All the details and responses from the system were recorded, and the results are discussed in the discussion section.

C. Determining the Accuracy of the Angles Measured by the 3D Depth Sensor

The winged character in the game was controlled by gestures made by the survivors. The Neuromender system instructs survivors to lift their affected arm up and down as a part of the rehabilitation. The survivor has to raise one’s arm to a particular angle to get the winged character through the rings. This angle was measured and recorded by the 3D depth sensor. A goniometer was used to determine whether the angle measured and recorded by the 3D depth sensor corresponded to the angle produced by the survivor’s arm movements. The recorded data contained the following variables: Time, Date and the angle measured by the goniometer. Then the recorded angles were manually matched with the data of angles recorded by the 3D depth sensor and stored in the database on the online server.

VII. DATA ANALYSIS

The Neuromender system records the survivors’ rehabilitation progress data, and these are stored in its database. The data can be viewed by both the stroke survivors and clinicians by logging into the Neuromender system’s web portal using their user credentials. The data stored contains various constructs such as TrackingID, SessionID, Date, Time, right arm angle, left arm angle, etc. Most of the variables stored are not required for the experiment discussed in this paper. The only data required for the experiments were SessionID, Date, Time, StartTime, EndTime and Left Angle (Fig. 5).

In Fig. 5, the SessionID is a unique ID assigned by the Neuromender system for each session, the LeftAngle represents the angle produced by the affected arm, and Time indicates the date and the time of the experiment. The StartTime and EndTime indicate the start and the end time of each arm’s movement. The variable “Time” is crucial as it is matched with the date and the time recorded manually during the test to identify the SessionID. The data recorded in the variable “LeftAngle” is then matched against the angle recorded by the goniometer to determine whether or not the angle measured by the 3D depth sensor was accurate.

VIII. RESULTS AND DISCUSSION

A. Determining the Optimal Position of the 3D Depth Sensor

As mentioned in the methodology section, the table was divided into four quadrants. Four tests were conducted by placing the 3D depth sensor in all of the four quadrants. The beach mode of the game (low-detail) was played in all the four experiments. Moreover, the position of the tester’s chair was kept constant at 1.5m from the table to avoid redundancies. In the first test, the 3D depth sensor was placed in the first quadrant, and the laptop in between the second and third quadrant. The user played the game in beach mode (low detail). During the gameplay, some disruptions occurred. Firstly, the 3D depth sensor was not able to capture the gesture movements. As the 3D depth sensor was placed in the first quadrant, the sensor and the user's affected left arm was not aligned in-line. On the contrary, the laptop placed between the second and third quadrant was aligned in-line with the user’s affected left arm. As the sensor was not upright to the left arm, the sensor was not able to capture the left arm movements, hence resulting in disruptions in controlling the winged game character. Moreover, the user experienced unnecessary fluctuations in the "black" line indicator which was used to mimic the arm’s movements of the user.

Secondly, the sensor was placed in the second quadrant of the table, and the winged game was played. The sensor performed adequately in capturing the arm’s gestures, and there was no delay in capturing them. The user did not experience any disruptions in controlling the winged game character. Moreover, there were no disruptions in the "black" line indicator indicating that arm tracking was working correctly. Overall, the user did not experience any disruptions during the second experiment. There were no disruptions because the sensor was in-line with user’s affected left arm and there were no other obstructions between the arm and the sensor that could possibly affect the capturing of the arm’s movements.

The third test began by placing the sensor in the third quadrant, and the laptop was placed in-between the first and fourth quadrant. The user played the beach mode (low-detail) of the game, and there were no disruptions during the experiment. Finally, in the last test, the sensor was placed in the fourth quadrant and the laptop in-between the second and the third quadrant. The user experienced similar disruptions that occurred during the first experiment. It was determined that the reason was that the sensor device was not aligned in-line with user’s affected left arm.
Based on the results of the experiment, it can be concluded that the second quadrant and third quadrant of the table is the optimal position for the placement of the 3D depth sensor. There were no disruptions in controlling the winged game character or in the black line indicator when the sensor was placed in the second and third quadrant. On the contrary, there were many disruptions when the sensor was placed in the first and fourth quadrants. Disruptions occurred because the sensor was not in-line with the user’s affected arm. There were no interruptions when the sensor device was aligned up straight with user’s affected arm i.e. when the sensor is placed in the second and third quadrant of the table. Based on the experiment and the user experiences, it can be concluded that the optimal position to use the 3D depth sensor is either the second quadrant or the third quadrant.

B. Determining the Optimal Distance when using the Neuromender System

Four different distances of 0.5m, 1.0m, 1.5m, and 2.0m were measured from the edge of the table and marked. The winged character game was played at each distance separately to determine the best position/distance to use the Neuromender system. All the three modes of the winged game were played at the listed distances. Each mode has three levels of difficulties as in flying speed i.e. slow, medium and fast, respectively. The 3D depth sensor was placed in the second quadrant as it was concluded as one of the optimal positions for placing it. The laptop was placed in-between the first and fourth quadrant. This set-up was kept constant to avoid discrepancies.

The test began at a distance of 0.5m where the chair was placed, and the user started playing the game. At first, the beach mode (low-detail) of the game was played. All of the three levels in this mode were played, and the results were recorded manually. In this mode, the user endured issues controlling the winged character. The sensor did not capture the movements of the user’s arm adequately. As a result, the user was not able to control the winged game character accurately. Moreover, continuous in-game fluctuations appeared when the winged game character attempted to cross the rings. There was a pattern in these variations i.e. fluctuations arose when the winged character sought to pass the first, fourth and the fifth ring of the game. In addition, the user underwent delayed response in controlling the winged character, and these disruptions appeared in all the three modes of the winged game played at a distance 0.5m.

The next test began at 1.0m. As mentioned earlier, all the three modes of the winged game were played to avoid redundancies. At this distance, the same disruptions appeared. Also, the user underwent additional disruptions. The user did not receive any instructions from the Neuromender system when the winged game began. The same pattern appeared in all of the three modes of the winged game. Likewise, there were continuous fluctuations in the black line indicator, which is used to reflect the user’s arm movements. The black line (Fig. 1) indicator swung even when the arm was held still. Furthermore, the user experienced some delays in the winged game. The winged character in the game was not responding according to the user’s arm movements, and errors appeared in the angle indicator. The “blue” line indicator is used to signify the designated angle. To complete the task of getting the winged character through the rings, the user has to lift one’s arm to the level (blue line indicator) as prescribed by the clinician and executed by the Neuromender system. During the test, the user encountered inconsistencies in the blue line indicator i.e. the blue line indicator shifted rapidly, but there were no patterns observed in the shift. On the contrary, the fluctuation of black line indicator had a pattern. The black line indicator repeatedly shifted while crossing the first, third and the seventh ring of the winged game. This pattern was observed in all of the three modes of the winged game.

The test continued by playing the game at distances 1.5m and 2.0m. Unlike the previous tests, there were no disruptions. There were no fluctuations in the two line indicators. The sensor captured the user’s arm movements adequately. There were neither interruptions nor delays in controlling the winged game character. The winged character responded appropriately to the arm movements. Both blue and black line indicators performed accurately. As opposed to the results from the previous experiments, there were no performance lags in this experiment. Moreover, the black line indicator responded promptly. Also, instructions were provided by the Neuromender system appropriately.

A set of 27 tests were performed to determine the optimal distance to use the Neuromender system. The results of the tests revealed that many disruptions occurred at the distances of 0.5m and 1.0m compared to at the distances of 1.5m and 2.0m. The Neuromender system performed adequately at 1.5m and 2.0m. Hence, based on the experiences encountered, it can be concluded that the optimal distance when using the Neuromender system is at 1.5m and 2.0m respectively.

C. Determining the Accuracy of the Angles Measured by the 3D Depth Sensor

The following experiment was conducted using the goniometer to verify the angle measured by the 3D depth sensor. The game was played at a distance of 1.5m as it was concluded as the optimal distance when using the Neuromender system. Moreover, based on the results, the sensor was placed in the second quadrant of the table.

When the user starts playing the winged game, the Neuromender system will instruct the tasks to be performed. For instance, the system will instruct the user to lift one’s affected arm. A blue line indicator will show the angle to be reached, and a black line indicator will move according to the user’s affected arm movements. Once the user reaches the designated angle, the user has to hold one’s affected arm still to allow the winged game character pass through the rings. The Neuromender system will record this action. Once, the winged game character passes through the ring, the Neuromender system prompts the user to lower one’s affected arm, and the tasks will be repeated throughout the rehabilitation session. The Neuromender system will record the angle of the user’s affected arm each time the user performs the lowering and lifting the arm actions.

The goniometer was used to ensure that the angle measured by the 3D depth sensor device was accurate. In keeping track of
the experiments, the date and time of each test were recorded manually along with the angle measured by the goniometer. For example, as mentioned earlier, the sensor records information such as session ID, date, time, the angle made by the users, etc. The date and time that were recorded manually were then matched with the time and date recorded by the sensor in order to identify the session ID. Then using the variables such as session ID, Date, and Time; the angle measured by the sensor will be identified and matched against the angle measured by the goniometer for that particular session. Three different experiments were conducted, and the results revealed that the angle measured by the sensor was accurate.

IX. CONCLUSION

Using games for rehabilitation is not new. Studies reveal that computer games have been making progress into therapeutic rehabilitation with the objective of making rehabilitation fun and contextual [8, 12]. Several studies on the effectiveness of the off-the-shelf computer games also report that game-based techniques can improve the upper body extremities [9-11].

This paper reports on the usability studies conducted on a serious game-based rehabilitation system that uses off-the-shelf hardware components. Experiments were conducted to determine the correct placement of the primary data capture component and the impact of the placement on the usability of the rehabilitation system. The accuracy of the data capture was also investigated.

Based on the experimental results, it was determined that the optimal distance to utilise the Neuromender system for upper limb rehabilitation was either at a distance of 1.5m or 2.0m. Although not tested, it is possible that any distance between 1.5m to 2.0m would do. Also, a set of four experiments conducted determined the optimal position of the 3D depth sensor. It can be concluded that the optimal position to place the sensor is either in the second quadrant or the third quadrant. The final experiment conducted was to ensure that the angles measured by the 3D depth sensor device were accurate. The results of the experiment revealed that the data recorded i.e. the angle recorded by the sensor was accurate. Although the experiments revealed promising results, the experiments were subjected to limitations. The experiments were conducted in a controlled lab environment where there were no external factors that could possibly interrupt or hinder the process of capturing the user’s arm movements by the 3D depth sensor. It may be possible that when a survivor utilises the Neuromender system at home, there could be several external factors such as other objects, pets, lighting conditions, internet connection, internet signal strengths, etc. that may affect the Neuromender system. Performing further experiments with a diverse set of users and in the real world, settings might provide further insight and improvement in evaluating the usability of the Neuromender’s upper limb game-based rehabilitation system for stroke survivors.

ACKNOWLEDGMENT

The authors would like to thank the School of Engineering and Information Technology, Murdoch University for providing internal seed funding for Project Neuromender. The authors would also like to express their gratitude to their external advisors Craig Watts, Noel Ashcroft, Shane Hopkins, John North, Samantha Bay, Kevin Ong; their students Alex Arif, Mark Ellis, Michael Garner, Steven Impson, Benjamin McLeary, Michael Vatskalis, Karl Tysoe, James Brine, Jak Gem, Hazem Kahlbouneh, Cameron Thompson, Swaminathan Krishnamurthi, Gurjot Singh; and colleague Peter Cole.

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