# Chapter 9
# Multi-sensory Environmental Stimulation for Users with Multiple Disabilities

**Cristina Manresa-Yee, Ann Morrison, Joan Jordi Muntaner and Maria Francesca Roig-Maimó**

**Abstract** Multi-sensory environments can improve and maximize the well-being of individuals with multiple disabilities, that is, individuals who have more than one significant disability (one of which is a cognitive impairment). In this chapter we present a multi-sensory environmental stimulation system that combines different technologies such as computer vision and tactile cues in the form of vibrations. The system offers users control over the environmental stimulation by responding to their body movements. A vision-based interface detects the user's hand position and activates meaningful and motivational outcomes when the hand is positioned over specific regions. Further, we extended the system by including a wearable vibrotactile interface that encourages users to move their arms by using vibrations that exploit the saltation perceptual illusion known for inducing movement.

**Keywords** Multi-sensory environmental stimulation · Interactive environment · Multiple disabilities · Well-being · Vision-based interfaces · Vibrotactile interfaces · Saltation

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## 9.1 Introduction

People with multiple disabilities have severe or profound dysfunctions in different development areas (such as physical, sensorial…), and will always include some form of cognitive impairment. Consequently, these individuals have limited functionality, slow development processes and they need permanent support in all basic activities of daily living [1]. People with this profile often face a lack of control and opportunity in their everyday life [2] and they are likely to be severely impaired in their functioning in respect of a basic awareness and understanding of themselves, of the people around them and of the world they live in [3].

While it is recognised that technology can provide impaired users with opportunities to learn, share information, and gain independence [4, 5], users with multiple disabilities frequently find difficulties in using it due to their physical and/or cognitive impairments [6]. As a result, there is not a wide range of interactive applications for this group.

According to Vos et al. [7], people with multiple disabilities are "greatly at risk [of experiencing] low subjective well-being". Vos et al. [7] highlight the importance of finding ways to improve the subjective well-being of this group. Studies show that multi-sensory environments can improve and maximize the well-being of individuals with impairments [8, 9]. The goal of a mutli-sensory environment is to actively stimulate the individual's senses (vision, hearing, touch, smell and taste) with limited need of higher cognitive processing [10]. Further, early stimulation is also known to be a useful and necessary treatment aimed at developing as much as possible the social psychophysical potential of any person at high environmental and/or biological risk [11]. Multi-sensory stimulation for these individuals provides enjoyment, facilitates relaxation and may suppress self-stimulation [12]. As a result, in different therapies we find all kind of tasks related to multisensory stimulation (e.g., Snoelezen rooms, sensorial cards and bids, playing with different temperatures, tastes, smells, etc.).

With this in mind, we designed SINASense, a multi-sensory environmental stimulation system that combines different technologies such as computer vision and tactile cues-specifically vibrations. The system encourages users to execute particular body movements to trigger meaningful stimuli in their immediate environment and offers control of the situation to these users who experience a continual lack of a sense of ownership and/or control of their own interactions with environment in most of their daily activities.

In this chapter we describe the system's design and development, together with the evaluation carried out on children who presented with multiple disabilities. The chapter is structured as follows: after summarising the related work, we describe the system and its rationale. Then we present the results of an experiment that was conducted to evaluate the system, and discuss the findings and challenges of our experience.

## 9.2 Related Works

Work related to the SINASense project includes interactive systems for users with disabilities that offer control on the environmental stimulation and vibrotactile interfaces, specifically those that motivate users' actions.

### *9.2.1 Interactive Systems for Controlling Environmental Stimulation*

In reviewing the literature, we found different design approaches of interactive systems aiming to offer interactive experiences and control over environmental multi-sensory stimulation to users with multiple disabilities. There are works that use single or multiple switches to trigger diverse responses using vocalization-detecting devices [13, 14], mechanical switches [15] or hand-tapping responses together with a vibration-detecting device [16] for users who lack specific motor coordination and spatial accuracy. Other standard commercial products have been used such as a mice [17], air-mice [18], the Nintendo Wii Balance Board [19] or the Nintendo Wii remote Controller [20]. Finally, we focus our attention on interactive systems based on computer vision techniques: Lancioni et al. [21] used an optic sensor to detect the deliberate blinking of a user with minimal motor behaviour to trigger motivational outcomes and Mauri et al. [13] detected the user's movement in regions of interest marked by the facilitator of the sessions to activate the feedback.

All these works, albeit presenting positive results, were evaluated with a small group of users. Aside from [13, 15] who tested their systems with seven and eight users, the others studies evaluated the system with one or two users. Further, there is a high variability in the users' characteristics, which complicates the result comparisons.

### *9.2.2 Vibrotactile Interfaces for Users with Disabilities*

Vibrations are a form of cutaneous stimulation, as they produce a distortion on the cutaneous surface [22]. When vibration cues are included in interfaces, these can be used both as feedback–such as the vibration in a mobile phone– and as a supportive function to motivate users' actions [23–25].

Vibrotactile interfaces for disabled users have specially focused on solutions for users with vision impairments. In this case, the purpose is to improve users' interaction with the environment and with other people to enhance navigation abilities [26–28], interact with nearby objects [29], present graphical information non-visually [30], enrich interpersonal communication [31, 32], play with videogames [33, 34] or generate Braille on a mobile phone [35].

Users with hearing impairments can benefit from these interfaces too, as vibrotactile cues can translate sounds (music, speech or environmental noises) into physical vibrations [36, 37].

Although limited prior work exists that describes the use of vibrotactile cues as an interaction style for people with cognitive impairments, Grierson et al. [38] and Knudsen et al. [39] presented vibrotactile interfaces to help users with dementia or with mild cognitive impairments to navigate.

## 9.3 SINASense

SINASense is an interactive system addressing the needs of users with multiple disabilities that normally depend on others to interact with the environment, but when there is a meaningful stimulus in the environment, they can pay attention to this. We have experience designing accessible interfaces and collaborating with a centre for users with cerebral palsy [40–44], but this project was focused on those users with severe or profound impairments (physical, sensorial and cognitive impairments). The main aims of this system for therapists to work with the users were:

- Increase the intentional movements of their upper body limbs.
- Reduce their isolation.
- Control the interaction with the surrounding world.
- Achieve their active participation in the task.
- Suppress the self-stimulation by offering them external senses stimulation.

The system comprises different modules. First, a simple motion-based interface that uses computer vision to track a coloured band placed on the user's arm to detect its movement and position [45] by means of the Camshift probabilistic algorithm [46]. This module is combined with a set of action/reaction applications controlled by the user's body motion that will trigger meaningful and motivational outcomes–music, images, videos—from the system when the user maintains the arm in particular positions.

When evaluating this first module, we observed that the therapist conducting the session assisted users orally and sometimes physically (e.g., tapping their arm, helping them to carry out the movement) to help them to be aware of the reaction in the environment that their body motion was causing. Due to this observation and taking into account the importance of touch with these users, we extended the system with V-Sense to include vibrotactile cues aiming at avoiding the physical help and reduce the oral support.

V-Sense, is a wearable vibrotactile interface placed on the user's arm that encourages movement [47] by exploiting a perceptual illusion. Therefore, instead of

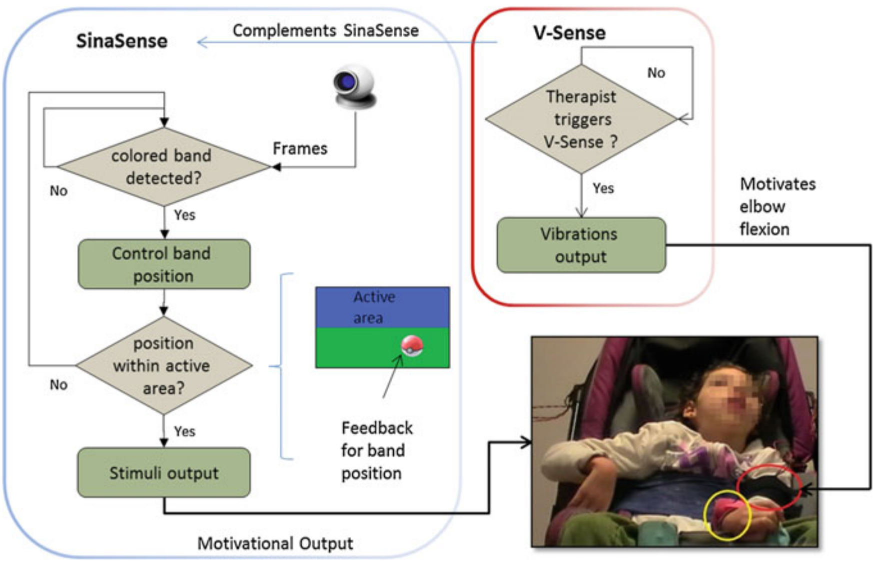


**Fig. 9.1** Overview of the system. *Yellow Circle* is the colored band for SinaSense. *Red circle* is V-Sense

helping the user to physically raise their arm, the therapist would trigger the vibrations. An overview of the system is depicted in Fig. 9.1.

## 9.4 Motion-Based Module and Multi-Sensory Stimulation Applications

The motion-based interface is based on detecting and tracking a coloured band placed on the user's wrist with a standard webcam. This system is "invisible" to the users, as they are not aware of the presence of a computer or any input devices.

The user is located in front of the camera, and the system responds to his or her actions by triggering motivational stimuli into the environment. These actions are arm movements as for example raising the arm or moving the arm horizontally. A standard webcam is used, as tests with a Microsoft Kinect™ to obtain depth information to work other arm movements–towards the screen–were ineffective due to the proximity of the background (wheelchairs or prams) to the user's body.

The multi-sensory stimulation application detects whether the coloured band attached to the user's body is within a particular region, giving multi-sensory feedback when it is. The application enables the therapist to divide the screen in different regions whose colour backgrounds can be selected to adapt it to the user's vision skills, and to select the outcomes to be triggered when the user places the hand in that region: images, videos or music (see Fig. 9.2). The regions that offer

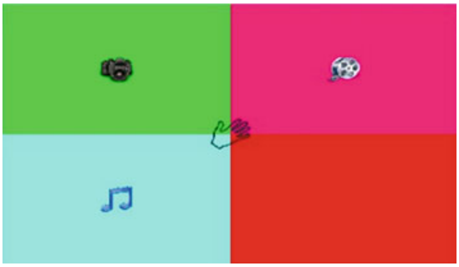

**Fig. 9.2** Four regions with different feedback: *green* region shows an image, *pink* region plays a video, *blue* region plays a song and the *red* region has no feedback. The hand icon maps the position of the coloured band on the screen

the feedback are configured depending on the work to be carried out with the user and the kind of intentional movement to motivate. Further, the image representing the position of the user's band on the screen can be configured and serves the therapist (and the user) as feedback to be aware of the position of the hand.

In order to trigger the outcomes, the user has to move their hand within an active region. When the hand is not placed in that area, the stimulus stops. It is very important for the system to be configurable to include the users' preferences, as it needs to provide entertainment, joy and recreation to increase the motivation and engagement of the user.

## 9.5 Vibrotactile Module

The vibrotactile module is based on the saltation 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 [48].

The saltation illusion has been used in vibrotactile interfaces for users with no disabilities to communicate motor instructions for snowboarding [23] or to incite users to perform fundamental movements, that is, flexion, extension, abduction, adduction and rotation [49]. In this last case, the vibrotactile patterns help the user to remember an already known set of movements. However, as far as we are aware, there are no studies that have used the saltation illusion to motivate movements in users with impairments [50].

In this stage of the project, due to the users' conditions, therapists wanted to specifically work two kinds of arm/forearm movement. On the one hand, elbow flexion for users with very little movement who found difficulties lifting totally their arms. On the other hand, shoulder flexion for people capable of lifting their arms completely (see Fig. 9.3).

In order to design both vibrotactile interfaces– for the elbow or shoulder flexion- we considered the next factors to achieve intuitive interfaces [51]:

- Pattern of vibration: the vibrotactile pattern should exploit the effects of saltation.

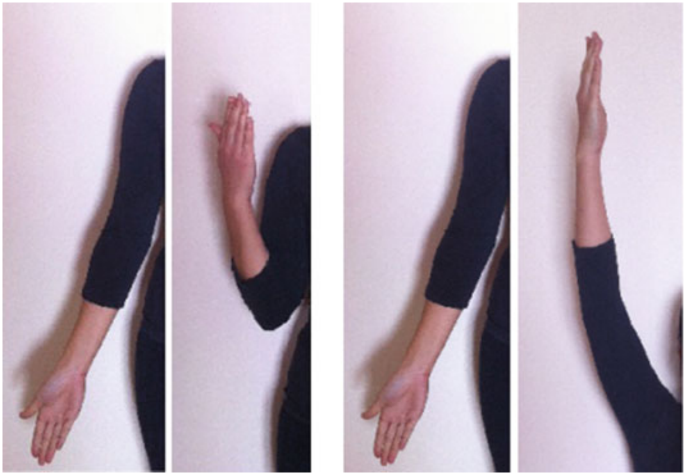

**Fig. 9.3** *Left* Elbow flexion. *Right* Shoulder flexion

- Direction of vibration: for example the push/pull or “follow me” metaphors [52].
- Location of vibration: vibrators should be placed on the skin close to the area where the movement is going to occur.

To implement the interfaces, we used an Arduino Mega microcontroller and three vibrators (Precision Microdrives 310–103 Pico Vibe™ 10 mm). A switch was provided to trigger the vibrations whenever the therapist felt it was required.

### 9.5.1 Elbow Flexion

The vibrators should be placed on or near the muscle/joint/body part involved in the movement. In this case, 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 [49], as it has been tested with successful results (with users with no disabilities). Therefore, three vibrators are set up in line on an armband and placed on the bicep muscle above the elbow joint, as shown in Fig. 9.4 (left).

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. [49] 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 previous works.

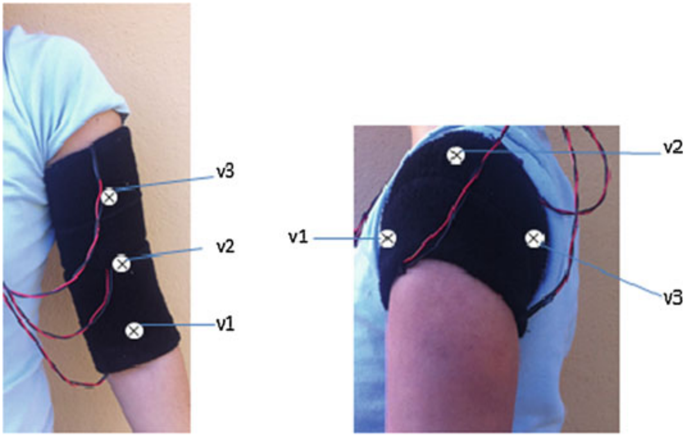


**Fig. 9.4** Localization of vibration actuators for elbow (*left*) and shoulder (*right*) flexion

### *9.5.2 Shoulder Flexion*

Three vibration actuators are set up on a shoulder pad embracing the shoulder as shown in Fig. 9.4 (right). 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.

## 9.6 Evaluation

The preliminary evaluation was conducted in a centre for users with cerebral palsy, and took place in two separate stages. In the first stage, the motion-based interface and the multi-sensory stimulation applications were tested. Then, a year later, the vibrotactile module was evaluated.

The system was evaluated with children with cerebral palsy. The children were selected by the therapists based on their conditions. Additionally, together with assistance from the users' parents, they collected motivational material to include in the system.

Two educational psychologists were hired specifically to conduct the sessions. At the beginning, the sessions were also supervised by the user's therapist to help the educational psychologists learn more efficiently about the user's preferences, skills, communication and behaviour.

## *9.6.1 Evaluation of SINASense*

SINASense was evaluated during three months with seven users (two girls, five boys), whose ages ranged from 4 to 12 years. Therapists selected the users based on their characteristics, the impact the system could have in their daily activities and their schedule in the centre. All users have a unique profile regarding cognitive, physical and sensorial skills (none had hearing impairments). The users have severe to profound intellectual disabilities accompanied by impairment of sensation, communication, perception, behaviour, and/or by a seizure disorder. However, they show interest (to a greater or lesser extent) when stimuli are produced in the environment. They all use wheelchairs or prams. Therapists are still assessing the learning and communication skills of each child and their levels of attention and their levels of understanding are different.

### 9.6.1.1 Procedure

The evaluation took place over the course of three months. Each session had a duration of 15 min and was carried out in a private room set aside in the centre. The room had a large TV connected to a computer and the user was sitting in front of the TV (and a webcam). A minimum of nine sessions per user and a maximum of 23 were performed over the course of the three months. Due to physical decay, one user completed only nine of the sessions therefore, he did not participate in the evaluation.

Sessions were video recorded for posterior analysis and notes of important events were taken during the sessions, such as “the intentional movements are clear”, “the user laughs” or “the user is very agitated”.

Depending on the user, the lights were dimmed to allow him or her to concentrate and focus on the stimuli provided by the system. Therapists selected the most functional arm/hand for each user to train with the aim of being able to produce some impact with the use of this arm/hand in their daily lives (see Hand/App column in Table 9.1). A pink band bracelet was placed on the user’s wrist in order for them to perform the movements.

In this case, the configuration of the screen was divided into two horizontal/vertical regions (see Fig. 9.5). The region that required more physical effort from the user was the one that gave the motivational feedback in form of audio (see Hand/App column in Table 9.1). This audio was configured to be pleasing and meaningful to the user.

### 9.6.1.2 Results and Discussion

At the beginning of the session, users were not really aware that their arm movement was the one causing the feedback. The educational psychologist had to work

**Table 9.1** Results. In Hand/App column: LH: left hand, RH: right hand, HAM: horizontal arm motion, VAM: vertical arm motion. Frequency and Duration columns: darker colours mean better results

| User | Hand / App | Frequency of intentional movement | Duration |
|---|---|---|---|
| 1 | RH, VAM | Very low increase | Very high increase |
| 2 | LH, VAM | High increase | Low increase |
| 3 | LH, VAM | Low increase | High increase |
| 4 | RH, HAM | High increase | High increase |
| 5 | RH, HAM | Low increase | Low increase |
| 6 | RH, VAM | Very low increase | Very high increase |
| 7 | RH, VAM | Very low increase | Very high increase |

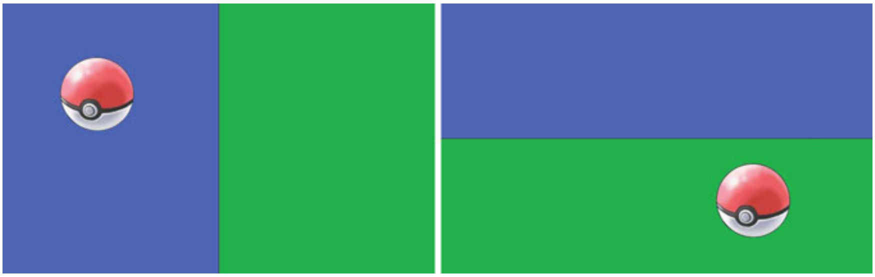

**Fig. 9.5** System's configuration for the evaluation. The ball is the feedback of the user's hand. *Left* the zone further to the functional hand is the active region. *Right* The *blue* zone is the active region

with them by encouraging them orally and in some occasions touching or tapping their arm or even helping them to raise or move it.

However, the continued work with the system helped users to build the relationship between their actions and the reactions. Users seemed to enjoy the stimuli (audio) as several of them smiled when listening to the music, made noise and one even started laughing and tapping the table when he heard his mother's voice.

After three months of work, the educational psychologist reported an increase in the intentional movement of all users and she highlighted the increase in the duration of maintaining the arm in a specific region (see Table 9.1). The results in Table 9.1 are qualitative and based on the observation of the educational psychologist. It is important to highlight that usually, since users increase the duration of maintaining the arm in a desired position, they have a low increase in the number of times they move it (users 1, 3 and 6).

From this evaluation we also obtained important insights that should be considered in the development of an interface based on vision to detect the movement of a user with multiple disabilities and the multi-sensory applications.

First, the positive feedback has to be very clear, motivational and especially promptly. The feedback has to help the user to be aware of the relationship between the action (of the body) and the reaction (in the environment), but also provide him or her with entertainment and recreation to increase the engagement with the stimuli [41].

The tracking of the coloured band has to be very robust to not confuse the user with feedback not triggered by his or her movement. In this particular study, difficulties appeared when the user's dressing had similar colours to the band, which we solved by using other clothing. The colour of the band to track could be configurable in the system to offer more flexibility.

Finally, the system has to be highly-configurable [53], setting it up has to be fast and profiles have to be able to be saved. In this way, therapists can focus on the user and not on the system. Settings have to include background colour to adapt to the user's vision skills, number of regions and the selection of the image that will offer the feedback of the hand's position. This feedback will help the therapist to monitor the user's hand, but also to place correctly both the webcam and user depending on the arm movement range, the user's height and the proximity of the user to the TV, sometimes limited by the kind of wheelchair or pram the user has. Outcomes must also be configurable, to adapt the system to the user: e.g. users with hearing impairments will be more attracted to visual material and users with vision difficulties will pay attention to audio material.

In the future, other feedback could also be included by switching on/off any device (e.g. a vibrator mat, lights, a radio, an electric mirror ball) which works in binary mode and can be connected to a radiofrequency (RF) remote plug or to the USB connector.

### *9.6.2 Evaluation of V-Sense*

The initial tests with V-Sense were to evaluate the interface to motivate the elbow flexion. In this case study, as we were working with children, their limbs are short and with two vibrators it was enough to cover the region from the elbow to the shoulder considering the distance needed to exploit the saltation illusion.

We worked with five children whose ages ranged from six to 14 (two girls, three boys). Four of the five users had participated in the SINASense evaluation. The selection of the users was due to their characteristics, the impact the system could have in their daily activities and their schedule in the centre. Once again, the users had unique and similar limitations as the ones mentioned in SINASense's evaluation. Regarding communication, two of them have gestures for YES and NO, one is learning them and for the other two there is still no way for them to answer simple questions. With respect to participant levels of attention and levels of understanding: three of them seem to understand the instructions on how the system works and for the other two it is difficult to assess.

#### 9.6.2.1 Procedure

We conducted sessions during two periods: three weeks before summer holidays and four weeks after. The sessions had a duration of ten minutes and were carried out in the same private room as when testing SINASense. Users did between 6 and 7 sessions (one session per week).

Once again, therapists selected the most functional arm/hand for each user. The left arm was selected for all users, but with several children, therapists are still not sure which arm is more suitable. When testing SINASense, it may have been the case that they were using the right arm, and in this test they were testing the left one.

Before placing the vibrotactile interface or the coloured band, the educational psychologist instructed the user the movement to perform to trigger the outcomes and help him or her to perform it several times. Then, the coloured band and the V-Sense prototype were attached to the arm. Finally, V-Sense was activated several times to show the user the vibrations and what action was expected from them.

During the first three weeks there were no restrictions when triggering the vibrations or helping physically the user. Then, initially it was decided that during the first two minutes, the therapist could physically help the user and trigger the vibrations. But for the remaining eight minutes, the physical support would be replaced totally by the vibrations (and maximum two vibrations per minute for users not to get used to them).

Once again, sessions were video recorded and notes of important events were taken during the session, related to the interface and the system in general. Events were usually related to the behaviour or state of the user: e.g. "the user falls asleep", "the user does not respond with a physical arm movement, but smiles", "the user is tired/agitated" or "the user does not change the facial expression when V-Sense is triggered".

#### 9.6.2.2 Results and Discussion

We achieved mixed results from the users. First of all, it is important to note that all sessions varied greatly depending on the user's behavioural state on that particular day. Until this point the educational psychologist has always had to motivate and encourage the user orally.

User 1 did not express with any sign whether he enjoyed the music. He usually raised his arm when the educational psychologist encouraged him, although, when vibrations were triggered he did not respond immediately raising his arm, but a few seconds later he raised it (not always). Therefore, it is difficult to confirm the connection between both events. His facial expression did not change much when vibrations were activated. And frequently he felt asleep in the evaluation sessions (this also happened in the classroom when working on any other activity).

We believed that user 2 did not have sensibility on the working arm, as his facial expression did not change at all when vibrations were triggered. However, the tutor suggested that maybe he was too used to vibrations as they already work with vibrations in the classroom (e.g. vibrating mats, vibrating objects). He raised his arm due to the therapist oral encouragement and enjoyed the audio-visual stimuli.

There were sessions with User 3 where he actively participated by raising his arm when the therapist motivated him orally. However, in other sessions he appeared to be in no mood to cooperate generally or to respond to the stimuli. However, he did not respond to the vibration in any way, not by raising his arm, nor by changing his facial expression.

User 4 understood the instructions (and she communicated with us when we asked her simple questions) but her response to the vibrations was variable. Some days she seemed not to acknowledge them, but most of the times she smiled when she felt them and few times she raised her arm directly after triggering the vibrotactile interface. User 4 has more strength in the right arm, but the therapist wanted to strengthen the musculature of the left arm for it to be more functional. On the fifth session, she seemed to want to help herself to raise the left arm with the right arm, so we may assess again which arm to work with. She really enjoyed the stimuli offered by the system.

Finally, user 5 was very participative and engaged with the activity and the stimuli offered when she raised her arm. She laughed, made sounds and seemed to sing along to the songs. The motivational outcomes were enough to engage the user, so although she responded to the vibration, especially at the first activations, we did not trigger the vibrations frequently due to her active participation.

An excerpt of a video captured in one of the sessions using the vibrotactile interface can be seen in Fig. 9.6.

This preliminary study showed that haptic feedback to encourage limb movement can be suitable for some users with multiple disabilities. However, several issues have to be taken into account.

First, the selection of the arm can sometimes be unclear. In some cases, the user will prefer to work with an arm because he or she has less difficulties moving it, but therapists may decide to work with the other one due to health decisions (e.g. stereotypies) or user's skills assessment (especially with the young users).

It is very difficult to assess the use of vibrations with those users who do not express in any manner noticing the vibrations. The arm selected can lack of sensitivity or users may be too used to work with other vibrating devices.

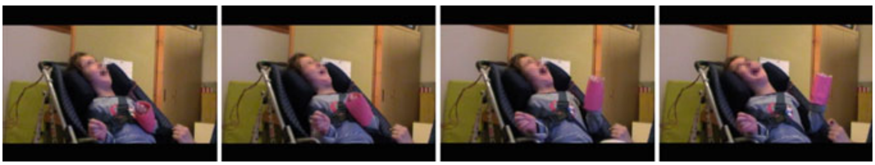

**Fig. 9.6** User working with the system: from *left* to *right*: Initial arm position. The user raises her arm due to the vibrations. Final arm position which triggers motivational outcomes

To use effectively the saltation illusion, users need to understand the instructions. With several users participating in this study, we think it would not make a difference to use the saltation illusion or to just activate all vibrators at the same time as their understanding is limited. But in the case where the user understands the vibrating signal, more sophisticated patterns can be developed to motivate different movements.

## 9.7 Conclusions

In this chapter we described a multi-sensory environmental stimulation system which provides control and enjoyment to users with multiple disabilities. We used a vision based interface to develop a system, which detects the user's body motion and uses it to activate meaningful stimuli in the environment when the body part is in particular positions. The material used in the system has to be motivational to engage users in the activity, increase their active participation and their intentional movements to reduce their isolation, promote their well-being (e.g. relaxation, pleasure) and suppress the stereotypies or self-injuries.

Due to the participants' conditions, we worked with arm movements. In the first evaluation sessions, we observed that the therapist conducting them had to be continuously supporting the user orally and sometimes even physically (e.g. tapping their arm, helping them to carry out the movement). Therefore, we decided to extend the system and include a vibrotactile interface that exploits the saltation perceptual illusion to motivate users to perform the arm movements on their own.

The evaluation with users with multiple disabilities varies in difficulty levels as each case presents unique intellectual, behavioural, physical and sensory conditions. The lack of communication skills hinders our interaction with them. Additionally, the user's state on a particular day results in unique sessions.

In these kinds of evaluations, we face diverse challenges including: therapists usually need to support the activity continuously, the users' learning and progress is very slow, we are not sure that all users understand the instructions, users may have difficulties when performing certain movements (inappropriate muscular strength, bad body posture) and they present involuntary movements which can disturb the main activity.

The preliminary results with SINASense showed that our proposal promotes the users' active participation and engagement with what is happening around them and increases their respond –increasing the number of times users perform the desired movement or by maintaining the arm position. Mixed results were achieved with the vibrotactile interface. Several users understood the actions expected when vibrations were triggered and they responded with an arm movement or acknowledging them by a change in their facial expression. With other users, it is complicated to understand what they feel when vibrations are triggered, as they do not express any sign of noticing them.

However, we are encouraged with the results to continue working in this research line. SINASense is intuitive and easy-to-use, but we realised that for using the vibrotactile interface users should understand the instructions. In this evaluation, we tested one set of connected vibrators, but in the future, other vibrators could be placed on the user to motivate different body movements such as flexions, extensions or even rotations. Testing different vibration intensities and frequencies could be also interesting to observe if these characteristics could influence the perception and the response of the users. Further, another future work line will be to try the interface with users who present a mild cognitive impairment to analyze their interaction.

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## References

1. Soro-Camats E, Rosell C, Basil C (2012) El alumnado con pluridiscapacidad: características, evaluación y necesidades educativas. In: Soro-Camats E, Basil C, Rosell C (eds) Pluridiscapacidad y context. Universitat de Barcelona, Interv, pp 5–32
2. Brown D, Standen P, Evett L et al (2010) Designing Serious Games for People with Dual Diagnosis: Learning Disabilities and Sensory Impairments. In: Zemliansky P, Wilcox DM (eds) Des. Implement Educ Games Theor Pract, Perspect, pp 1–16
3. Services SES (2010) Section 6: General Learning Disabilities. Signposts, A Resour. pack Teach
4. Seegers M (2001) Special Technological Possibilities for Students with Special Needs
5. Manresa-Yee C, Muntaner J, Sanz C (2012) Educational e-inclusion for students with severe motor difficulties. J Access Des All 2:165–177
6. Hersh M (2014) Evaluation framework for ICT-based learning technologies for disabled people. Comput Educ 78:30–47. doi:10.1016/j.compedu.2014.05.001
7. Vos P, De Cock P, Petry K et al (2010) What makes them feel like they do? Investigating the subjective well-being in people with severe and profound disabilities. Res Dev Disabil 31:1623–1632. doi:10.1016/j.ridd.2010.04.021
8. Cox H, Burns I, Savage S (2004) Multisensory environments for leisure: promoting well-being in nursing home residents with dementia. J Gerontol Nurs 30:37–45
9. Pagliano P (2012) The multisensory handbook: a guide for children and adults with sensory learning disabilities. Routledge
10. Jakob A, Collier L (2013) Multisensory environments (MSEs) in dementia care: the role of design—an interdisciplinary research collaboration between design and health care. In: Proceedings of the 2nd European conference on design 4 heal. Sheffield UK, p 135
11. García-Navarro M, Tacoronte M, Sarduy I et al (2000) Influence of early stimulation in cerebral palsy. Rev Neurol 31:716–719

12. Singh NNN, Lancioni GEG, Winton AASW et al (2004) Effects of Snoezelen room, Activities of Daily Living skills training, and Vocational skills training on aggression and self-injury by adults with mental retardation and mental illness. Res Dev Disabil 25:285–293. doi:10.1016/j.ridd.2003.08.003
13. Mauri C, Solanas A, Granollers T (2012) Nonformal interactive therapeutic multisensory environment for people with cerebral palsy. Int J Hum Comput Interact 28:202–2012
14. Lancioni GE, O'Reilly MF, Oliva D, Coppa MM (2001) A microswitch for vocalization responses to foster environmental control in children with multiple disabilities. J Intellect Disabil Res 45:271–275. doi:10.1046/j.1365-2788.2001.00323.x
15. Saunders M, Questad K, Kedziorski T et al (2001) Unprompted mechanical switch use in individuals with severe multiple disabilities: an evaluation of the effects of body position. J Dev Phys Disabil 13:27–39. doi:10.1023/A:1026505332347
16. Lancioni GE, Singh NN, O'Reilly MF, Oliva D (2002) Using a hand-tap response with a vibration microswitch with students with multiple disabilities. Behav Cogn Psychother 30:237–241
17. Shih C, Shih C, Lin K, Chiang M (2009) Assisting people with multiple disabilities and minimal motor behavior to control environmental stimulation through a mouse wheel. Res Dev Disabil 30:1413–1419. doi:10.1016/j.ridd.2009.07.001
18. Shih C, Chang M, Shih C (2010) A new limb movement detector enabling people with multiple disabilities to control environmental stimulation through limb swing with a gyration air mouse. Res Dev Disabil 31:875–880
19. Shih C-H, Shih C-T, Chu C-L (2010) Assisting people with multiple disabilities actively correct abnormal standing posture with a Nintendo Wii balance board through controlling environmental stimulation. Res Dev Disabil 31:936–942. doi:10.1016/j.ridd.2010.03.004
20. Shih C, Chang M, Shih C (2010) A limb action detector enabling people with multiple disabilities to control environmental stimulation through limb action with a Nintendo Wii Remote Controller. Res Dev Disabil 31:1047–1053
21. Lancioni G, O'Reilly M, Singh N et al (2005) A new microswitch to enable a boy with minimal motor behavior to control environmental stimulation with eye blinks. Behav Interv 20:147–153
22. Dahiya RS, Valle M (2013) Robotic tactile sensing technologies and system
23. Spelmezan D, Jacobs M, Hilgers A, Borchers J (2009) Tactile motion instructions for physical activities. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM, New York, NY, USA, pp 2243–2252
24. Morrison A, Manresa-Yee C, Knoche H (2015) Vibrotactile vest and the humming wall: I like the hand down my spine. In: Proceedings of the interacción 2015, Artic. 3. ACM, New York, NY, USA, Vilanova i la Geltrú, Spain, pp 3:1–3:8
25. Morrison A, Knoche H, Manresa-Yee C (2015) Designing a vibrotactile language for a wearable vest. In: HCII2015, design user experience usability users interact. (LNCS 9187), pp 655–666
26. Ghiani G, Leporini B, Paternò F (2008) Vibrotactile feedback as an orientation aid for blind users of mobile guides. In: Proceedings of 10th International Conference on Human-Computer Interaction with Mobile Devices and Services. ACM, New York, NY, USA, pp 431–434
27. Uchiyama H, Covington MA, Potter WD (2008) Vibrotactile Glove Guidance for Semi-autonomous Wheelchair Operations. In: Proceedings of 46th Annual Southeast Regional Conference *on* XX. ACM, New York, NY, USA, pp 336–339
28. Flores G, Kurniawan S, Manduchi R, Martinson E (2015) Vibrotactile guidance for wayfinding of blind walkers. IEEE Trans Haptics 8:306–316
29. Bahram S, Chakraborty A, Ravindran S, St. Amant R (2013) Intelligent interaction in accessible applications. In: Biswas P, Duarte C, Langdon P, et al (eds) A multimodal End-2-End approach to accessible Computing SE-5. Springer, London, pp 93–117
30. Giudice NA, Palani HP, Brenner E, Kramer KM (2012) Learning non-visual graphical information using a touch-based vibro-audio interface. In: Proceedings of the 14th

international ACM SIGACCESS conference on computers and accessibility. ACM, New York, NY, USA, pp 103–110

31. Krishna S, Bala S, McDaniel T, et al (2010) VibroGlove: an assistive technology aid for conveying facial expressions. In: CHI'10 extended abstracts on human factors in computing systems. ACM, New York, NY, USA, pp 3637–3642
32. Réhman S, Liu L, Li H (2008) Vibrotactile rendering of human emotions on the manifold of facial expressions. J Multimed 3:18–25
33. Yuan B, Folmer E (2008) Blind Hero: Enabling Guitar Hero for the Visually Impaired. In: Proceedings of the 10th international ACM SIGACCESS conference on computers and accessibility. ACM, New York, NY, USA, pp 169–176
34. Morelli T, Foley J, Folmer E (2010) Vi-bowling: A tactile spatial exergame for individuals with visual impairments. In: Proceedings of the 12th international ACM SIGACCESS conference on computers and accessibility. ACM, New York, NY, USA, pp 179–186
35. Jayant C, Acuario C, Johnson W, et al (2010) V-braille: haptic braille perception using a touch-screen and vibration on mobile phones. In: Proceedings of the 12th international ACM SIGACCESS conference on computers and accessibility ACM, New York, NY, USA, pp 295–296
36. Nanayakkara S, Taylor E, Wyse L, Ong SH (2009) An enhanced musical experience for the deaf: design and evaluation of a music display and a haptic chair. In: Proceedings of the SIGCHI conference on human factors in computing systems. ACM, New York, NY, USA, pp 337–346
37. Yao L, Shi Y, Chi H, et al (2010) Music-touch shoes: vibrotactile interface for hearing impaired dancers. In: Proceedings of the fourth international conference dedicated to research in tangible, embedded, and embodied interaction. ACM, New York, NY, USA, pp 275–276
38. Grierson LEM, Zelek J, Lam I et al (2011) Application of a tactile way-finding device to facilitate navigation in persons with dementia. Assist Technol 23:108–115. doi:10.1080/10400435.2011.567375
39. Knudsen L, Morrison A, Andersen H (2011) Design of vibrotactile navigation displays for elderly with memory disorders
40. Manresa-Yee C, Ponsa P, Varona J, Perales FJ (2010) User experience to improve the usability of a vision-based interface. Interact Comput 22:594–605. doi:10.1016/j.intcom.2010.06.004
41. Manresa-Yee C, Ponsa P, Salinas I et al (2014) Observing the use of an input device for rehabilitation purposes. Behav Inf Technol 33:271–282
42. Manresa-Yee C, Varona J, Perales F, Salinas I (2014) Design recommendations for camera-based head-controlled interfaces that replace the mouse for motion-impaired users. Univers Access Inf Soc 13:471–482. doi:10.1007/s10209-013-0326-z
43. Manresa-Yee C, Mas R (2014) Designing an accessible low-cost interactive multi-touch surface. Univers Access Inf Soc 1–11. doi:10.1007/s10209-014-0396-6
44. Varona J, Manresa-Yee C, Perales FJ (2008) Hands-free vision-based interface for computer accessibility. J Netw Comput Appl 31:357–374. doi:10.1016/j.jnca.2008.03.003
45. Manresa Yee C, Muntaner JJ, Arellano D (2013) A motion-based interface to control environmental stimulation for children with severe to profound disabilities. In: CHI'13 extended abstracts on human factors in computing systems. ACM, New York, NY, USA, NY, USA, pp 7–12
46. Bradski GR (1998) Computer vision face tracking for use in a perceptual user interface. Intel Technol. J. Q2
47. Manresa-Yee C, Morrison A, Larsen J, Varona J (2014) A vibrotactile interface to motivate movement for children with severe to profound disabilities. In: Proceedings of the XV international conference on human computer interactions ACM, New York, NY, USA, NY, USA, pp 10:1–10:4
48. Geldard F, Sherrick C (1972) The cutaneous "rabbit": a perceptual illusion. Science 178 (80):178–179

49. McDaniel T, Villanueva D, Krishna S, Panchanathan S (2010) MOVeMENT: A framework for systematically mapping vibrotactile stimulations to fundamental body movements. In: 2010 IEEE International symposium on haptic audio-v. environment games (HAVE), pp 1–6
50. Manresa-Yee C, Morrison A, Muntaner JJ (2015) First insights with a vibrotactile interface for children with multiple disabilities. In: CHI'15 extended abstracts on human factors in computing systems ACM, New York, NY, USA, pp 905–910
51. McDaniel T, Villanueva D, Krishna S, Panchanathan S (2010) MOVeMENT: a framework for systematically mapping vibrotactile stimulations to fundamental body movements. In: Proceedings of the HAVE 2010. IEEE, pp 1–6
52. Spelmezan D, Hilgers A, Borchers J (2009) A language of tactile motion instructions. In: Proceedings of the 11th international conference on human-computer interaction with mobile devices and services. ACM, New York, NY, USA, pp 29:1–29:5
53. Davis AB, Moore MM, Storey VC (2002) Context-aware communication for severely disabled users. SIGCAPH Comput Phys Handicap 106–111. doi:10.1145/960201.957224