ABBI, a new technology for sensory-motor rehabilitation of visual impaired people

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ABSTRACT

ABBI, the audio bracelet for blind interaction, aims to rehabilitate spatial cognition, mobility and social interaction in children and adults with visual deficits through natural audio-motor and tactile-motor interactions. ABBI is a new tool that provides spatial information on where and how the body is moving, providing significant information regarding spatial orientation, postural control, and motor coordination. Furthermore, ABBI is easy to use, and it can be applied in the first years of life.

INTRODUCTION

Blindness affects over 161 million people around the world. About 37 million of them are completely blind, and 1.4 million are children below the age of 15 years [1].

Early onset of blindness adversely affects psychomotor, social and emotional development. In fact, the delay in the acquisition of language, motor or cognitive skills can have a direct impact on a child's social competence [2, 3]. For example babies and toddlers with visual disabilities often have difficulties engaging in social interactions and many of these children do not also display a full range of play behaviors [2, 4]. This creates societal challenge, as assimilation into preschool programs can be difficult.

The absence of visual information is the main cause of these difficulties but it has been recently demonstrated that blindness significantly affects spatial cognition: the localization of sounds in space as well as the perceived posture of one's own body with respect to the world [5, 6]. Multiple studies suggest that the development of spatial representations plays a role not only in sensory-motor control of action but also in the development of mobility and social interaction skills [7-9]. The reason is that vision plays an essential role in building up spatial representations during the early years of sensorimotor development.

Consequently, the core idea of the Audio Bracelet for Blind Interaction (ABBI) system at the center of this project is to improve spatial cognition abilities of visually-impaired individuals through the use of another sensory modality, such as hearing. This technology will rehabilitate brain processes and functions involved in spatial cognition of children and adults with visual disabilities through natural audio-motor associations.

This approach is innovative, because unlike most existing sensory-substitution devices introduced in late childhood or adulthood, it does not require learning new "languages", and can be applied in the first years of life.

ABBI: A NEW REHABILITATIVE SOLUTION

The core idea of the Audio Bracelet for Blind Interaction (ABBI) system, shown in Figure 1, is to improve the spatial cognition abilities of visually-impaired individuals through the use of other sensory modalities (e.g. hearing and touch). In particular, the auditory modality could play the role that visual signals normally have in the development of sensorimotor skills, spatial cognition, navigation and social interaction skills.

ABBI is based on the idea of using the auditory modality to convey spatial information about the movement of the person's own body within the personal, peripersonal and extra-personal space. It provides sources of sounds positioned on the main effectors/limbs (such as the wrists and feet) of children and adults with visual deficits. The movement of the visually-impaired person is therefore associated with an auditory feedback that provides spatial information related to the position of the body in space (similar to sensory feedback that is provided by the visual modality for the sighted person).

The sound from ABBI allows the visually-impaired child or adult to build a representation of his/her movement in space and, ultimately, a representation of space by associating these movements with sensory feedback that conveys spatial information in an intuitive and straightforward manner. In addition, sound sources placed on other people provide a better sense of the events taking place in the environment and to improve social skills of these children and adults.

Figure 1. Image representing the use of the ABBI bracelet in babies. The baby is able to locate his moving arm via the ABBI bracelet positioned on the wrist. Furthermore, ABBI can be used also in social context through multiple bracelets interacting with each other.

In particular, from a rehabilitation point of view, the ABBI system can be used in diverse contexts (e.g., home, street, park) besides rehabilitation centres and in order to provide extended periods of training and rehabilitation also in everyday environments. In addition, the characteristics of the ABBI system make it also possible to envision other applications beyond the particular rehabilitative context.

Progress beyond the state-of-the-art

The technology and the approach proposed in ABBI is innovative for multiple reasons:

- it takes advantage of the plasticity of our nervous system by allowing audio feedback replace visual feedback
- it does not require the learning of new "languages", as most of the present sensory substitution devices (SSD) do;
- it allows children to rehabilitate spatial cognition in a natural way, since it can be used form the first years of life, as opposed to other sensory substitution devices that are introduced in late childhood or adulthood;
- it doesn't require the use of additional attentive sources which increase the cognitive load, as the interpretation of new languages required in other SSDs do;
- it uses the natural links between movement and perception which, as observed with the use of sensory substitution devices, are thought to be essential for learning;
- it can easily be integrated to the lives of blind children and their families at home;
- it is planned to be a low cost and affordable device;
- in opposition to other SSDs, that are purely assistive, the ABBI system rehabilitates spatial cognition and its underlying cognitive processes. After the rehabilitation period, both children and adults will have an improved sense of space and be superiorly able to process the available information such as sounds in the environment;
- visual impaired children will develop something similar to echolocation, avoiding the creation of a stigma connected with the use of the device.

The non-invasive and natural form of the ABBI approach allows the improvement of spatial and social skills in a sustainable way in visually-impaired persons from the first years of life. In addition, the characteristics of the ABBI system make it also possible to envision other applications beyond the particular rehabilitative context that is at the core of this project.

Development of Audio Feedback

The primary aim for the audio feedback design is to convey the location and movement of the limbs in real-time and best substitute visual information with auditory signals. This information includes: location, acceleration, orientation and distance. ABBI will be capable of producing dynamic abstract sounds that vary in along a number of dimensions, including pitch, waveform/timbre, volume and rhythm. It will also be able to play pre-defined sound files for richer sounds, such as animal sounds.

As ABBI emits sound, it is naturally spatialised in 3D, so the location (or at least the azimuth) can be automatically perceived. Therefore, no explicit feedback cue is needed for location. The audio feedback designs for the other information will be tailored to the age of the child, in order to not overwhelm or confuse. Auditory perception and scene analysis research will be used to design cues that are clear and inherently identifiable, even when in noisy home/play environments.

As well as conveying to the child the location and movement of their own limbs, the project will investigate the use of environmental sounds from inanimate objects (e.g., toys) and other people (parents and friends) to make the child aware of, and encourage its engagement with, activity in the peripersonal and extrapersonal space. Parents will also be given ABBI devices that make sound to encourage the child to mimic play (e.g., waving, clapping) or reaching behaviours.

User-centered design

Since the ABBI system is to be used for training and development of spatial cognition, it is important that we use pleasant sounds and materials in our designs so that the users of ABBI enjoy it. It is important that users do not get fed up or so annoyed that they don't want to keep training with ABBI.

Workshops with 19 children with total or partial visual deficits have been performed to explore what kind of sounds and materials are pleasant and also which sounds of materials are unpleasant for them.

In the workshop, 30 different natural (recorded) sounds and 40 synthetized (generated) sounds were played back to the children. The children had to state if they liked, disliked or were neutral to the sound by raising hands. Sounds were classified in groups according to the type of sound, the pitch, timber and duration. Moreover, children were given a set of 6 different objects with different tactile qualities (soft, rough, rubbery, hard, smooth, furry, etc..). The children had to select an object of their like and associate a sound (from the presented sounds or vocalized by the children) and an action that triggers or stops the sound (stroke, wave, squeeze) to the material.
Both children with total or partial vision deficit found really unpleasant (> 34%) sounds with a clear timbre while they found pleasant (> 51%) sounds with fuzzy timbre. The soft rubbery toys were more popular in the group with partial visual deficit, while the fur and the hard materials were mostly preferred in the total visual deficit group.

Results from these workshops will help to design an ABBI system that is pleasant and fun to use, based on the preferences of the potential users of the system.

Development of the SMART station system

ABBI bracelet is associated with a "smart station", such a mobile phone, tablet or computer. The ABBI smart station will be placed on (or accessible to) the person wearing ABBI, i.e. a parent, or another person in the proximity, so that it can communicate with the ABBI to give it more "intelligence" and functionality. A localization function which might permit, for example, the calculation of the distance between two persons wearing ABBI bracelets and/or where the person wearing the ABBI bracelet is inside the room or the house will be developed. It will be able to read the behaviour of the child and report such things as rolling over, sitting up and overall activity levels. This will help the parent understand whether the child is in difficulty or how well they are progressing in the development of various behaviours.
The following is an example of how this smart functionality of the ABBI system will be important.
If a visually impaired child goes to a party he could bring a series of ABBI bracelets and distribute them to his friends. Afterwards he/she could just turn on his ABBI bracelet by the smart station. As soon as the bracelet would start to produce the sound, he could reach his friend.

Figure 2. ABBI wireless smart station. The bracelet is communicating with a smart station (i.e. smartphone or computer) that allows changing parameters as the preferred sound and the volume. The station also stores data regarding the movement of the subjects.

A similar approach could be used for sport activities as football. Each player could wear an ABBI bracelet and interplay with the others during a game.

ABBI and motor learning

ABBI in sport activities may provide not only information about team players, but enhance the perception of own body-movements. The audio feedback in real-time will facilitate dynamic movement coordination and motor learning as well as detection of irregularities in movement. It may help blind or visually impaired individuals to compensate for deficits in locomotion and posture.
A high physical activity level of blind individuals was found to be linked to higher performance in spatial navigation tasks [10]. It will therefore be tested if ABBI, implemented in a movement intervention, improves orienting of the body in space and enhances spatial performance.

PRELIMINARY RESULTS WITH ABBI

ABBI short training effects on a hand pointing task

Preliminary results in adults show that a short training session with ABBI greatly improves the pointing accuracy in a hand pointing task in visual impaired subjects.

Methods

Three early blind subjects (age range 20-26 years, three females), three late blind subjects (age range 27-63 years, one female), and five healthy blindfolded controls (age range 27-36 years, four females) participated in the study. The subjects had no hearing problems and provided written informed consent prior to inclusion in the study.

The experiment consisted of 2 identical sessions spaced out by 2 minutes of training.

Subjects had to listen to the pointing movement of an ABBI held by the experimenter from the center of the plane toward one of eight possible equally-spaced positions presented in a virtual circle, and to point toward the end point of the audio motion at his own pace (see Figure 3).

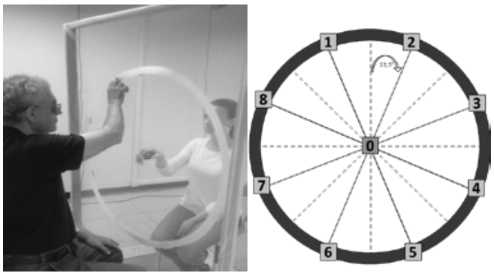


Figure 3. The experimental set-up. On the left, a visual impaired subject performing the task. On the right, the 8 points around the circumference are indicated. The diameter is 90 cm and the angle between two points is 45 degrees.

A marker was mounted on the index finger of both the subject and experimenter, in order to track the trajectory movement with a motion caption system (Vicon, USA). All the eight position were reached five times, for a total of 40 trials per subject.

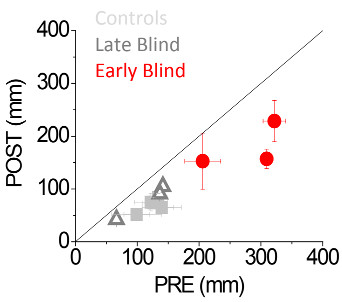
During the training session, the subject had to hold the ABBI in the hand and continuously move it in the peripersonal space in a free manner for two minutes.

The spatial accuracy indicated by the average localization error was evaluated before and after the training.

Results and Discussion

In the first session, early blind performed far worse in comparison to late blind or blindfolded controls, presenting on average an error two times bigger (Figure 4). After the two minutes short training, the performance of all the three groups increased. Early blind performed 69% better, late blind 65%, and healthy blindfolded controls 58 %, respectively (T-test, P<0.05).

These results show that even a short training with ABBI may enhance the spatial knowledge in blind people.



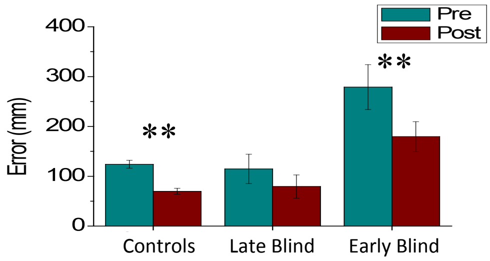


Figure 4. Localization error (mm) pre and post training.

CONCLUSIONS

ABBI, the Audio Bracelet for Blind Interactions provides spatial information on where and how the body movement is occurring. This supports postural control, motor coordination and spatial orientation of visually impaired persons. Importantly, the approach proposed in ABBI does not require any learning of new "languages" and it can be applied in the first years of life. Both technological rehabilitative solutions will bring further distinction, with both scientific and technological advancements.
The full-fledged ABBI system will transform the ABBI bracelet into an intelligent system that will deliver the stimuli in a context-dependent manner to maximize its rehabilitative potential. For example the development of activity logging and indoor localization feature in ABBI will make it possible to envision other uses than its original rehabilitative function.

REFERENCES

[1] S. Resnikoff, D. Pascolini, D. Etya'ale, I. Kocur, R. Pararajasegaram, G. P. Pokharel, *et al.*, "Global data on visual impairment in the year 2002," *Bulletin of the World Health Organization,* vol. 82, pp. 844-851, 2004.

[2] M. J. Guralnick, *Assessment of peer relations*: Center on Human Development and Disability, University of Washington, 1992.

[3] M. Rettig, "The play of young children with visual impairments: Characteristics and interventions," *Journal of Visual Impairment & Blindness,* 1994.

[4] S. Sacks, L. Kekelis, and R. Gaylord-Ross, *The development of social skills by blind and visually impaired students: Exploratory studies and strategies*: American Foundation for the Blind, 1992.

[5] M. Gori, G. Sandini, C. Martinoli, and D. Burr, "Poor haptic orientation discrimination in nonsighted children may reflect disruption of cross-sensory calibration," *Current Biology,* vol. 20, pp. 223-225, 2010.

[6] M. Gori, G. Sandini, C. Martinoli, and D. C. Burr, "Impairment of auditory spatial

localization in congenitally blind human subjects," *Brain,* p. awt311, 2013.
[7] G. Conti-Ramsden and M. Pérez-Pereira, "The use of directives in verbal interactions between blind children and their mothers," *Journal of Visual Impairment & Blindness (JVIB),* vol. 95, 2001.
[8] A. C. Skellenger and E. W. Hill, "Effects of a shared teacher-child play intervention on the play skills of three young children who are blind," *Journal of Visual Impairment and Blindness,* vol. 88, pp. 433-433, 1994.
[9] H. Troster, W. Hecker, and M. Brambring, "Longitudinal study of gross‐motor development in blind infants and preschoolers 1," *Early Child Development and Care,* vol. 104, pp. 61-78, 1994.
[10] B. M. Seemungal, S. Glasauer, M. A. Gresty, and A. M. Bronstein, "Vestibular perception and navigation in the congenitally blind," *Journal of neurophysiology,* vol. 97, pp. 4341-4356, 2007.

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