Self-awareness rehabilitation through a multi-touch virtual game board after acquired brain injury

Roberto Lloréns, Mariano Alcañiz

Instituto Interuniversitario de Investigación en Bioingeniería y Tecnología Orientada al Ser Humano Universidad Politécnica de Valencia Valencia, Spain CIBER. Fisiopatología Obesidad y Nutrición, CB06/03 Instituto de Salud Carlos III, Spain rllorens@labhuman.i3bh.es

María Dolores Navarro, Joan Ferri, Enrique Noé

Servicio de NeuroRehabilitación de los Hospitales NISA Fundación NISA Valencia, Spain

Abstract—**The clinical consequences of an acquired brain injury can lead to a lack of insight or self-awareness. These symptoms are associated with a lack of motivation and adherence to the treatment. We have developed a virtual game board on a multi-touch table that promotes the collaboration and competition among patients while developing the role-playing and the self-assessment strategies. This paper presents an initial clinical trial to study the effectiveness and usability of the virtual board game in the rehabilitation of self-awareness. The results showed improvement in self-awareness and in frontal lobe dysfunctions with successful usability results.**

Keywords—self-awareness; social skills; acquired brain injury; virtual rehabilitation

I. INTRODUCTION

The clinical consequences of an acquired brain injury (ABI) can be heterogeneous in both the nature and in the severity of the affected skills. In the neuropsychological domain patients can present impairments in their attention, memory, and reasoning that in turn can cause deficits in their self-monitoring skills [1]. All these deficits together with also possible concurrent problems of emotional coping and acceptance can lead to a lack of insight or self-awareness. An impaired awareness of deficits refers to reduced ability to appraise one's strengths and weaknesses and the implications for daily life activities at present and in the future [2, 3]. Self-awareness deficits can make patients not understand the purpose of their participation in a neurorehabilitation program. In consequence, patients can present lack of motivation and cooperation, and even irritability. Self-awareness deficits can finally lead to difficulties in community integration and vocational reentry [2].

Current holistic neurorehabilitation programs try not only to hierarchically restore or compensate the deficits derived from the brain lesion but also to instill awareness of them. Self-awareness rehabilitation tries to highlight the patients' own limitations, to make them able to measure the daily challenges, to facilitate their social reintegration and to help them to establish realistic future plans. Therefore, the rehabilitation strategies focus either on pedagogic lessons to awaken in the patients the self-assessment ability [4] or in role-playing strategies to evidence their limitations [5].

The application of new technologies in the neurorehabilitation field has given rise to many computerized tools that mainly aim to rehabilitate basic cognitive functions, such as attention, memory, or executive functions [6, 7]. Virtual rehabilitation (VR) systems handle more realistic and immersive environments, allowing therapists to imitate real environments but controlling the patients' activity and the sensory feedback provided to maximize functional recovery [8]. There are an increasing number of studies reporting the clinical benefits of introducing VR systems in the rehabilitation programs of cognitive and psychological deficits in ABI population [9].

Different applications have been presented to assess or train different skills after an ABI, such as cooking [10], using an automated teller machine [11], or street-crossing [12]. Some previous work in people with autism has suggested the potential of VR on treating social cognition [13]. However this data have not been replicated in ABI population. Regarding self-awareness, there is no known application that focus on the remediation of this deficit. We have developed a virtual game board on a multitouch table to rehabilitate self-awareness and social skills deficits in patients with ABI. The initial results achieved with the system have been promising [14]. In this paper we describe the system and present the clinical results of 15 participants with chronic ABI in more standardized scales, as well as the usability considerations.

II. METHODS

A. Participants

All the ABI outpatients that were attending a neurorehabilitation program at NISA Valencia al Mar Hospital were potential candidates to participate in the study. Inclusion criteria were: 1) age $\geqslant$ 18 and $\leqslant$ 75 years; 2) chronicity > 6 months; 3) fairly good cognitive condition, as specified by Mini-Mental State Examination [15] > 23; 4) fairly good

language comprehension, as specified by Mississippi Aphasia Screening Scale [16] > 45. Exclusion criteria were: 1) patients with reported high irritability; 2) patients with visual or hearing impairments that prevent their interaction with the system; 3) patients with severe dementia or aphasia.

After inclusion/exclusion criteria 16 participants remained from the total pool. One participant did not finished the intervention protocol and consequently is not considered in the study. The final sample included 15 participants (10 men and 5 women). The characteristics of the participants are detailed in Table 1.

B. Instrumentation

1) Hardware. The developed system was based on a multitouch table (Figure 1). The visual feedback was provided by a conventional 42" LCD screen oriented in a horizontal plane (parallel to the ground).

The interactive capability was provided by a multitouch frame fixed over and along the screen frame. The frame consists of 4 segments, two of them oriented in each axis of the screen. An infrared LED array distributed on a segment of each axis emits IR rays that are detected in the opposite segment (Figure 2). When the participants touch the screen the rays are occluded, which allows the frame to detect the exact position
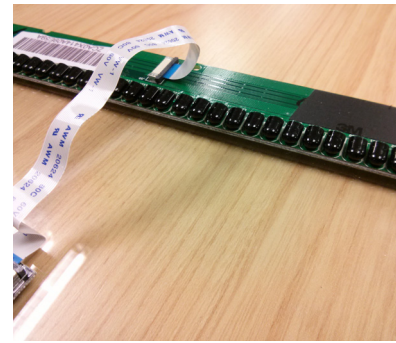

Figure 2. Detail of the infrared LED array

of each touch. A maximum of 32 touches can be simultaneously detected.

The multitouch surface is embedded in a conventional table at a height that allows the wheelchair accessibility. The separation of the table legs also takes into account this requirement. For comfort considerations, an additional 10 cm wide wooden frame covers the surface to provide patients enough space to rest their arms, which is even more important in presence of hemiparesis (Figure 3). A wood sheet with the same size of the surface was provided to cover the screen, which allows therapists to use the table like a conventional one for other purposes without reorganizing the room.

For the clinical validation, the system run on an Intel® Core™2 E7400 @2.8GHz with 3 GB of RAM and a NVIDIA® GeForce® 9800 GT video card with Windows 7. The auditory feedback was provided using the TV speakers.

2) Software. The developed virtual game board is named 'The awareness climbing' since the objective of the game is to reach the top of a mountain. A maximum of four groups, each one consisting of one or two participants, are allowed to play at the same time. Each group sits in one side of the multitouch table. In the game, the groups compete to reach the top in first place, for which they have to move forward as faster as possible by correctly answering different question cards, similarly to other off-the-shelf board game.

TABLE I. CHARACTERISTICS OF THE PARTICIPANTS

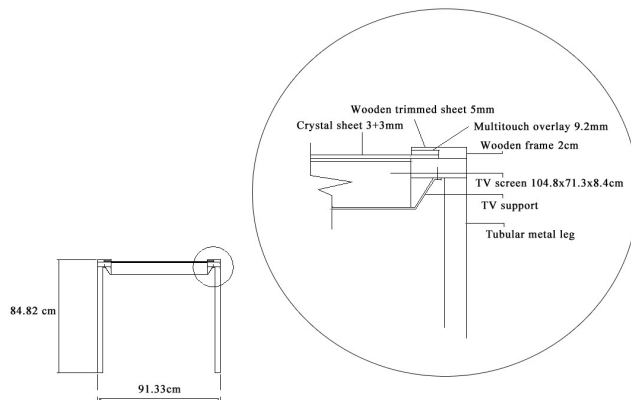| Characteristic	Values
Gender (n, %)	
Males	10 (66.6 %)
Females	5 (33.3 %)
Age (years)	45.67 ± 14.57
Chronicity (days)	265.40 ± 130.91
Etiology (n, %)	
Ischemic stroke	5 (33.3 %)
Hemorrhagic stroke	6 (40.0 %)
Traumatic brain injury	4 (26.7 %)

Figure 1. Drawings of the developed multitouch system

Figure 3. Multitouch system

There are 4 different types of question cards:

- Knowledge (red cards). Anatomical and pathological matters. For instance: 'Lesions of the right hemisphere often cause language problems. True or false?'.

- Reasoning (blue cards). Situational exercises. For instance: 'You are with your friends and some are talking at the same time and you can't follow the thread of the conversation. What would you do?'

- Action (green cards). Role-playing exercises. For instance: 'After the brain injury, you have motor problems with your dominant hand. How would you put your socks and shoes on?'

- Cohesion (yellow cards). Jokes and sayings. For instance: 'Give a riddle'.

When a group has the turn, their participants throw the dice to move their counter to the corresponding square and are required to answer a random question from those categorized with the same color of the square (Figure 4). If the participants answer correctly, they move to the following square (without answering a question). Some squares, distributed in the game board, make the participants loose the turn (avalanche, bear attack, etc.). On the contrary, when overtaking some other squares, the participants achieve bonus that provide them special features like stealing somebody's question or assigning their own questions to other participant.

To promote the intervention of all the participants the text of the cards is oriented to the opposite side of the table. This way, the group of the opposite side has to read the text and the group with the turn has to listen, reason, and answer.

Figure 4. Snapshots of 'The Awareness Climbing' game. The figure shows two random questions that can appear in the game. The red card says 'The peripheral nervous system consists of the brain and the spinal cord. The brain is protected by the cranium and the spinal cord is protected by the vertebral column. ¿True or false?'. The yellow card says: 'Say a saying, explain it and relate a story where it can be applied'

C. Intervention

The participants were distributed in groups of two people, and each group sat in one side of the table. All the participants underwent 1 hour session each week during 6 months. All the sessions were conducted by the same neuropsychologist, who tried to involve all the participants in the game and debated each answer.

In the same way that the rest of the patients, from the moment when the participants were included in the neurorehabilitation program and along their rehabilitation process, all they were taught about topics of the pathology, such as anatomy, causes, clinical consequences, etc. as a part of a continuous training.

The participants were assessed at the baseline and after the treatment with the Patient Competency Rating Scale (PCRS) [17] and the Frontal Systems Behavior Scale (FrSBe) [18]. The PCRS specifically evaluates self-awareness after an ABI. The scale consists of 30 items in which the subjects evaluates in a 5-point Likert scale their skills at performing some tasks. The subject's responses are compared to those of a relative or therapist who rates the subject on the identical items. The FrSBe measures three frontal systems behavioral syndromes: apathy, disinhibition, and executive dysfunction. The scale consists of 46 items that are administered to a relative to evaluate the condition of the patient before the injury, and before and after the treatment.

In addition to the clinical scales, the System Usability Scale (SUS) [19] and the Intrinsic Motivation Inventory (IMI) [20] were administered to all the participants after the treatment. The SUS is a simple, ten-item scale that gives a global view of subjective assessments of usability. The SUS is a Likert scale, and the score ranges from 0 to 100. The IMI is a multidimensional questionnaire structured in different subscales. Each of these subscales is formed by different questions rated on a 7 point Likert- Scale. In his study the IMI was to assess the participants' interest/enjoyment, perceived competence, pressure/tension and value/usefulness. Scores close to 7 in each subscale represent positive value in terms of motivation with the exception of the pressure/tension subscale where high scores represent high levels of tension.

III. RESULTS

When comparing the percentage of participants in each category according to the PCRS and FrSBe at the beginning and at the end of the clinical trial, a significant time effect in the FrSBe (χ^2, p=0.001) and a tendency towards significance in the PCRS (χ^2, p=0.057) was detected (Table 2).

When comparing the scores of patients and relatives, the results showed a reduction of the difference in both evaluations between the initial (14.56 ± 13.02) and the final assessment (7.62 ± 9.58). A paired samples t-test showed a tendency towards signification (p=0.097).

TABLE II.   CLINICAL DATA

Scale	Classification	Before the treatment	After the treatment	Significance
PCRS	Normal	6 (40.0 %)	11 (73.3 %)	χ2, p=0.057
	Pathological	9 (60.0 %)	4 (26.7 %)	
FrSBe	Normal	2 (13.3 %)	4 (26.7 %)	χ2, p=0.010
	On the edge	3 (20.0 %)	3 (20.0 %)	
	Pathological	10 (66.7 %)	8 (53.3 %)	

TABLE III.   USABILITY DATA

Scale	Values
SUS	80.9 ± 9.1
IMI	
Interest/enjoyment	5.7 ± 0.8
Perceived competence	5.4 ± 0.7
Pressure/tension	2.4 ± 1.3
Value/usefulness	6.2 ± 0.6

With regards to the usability experiences, the mean SUS score for the whole sample was 80.9 ± 9.1 (Table 3) with individual scores ranging from 64.0 to 92.5. Similarly, the IMI scores were higher than 5 for all the subscales with the obvious exception of the pressure/tension subscale. Interestingly, the higher score corresponded to the Value/Usefulness subscale.

IV.   DISCUSSION

This paper describes the therapeutic effectiveness of a virtual board game to rehabilitate self-awareness and social skills after an ABI. The virtual game board uses a multitouch system to allow different participants to compete and collaborate using natural metaphors such as finger touches (Figure 5).

According to the PCRS, 9 participants (60.0%) were classified as having self-awareness deficits at the baseline. After the treatment, only 4 participants (26.7%) were classified as pathological. In spite this, no significance was detected in those scores (Table 2). With regards to the FrSBe, significant time effect was detected between the initial and the final assessment (p=0.010). Only 2 participants (13.3%) were classified at the baseline as having normal behavior in relation of frontal lobe functions. After the treatment, 4 participants (26.7%) were classified in this category. These results support the basis that pedagogic intervention and role-playing strategies are effective in self-awareness [4, 5]. The developed system also promotes the socialization of the participants, making them collaborate, compete, and debate each answer,
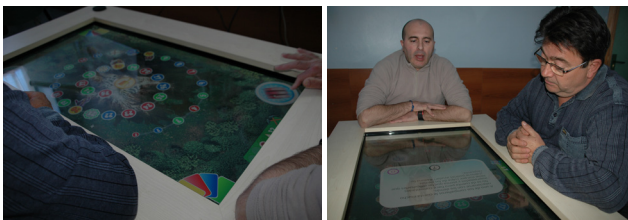
which can lead to improvement in their social skills. This hypothesis is also supported by previous studies [14]. This is particularly relevant since impairment in psychosocial fucntioning is considered one of the strongest predictors of long-term outcome in stroke patients.

The design of the system is based on the fact that social interaction should facilitate general cognitive functioning [21]. Previous studies have also used multitouch surface with rehabilitative purposes [22]. In this study, a multitouch system was developed to allow several participants to interact within the same virtual environment. Even though other options were available, such as the Samsung SUR40 (formerly known as the Microsoft® Surface), the manufacture of our system allowed us to take into account the special needs of ABI individuals and the requirements of the clinical setting, with a significant lower cost.

Regarding usability, the SUS mean score was very high and clearly above the suggested cut-off of 70 that classifies products as acceptable. This suggests that our system is easy to use, easy to learn, robust and consistent. Regarding motivation, the results of the IMI showed that most of the participants found the system enjoyable and defined it as a 'useful system to improve their deficits'.

The intervention sessions were programmed and conducted by a neuropsychologist who always tried to involve the participants and encouraged them to participate more actively. A management tool also allowed them to monitor the evolution of the patients [14].

Even though these results support the fact that this therapy can help ABI patients to improve their self-awareness deficits while improving their social skills, new studies must be carried, either controlled or comparing with other rehabilitation programs.

Figure 5. Patients interacting with the system.

REFERENCES

[1] G. P. Prigatano and D. L. Schacter, Awareness of Deficit After Brain Injury: Clinical and Theoretical Issues: Oxford University Press, 1991.

[2] M. Sherer, P. Bergloff, E. Levin, W. M. High, Jr., K. E. Oden, and T. G. Nick, "Impaired awareness and employment outcome after traumatic brain injury," The Journal of head trauma rehabilitation, vol. 13, pp. 52-61, Oct 1998.

[3] M. Sherer, T. Hart, T. G. Nick, J. Whyte, R. N. Thompson, and S. A. Yablon, "Early impaired self-awareness after traumatic brain injury," Arch Phys Med Rehabil, vol. 84, pp. 168-76, Feb 2003.

[4] D. Dirette, "The development of awareness and the use of compensatory strategies for cognitive deficits," Brain Inj, vol. 16, pp. 861-71, Oct 2002.

[5] W. R. Chittum, K. Johnson, J. M. Chittum, J. M. Guercio, and M. J. McMorrow, "Road to awareness: an individualized training package for increasing knowledge and comprehension of personal deficits in persons with acquired brain injury," Brain Inj, vol. 10, pp. 763-76, Oct 1996.

[6] Cognifit. (2013). Cognifit. Available: http://www.cognifit.com/

[7] Lumosity, "Lumosity, reclaim your brain," 2013.

[8] R. T. Stone, K. P. Watts, P. Zhong, and C. S. Wei, "Physical and cognitive effects of virtual reality integrated training," Hum Factors, vol. 53, pp. 558-72, Oct 2011.

[9] A. A. Rizzo and J. G. Buckwalter, "The status of virtual reality for the cognitive rehabilitation of persons with neurological disorders and acquired brain injury," Stud Health Technol Inform, vol. 39, pp. 22-33, 1997.

[10] L. Zhang, B. C. Abreu, G. S. Seale, B. Masel, C. H. Christiansen, and K. J. Ottenbacher, "A virtual reality environment for evaluation of a daily living skill in brain injury rehabilitation: reliability and validity," Arch Phys Med Rehabil, vol. 84, pp. 1118-24, Aug 2003.

[11] K. N. Fong, K. Y. Chow, B. C. Chan, K. C. Lam, J. C. Lee, T. H. Li, et al., "Usability of a virtual reality environment simulating an automated teller machine for assessing and training persons with acquired brain injury," Journal of neuroengineering and rehabilitation, vol. 7, p. 19, 2010.

[12] R. Lloréns, M. D. Navarro, M. Alcañiz, C. Colomer, and E. Noé, "Convergent validation of a virtual reality-based street crossing with neuropsychological tests in neglected and non-neglected stroke patients," in Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies, Laval, France, 2012, pp. 467-470.

[13] S. Parsons and P. Mitchell, "The potential of virtual reality in social skills training for people with autistic spectrum disorders," Journal of intellectual disability research : JIDR, vol. 46, pp. 430-43, Jun 2002.

[14] R. Llorens, M. D. Navarro, M. Alcaniz, and E. Noe, "Therapeutic effectiveness of a virtual reality game in self-awareness after acquired brain injury," Stud Health Technol Inform, vol. 181, pp. 297-301, 2012.

[15] M. F. Folstein, S. E. Folstein, and P. R. McHugh, ""Mini-mental state". A practical method for grading the cognitive state of patients for the clinician," Journal of psychiatric research, vol. 12, pp. 189-98, Nov 1975.

[16] R. Nakase-Thompson, E. Manning, M. Sherer, S. A. Yablon, S. L. Gontkovsky, and C. Vickery, "Brief assessment of severe language impairments: initial validation of the Mississippi aphasia screening test," Brain Inj, vol. 19, pp. 685-91, Aug 20 2005.

[17] S. R. Borgaro and G. P. Prigatano, "Modification of the Patient Competency Rating Scale for use on an acute neurorehabilitation unit: the PCRS-NR," Brain Inj, vol. 17, pp. 847-53, Oct 2003.

[18] J. Grace, P. Malloy, and I. Psychological Assessment Resources, FrSBe, Frontal Systems Behavior Scale: Professional Manual: Psychological Assessment Resources, 2001.

[19] J. Brooke, "SUS: A quick and dirty usability scale," in Usability evaluation in industry, P. W. Jordan, B. Weerdmeester, A. Thomas, and I. L. McLelland, Eds., ed: Taylor and Francis, 1996.

[20] R. W. Plant and R. M. Ryan, "Intrinsic motivation and the effects of self-consciousness, self-awareness, and ego-involvement: An investigation of internally controlling styles," Journal of Personality, vol. 53, pp. 435-449, 1985.

[21] O. Ybarra, E. Burnstein, P. Winkielman, M. C. Keller, M. Manis, E. Chan, et al., "Mental exercising through simple socializing: social interaction promotes general cognitive functioning," Personality & social psychology bulletin, vol. 34, pp. 248-59, Feb 2008.

[22] C. Müller-Tomfelde, Tabletops - Horizontal Interactive Displays: Springer Publishing Company, Incorporated, 2010.