A Wearable System for Multisensory Stimulation Therapy for Children

Foad Hamidi
Information Systems Department
University of Maryland, Baltimore County
Baltimore, MD, USA
foadhamidi@umbc.edu

Manuel Merino
Isabel Gomez
Department of Electrical Engineering
Universidad de Sevilla
Seville, Spain
manmermon@dte.us.es
igomez@us.es

Setefilla Lopez
Educación Especial Directora
Mercedes Sanroma
Seville, Spain
setefilla03@gmail.com

Alberto Molina
Department of Electrical Engineering
Universidad de Sevilla
Seville, Spain
almolina@us.es

Melanie Baljko
Lassonde School of Engineering
York University, Toronto, Canada
mb@cse.yorku.ca

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Abstract
Multisensory stimulation therapy involves the simultaneous stimulation of several senses in a relaxing environment to achieve a variety of therapeutic outcomes for client with conditions affecting sensory and cognitive processes. We present, *StimuHat,* a wearable system for therapists to visually stimulate patients. We conducted a pilot study in which a therapist used StimuHat in sessions with three children with profound brain damage. The results showed that StimuHat appears to have stimulated the children and created positive relaxation and engagement in them.

Author Keywords
Wearable Systems; Affective Computing; Multisensory Stimulation Therapy; Brain Damage.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction
Rapid innovations in embedded and ubiquitous technology provide new opportunities to develop novel therapeutic interfaces. *Wearable interfaces* (or simply *wearables*) are computational systems that are worn on the body and often incorporate sensors and actuators that can be activated by users [1]. Additionally,

adaptive affective systems are computational systems that use biosignals collected from sensors connected to a user's body to monitor and respond to a user's affective and emotional state [22]. The emergence and convergence of wearable and affective technologies provide possibilities for the development of novel and "smart" tools for use by therapists to support their practice [12, 23, 24, 27, 28].

These systems are particularly promising for supporting therapy that involves sensory stimulation to positively impact a client's affective state. *Controlled multisensory stimulation therapy* is a popular form of therapy that involves the simultaneous stimulation of several senses in a relaxing environment [14]. In this work, we present *StimuHat,* a wearable system for therapists to provide visual stimulation to clients and to monitor their affective state while undergoing multisensory stimulation therapy.

Background

Controlled multisensory stimulation therapy is a form of therapy in which the therapist uses a combination of environmental factors, such as music and lights, and techniques such as calming touch and movement to provide calming and relaxing sensory stimulation to a client [14]. Over the years, this method has been used for therapeutic activities for many user populations including children with severe sensory disabilities [15, 25], older adults with dementia [4] and children with severe brain damage [14] with positive effects including increase in adaptive behavior [26], decrease in agitation, heart rate and muscle tone [14], among others [15]. We are particularly interested in how this therapy can support the sensory stimulation necessary for the appropriate brain development [2, 3, 11] for children with brain damage.

Controlled multisensory stimulation therapy is often conducted in *multisensory environments* (MSEs). MSEs (also referred to as Snoezelen™ rooms) are dedicated spaces that are equipped with a range of sensory stimulation equipment, including audiovisual equipment and adjustable lights, and are used for therapeutic and relaxing activities with children or adults with a range of disabilities [8]. The equipment in MSEs usually consists of a range of visual, auditory, olfactory and tactile equipment, including fiber-optic cables, ball pools, mirror light balls, projectors and music playback units among other things [5]. While some studies have looked at the use of computational interfaces in MSEs (e.g., [6, 7]), they have focused on systems designed for clients, rather than therapists. Additionally, to our knowledge, the possibility of using interactive wearables is not previously explored in MSEs.

In recent years, many wearable systems have emerged that support of different therapies including bright light therapy [23, 24], touch therapy [27] and neurofeedback training [12], among others [28]. Vaucelle et al. developed four wearables for mental health therapy [27]. *Touch Me* is a wearable that allows a therapist to remotely apply touch pressure to a user's body. *Squeeze Me* is an interactive vest that allows its wearer to use a portable air compressor to simulate therapeutic holding to help avoid panic attacks. *Hurt Me* allows the activation of controlled pain as a form of sensory grounding for users with tendencies towards self-harm. Similarly, *Cool Me Down* allows the discreet self-application of heat or cold to parts of the body as a form of sensory grounding. Profita et al. have developed and evaluated *lightware,* a series of light-emitting wearables to administer light therapy to users with *seasonal affective disorder* (SAD), a disorder that causes depressive-type symptoms during fall and

Figure 1: The *StimuHat* interface consists of a hat augmented with LED lights and biosignal sensors.

winter [23, 24]. Different lightwear garments are augmented with light-emitting elements that administer bright light to a user's head and face. The researchers employed a user-centered design approach to identify aesthetic, social and functional elements that would make the garments desirable to users. Finally, Hao et al. described the preliminary design of a wristband embedded with a series of LED lights that are controlled by a user's *electroencephalograph* (EEG) signals and is meant to support neurofeedback training for adults who work under stress or need emotional regulation [12]. In contrast to our approach, these efforts have focused on wearables worn by a client rather than the therapist. Additionally, while some of these systems can be used in MSEs, they are not specifically designed to support controlled multisensory stimulation therapy.

StimuHat: A Wearable System for Multisensory Stimulation Therapy

StimuHat (Figure 1) is a wearable system designed for a therapist to wear and to provide visual stimulation to clients with brain damage in a MSE. StimuHat consists of a hat augmented with a microcontroller and programmable LED lights, and a fingerless glove with activation buttons. It can be combined with biosignal sensors that detect the client's affective state during therapy and change the color, intensity and movement patterns of the embedded lights based on a client's affective state (a feature that is not currently implemented and will be added in the future).

StimuHat offers several benefits over existing non-interactive tools used in multisensory stimulation therapy. First, since it is worn on the therapist's head, it frees up their hands to move or touch the person undergoing therapy or use other tools for increased stimulation. Second, the intensity, colors and movement patterns of the lights can be customized for each client based on their needs (or preferences). Third, StimuHat can use data from biosignal sensors to respond dynamically to a client's affective state.

The biosignal data can be used to adjust the light patterns and speed in response to a client's affective state and be recorded for future review by the therapist. This feature would be particularly useful when working with non-verbal clients (such as clients with profound brain damage). We considered both *electrocardiogram* (ECG) signals and *galvanic skin response* (GSR) signals, as their collection is less intrusive than other types of biosignals. After initial difficulties with collecting GSR signals, we decided to only use ECG signals. Currently, the biosignals are only used to monitor the affective state of the client during therapy and do not impact the light patterns in real-time.

Design Process

StimuHat was developed in close collaboration with the medical staff of a special education school with extensive experience with working with children with varying degrees of disabilities. Prior to any user evaluations, we conducted two collaborative design sessions at the school (each lasting one hour), with the school psychologist and the school medical doctor, where we discussed the use digital wearable systems in MSEs. The school psychologist who administers therapy described that typically, sessions with the children in the MSE room take place over 10-20 minutes and involves stimulation using soft lights, black light lit cards and calming music and speech. The aim of the therapy is to encourage the children's non-verbal expression (through sounds, gestures, facial expressions and touch) and to stimulate their senses in a peaceful and pleasurable environment.

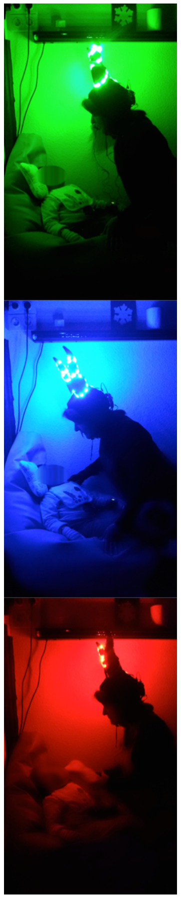

Figure 2: A therapist wearing *StimuHat* during sessions; the child is lying down with the lights in their line of vision.

She identified that a wearable system with programmable electronic lights could be useful for the multisensory stimulation of children with brain damage and low vision. For this population, visual stimulation is a goal of therapy that can support brain development. The school psychologist further offered suggestions on how to set light patterns (see below) and what affective states to target when analyzing biosignal data from the children (described in next section). She also advised that the form of the hat is promising as it places lights near the face of the therapist and can cover a large area of space in front of the children's eyes. She described that she often leans towards the children during sessions and tries to capture their attention with shining objects.

Light Pattern Design

The lights in StimuHat are used to engage and stimulate the person undergoing therapy. We consulted with the school psychologist and medical doctor to determine a series of suitable light patterns. Since many children undergoing MSE therapy have epilepsy, it was important that light patterns would not trigger seizures in the children. Thus, we avoided using flashing lights and instead used progressive and continuous patterns.

The final light patterns consisted of several sequences: in one sequence, the LED lights simulate a marquee-effect of a single light spiraling around the hat; in another sequence, the hat gradually lights up (this is repeated in the three primary colors); finally, another sequence involves the hat glowing in several colors. Currently, the main purpose of these sequences is to engage the attention of the subjects using a variety of colors and movements. In the future, the lights can further be tweaked and used to communicate data or system state information (e.g., by following these guidelines [10]).

Pilot Study

We conducted a preliminary evaluation to determine whether StimuHat is useful for therapists in the context of multisensory stimulation therapy and how does it compare or complement existing low-fi tools. We were also interested in the potential effect of using StimuHat on the (i) engagement and the (ii) affective state of children undergoing therapy.

Study Design

We used an AB study design: in Condition A, the baseline condition, an established stimulation method using reflective cards shining in black light was used to stimulate the children. During this condition, the therapist would hold a card in her hand and move it slowly in front of the subject's eyes to engage and stimulate them. In Condition B, StimuHat was worn by the therapist and used to stimulate the children (Figure 2). In both conditions, calming music was played in the background and the therapist would talk to the children in a calming voice. Each session lasted 15 minutes, consisting of initial and final rest periods (5 minutes each) when no stimulation was provided and a stimulation period (5 minutes).

One of our team member, a professional therapist, administered both conditions. The school's medical doctor, who is familiar with the children's health condition, was on call during the sessions and would postpone any sessions if the children's health required. During the pilot study, the unstable health state of the subjects required many sessions to be cancelled and re-scheduled. We needed to discard some of the data: During the rest periods of some sessions, the children fell sleep because they did not have enough sleep the night before the session day. On other days, they showed signs of discomfort without apparent reason.

Subject Descriptions

Subject 1: Male, 9 years old, with a diagnosis of severe encephalopathy and refractory epilepsia; major problems of visual perception.

Subject 2: Female, 10 years old, with a diagnosis of severe encephalopathy secondary West syndrome, hydrocephalus, major problems of visual perception.

Subject 3: Female, 4 years old, a diagnosis of cerebral dysplasia complex; major problems of visual perception.

All three subjects had level 5 (lowest capability level) on all of the following measures: the Communication Function Classification System (CFCS) [13], the Manual Ability Classification system (MACS) [9], and the Gross Motor Function Classification System (GMFCS) [23].

The therapist stated that it is common for children in this population to have discomfort due to varying health condition and that the discomfort was most likely not due to the use of StimuHat. Thus, it was difficult to complete all the planned sessions and a maximum of five and a minimum of three sessions of each condition (A and B) were conducted.

To characterize the subject's degree of *engagement*, we employed qualitative observations provided by the team member administering therapy, during and immediately after the multisensory engagement and recorded by the experimenter (another member of the team). Given the exploratory nature of the pilot study and that the subjects are non-verbal, we relied on the therapist's experience of working with this population for many years to identify whether the children were engaged and stimulated during the sessions. She observed the children's head and neck movements, as well as, non-verbal vocalizations and interpreted subtle signs of relaxation and positive stimulation.

To characterize the subject's *affective state*, we employed quantitative measures derived from biosignals. We first calculated the *heart rate variability* (HRV) from *electrocardiogram* (ECG) signals and, then, extracted 6 features from it: Low Frequency Band (LF) [0.04 – 0.15] Hz., High Frequency Band (HF) [0.15 -4] Hz., LF/HF, *root mean square of successive differences* (RMSSD) of successive RR segments, and the Entropy and Median of RR segments. These measures and their relationship to a subject's affective state are discussed in previous research [17, 19, 20, 26]. We chose ECG-based measures, as their collection is less intrusive than other types of biosignals. Our instrument was the g.MOBIlab+ bioamplifier (Guger Technologies, Schiedlberg, Austria). Please see the Auxiliary Material document for more details on our data analysis.

Subjects

Our target user group consisted of children with severe congenital brain damage and sensory impairment (specifically, low-vision) who were already undergoing therapy at the special education school.

Given the logistical challenges of working with our target group, we decided to have a small number of subjects in the current preliminary evaluation. We decided to include subjects who were strong therapy candidates: we choose subjects who had both brain damage and partial visual impairment and who had previously demonstrated some partial success with multisensory therapy. Three subjects were identified in consultation with school staff. Their conditions are described in the Subject Description sidebar.

The Ethics Committee of the hosting institutions reviewed and approved the study protocol. Prior to the study, informed consent was obtained from the families of the children.

Evaluation Results

The therapist observed that StimuHat was easy to use and freed her hands during therapy to do additional things (e.g., touch the subjects or adjust ambient lights or music). She also observed that having the lights around her head were helpful as it drew the subjects' attention to her face as she looked over them and talked to them in a soothing voice during the sessions. The glove was not limiting and she could use other tools or touch the subject during therapy.

We examined the qualitative data for indications of positive response to the therapy stimuli (light cards or StimuHat's lights) by the subjects via non-verbal vocalizations and movements. During the administered sessions, many signs of engagement in the children were observed. These signs included non-speech vocalizations and the turning of their heads and upper body towards the therapy stimuli. All three subjects responded to both StimuHat and reflective lights. Subject 1 responded more often to StimuHat rather than to the reflective cards.

We also examined the quantitative data gathered for the measures described above. The results showed that the High-frequency (HF) activity increased during the intervention phase in most of the sessions under both conditions. This corresponds with reduced stress and anxiety in the children, as indicated by previous research [16, 17]. The results also showed slightly greater values on LF/HF (indicative of relaxation) when StimuHat was used. The analysis also showed that all the subjects had increased HRV (indicating relaxation) in almost all sessions with reflective cards and in some sessions with StimuHat. Please see the Auxiliary Material document for the quantitative data set.

Discussion and Future Directions

The pilot study showed that the therapist found StimuHat a useful tool for use during sessions. The qualitative data showed that all three subjects demonstrated signs of engagement and relaxation, including non-speech vocalizations and the turning of heads towards lights.

Analysis of biosignal data also showed that using both StimuHat and the control appeared to be effective in relaxing and engaging subjects at different times during the sessions. There was a high degree of variability in the data from session to session, which makes it difficult to identify strong differences between StimuHat and the low-fi control.

This result is in accordance with the therapist's observation prior to the study that in this form of therapy, it is common for clients to respond to tools and stimuli differently at different times. Often the therapist should dynamically scan the repertoire of tools that he or she has at their disposal to choose ones that a client is responding to in a session. Given this context, the goal of the evaluation is not to determine if StimuHat is a better tool than existing low-fi ones and whether it should replace them, but whether it can be used as *one* tool, as an alternative or possibly in conjunction with other ones. Given this question, the evaluation showed that the system has potential to support controlled multisensory stimulation therapy. In the future, we will explore using StimuHat in combination with other tools (such as reflective cards or non-programmable LED strips) for this kind of therapy, and as part of a toolbox that can be tweaked based on client responses.

In future, we plan to conduct a longitudinal study with a larger number of subjects and with different therapists to further assess and evaluate the usefulness of StimuHat in this context. Additionally, we plan to use real-time information from the affective biosignals from the client to activate different light patterns in StimuHat. A study can investigate whether changing the intensity, color, movement speed and patterns of the lights in response to the client's affective state provide useful information to the therapist.

Finally, as in the current study we focused on multisensory stimulation therapy for children with brain damage, future research can investigate the use of StimuHat with other populations, such as children on the autism spectrum and older adults, especially as new evidence points to the potential of light therapy for conditions such as Alzheimer's disease [16].

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