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ABSTRACT
V-Sense is a vibrotactile interface that encourages children with severe or profound cognitive, sensory and physical impairments to move. The interface makes use of touch, in particular vibrations, as a supportive function to motivate users' actions. Specifically, we propose a vibrotactile interface on the arm and around the shoulder using the saltation perceptual illusion to induce movement of the corresponding joint. In this paper we describe the design principles of the interface and the proposed experimental design to evaluate it.

Categories and Subject Descriptors
H.5.1 Multimedia Information Systems; H.5.2. User interfaces.

General Terms
Design

Keywords
Vibrotactile interface; children with special needs; interactive environment; user interface

1. INTRODUCTION
People with severe to profound developmental disabilities are often isolated and limited in their interactions with the surrounding world. Endeavors to improve their interaction potential and offer them more control over their environment supported by technology have been carried out [1][2][3].

In a previous work, we developed and evaluated SinaSense [3], which is a motion-based interface that serves as an educational application for children with severe to profound developmental disabilities that depend on others to interact with the environment. This interface makes use of computer vision to detect the body movements of the user by tracking a colored band, which in turn triggers meaningful outcomes from the system (music, images, videos and so on). An example of use of SinaSense is to attach the colored band to the user's wrist and while the user keeps his or her arm raised, music plays and it is paused when the user lowers the arm.

The results of the evaluation with end-users for three months showed that by using SinaSense, children increased their intentional movement and the duration of the movement. However, while evaluating the system, we observed that the educational psychologist who conducted the evaluation assisted children physically and orally to help them to be aware of the reaction in the environment that their body motion was causing. Both this observation and the therapists' comments on the importance of touch with these users motivated this work.

We have designed V-Sense, a vibrotactile interface to complement SinaSense, which seeks to encourage and motivate the user to raise their arm using vibration cues. The aim of V-Sense is to reduce the need from the therapist for both physical and oral support.

In the following paper, we present the related works and our proposal for the design of the system.

2. RELATED WORK
Touch can be defined as the sensation elicited when the skin is subjected to mechanical, thermal, chemical or electrical stimuli. The sense of touch comprises two sub modalities: kinesthetic and cutaneous. The former provides information about the static and dynamic body postures and the latter provides awareness of the stimulation of the outer surface of the body [5]. In particular, vibration is a form of cutaneous stimulation, as it produces a distortion on the cutaneous surface [6].

In order to communicate information through the sense of touch by the application of pressure, vibration or force, haptic interfaces are used. These haptic interfaces can be wearable interfaces and they can mounted on different devices for the users to wear such as glasses, gloves, watches, vests, pendants, caps, and so on. The use of vibrotactile information can be twofold: to provide feedback [7] or as a supportive function to motivate users' actions [8].

2.1 Vibrotactile interfaces and disability
Research on vibrotactile interfaces for disabled users has specially focused on visually-impaired users to help them in their interaction with the environment or with other people: to enhance navigation abilities [9][10], to interact with nearby objects [11], to present graphical information non-visually [12], to enrich interpersonal communication [13][14], to play with videogames [15][16][17], to teach choreographed dance [18] or to generate Braille on a mobile [19].

We also found studies addressing problems encountered by users with hearing impairments. In this case, vibrotactile interfaces are used to translate sounds (music, speech or environmental noises) into physical vibrations [20][21].

Very few works using vibrotactile information for interaction purposes and addressing users with cognitive impairments can be found in the literature. Knudsen et al. [22] presented a vibrotactile system for navigation support of people with mild cognitive impairment.

2.2 Interface and the saltation illusion

Saltation, or cutaneous rabbit, is a perceptual illusion, where a rapid vibrotactile pulse delivered first to one location and then to another on the skin produces the sensation of a virtual vibration between the two vibrators [23].

This illusion has been used in vibrotactile interfaces to motivate particular movements. Spelmezan et al. [24] defined tactile motion instructions as tactile feedback that communicates how to move the body, that is, they provided tactile motion instructions by mapping vibrotactile patterns to body motions (specifically for snowboarding). McDaniel et al. [25] proposed a framework, MOVeMENT (Mapping Of Vibrations to moveMENT), to use vibrotactile stimulation to incite the user to perform fundamental movements, that is, flexion, extension, abduction, adduction and rotation.

MacDaniel et al. [25] stated that all approaches to instruct motor skills through vibrotactile stimulations can be organized based on the level of abstraction of the vibrotactile-movement mapping: there is a continuous spectrum from no abstraction to high abstraction. On the end of no abstraction, there are for example those systems that use of vibrotactile stimulation to indicate a movement error. And at the other end of the spectrum, the high abstraction, the vibrotactile stimulation incites the user to perform a movement. Since the level of abstraction is high, users must recognize particular vibrotactile patterns of an already *known* set of movements.

In the experiments presented in these works, users interpreted the directionality of the vibration patterns as "pushing"/"pulling" or as a "follow me" instruction.

As far as we are aware, there are no studies that have used the saltation illusion to motivate movements in users with disabilities.

3. V-SENSE RATIONALE

Based on the saltation illusion and the characteristics of the users we designed a vibrotactile interface to motivate two kinds of arm/forearm movements:

- Elbow flexion: for children with very little movement who find difficulties lifting totally their arms (see Fig. 1 (a)).
- Shoulder flexion: for children capable of lifting their arms completely (see Fig. 1 (b)).

To design an intuitive interface, we considered the following issues [25]:

- Pattern of vibration: the vibrotactile pattern should exploit the effects of saltation.
- Direction of vibration: for example the push/pull or "follow me" metaphors [24].

- Location of vibration: it is intuitive to vibrate the skin close to the area where the movement is going to occur.

Furthermore, we have to take into account the three stages in the kinematic-vibrotactile mapping to facilitate motor learning [26]: (1) the design of the vibration signal to be applied to the skin; (2) the conceptual mapping of the perceived vibration signal to the movement it is intended to elicit or cue; and (3) the type of movement to be performed based on the cue.
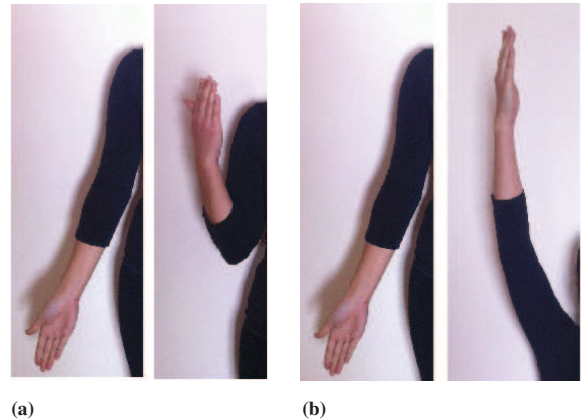

Figure 1: (a) Elbow flexion (b) Shoulder flexion

3.1 Elbow flexion

The vibration motors should be placed on or near the muscle/joint/body part involved in the movement. For example, to flex and extend the elbow, the vibration motors could be placed on the bicep muscle or across the elbow joint. We follow the location used for elbow flexion/extension described in [25], as it has been tested with successful results (with users with no disabilities). Therefore, three vibration motors are set up in line on an arm band and placed on the bicep muscle above the elbow joint, as depicted in Fig. 2(a).

The vibrotactile stimulations will travel up to simulate the pull metaphor of the forearm. The pattern will consequently pulse the three vibrators (V1-V1-V1-V2-V2-V2-V3-V3-V3), where each vibration cue will be repeated as recommended by McDaniel et al. [25] for improved user perception. The burst will be of a 100 ms, with a 50 ms inter-burst interval, which is considered optimal to elicit saltation and has been successfully evaluated in the aforementioned works.

3.2 Shoulder flexion

Three vibration motors are set up on a shoulder pad embracing the shoulder as shown in Fig. 2(b). The vibrators could be placed on an armband on the biceps but closer to the shoulder than the ones used for the elbow flexion. However, we chose the first approach to completely differentiate it from the elbow flexion.

The pattern of vibration will be: V1-V1-V1-V2-V2-V2-V3-V3-V3 to motivate the arm lifting. Once again the burst duration of 100 ms is used, with a 50 ms inter-burst interval.
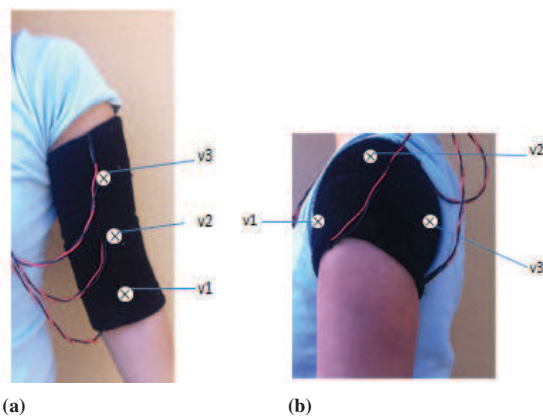
Figure 2. Localization of vibration motors for (a) elbow and (b) shoulder flexion

3.3 System implementation and lab testing

The interface uses an Arduino Mega microcontroller and the three vibrators are Precision Microdrives 310-103 Pico Vibe™ 10mm. Cables have been lengthened up to 2 meters to offer comfort and flexibility to the users when performing the movements. Further, a switch has been provided to trigger the vibrations whenever the therapist feels it is required.

The system is currently powered by a USB cable connected to a computer. The firmware stored on the microcontroller was developed using the Arduino development environment.

The interface was evaluated with users with no disabilities in a laboratory. We explained users how the system worked and then the system was set up, first the elbow interface and then the shoulder interface. The vibrations were triggered several times to observe the users reaction: if the vibrations were easy to feel, if movements were easy to carry out with the vibrators on or if the movement was intuitive, easy-to-learn and easy-to-remember.

The system proved to be an easy system to set up, with a comfortable and flexible interface for performing the movements. We observed that it was useful to hang the cable on the back rest of the chair, so that the user had more ease when raising the arm/forearm: it was lighter for the user as they did not have to lift all the cable and it was less cumbersome. Users reported having no trouble identifying the movement to perform (lifting the arm or forearm), as the location of the vibrators was on the region to move and directionality also improved the intuitiveness.
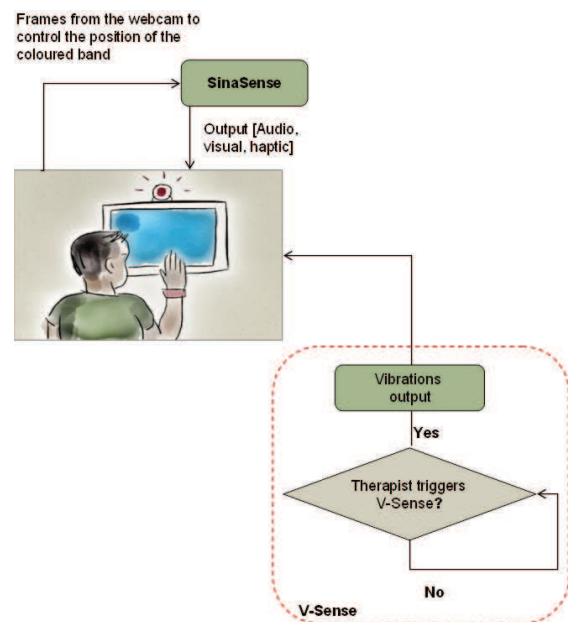
4. CONCLUSIONS AND FUTURE WORK

In a previous work, we designed and evaluated SinaSense, a motion-based interface that makes use of computer vision to detect the body movements, which in turn triggers meaningful outcomes from the system (music, images, videos and so on). The aim of the system was to offer the user more control over the environment and improve his or her interaction with it. Results were successful, but users needed physical and oral support from the therapist conducting the evaluation.

To avoid the physical assistance and to reduce the need for oral support, in this paper we have presented V-Sense, a wearable vibrotactile interface for children with severe to profound developmental disabilities. The interface exploits the saltation illusion to motivate users' actions, specifically, raising the arm or

forearm. We have described the design principles of the interfaces and a first working prototype has been developed (see Fig. 3) and evaluated successfully with users with no disabilities. Even if lab testing was carried out with successful results, it is very important to test a complete version with the intended end-users as their profile is totally different and they may present with sensory, physical and cognitive impairments.

The aim of the user evaluation will be to assess whether the use of vibrotactile information motivates the user's movement, increasing the number of times the user raises the arm or forearm autonomously.

Figure 3. The complete system: V-Sense and SinaSense

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