Benefits of a virtual play rehabilitation environment for children with cerebral palsy on perceptions of self-efficacy: a pilot study

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Summary

This paper presents the results of a clinical trial of a virtual reality play-based intervention. The results of three single case studies are presented. The virtual reality intervention used the Mandala® Gesture Xtreme technology. It was applied to three school-aged children with cerebral palsy. A pre-test–post-test design was used. The relevant outcome of interest was self-efficacy as measured with the Canadian Occupational Performance Measure (COPM). Group scores on the COPM indicated clinically significant changes in self-efficacy for all children. Two of the participants demonstrated the greatest changes in both perceived performance abilities and satisfaction with performance with respect to task specific domain areas. Qualitative comments from the participants revealed a high degree of motivation, interest, pleasure, and opportunity for engagement in play, activities not previously engaged in. Overall, this pilot study suggests the viability of a virtual reality play-based intervention as part of the rehabilitation process for children with cerebral palsy. These results form the basis of a larger scale randomized clinical trial.

Introduction

Cerebral palsy (CP) refers to a group of posture and movement disorders occurring as a result of a non-progressive lesion of the developing central nervous system [1]. Generally, a diagnosis is made before the age of two years, and therapy interventions are provided. The emphasis of therapy programmes, especially for younger children with CP, has been on promoting physical growth and development. There have been many popular forms of therapy over the years, however their real value and effectiveness has not been strongly supported by empirical evidence [2–3]. For the older school-age child with CP, the goal of intervention focuses on psychosocial growth and development as well as on motor performance [4]. This is critical given the challenges facing school-age children and adolescents as they grapple with both developmental issues and their motor disorder. However, a steadfast problem is that there is very little research documenting the effects of rehabilitation therapy on motor and psychosocial outcomes.

Virtual reality is defined as an immersive and interactive three-dimensional (3D) computer experience occurring in real time [5]. Virtual reality applications use 3D computer graphics that respond to the user’s movements, thereby giving the user the sense of being immersed in the virtual environment. The potential for the use of virtual reality (VR) with children with CP holds tremendous promise as a new and effective intervention for improving self-competence and motor performance. Inman et al. [6] showed that VR was effective in training powered mobility skills in children with CP. Nemire and Crane [7] allowed children with CP to access educational experiences not otherwise provided to them. The results of these two studies suggest that a simulated interactive environment available through VR can offer children with CP an opportunity to practice and try out new skills/movements without the worry of embarrassment or the risk of injury. This in turn can lead to improved motor performance and, perhaps even more importantly, a sense of personal control or self-efficacy. At the present time, the technology of VR and its application to the field of paediatric rehabilitation is in an infancy stage. Each new study being conducted is the first of its kind, however, with ongoing research, the evidence for judging the effectiveness of VR as a viable intervention will soon be available. Although, there have been only a limited number of studies exploring the potential of VR in rehabilitation, and fewer still in paediatric...
rehabilitation, previous applications with children with disabilities have demonstrated the potential of VR to improve life skills, mobility and cognitive abilities, quality of life, and social opportunities [6–14].

Well-developed theories of behaviour change have been proposed in fields beyond rehabilitation, and may be useful for developing hypotheses and specifying mechanisms by which rehabilitation interventions for children with disabilities may work. A combination of theoretical frameworks may be necessary to explain the role and impact of various aspects of an intervention. In this study, self-efficacy theory [15, 16] and motor learning theory [17–21] are used to explain the impact of a VR intervention with children with cerebral palsy. Self-efficacy theory states that behaviour is cognitively mediated by the strength of a person’s self-efficacy beliefs. Self-efficacy is defined as an individual’s assessment of his or her ability to perform behaviours in specific situations [15]. Perceptions of self-efficacy are not reflective of a global personality trait; rather, they vary across different behavioural domains (e.g. physical self-efficacy, productivity self-efficacy). Applied to children with CP, self-efficacy theory suggests that the use of VR may enhance motivation in children and provide them with a sense of mastery or self-efficacy. Theoretically, enhanced feelings of self-efficacy will, in turn, result in improved perception of performance and satisfaction with performance. Recent research by Rizzo et al. [21] underscores the advantage of the enjoyable game-like experience of VR and its relationship to motivation, performance, and satisfaction with performance among children.

A dynamical systems approach to motor learning proposes that behaviour emerges from the interaction of many systems [19] because the behaviour is not specified but emergent, it is considered to be self-organizing. This view holds that dynamic posture is the result of the functioning of perceptuomotor systems that work with gravity to achieve functional action [20].

Applied to children with CP, motor learning theory suggests that the use of VR may enhance postural control in children and provide them with a sense of mastery or sense of control over their actions. Theoretically, enhanced feelings of self-control will, in turn, result in improved motivation and a desire to practice movement patterns, thereby developing greater movement control and a resulting feeling that one is capable. Repetition of motor patterns is seen as a key factor in improving movement as postulated by motor learning theory [22]. Furthermore, knowledge of one’s performance through feedback, either visual or auditory, contributes to gains made in motor learning. VR is a powerful medium for providing stimulation in the form of visual and auditory events to increase the motivation and desire to continue practicing [21]. Thus, as shown in figure 1, self-efficacy and motor learning theory offers a testable pathway as to the mechanism by which children with CP may benefit from VR.

Methodology

DESIGN

A single case design was used. The basic feature of this design is the evaluation of clients for the outcome of interest both before (baseline) and after the intervention. This design allows an individual to serve as his or her own control. It was used in this case to evaluate the effects of a VR play intervention with a small number of children in a pilot study prior to conducting a large randomized controlled study.

PARTICIPANTS

Three children diagnosed with cerebral palsy between the ages of eight and 12 years participated in the pilot study. They were all able to communicate verbally. Table 1 presents relevant subject characteristics. The children were recruited from two large children’s rehabilitation centres in the greater Toronto region. Informed parental consent and ethical approval were obtained prior to commencing the study.

INTERVENTION

There have been problems with the use of different VR systems that have important implications for using VR successfully with children with disabilities. Critics of the head-mounted display systems have reported they tend to restrict movement, are heavy to the user, cause motion sickness, have a limited field of view, and are
not very comfortable [24, 25]. The major limitation with the use of desk-top VR which is accomplished through projecting the virtual environment (VE) onto the computer monitor and the user interacts with the VE with the use of a joystick, mouse, or keyboard is a diminished sense of immersion [25].

To overcome these problems, in this study we used the 1996 patented *Mandala*® *Gesture Xtreme* (GX) technology developed by Vivid Group Inc. from Toronto. This system uses a video camera as a capturing and tracking device to put the user inside VR experiences. With the GX technology, the user is at the centre of the action, inside a computer world, where by watching themselves on the screen they can physically participate in a virtual world. Sophisticated artificial intelligence and video gesture control technology allows them both intricate manipulation of virtual objects and 3D navigation of the virtual landscape. The GX technology offers an alternative to the problems inherent in other forms of VR, because users do not have to wear Head Mounted Displays (HMD), Data Gloves, or other devices that tether them to the computer. In fact, users do not have to wear, touch, or hold anything, leaving them free to actively move about in the real world while they use their entire body to interact with the computer. Through the use of the system’s ‘video gesture’ capability, the movements (e.g. reaching, bending) trigger visible or invisible icons to score points, and manipulate animations (e.g. playing a virtual drum kit, playing volleyball). The system requirements include an intel Pentium II BX Motherboard, 400 MHz CPU, 128 MB RAM, 4.3 GB HD, 12 meg HD, 3D video card, CCD video camera and cables, capture board, 4 MB S3 video card, 16 bit sound card, and the patented Gesture Xtreme (GX) software.

In a laboratory environment, children sat either in their wheelchair system or unsupported on a bench in a demarcated area viewing a large TV screen with a video camera mounted on the top (see figure 2). Two sessions a week for four weeks were provided. Each intervention session was 90 minutes; split into six sessions of 15 minutes each spent playing a different application. Each application except for three required the child to control his/her arm movements to interact with objects on the screen and to play the game. Examples were Orbosity, Drums, Paint, Volleyball and Soccer (figures 2–6). The other applications required the child to use mid-line control through using lateral flexion and trunk rotation movements (e.g. Snowboarding).

The software application ‘Orbosity’ will be described to provide some detail regarding what was typically expected from the child in most applications. On the

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Table 1  Subject characteristics

<table>
<thead>
<tr>
<th>Participant</th>
<th>Age</th>
<th>Grade</th>
<th>Diagnosis</th>
<th>Tone</th>
<th>Functional Status</th>
</tr>
</thead>
</table>
| 1           | 10  | 5     | Spastic Quadriplegia  | High  | GMFC score = 4
|             |     |       |                       |       | Does not ambulate; Uses manual wheelchair with sub-ASIS bar; Cannot sit unsupported on a bench |
| 2           | 12  | 7     | Spastic Quadriplegia  | Moderate | GMFC score = 4 |
|             |     |       |                       |       | Uses walker for short distances indoors; Uses power wheelchair; Can sit unsupported on a bench |
| 3           | 8   | 2     | Spastic Diplegia      | Moderate | GMFC score = 3 |
|             |     |       |                       |       | Uses walker; Can walk without aids for short distances Can sit unsupported on a bench |

*Gross Motor Classification score based on classification system develop by Palisano *et al.* [23].
television screen the child sees a tranquil background consisting of a green field surrounded by a fence. In the distance is a snow-capped mountain range. A bright blue sky surrounds the child’s image and in the sky are brightly coloured balls that float from different directions toward the child. The number, direction, and speed of the balls was graded so that three balls in sequential waves came from either the right side of the screen or the left side. Each virtual ball the child successfully touched burst electronically into numerous coloured particles. If touched gently, the ball transformed into a bird and flew off the screen. The child had to visually track and locate all balls and grade the amount of pressure when making contact with the balls. Auditory feedback was available when contact was made. The computer kept track of the points the child made each time contact was made, and these scores were shown to the participants at the end of each trial. In Volleyball the child was instructed reach over the head to hit the ball over the net to the other player or the computer robot. The option of selecting a two-player game allowed for some competition during the sessions. In this case, the research assistant was the second player. In Soccer, the child was the goalkeeper and was instructed to reach out to the sides and above the head to block incoming shots.

Every session was standardized starting with a 15-minute trial of Orbosity, the child was allowed then to choose the applications he/she preferred to play. The testers used this procedure to encourage choice and control.

**HYPOTHESIS AND OUTCOME MEASURE**

The study hypothesis was whether the sense of competence or self-efficacy among children with cere-
Virtual play rehabilitation for children with cerebral palsy on perceptions of self-efficacy

The occupational performance tasks that were identified by each participant using the COPM are listed in Table 2. The COPM’s occupational performance classification scheme, used to sort the tasks across participants, showed that 44% (12 of 27) were self-care tasks, while 42% (11 of 27) were leisure tasks, and 14% (4 of 27) were productivity tasks. Overall, a high level of importance was associated with the majority of the tasks, with 70% (19 of 27) of the tasks rated a ‘6’ or higher on the 10-point rating scale.

**Self-Efficacy**

Mean COPM performance and satisfaction scores were calculated for each participant by summing the ratings across the tasks identified for individual participants and dividing by the total number of tasks. These results are presented for each participant for the two test periods of the study in Figures 7 and 8. Mean performance change scores from pre-test to post-test ranged from 2.4 to 6.2 across participants and from 3.3 to 7.5 across participants for satisfaction scores. Performance and satisfaction change scores for each participant were respectively 1.3 and 1.6 for participant #1, 3 and 2 for participant #2, and 3.4 and 4 for participant #3. Except for participant #1, change scores of greater than 2 were found. This level of change is considered to be clinically significant [26].

All participants rated their satisfaction with performance higher at post-test as compared to the pre-test. Participant #2 rated his performance higher on all tasks at post-test as compared to the pre-test. The task with the least positive change was tying shoelaces. Participant #3 rated her performance higher on eight out of 11 tasks at post-test. For one of the tasks, she rated no change and for the other two tasks she rated them lower at post-test. The task with no change was tying shoelaces. The two tasks that were rated lower were making a ponytail and putting on ankle–foot orthoses. Interestingly, participant #3 rated all tasks except tying shoelaces higher at post-test on satisfaction.

**Discussion**

Overall, this pilot study has demonstrated beneficial results in terms of self-efficacy as measured with the COPM with three children with cerebral palsy. The majority of the tasks that these children self-identified

DATA ANALYSIS

The COPM scores were descriptively analysed for each participant. Given the design of the study and the small number of participants, the data were visually inspected for clinical significant changes.
### Table 2  Occupational performance tasks and COPM ratings

<table>
<thead>
<tr>
<th>Participant</th>
<th>Tasks</th>
<th>Total pre-test performance score</th>
<th>Total post-test performance score</th>
<th>Total pre-test satisfaction score</th>
<th>Total post-test satisfaction score</th>
<th>Importance ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pulling up pants</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Pulling t-shirt on over head</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Pulling t-shirt off over head</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Pushing own wheelchair</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Pushing chair lift button</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Lining up letter when printing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Increase computer typing speed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Blocking basketball</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Throwing basketball upwards</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Dribbling a basketball</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Hitting baseball for inside baseball game</td>
<td>3</td>
<td>4.4</td>
<td>3.3</td>
<td>4.9</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>Tying shoe laces when sitting up</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Reaching into fridge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Lifting 5 lbs weights</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Doing boxercise better</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Throwing a basketball higher</td>
<td>2.4</td>
<td>5.4</td>
<td>4</td>
<td>6.4</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Tying shoe laces</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Standing up to put one boots</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Putting on ankle foot orthoses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Brushing hair</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Putting hair into a ponytail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Writing on red-blue lined paper</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Throwing basketball higher</td>
<td>2.4</td>
<td>5.4</td>
<td>4</td>
<td>6.4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Hopping better for playing hop scotch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Bowling with heavy ball</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Hitting the ball for volleyball</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Increase computer typing speed</td>
<td>2.8</td>
<td>6.2</td>
<td>3.5</td>
<td>7.5</td>
<td>6</td>
</tr>
</tbody>
</table>

![Figure 7](COPM Pretest scores)
and rated in terms of functional competence were self-care and leisure types of activities. This is not surprising as school-aged children are expected to demonstrate competence in these areas. Following the intervention all children rated their satisfaction with performance and performance in their specific activities as greater than prior to the intervention.

With respect to individual participants, the performance and satisfaction change scores of participants #2 and #3 were two and greater. Unlike the other two participants, the satisfaction and performance change score of participant #1 was less than two, the critical unit for suggesting a clinically significant change. It is important to note that this participant’s physical abilities were less than the other children. His perception of performance regarding three tasks did not change, and as a result his satisfaction was less for these three tasks. Unfortunately, it is not clear how much opportunity he had over the intervention period to practice performing these tasks. A lack of opportunity may have contributed to poorer perceptions or a lack of perceived change regarding abilities in these areas. Asking the children how much time they spent performing the tasks they identified over the trial would have been helpful. It is clear to note that we were not measuring objective performance but rather the perception these children had with respect to their performance. Another measure such as a quality of life measure may have provided additional information regarding the effects on children’s perceptions.

Informal comments made from the children also suggest the VR intervention was a pleasurable experience and was motivating for them. The following are some quotes made to reflect this: ‘I didn’t think it would be this exciting’; ‘Its kinda like making a dream come alive’; ‘You get to be as crazy and wild as you want’.

Children also spoke about how playing the VR games provided them with new opportunities and increased their level of confidence: ‘Yes, I have done lots of things that I didn’t used to be able to do’; ‘Now I know that you can do anything you want to do if you put your mind to it’; ‘It was fun because it gave me a lot more confidence. I had to work really hard’; ‘Well, I think it has been very worthwhile and exciting because I wouldn’t get to learn all this stuff and do all this stuff’.

In summary, this pilot study suggests that a virtual play environment provides children with an opportunity to interact with virtual play activities that are enjoyable and non-threatening. This opportunity allows for increased play engagement and an opportunity to exercise control over their actions. This overall experience enables the development of a sense of mastery or
greater self-efficacy feelings. The results of this study will be used for conducting a randomized clinical trial with a larger group of children with cerebral palsy.

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