Chapter 5

Hand Rehabilitation after Chronic Brain Damage: Effectiveness, Usability and Acceptance of Technological Devices: A Pilot Study

Marta Rodríguez-Hernández,

Carmen Fernández-Panadero,

Olga López-Martín and Begoña Polonio-López

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Abstract

Purpose: The aim is to present an overview of existing tools for hand rehabilitation after brain injury and a pilot study to test HandTutor® in patients with chronic brain damage (CBD).

Method: Eighteen patients with CBD have been selected to test perception on effectiveness, usability and acceptance of the device. This group is a sample of people belonging to a wider study consisting in a randomized clinical trial (RCT) that compares: (1) experimental group that received a treatment that combines the use of HandTutor® with conventional occupational therapy (COT) and (2) control group that receives only COT.

Results: Although no statistical significance has been analysed, patients report acceptance and satisfaction with the treatment, decrease of muscle tone, increase of mobility and better performance in activities of daily life. Subjective perceptions have been contrasted with objective measures of the range of motion before and after the session. Although no side effects have been observed after intervention, there has been some usability problems during setup related with putting on gloves in patients with spasticity.

Conclusions: This chapter is a step further of evaluating the acceptance of technological devices in chronic patients with CBD, but more research is needed to validate this preliminary results.

Keywords: HandTutor®, rehabilitation, chronic brain damage, stroke, traumatic brain injury

1. Introduction

According to the World Health Organization [1], cerebrovascular accidents (stroke) are the second leading cause of death and the third leading cause of disability. The last update of the global Burden of Ischemic and Haemorrhagic Stroke [2] indicates that although age-standardized rates of stroke mortality have decreased worldwide in the past two decades, the absolute numbers of people who have a stroke every year are increasing. In 2013, there were 10.3 million of new strokes, 6.5 million deaths from stroke, almost 25.7 million stroke survivors and 113 million of people with disability-adjusted life years (DALYs) due to stroke.

One of the most frequent problems after stroke is upper limb (UL) impairments such as muscle weakness, contractures, changes in muscle tone, and other problems related to coordination of arms, hands or fingers [3, 4]. These impairments induce disabilities in common movements such as reaching, picking up or holding objects and difficult activities of daily living (ADLs) such as washing, eating or dressing, their participation in society, and their professional activities [5]. Most of people experiencing this upper limb impairment will still have problems chronically several years after the stroke. Impairment in the upper limbs is one of the most prevalent consequences of stroke. For this reason making rehabilitation is an essential step towards clinical recovery, patient empowerment and improvement of their quality of life. [6, 7].

Traditionally, therapies are usually provided to patients during their period of hospitalization by physical and occupational therapists and consist in mechanical exercises conducted by the therapists. However, in the last decades, many changes have been introduced in the rehabilitation of post-stroke patients. On the one hand, increasingly, treatments extend in time beyond the period of hospitalization and extend in the space, beyond the hospital to the patient's home [8]. On the other hand, new agents are involved in treatments, health professionals (doctors, nurses) and non-health professionals (engineers, exercise professionals, carers and family). Most of these changes have been made possible thanks to the development of technology [9].

2. Technological devices for upper limb rehabilitation

In the last 10 years, there has been increasing interest in the use of different technological devices for upper limb (UL) rehabilitation generally [5, 9], and particularly hand rehabilitation for stroke patients [10]. These studies have approached the problem from different points of view: (1) on the one hand, by analysing the physiological and psychophysical characteristics of different devices [11], (2) on the other analysing the key aspects of design and usability [12] and (3) finally studying its effectiveness in therapy [13, 14]. According to Kuchinke [12], these technical devices can be organized into two big groups: (1) on the one hand, devices based on virtual reality (VR) and (2) on the other robotic glove-like devices (GDs).

One of the main advantage of VRs and serious games [15] is to promote task-oriented and repetitive movement training of motor skill while using a variety of stimulating environments and facilitates adherence to treatment in the long term [16]. These devices can be used at home and in most cases do not require special investment in therapeutic hardware because they can use game

consumables existing at home such as Nintendo(R) Wii[1] [17, 18], Leapmotion[2] [19, 20] or Kinect sensor[3] [21, 22]. Although first systematic studies based in VRs indicate that there is insufficient evidence to determine its effectiveness compared to conventional therapies [8], more recent studies [13, 14, 23] offer moderate evidence on the benefits of VR for UL motor improvement. Most researchers agree that VRs work well as coadjuvant to complement more conventional therapies; however, further studies with larger samples are needed to identify most suitable type of VR systems, to determine if VR results are sustained in the long term and to define the most appropriate treatment frequency and intensity using VR systems in post-stroke patients.

On the other hand, robotic systems and glove-like devices that provide extrinsic feedback like kinaesthetic and/or tactile stimulation have stronger evidence in the literature that improve motion ability of post-stroke patients [10, 24, 25]. Most of the evidences about effectiveness of GDs are based in pilot studies with non-commercial prototypes [26–30], but nowadays, there are also several commercial glove-like devices that support hand rehabilitation therapies for these patients such as HandTutor® [31, 32], Music Glove [33–35], Rapael Smart Glove [36] or CyberTouch [16, 37]. The main disadvantages of GDs are price, availability, because they are not yet widespread, and in some case the difficulty of setup handling and ergonomics.

As far as we know, there is little evidence in the literature supporting commercial glove-like devices for hand rehabilitation. This chapter presents a randomized clinical study (RCS) to test HandTutor® System in patients with chronic brain damage (CBD). There are some promising studies that show positive results by applying the HandTutor® in different groups of patients with stroke and traumatic brain injury (TBI) [31, 32], but samples include only people who are in the acute or subacute disease or injury but do not include chronic patients. This may be due to the added difficulty of obtaining positive results in interventions aimed at this group, in addition to the characteristics of adaptability and usability of the device that it is also harder for this kind of patients. The present work focuses on hand rehabilitation for chronic post-stroke patients.

3. Experimental design

We have conducted a pilot study (PS) to test acceptance, usability and adaptability of HandTutor® device in patients with chronic brain damage (CBD). This work describes setup, study protocol and preliminary results.

3.1. Participants description

Eligible participants met the following inclusion criteria: (1) At least 18-year age, (2) diagnosed with acquired brain injury: stroke or traumatic brain injury (TBI) and (3) chronic brain damage (more than 24 months from injury). In the final sample, 18 participants aged between

[1]https://www.nintendo.es/Wii/Wii-94559.html.
[2]https://www.leapmotion.com/.
[3]http://www.xbox.com/es-ES/xbox-one/accessories/kinect-for-xbox-one.

30 and 75 years old, 28% of subjects included in the pilot study are diagnosed with TBI and the remaining 72% of stroke; of these, more than half (56%) have left hemiplegia. The time from injury time exceeds 24 months, reaching 61% of cases 5 years of evolution. All the subjects included in the study attend regularly to a direct care acquired brain injury centre.

3.2. Device description

HandTutor® is a task-oriented device consistent on an ergonomic wearable glove and a laptop with rehabilitation software to enable functional training of hand, wrist and fingers. There are different models to fit both hands (left and right) and different sizes. The system allows the realization of an intensive and repetitive training but, at the same time, is flexible and adaptable to different motor abilities of patients after suffering a neurological, traumatological or rheumatological injury. The software allows the therapist to obtain different types of measures and to customize treatments for different patients, adapting the exercises to their physical and cognitive impairments. The HandTutor® provides augmented feedback and allows the participation of the user in different games that require practising their motor skills to achieve the game objective. Game objectives are highly challenging for patients and promote the improvement of deteriorated skills.

3.3. Study protocol

A randomized clinical trial (RCT) has been conducted with an experimental group and a control group. Participants in the experimental group have been treated with HandTutor® technological device, combined with conventional occupational therapy (set of functional tasks aimed at the mobility of the upper limb in ADLs). The control group only received conventional occupational therapy. All participants in the experimental group attend two weekly sessions with HandTutor®. Both groups received a weekly session of conventional therapy. It is a longitudinal study with pre-post intervention assessment, in which each subject is his control.

This chapter describes the first phase of the RCT, consisting of a pilot study (PS) to test the acceptance, usability and adaptability of the device by patients. For the PS, 18 patients of the global group were selected. Each subject completed four sessions using HandTutor® in both hands and a weekly session of COT. Each session includes quantitative and qualitative evaluation. The former one includes pre-intervention, and post-intervention assessment evaluating passive and active joint range of fingers and wrist, the latter include patients' interviews and therapist's observations. During the session, participants receive immediate visual and sensory feedback about their performance during exercises.

Each session includes a pre-intervention assessment and a back, wrist and hand. At the beginning of the session, the therapist evaluated the passive and active joint range of all fingers and wrist (flexion and extension). After the session, patient and therapist reviewed the increased joint range achieved during therapy on the joints involved. The software allows analysing and comparing the minimum and maximum levels in each of the movements required by the exercise. Each session lasts 45 minutes and consists of two exercises that focus their activity in

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flexion and extension of wrist and fingers independently, reaction speed and accuracy of the selected motion to move some elements included in the exercise.

First exercise of the session consisted in score as many balls as possible in the basket situated at the left of the patient. Every ball came to the patient from his right side. The goal of the second exercise of the session was destroying cylindrical rocks that were going from the right side to a planet situated in the left side. In both exercises, none of the elements appeared at the same height. That is why the patient had to adjust the degrees of flexion and extension of wrist, fingers or both. The occupational therapist could modify the speed, number of balls and minimum and maximum of degrees to achieve the accomplishment.

In addition to the quantitative variables described above, the therapist evaluated with qualitative methodology through interviews and observation, the condition of the skin (redness in the contact area with the glove), increased muscle tone, pain, motivation and difficulty understanding the instructions, level of usability, applicability and functionality of the patient. During the intervention, the therapist verbally corrected offsets trunk and lower limbs, annotating associated reactions in the facial muscles.

4. Results and discussion

All the participants of the experimental group completed the pilot study (n = 18). **Table 1** shows the passive and active range of motion (ROM) of the preseason evaluation in fingers and wrist, divided by diagnostic (stroke vs. traumatic brain injury). Every data about ROM is shown in millimetres (average score). In the evaluation, it is noted that the hand of the participants with traumatic brain injury showed lower passive and active joints in all of the fingers (active: V: 9, IV: 10, III: 9, II: 8 and I: 10; passive: V and IV: 14, III: 11, II: 17 and I: 16), except in the wrist (stroke: active 8; passive 23 vs. traumatic brain injury: active 18; passive 20).

Participants with stroke show higher deficits in the flexion active of the first, second and fifth fingers (9, 5.6 and 5.6, respectively), while the extension appears more weakened in the second and third fingers (7 and 8.4, respectively). However, the participants with traumatic brain injury show higher deficit of flexion in the third finger and the extension in the second, fourth and fifth fingers.

In every session, exercises were configured with the same reaction speed and the same number of objects, to allow the participants to achieve the maximum number of hits. Some of them showed deficit of attention, which means that the speed and the increase of stimulations could decrease the final scores and the motivation of the intervention. In the case of the participants who show spasticity, this speed allows them to autorelax and control the hand between the stimulations. The length of exercises were modified according to the muscular and attentional fatigue of the participant, starting with 5 minutes and decreasing, in some cases, up to 3 minutes. All the participants reached the accuracy of movement calculated by the system, according to the preseason ROM evaluation. Also, all of them were allowed to work all of the primary movement range calculated in the evaluation.

	Stroke (average in mm)		Traumatic brain injury (average in mm)	
Range of motion (flexo-extension)	**Active**	**Passive**	**Active**	**Passive**
Wrist	8	23	18	20
Little	11	20.3	9	14
Ring	14.3	22.6	10	14
Middle	11	22.6	9	11
Index	10	22.6	8	17
Thumb	8.3	20.6	10	16
Active flexion deficit				
Wrist	9		2	
Little	5.6		0	
Ring	5		0	
Middle	4.3		2	
Index	5.6		0	
Thumb	9		1	
Active extension deficit				
Wrist	6		0	
Little	3.3		5	
Ring	3.3		4	
Middle	8.4		0	
Index	7		9	
Thumb	3.3		5	
Treatments sessions log				
Reaction speed	10		10	
Accuracy	Full		Full	
Time in seconds	240		240	
(half)	1		1	
Number of objects	Full		Full	
Primary ranger				

Table 1. Hand ROM evaluation pre-session and treatments sessions log.

At the beginning of the session, the occupational therapist explained the exercise to the participant and conducted a 1-minute test to check understanding. Only was necessary to provide additional verbal instruction to improve comprehension in the 11% of the cases.

Figures 1 and **2** show the ROM evaluation of the hand. In **Figure 1**, the active evaluation of flexion of wrist and extension of fingers is observed. **Figure 2** includes the graphic representation of the millimetres of active movements (in red colour) versus the passive ones (in blue colour) of two hands with left hemiplegia (1 and 2) and two hands of participants with traumatic brain injury (tetraparesis and predominance of affectation in the right hemibody).

Figures 3 and **4** display the functioning of the HandTutor® during the intervention. **Figure 3** shows the glove with the hand in flexo-extension, while **Figure 4** shows the assisted movement of the occupational therapist to obtain the higher ranges of flexion in a participant who shows rigidity and attentional issues. Besides, in the contralateral hand, it can be seen the associated reactions in the top member, which is not forming a part of the intervention. The hand replicates the movement that the occupational therapist is trying to get in the most affected member.

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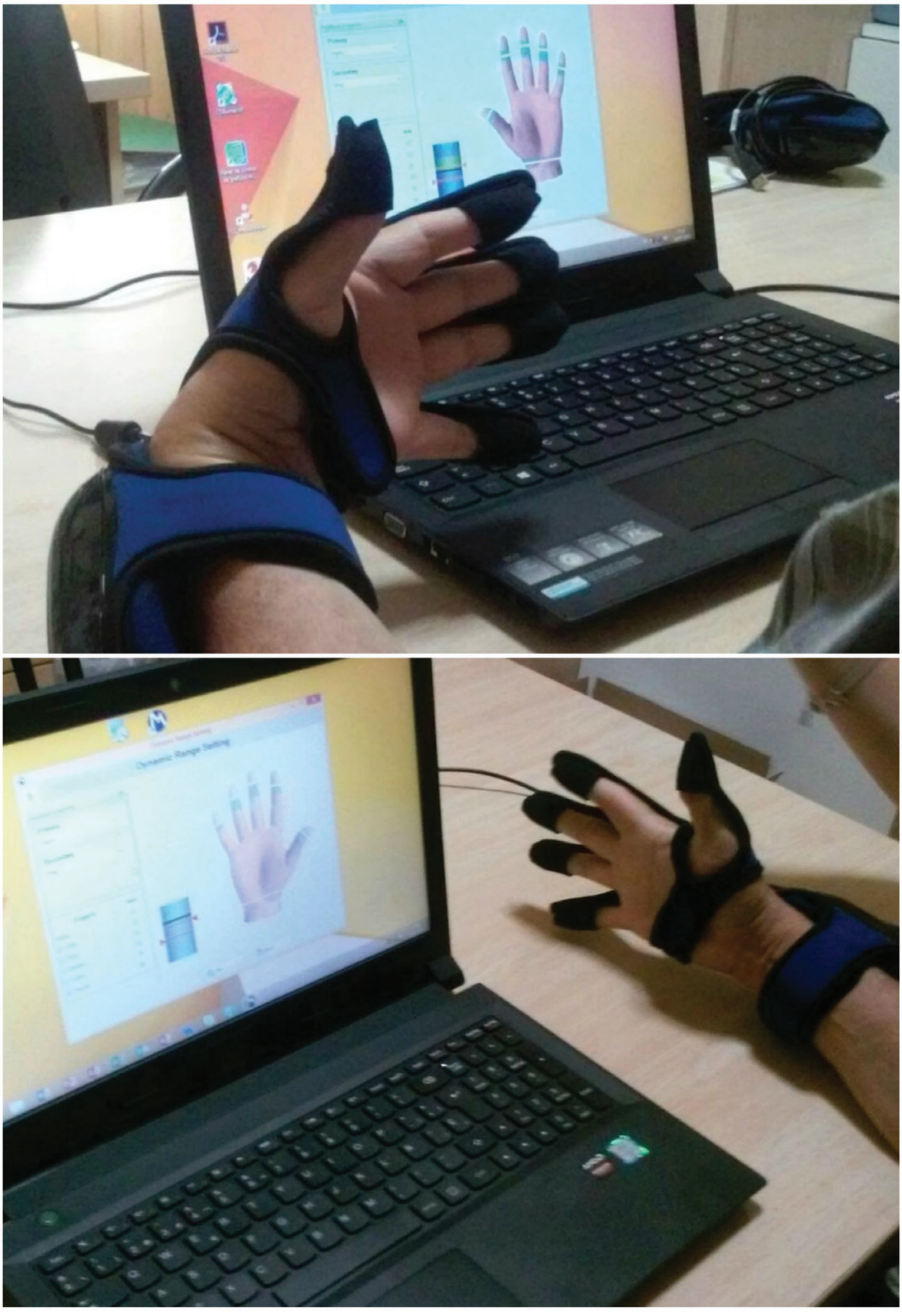

Figure 1. Hand ROM evaluation (active).

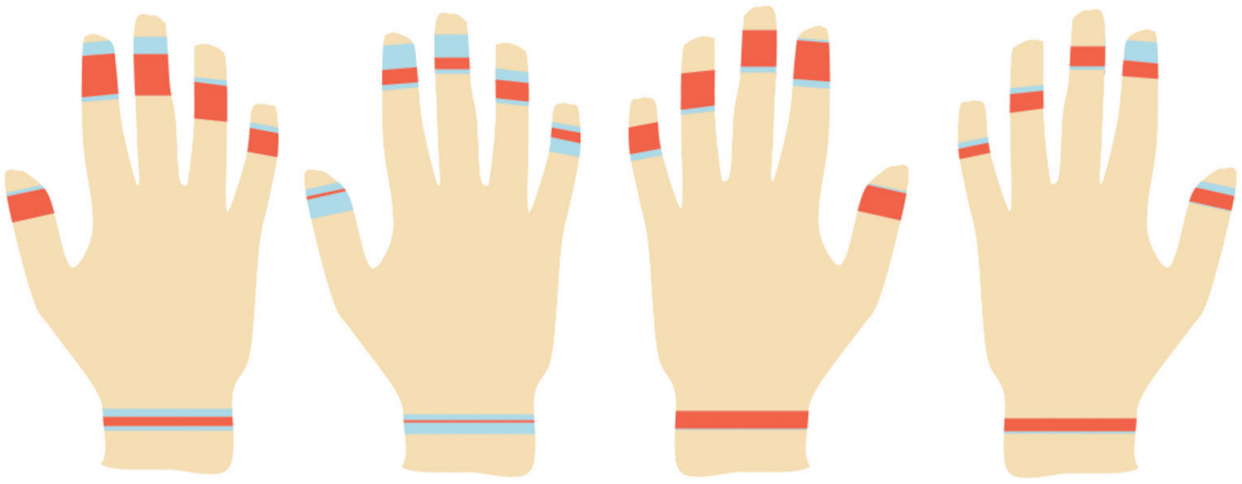

Figure 2. Hand ROM evaluation HandTutor® (passive and active).

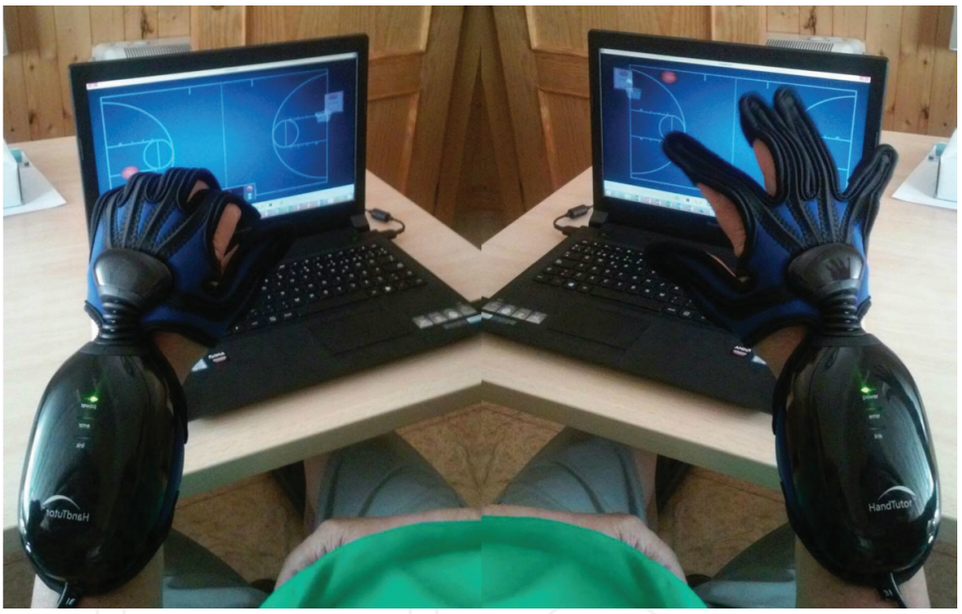

Figure 3. Flexo-extension hand with HandTutor®.

Figures 5 and **6** show maximum and minimum scores for diagnostic. In them, it can be observed the heterogeneity of the flexion and extension movement of the participants in the study. Regarding the wrist, it is not observed huge differences by diagnostic, except in the minimum flexo-extension of the stroke group, especially in the extension. Nevertheless, the articular ranges of the fingers differ until they reach a difference of 20 millimetres in the third finger in the case of the group diagnosed with stroke, coinciding with the group diagnosed with traumatic brain injury.

Participants referred increasing satisfaction with this new therapy. During the intervention, the software provided quantitative measures and immediate feedback of variations in patient mobility showing that HandTutor® sensors are highly sensitive to small variations in patient movement. In post-intervention interviews, patients reported that the glove decreases muscle tone of the hand and wrist, allowing ending the session with increased mobility.

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Figure 4. Example of assisted movement with HandTutor®.

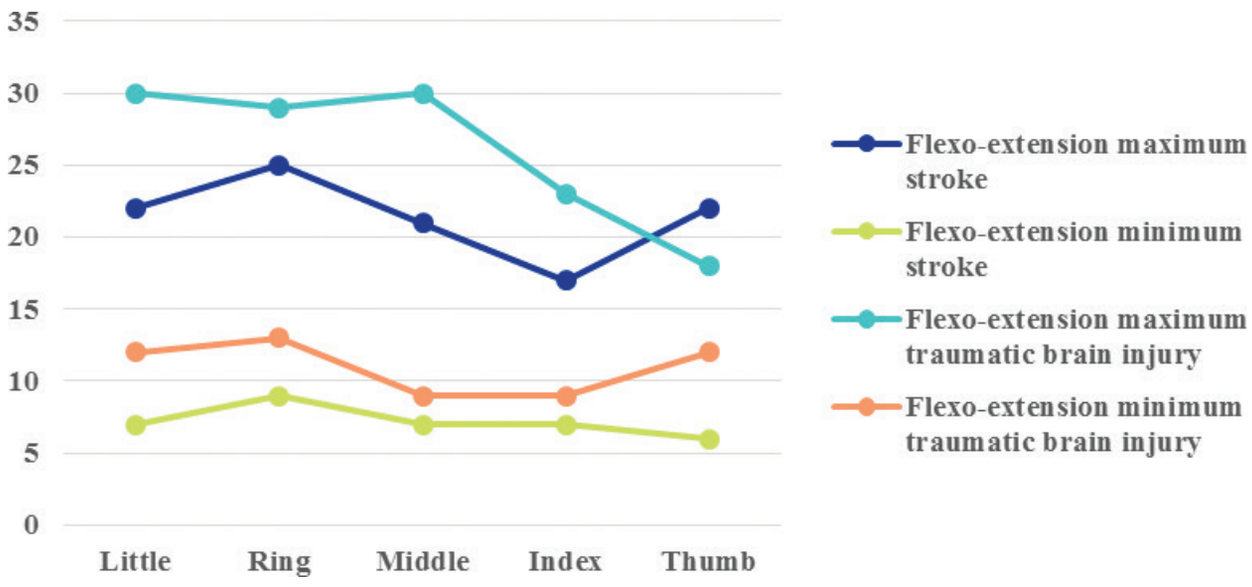

Figure 5. Flexo-extension maximum and minimum of fingers in treatments sessions log.

All sessions evaluated qualitatively, through an interview, the following parameters: skin condition, motivation, difficulty in the understanding of instructions, level of HandTutor® utility, clinic applicability and satisfaction.

During the sessions, no side effects were observed related to the skin or post-intervention pain related with the hand use. Every participant ended the sessions without any visible injury

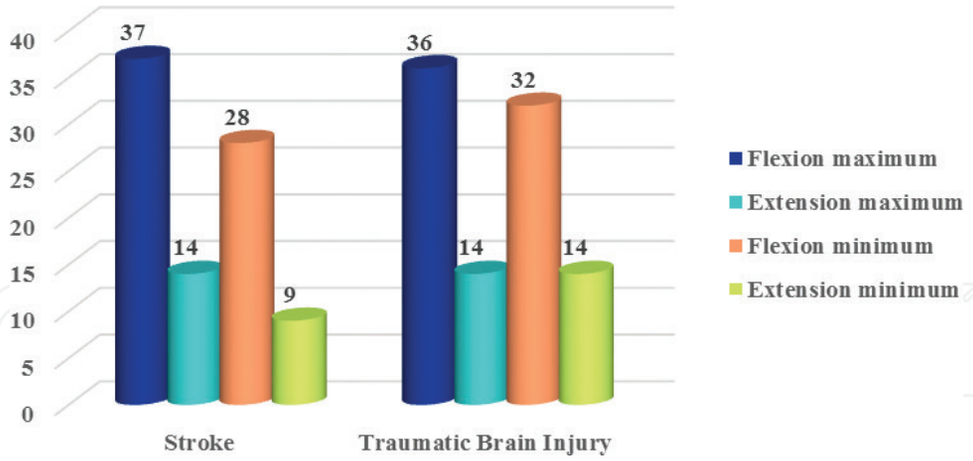

Figure 6. Flexo-extension maximum and minimum of wrist in treatments session logs.

in the skin (absence of redness, marks or changes in the coloration) and without any kind of pain. This was evaluated both at the end of the session and at the beginning of the next. To be able to contrast the information in relation with the skin condition and the pain, the data were triangulated by asking the participant and his/her primary caregiver the following day of every intervention. In both cases, they confirmed our data.

All participants referred high level of motivation and satisfaction at the end of the intervention due to the perceived higher performance of limb segments and joins involved in the exercises in their activities of daily life (ADLs). The subjective perception of the patient was checked by comparing the ROM (active vs. passive) pre-post measurement session. All participants showed and transmitted a great motivation and satisfaction with the HandTutor® intervention, except for one user. This one presents acoustic, visual and tactile hypersensitivity. After the pilot study, this participant transmitted that the glove, the sound and the images of the system induced in him/her nervousness and rejection. This information was contrasted with caregivers and professionals of the centre.

Some difficulties were found at the following of the exercise instructions, the motivation and interest maintenance during the 11% of the cases, as a consequence of the presence of attention and/or memory impairments.

All participants shared the sensation of decreasing the muscular tone, immediately at the end of every session and transmitted that this feeling stayed all day long, allowing them a higher mobility and independence at the ADLs.

During the study, some problems were observed associated with the difficulty in putting on the HandTutor® glove, especially in hands with high degrees of spasticity, mainly in diagnosed cases of traumatic brain injury (27.8%; **Figure 7**). Participants with lower ROM valued positively that the exercise was adapted to their possibilities, so they can reach and move objects even with their limited mobility. The 20% of the users valued negatively the weight of the system placed in the forearm, especially those with weak musculature. The occupational therapists reduced the gravity effect including a cradle to facility the placement of the forearm.

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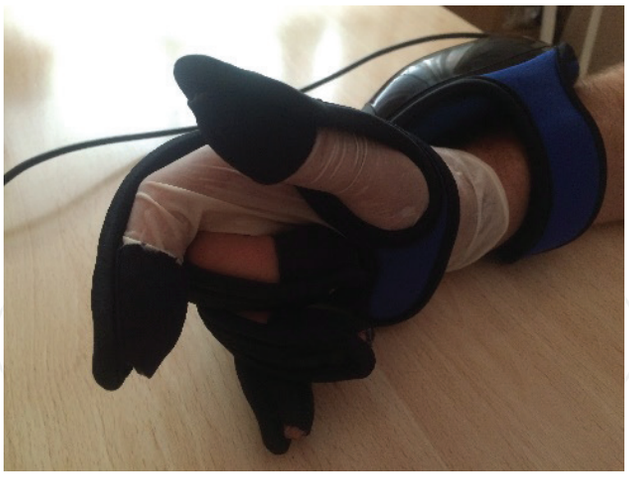

Figure 7. Spastic hand with HandTutor®.

In those patients that showed sweating, there were placed vinyl or latex gloves on their hands to avoid direct contact with the glove.

Therefore, it seems that the HandTutor® is a device with high degrees of acceptance and usability among patients with CBD.

5. Conclusions

This chapter is a step further of evaluating the acceptance of technological devices in chronic patients with CBD. On one hand, in the theoretical part of the study, we have found in the literature strong evidence confirming the effectiveness of glove-like devices in hand rehabilitation after brain injury, but no so solid evidence of VRs effectiveness over traditional treatment. On the other hand, the practical pilot study to test HandTutor points in the expected direction confirming participants' satisfaction about effectiveness and ergonomics of glove-like devices, but according to Ref. [12], there are still some issues to be solved in the usability of these devices for patients with spasticity.

The grade of usability of the HandTutor® device with chronic patients with CBD is high; we only find difficulties in those who show attention disorders and/or memory issues or sensorial hypersensibility. The degree of spasticity should also be taken into account in the design of the experience, because difficulties may arise in the placement of the device when the degree of spasticity is high or there is rigidity or other associated reactions.

Most of the studies performed with active gloves similar to HandTutor® device have been performed in patients in the acute or subacute phase of brain damage. It is important to emphasize that in this study, unlike the previous ones, the rehabilitation has been done with patients with more than 24 months of evolution since the diagnosis of the damage and therefore with a very high degree of chronicity in the neurological sequelae. This is one of the main contributions of the presented work since the more time has passed since the diagnosis of brain damage; the more difficult it is to achieve significant improvements with rehabilitation.

In our study, the HandTutor® device has performed effectively for the spasticity treatment in patients with CBD, producing improvements in the performance of the ADLs and elevating the motivation and satisfaction grades with his use in rehabilitation processes. However, this trial does not provide significant statistical evidence about HandTutor® effectiveness, and it would be recommendable to replicate the study with more participants to confirm our findings.

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Author details

Marta Rodríguez-Hernández[1], Carmen Fernández-Panadero[2]*, Olga López-Martín[1] and Begoña Polonio-López[1]

*Address all correspondence to: mcfp@it.uc3m.es

1 University of Castilla La Mancha, Talavera de la Reina, Spain

2 University Carlos III, Madrid, Leganés, Spain

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