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

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. Evaluation results provide promising evidence, indicating a high perception of usefulness, ease of use and intention of use of the proposed environment and principles. However, attention should be provided to overcome some of the challenges introduced by the elements proposed by the principles, notably regarding the patients’ perception of use.

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 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, 2, 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 kinaesthetic 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., [7, 6, 8, 9, 10, 11, 12], 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 [13, 14, 15, 16] or on the therapy usefulness [17, 18, 19]. 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 [20]. To this end, we present in this work the preliminary results that allows us to identify design 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.

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 Cali-
fornia, 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 hrs 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 analysed using grounded theory [21]. 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 therapist’s function to be strengthened is the kind of artefact 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. DESIGN PRINCIPLES
From the contextual study we have identified a preliminary set of design principles that take into account the therapists’ viewpoint. These design 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 haptic–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.

Patient’s safety:
- Careful 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 design 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 questionnaire (TAM Likert scale 5 [22]) 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 results 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 higher ease of use (Agree) that patients, which were Neutral about it. A possible explanation for this could be that patients find it difficult to interact with the haptic device, as it required for the indirect manipulation of the objects in the virtual environment. 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 [23]); allow for data access according to the specialist’s role; display a performance record of the patient.

Patient’s safety:
- Careful selection of the range of motion and strength of the therapy tasks according to the patient’s physical ability.

Figure 1: Non-participative direct observation sessions.

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.

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

5. DISCUSSION

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

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 perception of ease of use. Concerning the design principles, these aim at achieving therapy effectiveness and patient’s safety. Although other research works have proposed similar prin-

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

<table>
<thead>
<tr>
<th>Aspect analyzed</th>
<th>Patients</th>
<th>Therapists</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perceived usefulness</td>
<td>4.0/5</td>
<td>4.5/5</td>
<td>4.2/5</td>
</tr>
<tr>
<td>Perceived ease of use</td>
<td>3.0/5</td>
<td>4.2/5</td>
<td>3.6/5</td>
</tr>
<tr>
<td>Intention of use</td>
<td>4.5/5</td>
<td>4.6/5</td>
<td>4.5/5</td>
</tr>
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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 haptic–virtual rehabilitation environments for fine motor hand therapy, with an emphasis on safety 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.

7. REFERENCES


