Exploring Materials and Object Properties in an Interactive Tangible System for Upper Limb Rehabilitation

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ABSTRACT

Here we present an exploratory study to assess the feasibility, motivation and usability of a novel system that uses tangible objects of different shapes and materials to interact with virtual tasks designed for upper limb rehabilitation after stroke. 5 different tasks were developed and tested with 5 types of tangible interaction (3 grasp and 2 strength modalities). Data on 5 stroke survivors show that the proposed interactive paradigm is feasible and engaging, and that its usability is modulated by the user's functional abilities. Hence, tasks dynamics and features need to be improved to increase usability for patients with more functional and cognitive difficulties.

1. INTRODUCTION

Stroke remains one of the biggest health problems worldwide, being the third most common cause of disability (Feigin et al., 2014). After a stroke, approximately 70-80% of survivors will experience some level of upper limb impairment (Langhorne, Coupar, & Pollock, 2009; Party, 2012), with 50% remaining with permanent deficits after one year of rehabilitation. These deficits impact functionality and independence in Activities of Daily Living (ADL) (Haghgoo, Pazuki, Hosseini, & Rassafiani, 2013; Pollock et al., 2014), and often lead to social isolation (Kruithof et al., 2015; Northcott, Moss, Harrison, & Hilari, 2016; Volz, Möbus, Letsch, & Werheid, 2016). In addition, stroke survivors commonly present depressive symptomology, which can strongly hamper the recovery process (Ahn, Lee, Jeong, Kim, & Park, 2015; Flaster, Sharma, & Rao, 2013). As such, it is a research priority to find new rehabilitation strategies to foster functional improvement and well-being after stroke.

Technology-based rehabilitation paradigms, such as virtual rehabilitation, have been widely studied for motor and cognitive recovery after stroke (Laver, George, Thomas, Deutsch, & Crotty, 2015; Lohse, Hilderman, Cheung, Tatla, & Van der Loos, 2014). These systems allow delivering structured rehabilitation programs through graded adaptations, and provide challenging and meaningful activities that have the potential to promote increased motivation and treatment compliance (Laver et al., 2015; Viñas-Diz & Sobrido-Prieto, 2016). However, it has been observed that the form of interaction can have an impact on outcomes and acceptance of these novel rehabilitation tools (Mousavi Hondori et al., 2016). For instance, with older populations, evidence suggests that interaction is easier the more direct it is. That is, using the body to interact through touch and getting immediate feedback right where the interaction occurred. Direct interaction through object manipulation better resembles ADL in terms of hand-eye coordination and has been shown to correlate with clinical scores (Khademi et al., 2014).

Research on the use and impact of tangibles in interactive systems for stroke rehabilitation is still scarce (Magnusson et al., 2017). Hilton *et al.*, conducted one of the first studies that explored the use of a tangible interface during a virtual reality task for upper limb rehabilitation (Hilton, Cobb, Pridmore, & Gladman, 2002). A tangible interface was chosen because it allowed having a naturalistic and realistic scenario to simulate instrumental ADL in Virtual Reality (VR). Nevertheless, several technical limitations concerning the use of objects during the task were encountered, such as feedback issues and undesired activation of sensors. During the last few years, this type of technology has however matured immensely, and the onset of new systems that support the use of multi-touch and tangible objects has facilitated their integration in rehabilitation (Jacobs, Timmermans, Michielsen, Vander Plaetse, & Markopoulos, 2013; Kelliher, Choi, Huang, Rikakis, & Kitani, 2017; Leitner, Tomitsch, Költringer, Kappel, & Grechenig, 2007). Recent studies indicate the feasibility of using this technology for stroke rehabilitation in a clinical setting or at home (Kelliher et al., 2017), with good levels of acceptance being reported by healthcare providers (Leitner et al., 2007; Wang, Koh, Boucharenc, Xu, & Yen, 2017). Particularly promising is the increased ecological validity of task execution by manipulating physical objects in these systems, which has potential to improve learned competences and transfer to real world execution of ADL (Jacobs et al., 2013; Kelliher et al., 2017). Similar advantages can be seen in haptic interfaces. In a study with chronic stroke, the use of haptics combined with VR led to improved outcomes 12 weeks after intervention in comparison to other modalities such as vision-based tracking or using a passive exoskeleton (Cameirão, Badia, Duarte, Frisoli, & Verschure, 2012). Particularly interesting are haptic interfaces that allow simulating grasping of objects. For example, the *Wolverine* system that is able to render 75% of a list of objects of daily life (Choi, Hawkes, Christensen, Ploch, & Follmer, 2016). Such devices are promising for an ecologically valid training of ADLs in VR.

While these preliminary studies show positive results on the use of interaction with tangible objects and/or touch surfaces, some issues have not yet been fully explored. Specifically, it is important to understand how tangible interactive systems, their objects and material properties can be designed to provide comprehensive rehabilitation tasks that are flexible and adaptable to users with different clinical profiles, and that can promote motivation for long-term use. For this purpose, we developed a prototype interactive surface that uses camera-based tracking to identify objects of different properties. Through 5 different tasks, the user can manipulate objects of different materials (for example, therapy putty and wooden objects), shapes, sizes, and resistances to accomplish specific goals. The different tasks were designed to train different motor competences of the hand, namely strength, dexterity, coordination and grasping. The objects tested in this study were specifically selected to address only three different types of grasp (power grasp, lateral grasp and tripod grasp) and strength training. With this prototype we want to achieve three research goals. The first goal is to analyze what types of objects and task mechanics are more feasible to be used for rehabilitation by stroke survivors with different levels of impairment. The second and third goals are to assess the motivation and usability of the proposed approach, respectively.

Here we present a detailed analysis of the performance and self-reported feedback of 5 stroke survivors that performed the 5 interactive tasks with different types of tangible objects. Our results show the feasibility of the proposed system for grasp and strength training, exploiting different material properties in an interactive tangible surface.

2. METHODS

2.1 Experimental Setup

The setup consists of a PC (OS: Windows 8.1, CPU: i7-4790 at 3.60GHz, RAM: 8Gb, Graphics: GeForce GTX 1060 6GB), a PlayStation Eye camera (Sony Computer Entertainment Inc., Tokyo, Japan), a 32” TV placed horizontally, and a set of tangible objects (Figure 1). A chair with adjustable height and a bench for feet rest were used to guarantee a correct posture during the session.

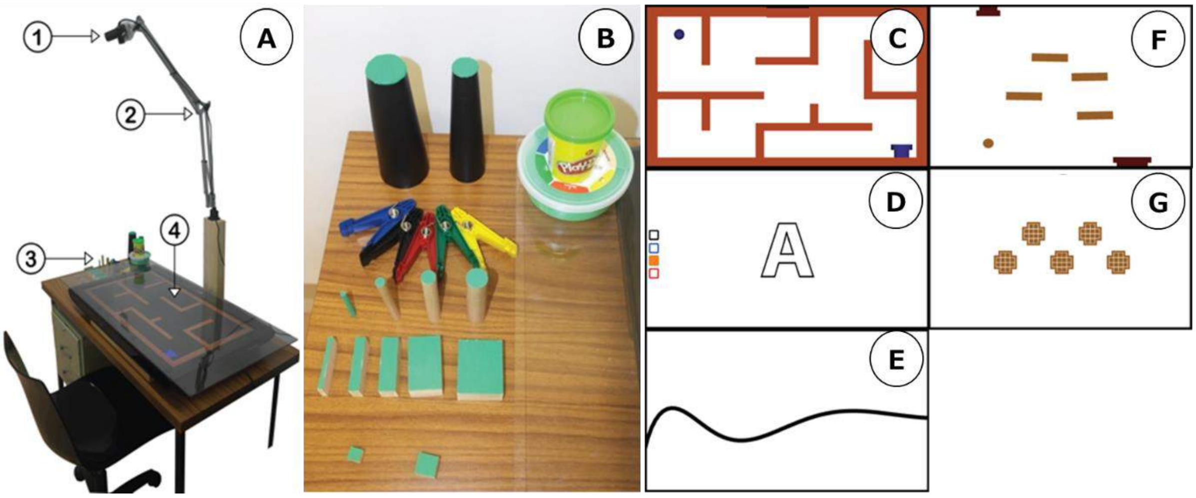

Figure 1. (A) Experimental setup (1-Camera; 2-Supporting arm 3-Set of tangible objects; 4-TV Screen), (B) Tangible objects used to interact with the tasks, and screenshots of (C) *Maze*, (D) *Paint*, (E) *Follow the line*, (F) *Slide*, and (G) *Fill the figure*.

For object tracking, we created a custom software using the OpenCV Source Computer Vision Library, able to detect an arbitrary number of objects from a previously defined colour list, providing their colour (Hue, Saturation and Value values), centre position relative to the camera, area, perimeter and more importantly, a list of coordinates defining the perimeter of each object. All this information is transmitted to the game, implemented in Unity3D, through a UDP socket connection. The tracking software requires a calibration process to account for the light conditions since colour properties can change from the camera's point of view. The software takes the values from the calibration and then applies to each frame thresholding operations to extract Binary Large Objects (BLObs), which refers to a group of connected pixels in a binary image. The term "Large" indicates that only objects of a certain size are of interest since "Small" binary objects are usually noise. The camera would not always be perpendicular to the display, so we created a perspective calibration procedure that corrects the image perspective and crops it by selecting the four corners of the display.

Objects with different characteristics were used for the interaction (Table 1). These were chosen based on materials used for upper limb rehabilitation in standard occupational therapy (Leung, Ng, & Fong, 2009). Objects of different sizes and resistances were used depending on the skill level of each participant. Objects were chosen to allow the three most frequently used types of grasp (power or global grasp, lateral grasp and tripod grasp) (Figure 2) (Feix, Romero, Schiedmayer, Dollar, & Kragic, 2016) and hand/finger strength training. Selection of the object to be used in each competence (grasps and strength) training for each task was made by a therapist based on the initial assessment and the ability of the user to manipulate the object. It was ensured that the manipulation of objects was comfortable but also challenging, as it is intended to simulate a rehabilitation task. We opted to use only one object per competence and task because of the large number of possible objects and to avoid exposing the user to very easy or very difficult performances, thus preventing boredom or frustration, respectively.

Table 1. *Objects' characteristics.*

Cubes	**Cylinders**	**Parallelepipeds**	**Cones**	**Pinch Pins**	**Putty/Plasticine**
Edge (mm)	Diameter(mm)	Length (mm)	Diameter	Resistance (Kg)	Resistance
15	22	45	Small	Yellow – 0,45	Plasticine (Play-doh®)
	15	30	Bottom - 50	Red – 0,9	Extra-soft putty
	10	15	Top - 30	Green – 1,8	Soft putty
1	6	10	Large	Blue – 2,7	Medium putty
		5	Bottom - 70	Black – 3,6	Firm putty
			Top - 50		Extra-firm putty

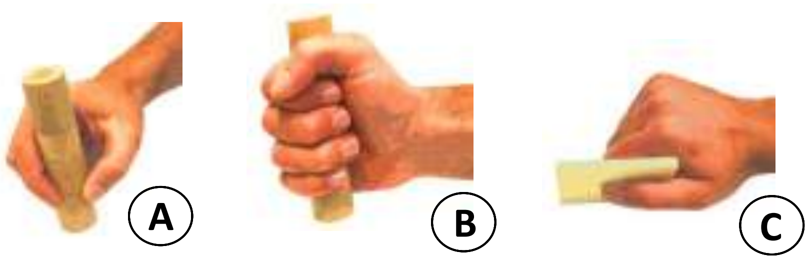

Figure 2. (A) Tripod grasp, (B) Power grasp and (C) Lateral grasp.

2.2 Tasks

5 tasks (*Maze, Paint, Follow the line, Slide, Fill the Figure*) were developed to exploit different object properties and to train specific competences of the upper extremity (Figure 1). All tasks were developed as independent applications using Unity and receiving information from the tracking software through a UDP connection. The tasks are the following:

- *Maze* - the participant has to push a ball through a maze and introduce it into an exit tube at the other end of the maze;
- *Paint* – the participant chooses a colour (blue, yellow or red) and the objective is to paint the letter "C" in a free style. The participant can erase and rewrite the letter until he/she is satisfied with the result;
- *Follow the line* – the participant has to follow a line with an object, trying to be as precise as possible. When performing the task, a trace is drawn with the object. To avoid occlusion of the feedback with the hand, when the left hand is used, the line must be followed from right to left, and vice-versa in order to avoid the object to occlude the feedback of the line being drawn;
- *Slide* – the participant has to create a path with objects for a ball that falls and bounces on them to guide it to the exit tube at the bottom of the scenario;

- *Fill the figure* – the participant has to fill a given shape using objects.

2.3 Sample, Recruitment, and Clinical

Participants of the study were a convenience sample recruited from two public hospitals in Funchal, Portugal. The inclusion criteria were to have suffered a stroke and having upper limb impairment. Exclusion criteria included: null or full functionality of the upper extremity as measured with the Action Research Arm Test (ARAT) (Carroll, 1965; Lyle, 1981); severe cognitive deficit that compromises the understanding of the task, with a score lower than 17 in the Token Test (De Renzi & Vignolo, 1962); hemispatial neglect, assessed through a cancellation test; and no literacy. The study followed established guidelines concerning research with human participants, and all participants provided informed consent.

Fifteen stroke survivors were considered potential participants for this study and 5 met inclusion criteria (Table 2). Our sample is composed of four males and one female, with a mean age of 67.4±13.7 years (range: 51-80), and 27.8±31.3 weeks post stroke. All had 4 years of schooling, were able to read and write, and none had previous experience with computers. Participants underwent motor and cognitive assessments through standard clinical scales in order to identify their level of skill. The motor assessment was done through the Fugl-Meyer Assessment (FMA) – Upper Extremity (Fugl-Meyer, Jääskö, Leyman, Olsson, & Steglind, 1975) and the ARAT for motor functioning; the Box and Blocks Test (BBT) (Cromwell, 1976; Mathiowetz, Volland, Kashman, & Weber, 1985) for gross manual dexterity; a dynamometer to measure power grasp strength; and the Modified Ashworth Scale (MAS) (Sloan, Sinclair, Thompson, Taylor, & Pentland, 1992) for spasticity. The cognitive characterization was done through the Montréal Cognitive Assessment (MoCA) (Freitas, Simões, Alves, & Santana, 2011). The motor and cognitive profile of the participants was diverse (Table 2). Participants had mild to no deficits at shoulder and elbow levels, but broader deficits at hand level. P1 and P3 presented mild deficits, P2 and P5 moderate deficits, and P4 had severe deficits. All the participants presented some level of spasticity but P1 and P5 were the ones with increased tone and movement resistance. Also, P5 showed difficulties to actively extend fingers (open the hand) due to spasticity, needing help in most of the tasks and P4 presented significant difficulties with manual dexterity.

Table 2. *Participants' demographics, cognitive and motor profiles.*

	Gender	*Age*	*Time post-stroke (wks)*	*Stroke type*	*Schooling*	*Computers experience*	**MoCA**	**FMA**	**ARAT**	**MAS**	***BBT (s)*** Paretic	Non-paretic	**Dynamometer *(kg)*** Paretic	Non-paretic
P1	Male	51	17	Haemorrhagic	4	No	11	51	56	1+	30	36	8	12
P2	Female	76	3	Ischemic	4	No	13	39	36	1	19	22	4	6
P3	Male	76	7	Ischemic	4	No	15	40	50	1	19	32	4	9
P4	Male	80	32	Ischemic	4	No	20	33	13	1	0	41	8	26
P5	Male	54	80	Ischemic	4	No	21	54	29	1+	3	49	25	57

2.4 Outcome Measures of the Study

The measures that were used aimed to quantify the feasibility of the prototype system as a rehabilitation tool, its usability, and the experienced motivation.

- Feasibility measures included the percentage of *success* in each task, *time* to complete the task, need of *assistance* to complete a task, and the *ease* of the task measured through a 7-points Likert-scale ranging from 1 (Very difficult) to 7 (Very easy), right after each task.
- Motivation was measured through a Portuguese version of the Intrinsic Motivation Inventory (IMI) (Fonseca & de Paula Brito, 2012). This is a shorter 18-items version from which we used the domains of Interest/Enjoyment, Perceived Competence, and Effort/Importance. Additionally, the level of engagement in each individual task was measured through a 7-points Likert-scale ranging from 1 (Disliked very much) to 7 (Liked very much), right after each task.
- Usability was measured through the Portuguese version (Martins, Rosa, Queirós, Silva, & Rocha, 2015) of the System Usability Scale (SUS) (Brooke, 1996). Additionally, we registered the difficulties experienced by the users during the interaction.

2.5 Experimental Procedure

Data collection was done in 2 different sessions, the first one for the motor and cognitive assessment (~60 minutes), and the second one for the tasks and self-report questionnaires (60-90 minutes). In the first session, participants signed the informed consent, followed by the motor and cognitive assessments performed in a random order. In the second session, the participants started by receiving a brief introduction on how the system worked. Participants were informed of the importance of not occluding the objects from the camera during the interaction. Subsequently, participants performed each task in a randomized order. For each task, multiple iterations took place to test its feasibility using different objects to train power grasp, lateral grasp, tripod grasp and strength. Before each task, the therapist demonstrated it to ensure that the participant understood it. After each task, participants reported on enjoyment and ease of the task using the 7-points Likert-scales. Plasticine and putty were only used with *Slide* and *Fill the figure* tasks. At the end of the session, the SUS and the IMI were administered.

2.6 Data Analysis

Due to the small sample size, only descriptive statistics were used. For each measure, values of central tendency and dispersion are provided. Interval type of data are presented through their mean and standard deviation (Mean±SD), and ordinal data as median and interquartile range (Median (IQR)).

3. RESULTS

3.1 Feasibility

We assessed feasibility through total task time, ease, success as the percentage of participants that completed the task, enjoyment (Table 3) and required assistance.

3.1.1 Time. Regarding the time needed to complete the tasks, *Paint* and *Follow the line* were not strongly affected by the grasp type. Instead, *Maze* took longer with the tripod grasp, *Fill the figure* with the lateral grasp, and *Slide* with the power grasp. However, overall, all grasping activities had similar average times, ranging between 66-82 seconds. For strength training, therapeutic putty/plasticine and pinch pins had opposite effects in *Fill the figure* and *Slide*, being putty/plasticine quicker to use in the former task and pinch in the latter. Strength activities revealed to take longer than grasp activities, mainly pinch pins, which took in average 167.5 seconds.

3.1.2 Ease. In terms of ease, overall, tasks using grasp were considered of similar difficulty (5 points), and harder when using strength (2.5-4.0 points). However, lateral grasp was the easier grasp in all tasks with the exception of *Follow the line.* Interestingly, data on both *Slide* and *Fill the figure* show a variable difficulty range, 2-6 and 3-6 respectively, depending on the trained skill, allowing for broad difficulty gradation.

3.1.3 Success. Success rate was not strongly modulated by the type of skill trained (84-100), but it was by the activity. *Paint* and *Follow the line* achieved a 100% success rate with all grasps whereas *Maze* achieved the lowest rate, being the worst case for power grasp (60%). Strength success rates were of 60% for *Slide* and 80% for *Fill the figure*, independent of using pinch pins or putty/plasticine. The remaining activities oscillated between 80-100%.

3.1.4 Enjoyment. When analysing enjoyment for each interactive activity and trained skill pair (Table 3), scores are mostly positive, being the use of parallelepipeds with lateral grasp (5.5) and cones and cylinders with power grasp (5.0) the preferred ones. For strength training, putty/plasticine was always preferred to the use of pinch pins (4.5 vs. 2.75). When looking at each task individually, the most engaging combination for *Paint*, *Maze* and *Fill the figure* was using the lateral grasp, for *Follow the line* and *Slide* the power grasp. Overall, all interactive activities were reported as engaging (5.5/7 or higher) for at least one of the tested combinations.

3.1.5 Assistance. Assistance during task performance was provided when needed with three different purposes: movement facilitation, difficulties in manipulating an object (due to the object's characteristics), and interaction problems. The most frequent assistance was movement facilitation, with all patients except P1. Assistance was provided mainly at shoulder, elbow extension and fingers extension/positioning, as well as verbal/touch cues for movement facilitation and avoiding body compensations and undesired postures. P1 and P5 needed assistance using cylindrical objects in the *Maze* task.

3.2 Motivation

To measure motivation, we used the Portuguese version of IMI and the Likert scale. We used only three sub-domains of IMI, rated in a range 1-5 (Interest/Enjoyment, Perceived Competence and Effort/Importance) indicating enjoyment of the system (3.5±1.2), with a slightly lower yet positive sense of competence (3.3±1.0) and increased levels of effort (3.8±0.4). Overall, the total score of the questionnaire was 3.5±0.8 in 5.

Table 3. *Completion time, ease, success rate and enjoyment data for each interactive activity and for each trained skill.* ^{Px} *indicates that patient X could not complete the task.*

			PAINT	***MAZE***	***FOLLOW THE LINE***	***FILL THE FIGURE***	***SLIDE***	***MEAN/ MEDIAN***
POWER GRASP	Cones & Cylinders	Time (s)	84.0±49.2	86.3±59.5	32.3±14.4	73.8±46.4	84.5±53.9	72.2±22.8
		Ease	5.0(5.0)	4.0(4.25)	5.0(1.0)	5.5(1.5)	4.0(0,75)	5.0(1.25)
		Success (%)	100.0	$60.0^{P2, P4}$	100.0	80.0^{P4}	80.0^{P2}	84
		Enjoyment	5.0(3.0)	5.0(2.5)	6.0(1.0)	4.5(1.75)	5.5(1,75)	5.0(1.0)
LATERAL GRASP	Parallelepiped	Time (s)	94.4±58.0	73.0±31.2	29.3±7.0	111.6±78.9	22.1±12.8	66.1±39.4
		Ease	5.0(1.0)	4.5(3.25)	4.0(2.0)	6.0(2.0)	6.0(1.0)	5.0(1.75)
		Success (%)	100.0	80.0^{P2}	100.0	100.0	80.0^{P2}	92
		Enjoyment	6.0(2.0)	5.5(1.75)	5.0(3.0)	6.0(2.0)	4.0(2,25)	5.5(1.5)
TRIPOD GRASP	Cylinders	Time (s)	91.4±37.5	121.8±97.6	47.8±24.9	95.0±34.7	55.0±37.0	82.2±30.6.3
		Ease	5.0(1.0)	3.5(2.0)	4.0(3.0)	5.5(1.5)	5.0(1.0)	5.0(1.5)
		Success (%)	100.0	80.0^{P2}	100.0	80.0^{P3}	80.0^{P2}	88
		Enjoyment	5.0(1.0)	4.5(2.0)	4.0(1.0)	3.0(1.0)	4.5(1.25)	4.5(1.25)
STRENGTH	Putty & Plasticine	Time (s)	-	-	-	104.5±44.2	89.0±55.0	97.0±11.3
		Ease	-	-	-	4.0(3.0)	4.0(2.0)	4.0
		Success (%)	-	-	-	80.0^{P4}	$60.0^{P3, P4}$	70
		Enjoyment	-	-	-	5.0(3.0)	4.0(1.0)	4.5
	Pinch Pins & Cubes	Time (s)	-	-	-	265.0±138.6	70.3±62.4	167.5±137.9
		Ease	-	-	-	2.0(1.0)	3.0(0.75)	2.5
		Success (%)	-	-	-	80.0^{P4}	$60.0^{P2, P4}$	70
		Enjoyment	-	-	-	3.0(1.0)	2.5(2.0)	2.75

3.3 Usability

To measure usability, we used the SUS and our observations. The reported SUS ranged from 25 (below poor) to 72.5 (good), with a mean of 46.1±18.2, corresponding to poor usability. SUS data do not seem to relate to schooling, MoCA, ARAT or MAS, but P1 and P5, who reported the highest usability scores (55.0 and 72.5 respectively) also had the highest FMA scores and reported the highest perceived competence in IMI (4.0 and 4.8 respectively) and were the youngest participants.

Our observations during the performance with the interactive tasks can be grouped in three domains:

- *Interaction.* Some objects have tendency to fall, turn over or tilt, such as small size cylinders, parallelepipeds and smaller cubes, becoming more difficult to detect by the system. In addition, there is a tendency to use movements associated to the affordances of the objects in some tasks, like in *Paint* or *Maze*, where participants tried to drag instead of pulling. Some tasks required a minimum reaching to accomplish them, hence, adding the ability to change the position and limits of the interactive area would improve accessibility.
- *Software.* The current technical implementation of the system relies on a camera with an unobstructed view of the interactive surface. Participants need to be instructed to avoid the occlusion of the interactive objects, which impacts tracking and interactive activities negatively. Some tasks need additional feedback and guidance about the task's next step, knowledge of performance and of results when using objects. This task was also extremely cognitive demanding for P1 and P2, the patients with lower MoCA (11 and 13, respectively).
- *Comprehension.* The complexity of the system and of some tasks, in particular for the participants with lower MoCA, required multiple explanations until an acceptable level of performance was achieved.

4. DISCUSSION

Here we presented a pilot study to explore the viability of a system that uses tangible objects of different shapes and materials to interact with virtual tasks designed for upper limb rehabilitation after stroke. The objects were selected to train hand grasping and strength, although the interactive tasks are designed to also address other domains such as coordination and dexterity. At the level of feasibility, all interactive tasks scored 80-100% success rate in at least one of the tested modalities, supporting their viability. This is encouraging considering that the resistances and sizes of objects selected for each participant were chosen to be challenging based on their motor profile. Moreover, the exploration of the different pairs of combinations interactive task-and-training skills revealed that tasks can be adjusted in difficulty and completion time, which can be exploited to address the different therapeutic needs of each patient. Strength tasks typically took longer than grasping tasks, particularly when using pinch pins that required grasping a cube with a pinch and releasing it in the desired place. Strength activities were also considered harder than grasps since these activities were more complex and required grasping and releasing combined with hand strength. Hence, strength tasks using putty/plasticine and pinch pins had lower success rates (70%). In contrast, lateral grasp was considered the easiest for interaction. In fact, the specific size and height of the parallelepipeds contributed to their physical stability and consequently were better detected by the camera, which increased the participants' sense of competence. Some participants -those with more functional difficulties- required some level of assistance by the therapist during the interaction. Directed assistance can be beneficial for facilitating muscle activity and movement, and exposing participants to new and correct patterns of activation/movement (Donaldson, Tallis, & Pomeroy, 2009; Hunter et al., 2017). Nonetheless, there is room for improving the feedback guidance delivered during the interaction.

Regarding motivation, the IMI (3.5±0.8) revealed that participants were motivated when interacting with the system. In addition, reported motivation levels for all interactive activities were on average high. Interestingly, these results were modulated by the patient's ability to perform the tasks. We observed that older participants and with lower FMA scores were less motivated, with a lower perceived competence and interest. This was particularly evident for participant P2, who had the lowest motivation score in IMI. Her motor and cognitive deficits made it very challenging sometimes, resulting in failing to finish activities. Nevertheless, these results are in line with results observed in technology based studies with chronic stroke, specifically on what concerns interest/enjoyment and the sense of competence (Colomer et al., 2016).

In terms of usability, we obtained a low average SUS score but with a high variability. Other system where tangible objects were used to interact with a virtual environment obtained higher usability scores (79±7.54) (Colomer, Llorens, Noé, & Alcañiz, 2016). However, the sample of that study had on average a considerably higher motor function (FMA=50.2 and BBT=22.4). We also need to consider that a single usability score was provided for all tasks and configurations tested, analysing the system as a whole and not its individual tasks. Consistent with the motivation data, it seems to relate to the functional capacity of the participants. P1 and P5 were the participants with greater mobility in upper limb (FMA) and also those that reported higher usability scores. It is also interesting to point out that both were the youngest participants. Although all participants reported no previous computer knowledge, age could have played a role. The fact of usability was lower for persons with lower motor skills in the tested configurations does not necessarily imply that the system has a poor usability for them, since task difficulty can be graded through task selection, grasp/strength selection and the material/object properties of it. Moreover, SUS is focused on the autonomous use of a system, and our proposed system is not designed for being used without supervision. Lastly, it is important to highlight that the system was tested without any prior exposure to the technology on a population without previous computer experience.

An important limitation of this study is the small sample size which only allows us to assess general feasibility of the approach and user motivation. However, as results are promising, we intend to increase the sample with a broader spectrum of profiles allowing for a better understanding how to exploit the different characteristics of the proposed tangible interactions. We also identified that interaction and performance could be improved through additional feedback, sounds and/or visual hints. In addition, the study also indicated the preferential use of specific objects to minimize software and interaction issues. Finally, in the future, tasks will incorporate different forms of content and pace to improve motivation and the graduation of difficulty (Hung, Huang, Chen, & Chu, 2016).

4. CONCLUSIONS

This study proposes a novel contribution for the exploitation of the affordances, shapes and resistance properties of tangible objects in an interactive setup, using task mechanics designed for motor rehabilitation with stroke survivors. Data show that tasks are feasible and engaging, even for first time users. Our findings show that grasping training activities worked better than strength training ones, however, both were satisfactory. Nevertheless, there is a need to improve self-efficacy through better object selection, feedback mechanisms and object tracking. Also, we want to add software adaptation mechanisms in the tasks to improve motivation and usability for those stroke survivors with more functional deficits.

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