User evaluation of a virtual rehabilitation system during reaching exercises: a pilot study

M Al-Amri[1], D Abásolo[2], S Ghoussayni[2], D Ewins[2,3]

[1]School of Healthcare Sciences, Cardiff University,
Heath, Cardiff, UK

[2]Centre for Biomedical Engineering, University of Surrey,
Guildford, Surrey, UK

[3]Gait Laboratory, Queen's Mary Hospital,
Roehampton, London, UK

Al-AmriM@cardiff.ac.uk, {d.abasolo;s.ghoussayni;d.ewins}@surrey.ac.uk

ABSTRACT

The aim of this paper was to evaluate the practicality of the Surrey Virtual Rehabilitation System (SVRS) for reaching exercises with children with CP. Five potential users or operators (two children with CP, a physiotherapist, and two clinical engineers) participated in the study. Using 11 closed-ended questions and an open discussion, the feedback collected indicates that the participants were generally positive about the practicality of the SVRS. Outcome measures obtained from data gathered during the session suggest that the SVRS can provide clinically relevant feedback on the performance of patients for themselves and their treating clinicians. In conclusion, the SVRS seems to be practical for rehabilitation purposes and further development and evaluation are warranted.

1. INTRODUCTION

Cerebral Palsy (CP) is a term given to a group of chronic non-progressive disorders in motor function resulting from damage that often occurs before the brain is fully mature (Bax et al, 2005; Gage, 1991). Motor system impairments are common in children with CP (Rosenbaum et al, 2007; Rosenbloom, 1995). The impairments lead to limitations in balance and coordination skills in children with CP, which can affect their everyday activities (Berker and Yalçin, 2010; Woollacott et al, 1998). Physiotherapy can provide a base to improve and/or preserve mobility and independence in children with CP for longer (Barber, 2008). This includes exercise programmes that focus on improving and maintaining ability to control and regulate postural stability, balance, and muscular strength (Berker and Yalçin, 2010). Postural control tasks require interaction between neural systems, to access position and control movements, and musculoskeletal systems to generate forces in order to achieve body movements (Chen and Woollacott, 2007; Shumway-Cook and Woollacott, 1995; Woollacott and Shumway-Cook, 2005). Improving the capacity to maintain posture while standing is one of the typical rehabilitation tasks for children with CP (Woollacott and Shumway-Cook, 2005). Positive results of physiotherapy can be obtained by high repetition of exercise programmes (Tsorlakis et al, 2004), which can be achieved whilst children are inspired and motivated to performing exercises in different situations (Tatla et al, 2013).

One possible approach of providing an intensive physical programme in a motivating and safe environment is the inclusion of Virtual Reality (VR) (Holden, 2005); it has become increasingly used for the rehabilitation of physical function in individuals with neurological conditions (da Silva Cameirão et al, 2011). The literature (Holden, 2005; Rizzo and Kim, 2005) shows that the potential effect of VR in rehabilitation is the capability to integrate the following important attributes for motor learning: intensity; motivation and engagement; and feedback on specific movements. However, most VR systems used in previous research (Galvin and Levac, 2011; Sandlund et al, 2008; Snider et al, 2010) had not been developed with rehabilitation in mind. Others have been designed specifically for use in rehabilitation, but these can be expensive, which has limited their use. In conjunction with a clinical team based in the rehabilitation centre in Queen Mary's Hospital, Roehampton, London, the Surrey Virtual Rehabilitation System (SVRS) has been developed by using existing facilities and basic components that can produce VR scene on a low-cost screen. The SVRS provides a variety of exercises for custom clinical use for children with CP (Al-Amri et al, 2011). As part of the development process, the need for postural control exercises was highlighted. Therefore two VR scenarios were prepared in order to evaluate the

practicality of the SVRS during functional reaching exercises, as discussed in the following section. The primary aim of this study was to examine the practicality of the SVRS during reaching exercises through involving potential end-users or operators of the system in this development stage. For this work, the term practicality has been adapted based on the definition of usability by Nielsen (2003) and the ISO standard (Bevan, 2001) and used to describe: "*satisfaction, comfort, safety and, to some extent, utility*" (Al-Amri, 2012). The secondary aim was to quantify whether the motion data from the SVRS is feasible in evaluating user performance.

2. METHOD

2.1   Apparatus of the SVRS

Details of the first prototype of the SVRS can be found elsewhere (Al-Amri et al, 2011). Briefly, the SVRS includes two personal computers. The first computer (PC1) generates virtual environments that were developed using the Vizard Virtual Reality Toolkit (version 3.18.0002, WorldViz LLC, USA) and communicates with the second personal computer (PC2). The Qualisys passive infrared motion system (Qualisys AB, Sweden) using Qualisys Track Manager software (version 2.4.546) was used to track marker positions. This system ran on PC2 and transmitted motion data to PC1 via a TCP/IP communication protocol. To increase the safety of the SVRS, a function was implemented in Vizard to freeze the virtual world if PC1 did not receive complete motion data from PC2.

2.2   Participant Recruitment

The National Research Ethics Services (NRES) NHS Committee gave ethical approval to recruit children with CP who have previously visited the Gait Laboratory at Queen Mary's Hospital. Criteria for inclusion of children with CP in this study were: female or male; a consultant's diagnosis of diplegic or hemiplegic CP; aged between 12 and 17 years; Gross Motor Function Classification System (GMFCS) rating of level I to level III; and no evidence of photosensitive epilepsy. At this development stage of the SVRS, it was also decided to recruit representatives from professions typical of those who may have to operate the system in the future. An invitation was therefore sent to clinical engineers and a physiotherapist, who were not involved in any discussion about the SVRS development.

2.3   Investigation Procedure

The investigation was carried out in the Gait Laboratory at Queen Mary's Hospital, London. Informed consent from all participants was obtained. The participants were then asked to perform the following two functional reaching exercises:

The first exercise was developed to allow subjects to touch a virtual balloon in the virtual environment through controlling a virtual hand; this exercise lasted for a 2-minute period. In this scenario, participants performed the exercise at a standstill in front of the screen at a preset position on the floor. A pointer (see Figure 1) to which reflective markers were fixed was used to allow participants to control the virtual hand. Participants were asked to touch a virtual balloon that appeared on the screen in selected random positions in the virtual environment every 3 s and then return their arm to the original start position (arm relaxed and lying close to the trunk in a neutral position – Figure 1) once the balloon had been touched or missed. Balloon positions were normalised based on the participant's arm length and body height, which were used to maximise the distance of the balloon from the start position and the floor, respectively. The arm length was measured from the acromion to the end of the fingers. Participants were asked to repeat the test three times: the first, when balloons appeared on their dominant arm side, which meant they needed to touch a balloon by using only that hand; the second was similar but this time using the other hand; the third, when balloons appeared on both sides and participants were asked to use either hand as they considered appropriate. At the end of this test, the participants were asked to complete five closed-ended questions on a questionnaire.

In the second reaching exercise, participants were asked to control the virtual hand (following the procedure outlined above in the first exercise) to grab a virtual object by using the nearest arm and then to place it into the correct virtual barrel. These objects were generated as boxes and balls that were initially placed on a virtual table inside a virtual room (see Figure 2). With the aim of encouraging participants to move forward and sideways to reach the virtual objects, the depth position of these objects was generated to be equal to the participants arm length for six objects, plus up to 20 cm for the other three objects. Participants were instructed to move backward to the start position once they grabbed the object and then to move sideways to drop it in the correct barrel. For more motivation, the scenario allowed them to watch a cartoon film if they had placed all the virtual objects into the correct barrels within 120 s. During the task, a virtual projection screen extended down if they had dropped the first three virtual objects into the correct barrels in order to provide participants encouragement to continue

performing the exercise. At the end of this test, the participants were asked to complete six closed-ended questions on a questionnaire, followed by an open semi-structured discussion between the first and the last authors of this paper, and in the case of the children with their parents/guardians. The overall aim of this discussion was to gather further information on their perceptions on the practicality of the SVRS during the exercises. Participants were asked during and at the end of each test whether they felt any discomfort from using the SVRS.
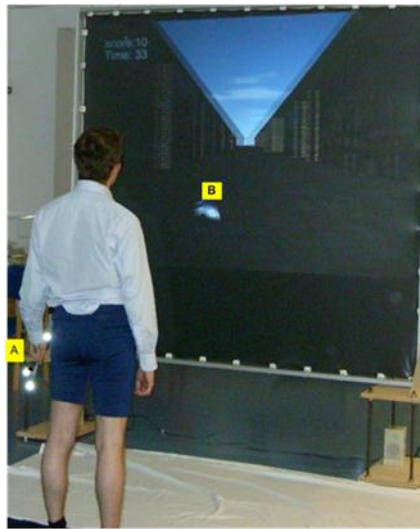

Figure 1. *An able-bodied volunteer using the SVRS to perform the first reaching exercise. A: pointer attached with reflective markers; and B: virtual hand in the virtual world.*
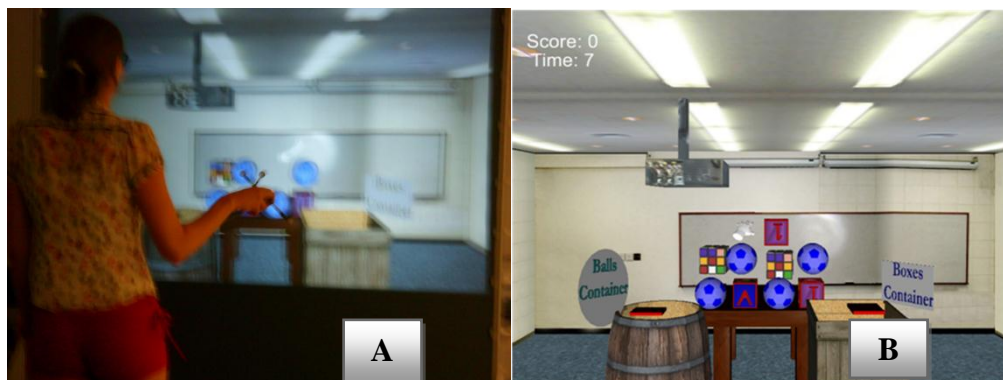

Figure 2. *An able-bodied volunteer using the SVRS to perform the second reaching exercise. A: during the actual test and B: a screenshot of the VR environment.*

2.4 Data Analysis

A questionnaire (Al-Amri, 2012) was developed in order to evaluate the first three components (satisfaction, safety, and comfort) of the practicality for each exercise. The open discussion was carried out in order to gather perspectives on the fourth component (utility) of the SVRS practicality.

Motion capture data from the participants were saved automatically in Microsoft Excel spreadsheets using code that was implemented in Vizard. These data were then used to quantify the following outcomes from the first exercise:

▪ Total number of balloons touched.
▪ Distance (normalised to arm length) that represents the path between the base of the hand and a virtual balloon.
▪ Time taken to cover the distance.

Whilst in the second reaching exercise, the following outcomes were selected:

- Distance (normalised to the arm length) that represents the path between the base of the hand and a virtual object on the table.
- Time taken to achieve the task.
- Amount of time taken to clear the virtual objects from the table.

3. RESULTS

A 14 year old girl with right CP hemiplegia (labelled as C1) and a 16 year old male with left CP hemiplegia (labelled as C2) participated in this study. C1 and C2 were classified as level I according to the GMFCS and receive on-going rehabilitation. A physiotherapist (labelled as A1) and two clinical engineering trainees (labelled as A2 and A3) also agreed to participate in this preliminary study. Participants A1-A3 had no past or present known issues with mobility and were considered to be able-bodied. Details of the participants are summarised in Table 1. A parent for each of the children with CP and a treating physiotherapist (PH) for C1 observed the testing.

Table 1. *Summary of general information about the participants. A1-A3 refers to able-bodied participants, while C1 and C2 refer to the children with CP.*

	C1	C2	A1	A2	A3
Height (cm)	168	177	180	190	169
Arm length (cm)	60	70	73	80	70
Vision deficiency	No	Yes	No	No	No
Dominant arm	Left	Right	Right	Right	Left

3.1   Perspectives on the First Reaching Exercises

After completing the three trials of the first reaching exercise, five closed-ended questions (see Table 2) were asked in order to examine the practicality elements of the SVRS as follows:

- Comfort was examined through the answer to Q1, and Q2.
- Satisfaction was tested by Q3.
- Safety was evaluated through the response to Q4, Q5, as well as the observation by the investigators.

For each question participants were asked to choose one of five possible responses ranging from 'Awful' to 'Brilliant'. For analysis purposes responses of 'Good' or 'Brilliant' were considered to be positive. The responses of each participant are presented in Table 2 and these show that the participants were positive about the Comfort, Satisfaction and Safety of the SVRS for this exercise.

Table 2. *The participants' responses to the first five closed-ended questions. A1-A3 refers to able-bodied participants, while C1 and C2 refer to children with CP.*

	Brilliant	Good	OK	Poor	Awful
Q1. I would rate my ease in controlling the virtual hand as:	A1,A3	C1, C2,A2	None	None	None
Q2. My ability to touch the virtual balloons was:	C1,A1,A3	C2, A2	None	None	None
Q3. I would rate my enjoyment in touching the virtual balloons as:	A2	C1, C2, A1, A3	None	None	None
Q4. I thought my safety when touching the virtual balloons was:	C1, C2, A1,A2,A3	None	None	None	None
Q5. My overall confidence when touching the virtual balloons was:	C1, C2, A1	A2,A3	None	None	None

The outcome measures results are summarised in Table 3, which indicate that the participants moved their dominant arm from the base to touch balloons within a range of median distance between 52 and 78 (% of a participant's arm length). The range of the median time that was taken to cover that distance was between 1.2 s and 1.9 s. For children with CP, C1 and C2 touched 18 balloons out of 19 with their dominant arm covering a median distance of 52% and 65% of their arm length, respectively. For able-bodied volunteers, the results show that A2 moved his left dominant arm from the base to touch balloons in the shortest median distance in comparison with A1 and A3.

In the non-dominant trial, the results show that C1 moved the affected arm from the base to touch balloons at a median distance of 19% (of actual arm length) more than distance used by C2. A2 moved the non-dominant right arm at least a median distance of 5% (of actual arm length) less than what A1 and A3 did to touch balloons, within a shorter time. In the third trial, the participants swapped the pointer between both hands to touch balloons that appeared on both sides.

Table 3. *Results of outcomes during the first reaching exercise.*

Dominant Arm Trial						
Outcomes		C1	C2	A1	A2	A3
Normalised Distance	Median (% of actual arm length)	52	65	78	65	68
	Range (% of actual arm length)	20– 99	28-87	22-97	36-95	25-97
Time taken to touch a balloon	Median (s)	1.3	1.2	1.9	1.2	1.8
	Range (s)	0.5 – 2.2	0.7-2.3	1.5- 2.3	0.8-1.8	0.7-1.8
Number of balloons touched	Score (out of 19)	18	18	19	19	19
Non-Dominant Arm Trial						
		C1	C2	A1	A2	A3
Normalised Distance	Median (% of actual arm length)	82	63	79	74	86
	Range (% of actual arm length)	51– 99	37.0-94.0	44-99	18-92	21-98
Time taken to touch a balloon	Median (s)	1.3	1.9	2	1.3	2
	Range (s)	0.8-1.8	1.2-2.6	1.8-3	0.8-2.3	0.8-2.5
Number of balloons touched	Score (out of 19)	18	17	19	19	19
Both Arms Trial						
		C1	C2	A1	A2	A3
Normalised Distance	Median (% of actual arm length)	68	60	72	76	65
	Range (% of actual arm length)	30– 99	20-90	58-91	58-94	37-92
Time taken to touch a balloon	Median (s)	1.3	1.5	2.2	1.6	1.5
	Range (s)	0.6 – 1.9	0.8-2	1.6-2.5	1.2-2.3	0.8-2.1
Number of balloons touched	Score (out of 19)	18	17	19	19	19

3.2   *Perspectives on the Second Reaching Exercises*

For the purpose of evaluating the practicality elements of the SVRS during the second reaching exercise, six closed-ended questions (see Table 4) were asked:

▪ Comfort was examined through the answers to Q6, Q7, and Q8.
▪ Satisfaction was tested by Q9.
▪ Safety was evaluated thro ugh the response to Q10, Q11, as well as the observation.

The results presented in Table 4 show that the perspectives of the children with CP on the practicality elements of the SVRS during this exercise were not notably different from those of the able-bodied volunteers. Both groups were positive about the Satisfaction and Safety of the SVRS, and there was a mix of positive to OK responses for the Comfort aspect.

The results for the outcome measures for the participants during the second reaching exercise are summarised in Table 5. The shortest median normalised distance for grabbing an object was achieved by subject A2 (71 %), followed by C2 (84 %). The shortest completion time for the task was 33 s and this was achieved by A3, followed by C1 (37s).

Table 4. *The participants' responses to the six closed-ended questions relating to the practicality during the second reaching exercise. A1-A3 refers to able-bodied participants, while C1 and C2 refer to children with CP.*

	Brilliant	Good	OK	Poor	Awful
Q6. I would rate my ease in controlling the virtual hand as:	A3	A2	C1, C2, A1	None	None
Q7. How easy was it to reach for the balls and the boxes that were on the table?	None	A2 A3	C1, C2, A1	None	None
Q8. My ability to drop the balls and the boxes in the correct container was:	None	C1,C2,A1,A2,A3	None	None	None
Q9. How enjoyable was it to clear the balls and the boxes from the table?	None	C1,C2,A1,A2,A3	None	None	None
Q10. I thought my safety when clearing the balls and the boxes from the table was:	C2,A2,A3	C1, A1	None	None	None
Q11. My overall confidence when clearing the balls and the boxes from the table was:	A3	C1, C2, A1,A2	None	None	None

Table 5. *Results of outcomes during the second reaching exercise.*

		C1	C2	A1	A2	A3
Normalised Distance	Median (% of actual arm length)	101	84	102	71	107
	Range (% of actual arm length)	26-156	24-129	36-151	46-146	33-179
Time taken to reach an object on the table	Median (s)	2.1	2.2	2.6	2.0	1.6
	Range (s)	1.0-4.5	1.1-4.4	1.2-6.6	1.2-3.1	1.2-2.8
Completion Time (s)		37	49	41	43	33

3.3   Perspectives on the Reaching Exercises

In the open discussion with the participants, only A1 and the parent of C1 commented on these exercises. First of all A1 reported that the explanation of how to perform the second exercise was not clear. However, A1 believed that the scenarios would be helpful for rehabilitation purposes - to improve reaching while maintaining balance during standing. She also suggested that for the first exercise there should be a way to ensure that subjects return their arm back to the correct starting position before touching the next balloon, e.g. through messages on the screen. The parent of C1 commented that the scenario motivated his daughter, however, he also suggested running the scenario at different speeds, which could make it more challenging. The physiotherapist for C1 (PH) was pleased with the motivation shown by C1 during the exercises. PH made positive comments about the utility of the SVRS in rehabilitation for children with CP noting that the SVRS may benefit the rehabilitation of children with CP and it would be helpful to have such equipment in the clinical environment. She also wondered whether automated performance measurement for each user in each session could be done in such a way as to provide immediate feedback to patients. None of the participants reported any discomfort when using the SVRS.

4. DISCUSSION AND CONCLUSIONS

The purpose of the present study was to evaluate the practicality of the SVRS and the feasibility of using motion data to provide performance feedback to end-users. In the first exercise, the results show that the children with CP and the able-bodied participants were positive about the first three elements of the practicality of the SVRS. The results presented in Table 3 suggest that each participant used a different approach to touch the balloons. It was also noticed that participants did not always return their arm to the required starting position though, which might be a key reason for differences in the results of outcome between individuals; none of the participants had difficulties with holding the pointer. Despite these limitations, the results generally show the feasibility of the SVRS to assess individual performance.

In terms of the perspectives on the practicality of the SVRS during the second reaching exercise, all participants were positive about the satisfaction and safety of the SVRS, but the results show that while A2 and A3 were positive about the comfort of the SVRS, the children with CP and A1 were not. This difference might be due to the fact that children with CP found it harder to control the hand while they were required to make movements. In the case of A1, the task was not clear to her as she commented afterward on the lack of the

explanation that was provided. For instance, making movements forward, backward, and to both sides were required in order to reach the virtual objects. Swapping the pointer between the arms to reach the nearest object and barrel was also encouraged as part of completing the task. To drop the grabbed object, the participant had to move it to touch a small red box that was placed on the top of each barrel. During the observation, it was noticed that only C2 and A2 performed the task based on these instructions, which reflect the median distance the arms moved to grab objects as can be seen in Table 5.

For the outcome of the discussion in order to evaluate the "utility" of the SVRS, the two physiotherapists (PH and A1) felt that the scenarios may challenge children with CP to develop a strategy in order to complete the tasks successfully. This may improve not only postural control and balance but also the ability to conceive and achieve different actions, which may have a positive impact on the ability to improve daily life activities.

There were several limitations inherent in this study. The small sample size was the main limitation and so it is possible that the results might have been altered with larger sample size. In addition, the current VR scenarios did not ensure subjects performed the exercises as was explained, which will have impacted on the differences seen in the results.

In conclusion, the results are encouraging, but further modifications and investigations need to be considered in the future work. For example, in the future design of these exercises, an algorithm to ensure that subjects will return the hand to the origin base will be implemented.

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