A Virtual Fine Rehabilitation System for Children with Cerebral Palsy: Assesment of the Usability of a Low-Cost System

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Abstract. Children with Cerebral Palsy (CP) have difficulty performing correct movements for activities of daily living. Impairments in the first stages of the birth produce motor disorders of the neuromuscular system. Specific goals in traditional rehabilitation are based on the outcomes obtained in the Gross Motor Function Classification System (GMFCS) and are focused on the improvements of muscle strength and length. In the last few years, novel Virtual Environments have been designed to reduce impairments in upper limbs, but few studies have been validated with the use of specific usability tests that are focused on the rehabilitation process of children with CP. The purpose of this study is to analyze the usability, enjoyment, and security of a novel virtual system. To do this, we tested the System Usability Scale with a child that has CP during one session. The outcomes show that our system achieves the goals in terms of usability, enjoyment, and security.

Keywords: Virtual motor rehabilitation · Children with cerebral palsy · Usability · Virtual fine rehabilitation

1 Introduction

Cerebral palsy (CP) in children can be defined as a group of motor impairments of the neuromuscular system (spasticity [1], postural control [2], reaching, grasping [3], etc.) in the first stages of birth, which are produced by an impairment in the non-developed brain [4, 5]. Disorders in the sensorimotor system [6] are common in this pathology.

In developed countries, the prevalence of this neurological impairment is from 1.2 to 3.0 per each 1000 live births with an estimate of 1 in every 500 children having CP [7]. Worldwide, the prevalence of children with CP ranges from 1.5 to 3.0 per 1000 live

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births [7]. The Centers for Disease Control and Prevention (CDC) announced an average of 3.3 per 1000 8-year-olds from Alabama, Georgia, and Wisconsin [8] having CP. The prevalence in western Sweden was 2.8 per 1000 live births (raw data), with a significant decrease in CP from 1980 to the period 1995–1998 [9].

Children born prematurely, with only 28 weeks of gestation, have a high prevalence of this pathology, with a range from 40 to 100 per 1000 [11].

The cost to rehabilitate patients with CP is high. Direct costs such as time spent in hospitals, technical assistance, house adaptation, and indirect costs, such as labor productivity, were analyzed in children with CP in the USA [10]. The authors indicated that the cost of CP in the USA in 2003 was 2,229 million dollars (direct costs), 9,241 million dollars (indirect costs), for a total of 11,470 million dollars.

According to the Surveillance of Cerebral Palsy in Europe (SCPE) [11], there are 16 registers from different European countries that provide studies of children with CP. The SCPE determined the classification of CP based on the movement disorders in four subtypes: (1) unilateral spastic; (2) bilateral spastic; (3) dyskinetic; and (4) ataxic. Similar classifications have been adopted in other countries such as Australia [12] and Canada [13].

Spasticity in children with CP is described by strange movements and impairment in muscle tone, where there is a variable improvement in muscle tone. The percentage of patients with CP that have spasticity ranges from 85% to 90% [14]. This disorder is sub-classified into two subtypes: unilateral which involves only limbs of one side of the body; and bilateral, which involves both sides of the body and involves all limbs.

Dyskinetic CP is characterized by an uncontrolled pattern of posture movements that is involuntary. This subtype of disorder occurs in only 7% of the cases [14] and can be either dystonic (with a reduction of muscle activity and an improvement in muscle tone), or choreo-athetotic (with an improvement in involuntary muscle tone, mainly in the face, arms, and trunk).

Ataxic CP is characterized by hypotonia with loss of specific muscular coordination that produces strange forces and strange rhythms and inaccurate movements. Only 4% of children with CP have this type of disorder [14].

Another formal taxonomy for children with CP is based on the severity of impairment and mobility disturbances independently of the CP motor type. The Gross Motor Function Classification System (GMFCS), together with the revised version in 2007 [15], is a classification with 5 levels to assess this pathology [16]. The GMFCS measures physical movements such as climbing stairs without limitation (Level 1), climbing stairs using a railing (Level II), walking indoors with the assistance of a wheelchair or specific assistive walker (Level III), walking short distances using the same assistive devices but with adult assistance (Level IV), and strong impairments with limitations in maintaining the head and the trunk in antigravity postures (Level V).

CP is defined by an alteration in the supraspinal activation of motor units, with slow stimulation of these units, which produces slowness of movements, muscle contraction, and thus, limitations in muscle coordination.

Another limitation of children with CP is related to the anticipatory planning of motor movements. Thanks to this capacity, people are able to estimate the next motor actions and perform the specific movements such as reaching and grasping an object [17]. Due to these motor disorders, these patients need to perform a great variety of motor training sessions based on the child's daily routines [18].

Traditional treatments are based on the levels of the GMFCS, where treatments for children with CP who are classified at the lower levels (Level I, II, III) focus on improving mobility. Treatments for children with CP who are classified at the higher levels (Level IV, V) focus on traditional techniques to improve in posture/mobility, pain, sleep disorders, etc. [19].

The main goals in traditional rehabilitation for children with CP focus on improvements in muscle strength and length. Since the main disorder in this pathology is spasticity, different complementary treatments are used to reinforce the rehabilitation processes: (1) surgical intervention [20]; (2) oral medication (baclofen, tizanidine, etc.) [21]; (3) intramuscular medication (botulinum toxin type A) [22]; and (4) intrathecal baclofen [23].

2 Related Work

The use of Virtual Reality (VR) to improve gross and fine motor coordination and alterations that children with CP have was described in [24–26]. Since these systems are characterized by high costs and limited accessibility, these technological systems lack portability.

In [27], five children with hemiplegic CP were assessed using a low-cost system, the IREX system. This study revealed improvements in the children's sensorimotor system. In this experiment, a novel usability study showed that the use of VR systems in rehabilitation processes is a good complement, with satisfactory usability outcomes. In [28], the authors tested two VR games for upper and lower limbs in eight children with CP and evaluated the usability and enjoyment of their system. The participants completed the System Usability Scale (SUS) and the Physical Activity Enjoyment Scale (PACES). The results showed improvements in usability and enjoyment due to the adjustability of the difficulty of the system, which provided specific gross and fine movements in the training sessions.

To date, there are few studies that have validated a usability test in children with CP using VR systems. It is important to use a specific usability test to reinforce the adherence to the rehabilitation processes and the motivation of children with CP.

The purpose of our experiment is to test the degree of usability of children with CP by using a customizable Virtual Rehabilitation system. Our tool, the Virtual Sort Doll (VSDoll) was designed with the assistance and the recommendations of a clinical specialist. The valuable suggestions of this specialist (an occupational therapist) has allowed us to adjust the final system and to focus the specific Virtual Environment (VE) for the inherent fine/gross rehabilitation sessions.

3 Methods

3.1 The Participant

The VSDoll virtual rehabilitation system was applied to one 10-year-old girl with CP. The participant has spastic hemiplegia. The girl has a Gross Motor Functional Classification System (GMFCS) Level II, with independent ambulation without assistive device. With regard to the relation of resistance to passive movement, the patient has an Ashworth Scale score of 2. Table 1 shows a summary of the characteristics of the subject.

Table 1. Characteristics of the Participant.

Height (cm)	Weight (kg)	Affected side	GMFCS score	Ashworth scale	GMFM	MACS	Barthel
135	25	Right	II	2	97.3%	II	90/100

The participant does not follow a rehabilitation program at home. The subject follows a rehabilitation program in clinical environment, twice a week.

3.2 Instrumentation

The hardware components of the system include a conventional PC, a projector and a Microsoft Kinect® 2.0 for Windows. Wearables are not needed since the hands of the user are the interface with the system.

The system has been designed in collaboration with clinical specialists. For the design of the system, the team considered two main goals: to improve fine motor skills in the hands and to reinforce the motivation and engagement of the patients during the rehabilitation sessions.

The first objective was achieved thanks to the way the patient participates in the system: the patient must grab and drop virtual objects by opening and closing her hand. The system allows the selection of different levels of difficulty regarding the degree of spasticity of the patient; this parameter permits the use of the system with a wider range of patients.

The second objective was obtained by designing the system as a game: the environment, the level-based scheme, and the music were developed taking these aspects into account.

In the game, the patient must grab different toys–dolls, balls, etc. and put them in the correct place. The system indicates which toy to grab in the Virtual Environment and where it must be placed. In addition, the system is adaptive: the difficulty evolves based on the patient's performance. Thus, the area where the toy must be placed and the height of this area can be different based on the level of difficulty.

3.3 Intervention

This study was carried out in a rehabilitation service of a large city. A child with CP trained with VSDoll for one session. The length of the session was 25 min of playing with VSDoll, with a 5-min rest period after playing. Finally, after the session, the occupational therapist used the Suitability Evaluation Questionnaire (SEQ) [24] with the goal of measuring the level of usability of our system. This specialist was with the patient while she answered the questionnaire. Figure 1 shows the participant interacting with the system.

Fig. 1. Participant testing the VSDoll system.

During the development of the activity, it was observed that the child improved the use of the paretic hand when the neuromuscular tape was applied.

Her motivation increased when the activity level increased and when she received positive reinforcement from the therapist.

4 Results

A first suitability evaluation was performed for the participant described above. The evaluation was conducted in a specialized rehabilitation facility under clinical supervision.

4.1 The Suitability Evaluation

The primary outcome measures are provided by the questionnaire. Table 2 shows the scores for the questions of the SEQ.

Table 2. SEQ Participant responses.

Question	Response				
	Not at all				Very much
Q1. How much did you enjoy your experience with the system?	1	2	3	[4]	5
Q2. How much did you sense being in the environment of the system?	[1]	2	3	4	5
Q3. How much success did you have with the system?	1	2	3	4	[5]
Q4. How much were you able to control the system?	1	2	[3]	4	5
Q5. How real is the virtual environment of the system?	[1]	2	3	4	5
Q6. Is the information provided by the system clear?	1	2	3	[4]	5
Q7. Did you feel discomfort during your experience with the system?	1	[2]	3	4	5
Q8. Did you experience dizziness or nausea during your practice with the system?	[1]	2	3	4	5
Q9. Did you experience eye discomfort during your practice with the system?	[1]	2	3	4	5
Q10. Did you feel confused or disoriented during your experience with the system?	[1]	2	3	4	5
Q11. Do you think that this system will be helpful for your rehabilitation?	1	2	3	[4]	5
	Very easy				*Very difficult*
Q12. Did you find the task difficult?	1	[2]	3	4	5
Q13. Did you find it difficult to use the devices of the system?	[1]	2	3	4	5
Q14. If you felt uncomfortable during the task, please indicate the reasons.	I didn't feel uncomfortable				

5 Discussion and Conclusions

We have validated a specific usability test for patients with neurological disorders by using a groundbreaking Virtual Rehabilitation system, the VSDoll. For this purpose, a child with CP trained for one session and filled out the SEQ Questionnaire. The outcomes show high enjoyment (Q1), high success (Q3), clear information (Q6), and low feel discomfort (Q7). We think that these results are due to the fact that our system was developed with the assistance of clinical specialist and VSDoll focuses on the typical movements that children with CP perform in gross/fine traditional rehabilitation. On the other hand, the participant did not experience dizziness (Q8), did not have eye discomfort (Q9), did not experience disorientation (Q10), and felt comfortable (Q14). This is because our system is composed of a non-invasive tracking device as well as a large screen to show our motivational VE.

We are currently recruiting children with CP to test our specific usability questionnaire and we are designing the protocol. Thanks to these preliminary outcomes, we will modify our system based on the suggestions of the occupational therapist and the 10-year-old participant.

For the validation of the tool, we are planning to perform the study with 20 participants with CP, performing 2 weekly sessions of 25 min each and the 5-min rest perios.

The participants must meet the following inclusion criteria: GMFCS level I–III, MACS level I–IV, be between 3–12 years old, and be able to understand simple orders.

The exclusion criteria of the study are: GMFCS level IV and V, MACS level V, Visual Impairment, and very severe affection of upper limbs (where there is spasticity that is evaluated in the Asworth scale with 4–5).

Strategies for using the affected limb(s) may be used, such as therapist support or the use of neuromuscular tape to improve hand function and posture.

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