Multisensory Training Intervention for Hearing Impaired Children: Preliminary Results of a Pilot Study

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ABSTRACT

This paper examines the influence of the Interactive Multisensory Environment (iMSE) on the training of deaf children in comparison to traditional methods. Over a 7-week duration, two groups of deaf children were evaluated and trained, one utilizing the iMSE (Experimental Group) and the other employing a traditional PC-based method (Control Group). The training encompassed four different thematic categories, each with nine associated sounds. The iMSE offered an immersive and dynamic learning experience, while the PC-based method presented stimuli through a desktop computer. Results indicate that the iMSE yielded positive effects on the training outcomes of deaf children, as evidenced by improved performance and engagement. This research sheds light on the potential benefits of innovative multisensory technology in educational settings for children with hearing impairments, offering insights for future educational interventions.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; **Interaction paradigms**; *Accessibility technologies*; • **Applied computing → Interactive learning environments**.

KEYWORDS

Interactive Smart Spaces, Deaf children, Interactive Multisensory Environment

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1 INTRODUCTION

One of the earliest and most crucial objectives of rehabilitative programs for hearing-impaired children, regardless of the chosen prosthetic approach, is auditory perception education. This aims to enhance their understanding of the surrounding world by developing awareness of acoustic phenomena, progressing towards the identification of linguistic sounds, and consequently comprehending conversations, with significant impacts on social integration and personal development. Moreover, auditory stimuli interact with other sensory modalities, contributing to cognitive enhancement and the construction of a comprehensive sensory experience [2]. Building upon the premise that multisensory stimulation is more effective than monosensory protocols [20], this work focuses on a research project involving the experimentation of an interactive Multi-Sensory Environment (iMSE) known as the Magic Room [5, 6, 9, 12]. It is intended for perceptual training activities with hearing-impaired patients. Specifically, our study aims to investigate whether the use of this multisensory environment offers equal or better learning opportunities compared to perceptual training conducted in a traditional therapeutic setting.

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The development of spoken language in children is directly linked to their auditory capacity. Most studies conducted on children with hearing loss indicate delayed development of verbal language, which might impact linguistic-communicative abilities into adulthood [24]. The degree of disability corresponds to the difficulties in perception. Language is crucial not only as a means of communication but also as a cognitive development tool, an educational instrument, and a foundation for social relationships. Hence, one of the objectives of speech therapy is to enhance perceptual abilities and communicative-linguistic skills in hearing-impaired individuals. In a complementary manner, auditory rehabilitation aims to optimize the daily functioning of those with hearing loss to ensure the best quality of life across physical, functional, social, emotional, and psychological domains [17]. One other aspect complicating the assessment of a deaf child is the frequent presence of comorbidity of other pathologies, especially those related to developmental disorders. Such comorbidity can complicate the work of clinicians in differentiating between failed tests due to sensory limitations and tests failed for the effects of other conditions.

In this paper, we report on the use of IMSEs for the training of deaf children, describing the codesign process that allowed us to define our approach and experience called the Association Game. We also conducted a very preliminary study, which is the first in this field to our knowledge. With all the limitations considered, results seem encouraging in supporting the use of iMSE approaches to improve the benefit of training for sound recognition in deaf children. We have also collected our experience in a set of lessons learned for the scientific community.

2 STATE OF THE ART

2.1 Methods for Deaf Children

Carney described three stages of development in verbal perception in young children, which can be summarized as follows [14]: Level 1: Sound awareness. Level 2: Discrimination of contrasting patterns from a phonetic perspective. Level 3: Word recognition, made possible through the maturation of the linguistic system.

The speech assessment of a child within the first three years of life involves identifying verbal and non-verbal communicative behaviors, as well as investigating perceptual-auditory skills. During this phase, the child's responses to presented auditory and verbal stimuli are evaluated, along with their willingness to use and potentially request the use of prosthetic aids (hearing aids or cochlear implants). Additionally, the child's ability to indicate any malfunctions in these aids is examined. These behaviors are probed using internationally recognized questionnaires, which are completed in conjunction with the family unit. While the development of verbal perception entails cortical processes that evolve in early childhood, the assessment of this skill through standardized tests (e.g., Speech, Spatial and Qualities of hearing scale [7], dedicated to the perception and understanding of spoken language) is currently feasible only at a later stage with the development of lexical abilities [3, 13]. Perceptual tests vary based on the patient's age, involving the initial presentation of environmental sounds and musical instruments, followed by linguistic sounds in a later stage. The rationale behind the primary presentation of environmental sounds and musical instruments is their ease of replication and convenient audibility [22]. The goal of these tests is to evaluate the child's abilities in detecting, categorizing, and distinguishing certain acoustic-perceptual properties that characterize verbal signals. These tests are administered under ideal listening conditions, with hearing aids or cochlear implants worn, and at conversation intensity (70 dB HL) [4]. The objective of the tests is to provide precise indications of the child's level of perceptual ability, facilitating their placement within the perceptual categories proposed by Moog and Geers [8].

Today, children with moderate to profound hearing losses identified in their early months of life and enrolled in early intervention, including both habilitative and prosthetic approaches, demonstrate significantly positive outcomes in terms of vocabulary development, receptive and expressive language skills, syntax, pronunciation, and socio-emotional development [1]. The state-of-the-art technology to support these children are hearing aids, recommended for mild-to-severe sensorineural hearing losses, and cochlear implants in the most profound cases [21]. It's crucial to note that there is currently no universally established standard procedure or treatment for enhancing the condition of deaf children. Therefore, each practitioner relies on individually crafted tools and methods for their patients.

2.2 The use of iMSEs in the care of children with Neuro-Developmental Disorders

The origin of Interactive Multi-Sensory Environments (iMSEs) can be traced back to low-tech Multi-Sensory Environments like Snoezelen [15], which was designed three decades ago. Despite limited empirical evidence, Snoezelen is extensively used in special education schools and therapeutic centers, mainly in the US, UK, and Australia. It aims to create soothing environments for individuals with profound cognitive impairments, reducing anxiety, promoting engagement, and facilitating communication with caregivers. MEDIATE [18, 19] is a pioneering initiative that employs full-body interaction with Autism Spectrum Condition (ASC) children. It delivers focused and simplified stimuli, fostering creative responses and adapting to the children's behaviors. Lands of Fog [16] introduces a full-body interaction system for high-functioning ASC children to develop social interaction skills and foster collaboration with non-ASC peers. The Magic Room [5, 9] enhances learning and inclusion for schoolchildren with cognitive disabilities, leveraging the Internet of Things technology to automate device control based on customized activities set by educators and caregivers. Other technologies in the reality-virtuality continuum have been tested. For example, Serafin et al. [23] used wearable VR technology to create spatial awareness with children with hearing loss.

3 THE ASSOCIATION GAME

3.1 Codesign process

Our methodology has been based on a two-step codesign involving two different specialized care centers for NDD children. During our first experience, three researchers participated for four days in the daily care center activities, observing the 24 children (among whom only one had hearing aids) and their 5 caregivers' daily routines. The care center offers daily daycare services for groups of children up to 13 years old with medium to moderate conditions in the spectrum of NDD. After the observation, three meetings were held to interview the caregivers and to discuss with the director of the care center the rationale and required improvements.

Among the many activities that caregivers proposed to children, there was a round-based game in which all children hear a sound focusing on human voices, and then one at a time, are asked to guess among a variable number of pictures depicting different people which one had more probability to have spoken in that manner. The objective of the activity was to train children to understand the correspondence between a visual element and a sound (e.g., a crying sound and a picture of an eye with tears). The round-based game was also intended to train the children's patience. When a child finds the correct answer, it is plastered on the wall in a grid, representing all the items to identify. If the answer was wrong, the picture was removed, and a new child was asked to answer. The game continues until all the items have been identified. The experience, while appreciated by the children, faced an incredible overload of complexity for the caregivers and allowed for a huge amount of possible mistakes and errors. Among them, the most common pain points of the experience were:

A The error prowess of the caregivers, who often had to undo previously performed answers to recover the correct opinions for the following examples.
B The difficulty of finding the source material, organizing it, and maintaining it (each piece of paper had to be printed, laminated, and equipped with plaster glue) after each use.
C The quality of the sound was not adaptable to the different needs of the children.
D The proposed rewards were limited.
E Children cannot decide to stop identifying one sound.
F Caregivers had difficulties in finding always proper alternatives for the children.

From this experience, we collected valuable information on the skeleton of the experience we desired to create, the key points we wanted to solve to help caregivers, and the impact that an iMSE could provide to the children. We used the multisensoriality of the space to provide controlled and controllable feedback for the children, simplify the gathering, checking, and maintaining of material, improve the quality of the rewards, and improve the agency of children and caregivers in offering the experience (further detail in Section 3.2).

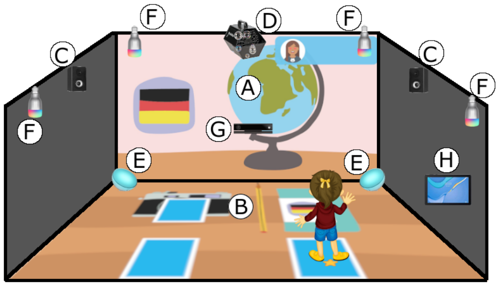
The second step in the experience's definition has been the co-design we conducted with the experts of a second Care Center, specialized in deaf children with comorbidity of other NDD pathologies. This care center specializes in the assessment and rehabilitation of language and communication disorders, also welcoming deaf children, some of whom present other pathologies. We proposed an initial prototype of the activity, using the technology of our iMSE described in section 3.3. In the co-design, we analyzed together with two speech therapists, the current training tool and tailored the experience to the needs of the new group of users (deaf children) and caregivers, and identified a set of potential sounds and images. We had defined: A) a set of sounds familiar to the children and that may also have a meaning in children's lives, B) a mechanism to adapt the intensity of the auditory stimuli at the speech therapist's request, and C) an experimental protocol to measure the utility of the iMSE intervention with respect to the traditional tools.

3.2 User Experience

We designed an interactive experience known as the "Association Game" to engage children playfully, consisting of three phases: Initialization, Turns, and Ending. In the Initialization phase, a grid is displayed on the front screen. The cells in this grid are numbered, making it easier for children to select an item. The number of cells can be adjusted according to the theme's complexity, as determined by the caregiver. To immerse the children in the experience, the floor and frontal projection feature images that simulate real-life settings where these sounds would be heard. The primary portion of the game involves the player's turns. Each turn begins with the player verbally indicating to the game character which hidden sound they wish to uncover by specifying its corresponding number. The caregiver, who is out of sight from the children, then selects the requested sound using a control application on a tablet. Once the sound is selected, the corresponding cell pulsates as visual feedback while the system plays the sound. After the sound concludes, a set of images appears on the floor screen. These images represent alternative choices for the player and are presented in a random order in a straight line in front of the user. Only one choice is correct, while the others act as distractors. The player can make a selection by physically standing on their chosen option. To encourage sustained attention and prevent hasty selections, confirmation of the choice is delayed for 5 seconds after the player stands on an option. If the association is correct, the child receives positive feedback, signaled by green lights illuminating the room and applause. Additionally, on the front grid, the selected number disappears, revealing the correct answer. In case of an incorrect association, the child receives negative feedback indicated by a red light only, and the number remains in place, concealing the correct answer. Once all the numbers have been revealed, the sequence of turns concludes, and the Ending phase commences. During this phase, the children are greeted with victory fanfare, the room is bathed in green light, and a shower of bubbles descends from the ceiling, creating a celebratory atmosphere.

3.3 Technology

The Association Game is powered by the iMSE called Magic Room [5, 6, 9, 12] depicted in Figure 1a, which is equipped with: (A) Frontal projector, (B) Zenith projector, (C) Audio System, (D) Bubble machine, (E) Portable and (F) Fixed controllable lights, (G) Full body motion sensor, (H) Tablet. The floor screen is dedicated to the children's main interaction: choosing the image. The motion sensor is hidden in the front wall, allowing the system to identify the user's position in the area. The identified position of the child during the game is marked by a digital star projected on top of the other elements of the floor projection. This is useful for the caregiver to understand whether the system is working properly and for the child to have more of a sense of agency. The Audio system uses a 5.1 Dolby System to offer the best audio quality and the most accurate performance for maximum loudness of the sounds without compromising on quality. Light systems (fixed and Portable) offer visually powerful feedback. The bubble machine serves as a robust form of feedback to reward the child for their efforts. All lights and the bubble machine are controlled through Web of Things technology within the framework of the iMSE.



(a) The Magic Room's components

(b) A child playing the association game during the Pilot Study

4 THE PILOT STUDY

4.1 Research questions and variables

In pursuit of our primary objective, this study aims to assess the effectiveness of iMSE technology in aiding the auditory recognition training of deaf children. This preliminary evaluation, although exploratory, lays the groundwork for further research with a larger sample size. Our investigation focuses on a fundamental question: *does training within the immersive iMSE environment yield differences in sound recognition compared to traditional PC-based interventions facilitated by speech therapists?* To answer this crucial question, we meticulously documented the number of correctly recognized items during each training session for all participating children. Our analysis specifically concentrates on discerning differences between their initial and final sessions, providing valuable insights into the potential of iMSE technology in enhancing auditory skills among deaf children.

4.2 Participants

We recruited 21 children from those present at the rehabilitation center. All children have been certified deaf with mild to severe conditions, with ten of them presenting comorbidity with other neurodevelopmental disorders. Our children all underwent protheticization and cochlear implantation interventions at an early age. However, we had to exclude some of our recruited participants based on the following exclusion criteria:

- A Age younger than 2 years or older than 9 years. Perception intervention is typically indicated in the early years or immediately after a prosthetic or cochlear implantation intervention, to maximize its effects.
- B Uncooperativeness of the child due to serious oppositional or attentive behaviors.
- C Complete hearing competencies reached with the support devices.
- D Rejection of a new and dark environment.
- E Severe cognitive impairment with difficulties in accepting and/or understanding the task.
- F Lack of residual hearing or inability to perceive any sound.

Unfortunately, six of them could not complete the entire experimental protocol due to comorbid conditions causing familiarization issues. Among the remaining eight children, two research groups were established: the Experimental Group (EG) comprised four children (3 males, 1 female, 2 with deafness only, 2 with comorbidities, mean age: 6.5, std: 0.25), and the Control Group (CG) included four children (3 males, 1 female, 2 with deafness only, 2 with comorbidities, mean age: 6.75, std: 2.19). All participants had neurosensory bilateral hyperacusis, ranging from moderate to profound. Two children required bilateral cochlear implants. Two needed a cochlear implant in one ear and a hearing aid in the other. Three participants used bilateral hearing aids, and the remaining child had a unilateral cochlear implant. Additionally, all children had a diagnosis of sensorineural hearing loss, with four of them also presenting other developmental disorders in comorbidity. Participants were randomly assigned to the two conditions to ensure group balance. All participants required prosthetic aid, and they used them during the sessions. Detailed participant data can be found in Table 1. The allocation of children to the two groups was randomized to ensure group balance. Legal guardians were informed in advance about the study, including its procedures, objectives, and data handling methods. They were recruited voluntarily and signed informed consent ensuring privacy. Comprehensive information, including exclusion criteria, was communicated through proper documentation.

4.3 Experimental Design

In this study, detailed in this paper, we collaborated closely with a local care center to investigate our research inquiries. Employing a between-subject 2X4 design with repeated measures, we analyzed two fixed factors: conditions (iMSE vs. PC method) and stimuli sets (Musical instruments, house noises, Animals, and Environmental noises). The primary variable of interest was the participants' score, indicated by the number of correctly identified items, which was recorded for each theme under both conditions (iMSE and PC method). For every participant, we collected four scores, each corresponding to one of the thematic categories.

4.4 Materials

In our study, each thematic category, or theme, comprised nine distinct sounds corresponding to specific images for the four themes and were presented with four images from which to choose. In each session, each participant is presented with all the stimuli divided by theme. The Experimental Group (EG) engaged with the iMSE version of the Association Game, outlined in Section 3.2. The Control Group (CG) worked with the same stimuli presented through a PowerPoint presentation on the therapist's PC, controlled by the caregiver. The PC was equipped with loudspeakers to improve the sound quality. To ensure the smooth operation of the iMSE, speech therapists participating in the study were trained to use the iMSE and the Association Game to operate the system independently.

User	Age	Level of bilateral sensorineural hearing loss	Comorbidity	Prosthetic aid
S1	6	profound	development disorder	cochlear implant (left) hearing aid (right)
S2	7	profound		cochlear implant (right)
S3	7	profound		cochlear implant (bilateral)
S4	6	profound	development disorder	cochlear implant (bilateral)
S5	7	profound	Autism Spectrum Disorder	hearing aid (bilateral)
S6	6	moderate		hearing aid (bilateral)
S7	9	profound		hearing aid (left) cochlear implant (right)
S8	5	medium-level	Autism Spectrum Disorder, Janz Syndrome	hearing aid (bilateral)

Table 1: Table reporting the Age, diagnoses, and prosthetic aid required used by each participant in the pilot study

4.5 Procedure

The study was conducted over 7 weeks, encompassing two evaluation sessions (T0 in week 1 and T1 in week 7) separated by 5 training sessions of 45 minutes each. In the CG sessions, children were seated at a desk in front of a PC with the therapist providing real-time feedback. In the EG sessions, children entered the immersive iMSE environment. Speech therapists were instructed not to provide hints or rewards to the children but could adjust the room behaviors via the tablet app if the system failed to recognize the children. To mitigate learning effects, the order of themes in each session was randomly assigned. In the EG, the order of stimuli and answers was randomized at each execution. However, in the CG, the order of the answers was not randomized, following common practice. The volume level inside the activity was carefully regulated, ensuring it did not exceed 80 dB, maintaining an average of 70 dB throughout the study sessions to create a consistent and comfortable auditory environment.

	Condition: EG				
Theme	μ T0	σ T0	μ T1	σ T1	Delta
Musical Instrument	59%	0.37	97%	0.05	39%
House noises	50%	0.38	94%	0.11	44%
Animals	81%	0.17	100%	0	19%
Environment Noises	84%	0.06	92%	0.16	8%
	Condition: CG				
Theme	μ T0	σ T0	μ T1	σ T1	Delta
Musical Instrument	53%	0.42	75%	0.36	22%
House noises	59%	0.17	94%	0.11	36%
Animals	89%	0.12	97%	0.06	8%
Environment Noises	61%	0.12	94%	0.06	33%

Table 2: Mean Results μ and standard deviation σ on the scores obtained by children in the two conditions for each theme

4.6 Data Gathering Methods

In each session, the speech therapist was provided with a scoring sheet detailing every item of each theme, along with indicators to mark whether the child's response was correct or not. This systematic documentation allowed for precise tracking of the participants' performance and facilitated accurate analysis of the study data. The score is computed by calculating the percentage of correctly answered objects using the formula: $score = (\#correct_i items/\#items) * 100$

5 MAIN RESULTS AND DISCUSSION

5.1 Effect of the iMSE with respect to traditional method

The results, detailed in Table 2, showcase the average scores of the children categorized by theme and condition, during the initial (T0) and final (T1) sessions. Results showed that the EG outperformed the CG in three out of four cases. Notably, the musical instrument and house noises themes both exhibited a lower initial recognition rate and displayed great improvements. Conversely, the animal theme appeared to be more familiar to the children, likely due to previous experiences, leading to a narrower margin for improvement. These findings provide valuable insights into the differential impact of training methods on various thematic categories and highlight the potential of the iMSE approach in enhancing learning outcomes for deaf children and better aiding the users. These results are probably related to the capability of the iMSE to provide more significant rewards and a gamified experience with respect to the exercise in the therapy room, which appeared plain and not sufficiently engaging. We state this conjecture based on our results and similar findings observed in other teaching scenarios [10, 11].

The Environmental Noises theme, instead, is peculiar: the iMSE has a lower performance than the PC and needs further investigation. This theme was the one with the most similar sounds to be discriminated (e.g., the ER siren and the police siren). As a result, children in the CG could have memorized the sequence of responses even without being able to differentiate the sounds, while children in the EG could not have done it. This hypothesis, based on our field observation and a post-analysis of the stimuli, will require further investigation. Another effect that could have caused this discrepancy is the fact that the starting scores for this theme in the EG were consistently higher than the CG. Nevertheless, it is important to remember that children's responses to tasks can fluctuate due to factors such as fatigue, willingness, dedication, and attention. These nuances underline the complex nature of perceptual learning and the importance of considering individual differences in the learning process.

We also observed that the two children with comorbidities did not show significant differences in terms of performance compared to the others. However, we did notice some distinctions in their general behaviors. Specifically, S8 exhibited fear of the dark environment of the Magic Room, necessitating the system to be turned on beforehand. Moreover, more than half of the children, particularly S4 and S5, demonstrated greater difficulty in maintaining attention during the intervals between the two themes. As a result, S4 and S5 required intervention from the therapist.

5.2 Limitations

Our research is subject to several constraints that require careful consideration. Firstly, the limitation of the sample size is noteworthy. While our target sample size was determined using T-test analyses and G-Power software, aiming for a power index of 0.95 and an anticipated effect size of 0.25 (leading to an estimate of 132 subjects), we faced challenges in finding a sufficient number of subjects. The inherent heterogeneity in our participant pool, which included variations in terms of hearing impairment and comorbidity conditions, provided a valuable opportunity to comprehensively test the benefits of a multisensory environment. A significant limitation in subject recruitment is the familiarization with the iMSE within a short acceptance period, given our organizational and clinical constraints. Unfamiliarity with the interaction modality cannot be overlooked (e.g., fear of the dark scared some participants initially), although its precise extent remains to be determined. Furthermore, we acknowledge the possibility of a learning effect in the PC experience. This lack of randomization might have influenced the performance in the control group, potentially leading to children memorizing response patterns instead of recognizing the sounds.

6 LESSONS LEARNED

In our research, we explored various alternatives to transform traditional testing methods into technologically enriched activities and identified key insights that could be valuable for other researchers in similar domains. The first crucial finding is the potential of multisensory spaces to assist individuals with sensory issues. While our study focused on deaf users, the same approach can be adapted for other populations that have often been overlooked in research involving interactive iMSEs. For example, our approach (based on sensory integration theory [25]) provides stimuli on multiple sensory levels (light, visual aid, and sound feedback) and employs motion interaction to better support the needs of each child. A second significant aspect is that it is important not to limit ourselves to digitalizing tests or exercises. It is now time for a new approach that involves a comprehensive UX translational process to the exercises in different technological media. This process not only supports patients and caregivers but also allows psychologists to gain profound insights into how measured skills function in different environments, especially compared to traditional rigid testing. Additionally, providing customization options at the beginning and throughout the experience is crucial, addressing a major limitation of traditional tools. Lastly, the technological framework must be flexible and reusable to offer various experiences within the same context. As children become acclimated to it, researchers can employ different applications during therapy to stimulate various use cases, enhancing the technology's adaptability and effectiveness.

7 CONCLUSION AND FUTURE WORK

The objective of this study was to investigate whether an interactive MultiSensory Environment (iMSE), capable of controlled and customized sensory stimulation, could provide comparable or superior support to conventional training methods for rehabilitating auditory perception in individuals with hearing impairments. While our results are preliminary, they indicate promising outcomes for the iMSE group: it enhances children's motivation and engagement and also delivers improved results. Additionally, the iMSE might mitigate potential biases caused by learning effects, providing a more accurate assessment of users' progress. However, it is crucial to approach these results with caution due to the limited sample size and the exploratory nature of the study. Further research involving a larger and more diverse participant pool is necessary to validate these initial observations. Moreover, detailed investigations into the specific mechanisms through which iMSE interventions influence intervention success are essential. Such research could uncover the nuanced ways iMSEs impact therapeutic outcomes and user experiences, offering valuable insights for interventions targeting diverse populations and conditions. These potential advancements have significant implications for the future development and refinement of innovative therapeutic approaches.

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