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Observing the use of an input device for rehabilitation purposes

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We designed and developed a vision-based computer interface which works with head movements. The system was implemented in a centre for users with cerebral palsy and they used it in contexts related with recreation or with education. During this process, it was observed that the continued use of the interface with a set of training tasks may act as a physical and cognitive rehabilitation tool and complement users' rehabilitation therapy. We comment on five case studies of users who have worked with the interface for five months and whose qualitative outcomes, observed by the therapists who accompanied them, were positive; specifically there was improvement in work posture, head control, increased endurance, decreased involuntary movements and improved spatial orientation. The case studies also showed the need to supervise the users' work in order to achieve these aims, along with the importance of motivation and active, voluntary participation of users in the rehabilitation process.

Keywords: human–computer interaction; vision-based interface; human factors; disabled users; motor and cognitive rehabilitation

1. Introduction

Cerebral palsy (CP) is a set of neurological conditions affecting the cognitive and physical development of a person and may lead, among other limitations, to problems of laterality, directionality, integration of body awareness, lack of language, depression, inappropriate muscular strength, abnormal muscle tone, impaired selective motor control, and control of head alignment, muscle–skeletal alignment, postural control and balance (Becher 2002, Bax *et al.* 2005).

These deficits require comprehensive, coordinated treatment from a multidisciplinary team (Hornof 2008) and the patient's family (King *et al.* 2000). The aim of the treatment is to maximise the person's abilities as much as possible as far as daily activities are concerned, covering physical, cognitive, affective, psychosocial and recreational activities, and offering answers to the needs arising in their personal, social and educational development.

There are several motor intervention methods (Siebes *et al.* 2002), but the most common treatments in patients with CP use a combination of physical therapy, biofeedback, occupational therapy, speech therapy, pharmacotherapy and neurosurgical and orthopaedic interventions. In addressing the physical rehabilitation of a person with CP, the aims depend on the physical and functional impairment in each case, but in general terms, they are:

- Restore postural reflex activity and muscular tone to normal.
- Make straightening reflexes and balance reactions easier.
- Maintain range of movement and muscle tone.
- Learn movement patterns that are as near normal as possible, avoiding abnormal movement patterns.
- Prevention and orthopaedic correction of possible deformities.
- Encourage personal autonomy in different aspects of life of the affected person.

Motivation and active, voluntary participation and cooperation of the patient are factors that help in the rehabilitation process (McLean *et al.* 2000, Sieger and Taylor 2004, Colombo *et al.* 2007). As well as the traditional treatments used in occupational therapy and physiotherapy, it is increasingly possible to find projects and studies that aim to incorporate technology as a rehabilitation and therapeutic tool in the sphere of daily activities (Ketelaar *et al.* 2001, Gordon *et al.* 2005) or games (Golomb *et al.* 2010) in order to involve, entertain and motivate the CP patient. The project by Nichols and Trey Cisco (2010) designed and developed toys for children with CP to help them rehabilitate their upper limbs. Deutsch *et al.* (2008) used the Wii remote control and sports games to train upper limb movements. The SiMuove Project (Fonoll Salvador and López Álvarez 2007) used computer vision techniques to develop a set of recreational applications to complement the rehabilitation work carried out by physiotherapists.

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Augmented reality and virtual reality are also techniques used for physical and perceptive rehabilitation of patients with CP (Holden 2005, Snider *et al.* 2010) and may improve users' participation (Koenig *et al.* 2008), exercise compliance and enhance exercise effectiveness (Bryanton *et al.* 2006). Instances of studies using these technologies include Reid (2002a, 2002b, 2002c), who captured patients' gestures in order to interact with games by exercising different parts of their body, or the study by Akhutina *et al.* (2003) who assessed improvement in spatial intelligence. Raya *et al.* (2008) and Plaisant *et al.* (2000) used robots for CP users and children's rehabilitation. The former used a vehicle to develop cognitive and physical skills in a recreational context. The latter designed a robot that can be remotely controlled by using a variety of body sensors adapted to the children's disability or rehabilitation goal.

By introducing physical rehabilitation into a context that places their attention beyond the rehabilitation itself, we get patients to focus on the output, on obtaining a result, and not so much on the actual physical activity being done.

In this study we used a computer access device for people with motor disability. The tool used, SINA (Varona *et al.* 2008), is an interface for users with physical limitations who cannot use traditional access devices such as a mouse or who have difficulties using other alternative input devices such as joysticks or headwands. The interface is similar to the CameraMouse (Betke *et al.* 2002), that is, the system captures users' head movements through a webcam in order to transform them into positions of the mouse pointer, so users need to control their head intentionally. The aim is to normalise the user's position in front of the computer, so the user will have no marker, device or sensor on him or her, nor will any lighting or special background be necessary. It is a low-cost system because the application is free and only needs a webcam.

A parallel effect that was noticed in the process of acquiring skills in handling the input system was improvement in head control, sensorial-motor integration and coordination and, in particular cases, improvement in spatial organisation, laterality, directionality and proprioception. This was an unexpected side effect of the implementation of the access system in the life of these users. The effects seemed to persist and it helped improve their quality of life. Therefore, a new line of research opened up, which is using the input system to carry out physical therapy, make motor development easier and improve users' skills. A set of activities was thus designed for working with SINA. These are entertainment applications which encourage repetition of movements and also the exercise of cognitive abilities.

The descriptive research (Rosenthal and Rosnow 2008) described in this paper is an explorative and descriptive case study (Yin 2003) of this new situation and the impact of these technologies that may be of interest in developing future educational or recreational applications for rehabilitation using SINA or similar systems. The aim of this paper is to present the observations and a qualitative study of five users' motor and cognitive skills learning arising through the use of SINA in recreational and educational activities in their education programme, that is, in real contexts. We employed common user-centred design methodologies including direct observation, interviews, logs and documentation analysis, participatory design and iterative prototyping. The insights observed by the professionals conducting the work sessions suggest there has been a persisting improvement in work posture, increased endurance, improvement in head control, decreased involuntary movements and improvement in spatial orientation, directionality and laterality.

Section 2 of this paper describes SINA and the training applications designed. Section 3 outlines the methodology used. Section 4 analyses the users and their results. Section 5 presents the insights of the case studies and finally, the last section discusses implications for using a vision-based interface for rehabilitation purposes.

2. SINA and applications

SINA is a vision-based interface which works with head movements to replace the mouse. On the basis of the clinical symptoms of a person with CP, a study of the needs of applications should cover requirements that do not only take into account motor issues, but may also cover a whole range of features including aspects related to improving cognitive and educational performance. If applications prove to be efficient for users with CP, they may be useful for a much larger group of users which may include other conditions involving motor and intellectual impairment. This is why, in order to analyse the requirements for the access system and the applications that go with it, it is necessary to have a multidisciplinary development team made up of professionals in special education, educational technology, occupational therapy, physiotherapy, ergonomics and information technology.

By using SINA, users are challenged to respond with body gestures which help them train movements that require a certain precision and to hold their head in fixed postures for a certain length of time in order carry out activities. Frequently games and educational applications are used in occupational therapy sessions. Users are actually performing physical therapy while carrying out a task they find entertaining or that will involve learning for their school curriculum. SINA has the potential to complement rehabilitation sessions as it is useful for working on physical exercises that improve development of residual voluntary movements in disabled users. In parallel to the processes involved in performing the movements, aspects related to cognitive rehabilitation are worked on, such as establishing a cause/effect relationship between a movement (which may not be intentional at first) and an action or result (on-screen event). For users with intellectual impairment, this mechanism is fundamental for interacting with

Figure 1. Nose tracking.

the computer. It is also important in an educational context and in other daily tasks.

2.1. The input device: SINA

To design and develop SINA, we worked mainly with children and adults with CP but also with other disabled users (multiple sclerosis, muscular dystrophy and multiple disabilities). We used a prototyping system during the design and development process which allowed us to implement the new requirements as they appeared and to carry out a user-centred design. This methodology is convenient for adjusting the system to the user and to achieve an efficient, effective and satisfying input device for this user profile (Manresa-Yee *et al.* 2010).

The operating of SINA is divided into two modules: Initialisation and Processing. In the Initialisation stage, the user's face and nose are detected automatically due to the anthropometrical measurements of humans. Once the nose is detected, the webcam's frames are sent to the Processing stage which carries out the nose tracking (Figure 1) and sends to the operating system the mouse's pointer position and mouse's event. In order to execute an event, the system counts with an event graphical toolbar that includes all mouse events: left click, left double click, right click and dragging action. The user selects and executes an event by dwelling during a preset duration. This duration is set in a configuration file for the user's personal settings. In this file there are other configuration parameters: range of click (an area around the mouse pointer where the pointer is considered to be steady, to help users with tremors), x jump and y jump (parameters used in the mapping of the nose point to the screen point. Higher values for these parameters will allow the user to reach the corners of the screen with less head movement but less precisely).

In order to use SINA, the user sits in a comfortable position without stretching the neck or forcing strange positions and the webcam is placed in front of the user viewing the user's face. We direct the reader to Varona *et al.* (2008) for more technical aspects of SINA and to Manresa *et al.* (2010) to read about the improvements done to the system due to users' feedback.

2.2. Training applications

The training applications that were developed took into account the fact that limitations caused by motor disorders can lead to low self-esteem. This is why it was very important to work on aspects that would raise the level of the user's self-esteem by creating a positive image from the activities that concluded in a positive result. In this sense, satisfaction for the result obtained exceeds the time and effort invested. Moreover, some of the applications aim at achieving repetitive task practice, which is the performance of functional tasks continuously for a period of time.

- *Action/reaction applications*: These activities allow the user to learn and to be aware that when she/he moves the head, the computer offers an immediate feedback. These tasks work without the need of mouse events; they simply work with pointer movement. Two applications were developed to train head control, to increase the neck range movement and to help users to be aware on how SINA worked. In the applications, users have to pass over the blocks

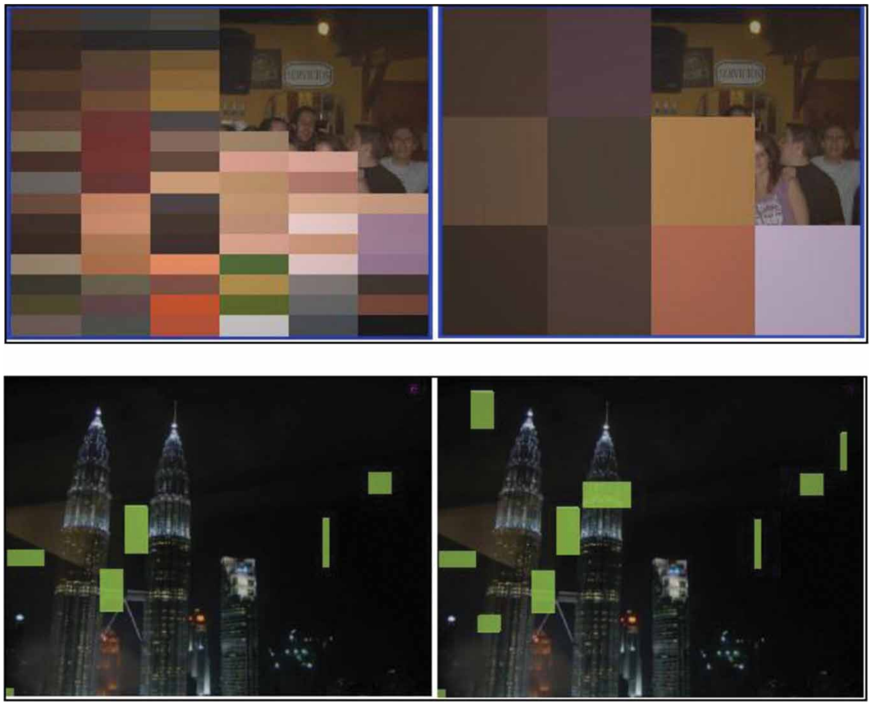

Figure 2. Action/reaction applications.

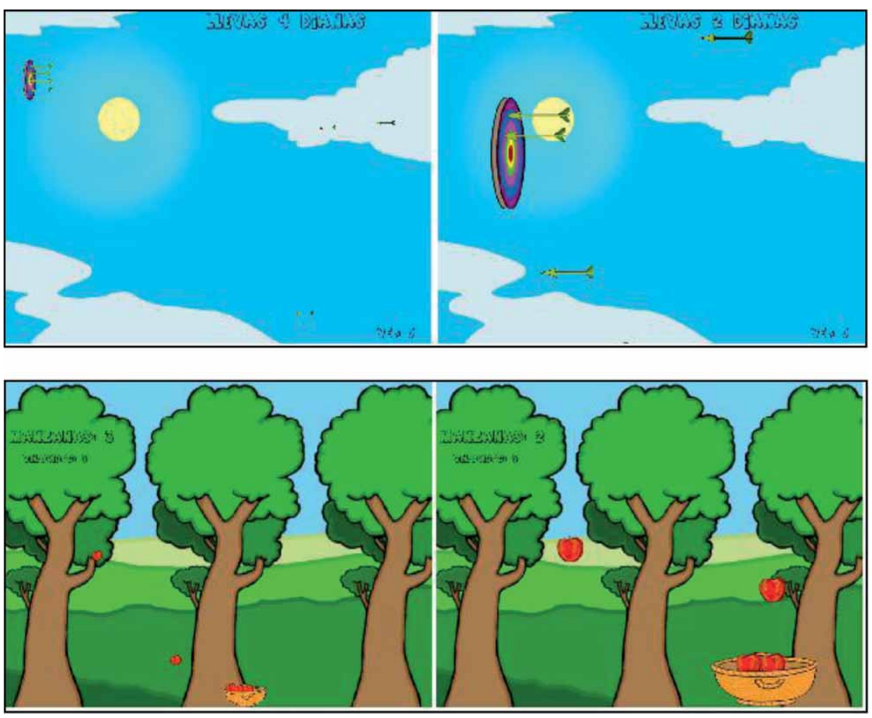

Figure 3. Movement applications.

to uncover the image which is used as an incentive (Connor *et al.* 2009) (Figure 2).

- *Movement applications*: These applications allow the user to work vertical and horizontal head movements. These applications do not use any mouse event, as they just control the mouse pointer position. Two applications were designed to practice the vertical movement (a dartboard that stops darts) and horizontal movement (a basket that collects falling apples) (Figure 3).

  A component of gameplay was added to the movement applications, with lives and levels in order to

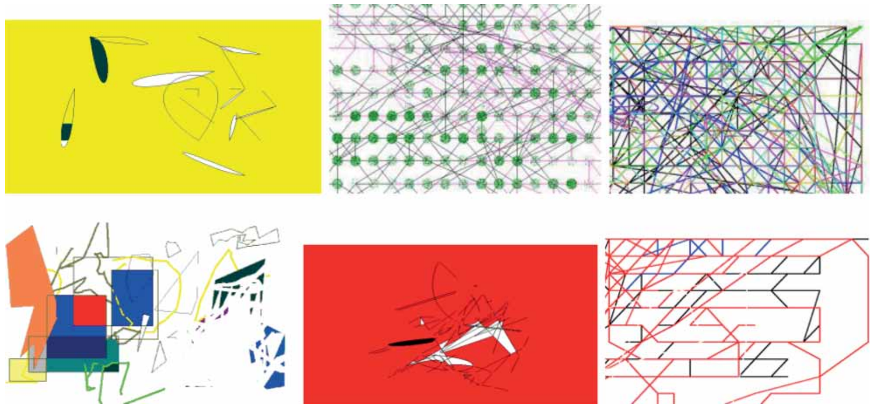

Figure 4. Drawings done with SINAPaint or Microsoft Paint using SINA.

involve the user more in the game with rewards and punishments. Initially, this playability was not introduced so as not to put pressure on users or to encourage competition, but the effect was that users were not motivated and learnt that without the need to move, at some time or another all the apples were picked or all the darts required were stopped, as the position they appeared in was random.

- *SINAPaint*: It is an adaption of drawing programs such as Microsoft Paint. Its particularity is that the user does not need to use the dragging function to draw, as dragging is the most complicated event with SINA. The application works just with the left click event, the first click is pressing down the mouse's left button and the next click is releasing the button. Other applications such as EaglePaint which only uses mouse pointer movement to draw can also be used (Cloud *et al.* 2002).
  Drawing and painting are a common activity in children who use them to express themselves and to have fun. These types of applications help children's development and increase creativity and imagination and motivate users to take an interest in the environment, culture and knowledge. Painting and drawing is a universal art that helps people with special needs, people who, for instance, cannot talk or move around freely, to express their feelings, emotions or experiences. This is why these sorts of tasks are very positive in their personal and emotional development. With this drawing application, as well as personal development, users can train body postures and improve fine motor coordination, orientation and attention. In Figure 4, drawings by the users are shown.
- *Cognitive applications*: These applications mix cognitive with physical training. The first application, SINAMemory, is about matching pairs of cards by turning them. This activity stimulates memory while working on attention and aspects related to spatial orientation. The images to be memorised are configurable so as to motivate the user. The aim of the second application is to remember a sequence of buttons, each of them associated with a sound and colour. The player will have to repeat a growing sequence in the same order, or she/he will lose points. This activity trains the visual and auditory memory, attention and concentration. Finally, in the third application, the player guides a ball through a maze by clicking on the next block to place the ball. The ball has to find the exit block in the shortest time to gain more points. This activity works reasoning and spatial orientation. Furthermore, it allows therapists to design mazes to work specific directions.
  Other activities to use with SINA carried out in the training sessions:
- The visualisation of presentations where the user must click on an element in the screen whose dimensions and placement are designed to make the user need to use a greater or lesser degree of neck movement range. The presentations are about issues of interest to the user to enhance their participation in the activity and their motivation.
- Educative games and applications for learning how to write, read, do math, solve jigsaws or play memory games.
- Online educative and entertaining activities.
- Internet surfing and communication applications.

3. Methodology

Information collection methodologies that allow a certain flexibility were used, with the aim of obtaining information concerning complex processes and being able to capture the changes due to the use of SINA. The techniques used were:

- *Document analysis*: Session records (logs) and institution reports were analysed.
- *Observation*: We analysed the sessions by means of direct observation, videos and photos of the sessions.

- *Interviews*: Users and professionals involved were interviewed.

The project worked with users with a number of different conditions when trying SINA for accessibility purposes (CP, multiple sclerosis, muscular dystrophy and multiple disabilities). Five users were selected for this case study (Lazar *et al.* 2010), using these criteria:

- Users' capabilities needed to be stable, so capabilities would not evolve during the study due to the pathology; therefore, users with CP were selected.
- Users were attending individual weekly sessions with a therapist, so they were not yet working in the classroom or at home with the computer. This criterion provided homogeneity to the context of study.

We worked in the centre for a whole school year (nine months). The first months were used to plan SINA's implementation, select the users, determine the users' aims, carry out meetings with the centre's professionals and parents to explain the project, teach the therapists the operation of SINA, prepare the equipment, the working material, the documentation on each user and decide on the information to be saved in the sessions and how to save and record all the information.

We worked with the users for five months. A timeline was decided in which the users had two weekly sessions: 20 minutes for children and 30 minutes for adults. Users performed between 20 and 26 sessions. The first sessions for each user were to configure the interface parameters, for instance, to make it easier to reach the corners of the screen with more or less rotation and flexion and extension of the neck, which enabled more or less precision, or the time necessary to keep the pointer in one place in order to execute an event. When necessary, in users with more cognitive difficulties, a number of sessions were also devoted to working on the cause/effect relationship.

All the sessions were supervised by an occupational therapist, sometimes together with a physiotherapist, and these were monitored by a member of the development team. Moreover, this person was in charge of filling in the log, recording some sessions in video (using an external video recorder or using software that captures the webcam's image and the screen), taking photos of the environment and the user's posture, and liaising with the rest of the development team, users and therapists. The activities were chosen for each user by taking into account their needs, objectives and skills. Initially, all users trained with the action/reaction applications, movement applications, SINAPaint and visualising presentations.

The aims were particular for each user, but they can be grouped as follows:

- Training with an access device for using the computer.
- Improve mobility, stability and body posture.
- Improve attention, memory, concentration, spatial organisation and other cognitive and educative issues.

The first aim, accessibility, has been reported in Manresa-Yee (2009). In this paper, we report on the second and third aims, related to rehabilitation.

3.1. Documentation and logging

A set of spreadsheets and documents were prepared and revised together by all the members of the development group to register data from the sessions and therapists:

- A record of the user profile with information concerning the user: personal details, diagnosis, medication, information regarding their motor skills and specially their head movement and control, their visual perceptual skills and their spatial organisation, their language skills, their psychological situation as far as behaviour, character, motivation, and finally educational information and their experience with computers. This profile would be filled in at the beginning of the experience to identify characteristics in common with other users.
- The session log, a form to be manually filled in at each session to be able to analyse the evolution of each user's experience. This log included environmental information concerning the session, for instance, the type of lighting and its direction, the location of the different components (webcam, screen height with respect to the user), configuration of the application parameters (click time, range of click, x and y jump), the physical and behavioural state of the user on the day of the session and the characteristics of the interaction using the access system (head motion (trembling, firm, uncontrolled, continuous and slow), fatigue and posture disorders), in order to identify aspects that could be improved or to analyse differences among sessions.
- End of year report from the centre, where the professionals in charge of the user sessions with SINA summarised the experience during the school year in a semi-structured way, carrying out a case-by-case assessment of the system and of the users. For each user they listed his or her personal objectives: they assessed the use of SINA at first, during the sessions, and at the end of the school year; and finally, they described the expectations of using SINA for the user.
- Semi-structured interviews with the therapists.
- Video recordings of sessions done with an external video camera and in some occasions using the Morae usability testing tool (recorder) by Techsmith to record visual information.

Table 1. Users profile.

	User 1	User 2	User 3	User 4	User 5
Holding head upright	With difficulties	Adequate	Adequate	Adequate	It is not his natural posture. He has difficulties to maintain during long periods the head upright
Controlling head movements	With difficulties	He does not control totally all the movements. He has difficulties with extension and his head falls backwards	Adequate	Adequate	Slow and not totally controlled movements
Limited range of movement	Left rotation is not totally controlled	No limitations	No limitations	Difficulties to left tilt the head	He carries out the right rotation doing a flexion. Left rotation is done accompanied by a rotation
Involuntary movements	Arms spasticity	Arms spasticity and extensor patterns	Head turns to the right	Hands, feet and face tremors	None
Personality	Depressive	Aggressive, rigid thinking	Outgoing	Shy, patient	Depressive
Concentration	Low	Low	High	Low	Low
Memory	Not assessed	Short-term	Short/long-term	Short/long-term	Short/long-term
Behaviour	Interested Participative	Interested Participative	Interested Participative Determined Creative	Interested Participative	Interested Participative

- Photographs of the user when starting the session and when working.
- Physical conditions: head control and sight control.

3.2. Users

Five[1] users were chosen: two women/three men, two adults/three children aged between 5 and 41. All the users employed wheelchairs and had poor movement coordination, involuntary movements, muscle weakness, impaired postural control and muscle-skeletal alignment which resulted in serious limitations in interacting with a computer.

In Table 1, the users' profiles can be found when they first started using SINA, highlighting specially the motor and psychological areas.

The centre's therapists chose the users with the following criteria in mind:

- The need for an alternative device to access the computer, prioritising users whose access system was not very effective.
- Users needed to be able to continue their educational programme with the computer.
- Previous experience with computers. Although the interface does not require previous experience, the therapists wanted the users to focus on the tasks and not on the use of a computer.
- Sufficient cognitive level to understand the interface and the instructions from the therapists.

3.3. Data analysis and triangulation

Once all data were collected and coded, we used triangulation to integrate multiple data sources to improve the understanding of the situation. A methodological triangulation was conducted: as data from different data collection techniques were compared and relationships between results were established. Variables of the study were analysed by different techniques and were present in more than one data collection tool, avoiding the analysis of a variable exclusively based on one data source.

4. Users analysis

In the following lines, we will describe case-by-case the therapists' observations.

4.1. User 1

User 1 was five years old when he started with SINA; he is a poorly motivated child in general, although the therapists who work with him know how to motivate him by paying him a lot of verbal, gestural and postural attention. He has poor head control due to the difference in size between his head and his body; therefore, in certain postures, he tires easily and rests his head on his shoulder. The objectives to be worked on with him were: improve his head control, broaden his horizontal head movement and train his head control so that he can perform all possible movements. SINA helped him to strengthen his neck muscles, dissociate his head movements from the shoulder girdle, work on the postural control of the head and train head movements in all directions. He mainly worked on horizontal movement with multimedia presentations and cause/effect tasks where he was capable of keeping his head upright throughout the activity and controlling his movements without jeopardising the shoulder girdle. A wider range was introduced into the movement and flexion–extension and diagonal neck movements were begun. The user was capable of performing them, but with difficulty and they caused fatigue. Besides, he needed help to perform them in a dissociated, controlled way. SINA served to work on these objectives but always in monitored training sessions, as if the user does it individually and spontaneously, this jeopardises all the paravertebral musculature and has associated arm reactions.

4.2. User 2

The objective for User 2 – 12 years old when he began with SINA – was to work on his spatial orientation, mainly directions in space in order to stimulate learning how to handle the joystick (the interface used normally by this user). He mainly worked with templates designed for this purpose and improved his proprioception and consequently his spatial organisation, laterality and directionality; therefore nowadays he uses the joystick more effectively and efficiently. It is also worth noting that when the user works with SINA, involuntary face and mouth movements decrease.

4.3. User 3

Nowadays, User 3 (14 years old when she began with SINA) works autonomously with SINA. She uses the interface outside cabinet sessions, both in the home and in computer rooms. User 3 trained with two input devices before SINA was introduced: with a joystick controlled by the chin and with a headwand, a rod tied around her head. Both devices produced significant fatigue and led her to work in an inappropriate posture. At the beginning of the introduction of SINA in the cabinet sessions, she worked with her neck bowed exerting a great motor effort like when she used the headwand, frequently losing focus because of involuntary movements or because of directing her attention towards other stimuli, and the path of the pointer was discontinuous and uncoordinated just like her head movement. Now she is able to perform more continuous, coordinated head movements and she works with a correct posture, with a straighter back. The therapists observed that the involuntary movements decrease when she sits in front of the computer:

> She had the pattern of always going towards the right . . . now you can't see it, she only does it on occasions, but at first she always went towards the right and got stuck in that pattern. And this has started to be inhibited. (interview with the occupational therapist)

This is probably due to the fact that she is concentrating more on the task to be performed, although a more exhaustive study should be conducted concerning this point.

4.4. User 4

When User 4, of 41 years age, started working with SINA she could not control the mouse pointer due to lack of head movement coordination and she was not able to keep the head still because of the tremors. Furthermore, she became physically and psychologically tired. She trained specific head directions and head steadiness. She improved her head control and started to use the interface without fatigue and in a more relaxed manner.

4.5. User 5

The natural posture of User 5 (29 years when he began with SINA) was to have his head bowed (Figure 5), which meant we had many difficulties when it came to introducing the interface to the user. He had very little head control and we considered excluding the user from the project because of the poor functionality. However, by working together with the physiotherapist, his control and head movements (horizontal, vertical and diagonal) were strengthened with

Figure 5. Natural body posture for User 5 (a) and when he is working with SINA (b).

Table 2. Therapists observation on the users' improvements when using SINA.

	User 1	User 2	User 3	User 4	User 5
Physical					
Improve head control	X				X
Increase neck range of movement	X				X
Improve coordination	X	X	X	X	X
Increase physical endurance	X			X	X
Dissociate head movements from other body parts	X				
Decrease involuntary movements		X	X		
Improve body posture			X	X	X
Decrease physical fatigue regarding other systems			X	X	X
Cognitive					
Decrease cognitive fatigue regarding other systems				X	X
Improve spatial orientation, proprioception, laterality or directionality		X			

templates. These templates were Powerpoint slides prepared by the therapists where the user had to click over elements placed in different zones to force him to move his head towards particular directions. Now the user is capable of keeping his head upright for longer periods and this also has an impact on his everyday life when, for instance, watching television or talking to someone: 'Before working with SINA he always did everything with his head tilted, now he sometimes watches TV with his head straight for a few minutes' (Dad's comment in a meeting with parents, developers and therapists).

Besides, he is working on cognitive aspects with educational and recreational programmes. The user managed to become autonomous when using SINA and is using the interface in the computer rooms alone. The use of the computer vision interface makes the user raise his head and keep it upright, which did not happen when working with the joystick. Moreover, unlike what happened when he worked with the joystick, his general body posture is much more correct. With the joystick, he bends the whole back forwards and bows his neck, with his face facing downwards; the user gets exhausted because he is continually looking down at the joystick and back up at the screen. The user is still making progress in his head control – strengthening neck musculature – and has increased his endurance.

In Table 2, the improvements observed for all users are summarised.

5. Insights

The user's performance evaluation required careful attention as users had a particular profile, a set of tasks and a behaviour that resulted in unique sessions. Throughout the therapists' note-taking, log analysis, video and photo viewing and interviewing sessions, we worked iteratively to capture our insights about limitations and potential use of the input system for rehabilitation. It was the therapists who originally pointed out the potential of using SINA as a rehabilitating tool as well as the initial functionality of offering accessibility. By repeating movements and incorporating them into daily activities, of learning or recreation, we sought automatic and spontaneous performance by the user within other contexts that are not in front of the computer.

Cognitive functions can be improved through the mental activities involved in handling SINA and the accompanying applications related with processes of reasoning, memory, spatial orientation or decision-making.

Two factors to observe in the sessions to help in the user's active participation in his or her physical and cognitive rehabilitation are the users' fatigue and motivation when carrying out tasks. This information was extracted from the sessions logging, where, among other information, there were questions to capture subjective information such as:

Q1. Is the user motivated? [Yes, No] If No, Reasons
Q2. Is the user fatigued? [No, Little, A lot]

We analysed the first 20 spreadsheets that were filled in during each session. We registered the spreadsheets for all users except for User 1, because due to a physical deterioration he temporally did not participate in the evaluation. The evaluation was especially difficult as users had fluctuating behaviour and different physical conditions.

5.1. Motivation and control

SINA and the training applications offered the user creativity, pleasure and control in the interaction (which users do not have in a physiotherapy session), therefore motivation was high in most of the cases even when some tasks were difficult to carry out (Figure 6). Activities were selected with educational or rehabilitation purposes but they always focused on the user's personal preferences trying to hold their attention and had reinforcement feedback in form of sounds and images to motivate the user.

Motivation was an important factor to engage users to use the system and to help them to concentrate on the task:

> Although they are tired and they have finished the session, they [users U2, U3] do not want to go to the next class. They want to continue [. . .] (interview to the occupational therapist)

There were several occasions where users were not highly motivated: when they were sleepy, they were tired or the activity was an educational one such as reading-writing

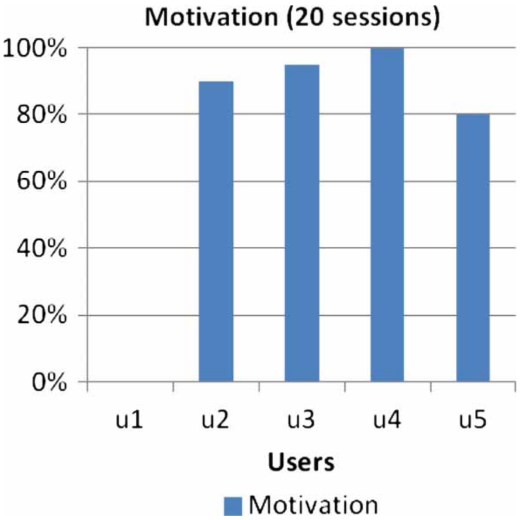

Figure 6. Percentage of sessions where the user answered to be motivated.

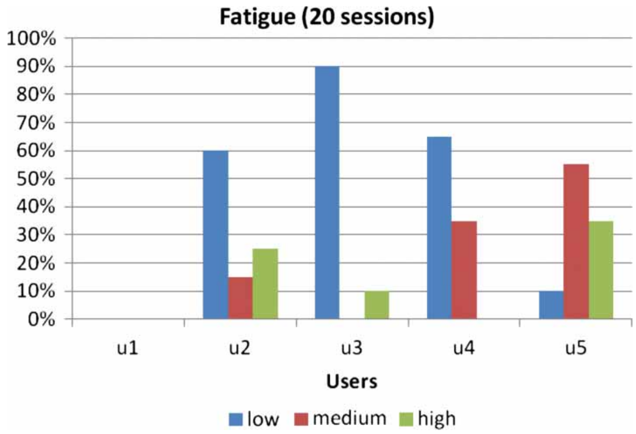

Figure 7. Assessment of fatigue.

which they did not enjoy as much as other entertaining games. Figure 6 shows the percentage of sessions where users were motivated.

In the case of the multimedia presentation templates, the issue was related to user preferences so as to encourage them to go through the slides and see the images and texts that had been prepared for them.

In the cause/effect applications, the image to be hidden was also configurable to make it possible to include a photo of relatives, colleagues or teachers from the centre, or any other issue of their interest. In the applications specifically designed to be used with SINA, on performing the task successfully, loud applause was heard, which the users enjoyed. In the movement applications, SINAManzanas and SINADiana, when an apple was not picked or a dart was not stopped, there was a sound that indicated a life had been lost.

Moreover, for some users, tasks had to be challenging to maintain motivation high:

> Lives were necessary [in SINAManzanas and SINADiana] because some users realized that sooner or later the basket [from SINAManzanas] would fill as apples fell randomly. At first they got really happy when they heard the applause . . . but after a few times without doing anything, they got bored . . . The next step is to compete with other users. (interview with the occupational therapist)

5.2. *Fatigue*

We used a three-level scale (low (1), medium (2) and high (3)) to measure the fatigue. Three out of four users considered their fatigue as low as the mode or most frequent response for these users was 'low'. Only User 5 had a higher mode in the 'medium' value due to his physical difficulties (Figure 7). Moreover, analysing the sessions, higher values for fatigue were found at the beginning of the intervention, in the initial sessions.

Task performing must be aimed at trying to keep the user's fatigue at a low, controllable level so that the user will not produce inappropriate movements and postures due to tiredness. Should great fatigue appear, the factors to be taken into account and on which work must be done, are:

- Limit the time spent with their head in a fixed posture.
- Limit the head movement range.
- Reconsider the number of tasks performed by the user.
- Reconsider the duration of the tasks.
- Reconsider the difficulty of the tasks' execution.

5.3. *User supervision*

It is important to note that the non-supervised use of SINA by some users did not turn out to be rehabilitative in the initial stages. These types of users had to be supervised and directed by a professional, giving indications and verbal or physical support to enable the generation of appropriate movements and postures. Otherwise, the intervention could have been harmful, by encouraging pathological patterns and associated reactions:

> When he [user U1] was with me very good, but when you left him alone [. . .] he used a pattern that was harmful for him and what he was doing was no longer beneficial, because he let his head drop, it lifted in extension [spastic extensor patterns]. . . (interview with the occupational therapist).
>
> If you are not on top [of users U2 and U5] they make their own patterns, because this is what they do in their everyday life, they are always doing them [. . .] it's their normal way of being. (interview with the occupational therapist)

6. Conclusion and future work

In this study we presented a qualitative study of the rehabilitation effects of an access interface which uses the automatic detection of head movements together with a battery of applications that complement rehabilitation treatment of users with a motivating, task-based context. Most of the activities have a training component with cognitive aspects and, in all of them, users need to exercise their neck musculature, control their body and head posture and perform a series of movements monitored by the therapist who prepared and directed the session. The applications are designed to entertain users or to facilitate their learning, so the users' objective on performing them is not physical or cognitive rehabilitation in itself, but rather to obtain a successful result for the activity. Users participate actively in their rehabilitation process with a purpose focusing on a result and with a stimulation and motivation that may not be present when doing physiotherapy sessions. The results obtained are qualitative and very promising as we have observed a persisting improvement in head control, increased endurance, improvement in work posture, decreased involuntary movements, cognitive progress and also improvement in spatial orientation, laterality, directionality or proprioception.

It is important to note that several users needed to work in sessions controlled by a professional to carry out the movements in a correct manner. An important added value to our system would be to enable the user to perform the exercises alone and for the system to control the correct performance. In this sense, it is very important to consider the system's feedback to inform the user and to help him or her to control the performance. For example, the work of Taieb-Maimon *et al.* (2011) is an interesting project where the use of photographs as feedback improves sitting posture of workers at computer workstations.

To control incorrect body postures when using SINA, we would first have to analyse the particular problems of each user who requires supervising. The technology itself could be used to control the body posture. For example, in order to control the head's upright position, if the user does not adopt this initial position, the system does not work. Technically, SINA itself could control 2D neck movement patterns. However, it cannot control back posture or the head's separation from the headrest, and additional systems should be used (gyroscopes, other cameras placed with different points of view). Then, feedback could be in visual, auditory or of a haptic form. It is important to highlight, that this information may help users with physical limitations, but it will be of less value for those users with cognitive problems (except for the haptic device if it restrains the user's body movement; Shull *et al.* 2010).

The case study is based on a small sample group of users with CP, but the system and training applications may be suitable for people with other motor impairments and similar skills. Working with users with CP has allowed us to identify not just motor difficulties but other problems, achieving a more accessible system.

The results of this project were achieved by using SINA, but it is reasonable to assume that other webcam head control-based systems like CameraMouse (Betke *et al.* 2002) or Nouse (Gorodnichy *et al.* 2007) could produce similar therapeutic results.

Proposals are currently being designed for future use of the interface in the field of cognitive and physical rehabilitation. On the one hand, a study is being conducted of the appropriate posture and gestures in the use of SINA, with the purpose of laying down ergonomic guidelines (Llaneza 2009) that will enable the use of this system and avoid overexertion, fatigue or triggering unwanted spasticity episodes or other uncontrolled movements. Another future work line is to design a package of tasks for exercising head control (directions, movement patterns) monitored by a professional, and also cognitive aspects such as memory, association, logic, calculation, analysis, reading–writing tasks and any sort of educational activity that the people in charge of the users' education may indicate. These applications should also compute automatically and measure quantitative parameters such as movement speed, head movement range, fine movement accuracy and others to analyse the users' performance. It would also be of interest to analyse what interactive games work best for which users and why.

One of the factors to study in the future will be to register bio signals when users are carrying out motor and cognitive tasks. The measurement of EEG (brain), ECG (heart) and EOG (eye movement) signals during different activities (in relaxation, performing cognitive tasks or performing motor tasks) can be a key factor in cognitive rehabilitation protocols (Jimenez *et al.* 2012).

The final release of the interface and the applications are available under a freeware license at the web page http://sina.uib.es. Other applications to work with SINA and similar vision-based interfaces can be found at http://www.cameramouse.org.

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Note

1. Six users were selected to analyse accessibility. The sixth user was the 'control user' as he had no problems accessing the computer with a standard mouse and keyboard. Therapists did not observe any change regarding physical or cognitive rehabilitation.

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