Towards a Set of Design Principles for Hapto–Virtual Rehabilitation Environments: Preliminary Results in Fine Motor Hand Therapy*

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ABSTRACT

In this paper, we propose a set of principles to facilitate the design of haptic feedback virtual environments for fine hand motor skills. Firstly, we conducted a contextual study in a rehabilitation center to identify preliminary design elements using grounded theory. Based on these results, we defined a set of principles to aid in the design of haptic feedback virtual environments to achieve therapy effectiveness and patient's safety. In order to evaluate the proposed design principles, we developed a haptic feedback virtual environment based on them and conducted a formative evaluation with 5 patients and 3 therapist. Although preliminary results provide promising evidence, indicating a high perception of usefulness, ease of use and intention of use of the proposed environment and principles; further evaluations are needed to investigate therapy effectiveness and patient's safety.

Categories and Subject Descriptors

H.1 [**Models and Principles**]: User/Machine Systems

General Terms

Human factors, Design

Keywords

Virtual Rehabilitation, Haptics, User-Centered Design, Design Principles

1. INTRODUCTION

In the recent years, several innovative strategies have been developed for improving post–stroke upper extremities motor recovery such as constraint induced movement therapy, electromyographic biofeedback, electromechanical assisted training, electrostimulation, high intensity therapy, robotics, repetitive task training, splinting and physical fitness training, among others [1–3]. In addition, the incorporation of emerging technologies such as virtual reality and haptic feedback in the rehabilitation therapy has attracted the attention of researchers and therapists because of its potential benefits, namely its capability of repetition, feedback, motivation, early intervention, and task oriented training—see for instance [1] and references therein.

As pointed out by [4,5], virtual reality allows for the design, creation and control of multi–dimensional simulated and interactive valid stimulus environments within which behavioral responding can be measured and recorded, providing in this way clinical assessments and rehabilitation tools that are usually not available in traditional therapy methods. Furthermore, when haptic feedback is also incorporated into the virtual environment, additional benefits such as force–feedback and tactile or kinesthetic input/output that are essential in many rehabilitation tasks are also provided [6].

Although there have been several proposals concerning the implementation of different kinds of hapto–virtual rehabilitation systems (i.e., haptic–enhanced virtual reality environments), e.g., [6–11], there is still a gap between the design phase of those systems and their usage with real patients due to the lack of design principles that take into account both the needs of patients and therapists. Most research works rely on the patient point–of–view to identify criteria (mainly for visual–based virtual environments) either focusing on the patient motivation and engagement [12–15] or on the therapy usefulness [16–18]. However, ensuring therapy effectiveness and patient safety while providing the therapist with the adequate parameters to track patients performance and progress in hapto–visual rehabilitation environments are among the questions that remain yet to be answered [19]. To this end, we present in this work the preliminary results that allows us to identify designing principles for hapto–visual rehabilitation environments in fine motor hand therapy.

The remainder of the paper is organized as follows: Section 2 describes the contextual case study performed at the regional rehabilitation center. Section 3 explains the design principles that were identified during the study. In 4 we explain the methodology carried out to obtain feedback regarding the design principles with patients and therapists. In Section 5 we discuss our results and we conclude with final remarks and future work in Section 6.

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2. CONTEXTUAL CASE STUDY

To understand traditional fine motor hand therapy, a qualitative study was carried out during three months at the regional rehabilitation center located in Ensenada, Baja California, México. Twelve specialists (e. g. rehabilitation medical specialist, occupational therapists, psychologists, etc.) take care of approximately 80 patients with motor and cognitive impairments in this center. We performed structured and unstructured interviews with five specialists, including one rehabilitation medical specialist, one occupational therapist, two physical therapists and one psychologist. All of them answered a 5–point Likert scale questionnaire of forty items. Additionally, eight non-participative direct observation sessions (30 min each, 4 hours total) involving five patients with different pathologies such as carpal tunnel surgery, cerebrovascular accidents, and brain lesions were performed (Figure 1).

Interviews and observation sessions were recorded, transcribed and analyzed using grounded theory [20]. Emerging themes about the characteristics of fine motor hand therapy in occupational therapy were obtained (see Table 1). As can be seen in Table 1, according to the the patient's function to be strengthened is the kind of artifact manipulation for movement execution for the exercise. Therefore, the main strategy used by occupational therapists in order to motivate the patient is to conduct base movements on ludic activities. As a result of this contextual study, the next section presents the identified design principles for haptic feedback virtual environments.

3. DESIGNING PRINCIPLES

From the contextual study we have identified a preliminary set of designing principles that take into account the therapists viewpoint. These designing principles are classified in two categories: principles that aim a) to guarantee therapy effectiveness and b) to ensure patient's safety when designing the interaction with hapto–visual environments.

Therapy effectiveness:

- Adaptability: According to occupational therapists, this principle is important to assess the range of motion and strength of the patient, to thereby adjust therapy.
- Therapy tasks tailored according to the patient's motor impairment.
- Motivation based on recreational activities to engage and entertain the patient during therapy.
- Suitable selection of the haptic interface.

Figure 1: Non-participative direct observation of a traditional occupational therapy session.

Patient's safety:

- Carefully selection of the range of motion and strength of the therapy tasks according to the patient's physical ability.

As a proof–of–concept of the aforementioned designing principles, we developed a haptic maze application with the Novint Falcon haptic device. Our main objective was to enhance the strength and wrist–movement accuracy of the patient by using a haptic–enhanced virtual environment. The virtual environment consists of three main components (Figure 2): a) a configuration screen where the occupational therapist selects not only the visual features of the virtual environment, but also the number of task repetitions and the simulated weight of the haptic proxy; b) the haptic maze; and c) the results screen where patient performance is displayed.

4. FORMATIVE EVALUATION

In order to evaluate the design principles that were used for the development of the virtual environment (see Figure 3), we conducted two therapy sessions with five patients. These sessions were supervised by two occupational therapists and one physical therapist. After each therapy session a TAM[1] Likert scale 5 questionnaire regarding perception of usefulness, ease of use and intention of use of the haptic virtual environment was answered by patients and therapists. Evaluation results are shown on Table 2. These re-

[1]Technology Acceptance Model [21]

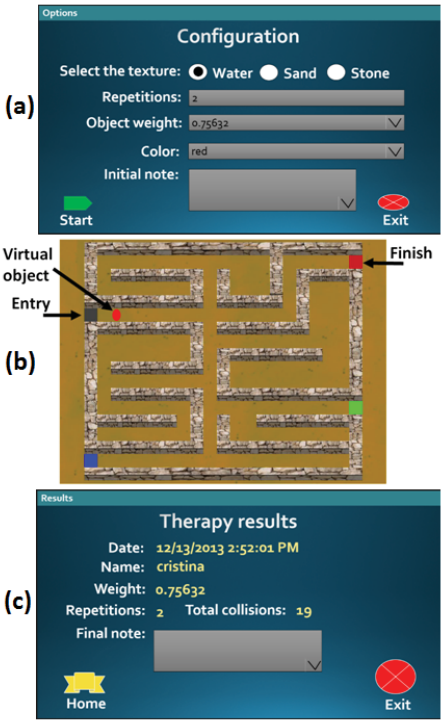

Figure 2: Haptic–enhanced virtual environment: (a) therapy configuration; (b) exercise in the haptic maze for wrist therapy; (c) therapy results.

Table 1: Traditional occupational therapy features.

Category	Property	Dimension
Fine motor skills hand therapy	Features	Based on formal or ludic activities
		Goal-based movements
		Exercises for specific movements
	Artifacts	Everyday toys, textures, mirror
	Movements	Fingers, palm and wrist flexion or extension
		Fingers and wrist abduction or adduction
		Fine clamp
		Wrist supination or pronation
	Functions to be enhanced	Strength
		Sensation
		Range of motion
		Precision (eye-hand coordination)
	Causes	Birth defect
		Injury or accident
		Degenerative disease
	Problems	Patient's absenteeism and lack of motivation
		Subjective assessment
		Lack of technology that motivates to exercise
	Strategy	Lack of ludic or formal activities according the patient's skills

sults provide evidence about patients and therapists having a high perception about the proposed environment's usefulness, although the latter perceived a higher usefulness (i.e. completely agree) than the former (i.e. agree). Also, therapists perceived the environment as having a high ease of use (agree), although this was not the case for patients which were Neutral. Finally, intention of use was projected as high (i.e. completely agree) by both kinds of users. Based on the lessons learned during the development and evaluation of the haptic virtual environment process, the design principles were modified (others were added) as follows:

Therapy effectiveness:

- *Patient's data accessibility:* store the patient's data according to the clinical record format (NOM-168-SSA1-1998 [22]); allow for data access according to the specialist's role; display a performance record of the patient.
- *Therapy adaptability:* execute a task that allows to determine objectively the level of difficulty of the exercise for the patient (for instance, number of repetitions, weight of the virtual object); automatically suggest the difficulty level according to the patient's performance record; learning level of the exercise that does not add excessive difficulty to the patient's motor rehabilitation.
- *Ludic activity based motivation:* gain the patient's attention by including auditory elements combined with strength feedback.
- *Goal-oriented movements for skill generalization:* repetitive and intense basic movements (such as finger and wrist flexion and extension, finger adduction and abduction, fine pincer grasp) for motor re-learning.
- *Suitable selection of the haptic interface for movement execution:* according to the movement to be enhanced in the patient is the selection of the haptic interface (for instance exoskeleton or haptic device with end effector).
- *Mechanisms for determining success of the therapy:* establish mechanisms that allow to identify patients' improvements based on quantifiable results (for example speed, position, weight of the virtual objects).
- *Continuous interactions:* guarantee the synchronization between the visual and haptic feedback according to the virtual objects' characteristics.

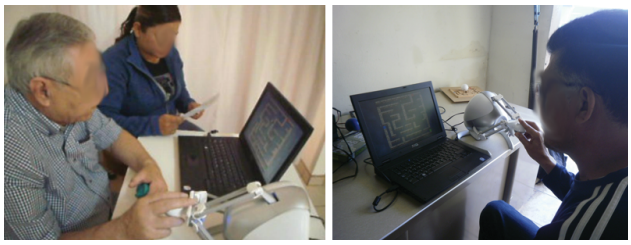

Figure 3: Patients conducting therapy sessions during the formative evaluation of the design principles.

Patient's safety:

- *Respect the range of movement and hand's maximum strength:* delimit the range of movement of the exercise and the maximum weight of the virtual objects according to the biomechanical properties of the patient's hands.
- *In case of failure, stop communication with the device at an appropriate time:* provide simple mechanisms that allow for stoping the activity in case of failure of the haptic device.

5. DISCUSSION

The results of the conducted evaluation allowed i) for gathering preliminary evidence towards the perception of participants about the usefulness, ease of use and intention of use of the developed environment, and ii) for obtaining a refined version of the principles for the design of haptic virtual environments for fine motor hand rehabilitation.

Regarding participants' perceptions, although this perception was high on usefulness and intention of use for both patients and therapists, this was not the case for ease of use. In the latter case, therapists perceived it high, but patients were neutral about it. This could be due to the challenge imposed to patients by the indirect manipulation required to interact with/through the haptic device. For this reason, it is necessary to further investigate about principles to balance this challenge, to try to increase the patient's ease–of–use perception. Concerning the design principles, these aim at achieving *therapy effectiveness* and *patient's safety*. Although other research works have proposed similar principles for therapy effectiveness (e.g. [16] considers principles about goal-based movements, ludic activity based motiva-

Table 2: Perceived usefulness, ease of use and intention of use.

Aspect analyzed	Patients	Therapists	Total
Perceived usefulness	4.0/5	4.5/5	4.2/5
Perceived ease of use	3.0/5	4.2/5	3.6/5
Intention of use	4.5/5	4.6/5	4.5/5

tion, and patient's performance), our proposal includes principles regarding accessing patient's information according to the specialist's role for decision making, and the appropriate selection of the haptic interface according to the movement to be enhanced. To the best of our knowledge, none of these principles have been included in previous efforts. Additionally, and also to the best of our knowledge, no other proposal have considered the inclusion of design principles for patient's safety, such as the importance of having a simple mechanism for stopping the haptic device in case of failure. Nevertheless, additional evaluations are needed to further investigate therapy effectiveness and patient's safety.

6. CONCLUSIONS AND FUTURE WORK

In this work we presented the results of a proposal and evaluation of a preliminary set of principles for the design of hapto–virtual rehabilitation environments for fine motor hand therapy, with an emphasis on safeness of the patient and effectiveness of the therapy. Our main findings suggest that although the elements introduced through the principles (e.g. the inclusion of haptic force feedback) are well appreciated by both the patients and the therapists regarding usefulness and intention of use, additional work should be conducted to overcome some of the challenges introduced by them regarding ease of use (e.g. the use of a haptic device to provide force feedback introduces indirect manipulation, which imposes an additional challenge to patients, whom need to "map" their movements in the physical to the actions on the objects in the virtual environment). We are particularly interested in following this last aspect as a line of future work.

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