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REHABILITATION EXERCISES USING SPATIAL SOUND

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ABSTRACT

This project presents an innovative approach to supporting the spatial orientation development of visually impaired children through auditory stimuli. The project aims to reduce anxiety related to outdoor environments and enhance spatial awareness through immersive audio plays. The training method incorporates exercises designed to teach spatial prepositions, direction assessment, and overall spatial orientation. The designed structure and format of these audio plays allows for both mentor and independent learning. Binaural recordings are used to create realistic soundscapes that faithfully reflect auditory landscapes. The created audio plays and their analyses are shared via YouTube, accompanied by forms for collecting listener responses. The analysis of the collected data provides valuable insights into how users perceive the audio plays and interact with them. Initial research confirms literature findings suggesting rehabilitation through binaural recordings. It also allows for senses correlation analysis. Thanks to its accessibility and carefully designed structure, the audio plays can be a tool for auditory spatial orientation training for everyone. The project is also being expanded to include a sound map and a dedicated application, which will allow users to track their progress in completing exercises.

Keywords: *spatial sound, auditory perception, auditory training, visual impairment*

1. INTRODUCTION

Teaching spatial prepositions to blind children requires specific methods to compensate for the lack of vision. The main difficulties include:

1. Perceiving space as a temporal sequence – Children initially perceive objects in a temporal relationship (e.g., first the table, then the chair) rather than a spatial one [1].
2. Delayed vocabulary development – A later understanding and use of prepositions such a under, above, between compared to sighted children [1].
3. Limited spatial imagination – The inability to visually monitor the surroundings makes it difficult to grasp abstract concepts [2].

One of the supporting methods is multisensory stimulation, which includes:

- Touch and proprioception – Exercises involving the identification of one's own body parts and those of others (e.g., Where is your hand?).
- Sound localization – Training in recognizing the location of sound sources in space (e.g., Where is the bell?) [1].

The aim of this study is to develop educational materials consisting of auditory exercises in a digital space. The child will be able to learn spatial prepositions either with a parent or independently at home. This approach will expand auditory experiences by introducing new sound sources that are easier to generate digitally than in a natural environment, while still imitating real-world sounds (e.g., bird songs) and simulating distant objects.

2. KEY CONCEPTS

Spatial prepositions are linguistic elements used to define spatial relationships between objects, places, or people. In Polish, they serve a referential function, replacing

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specific names of locations or directions [3]. They fulfill a localization function by:

1. Indicating position relative to the speaker (e.g., here – close, there – far) or relative to other objects (e.g., next to, above).
2. Creating spatial oppositions (e.g., front – back, top – bottom, left – right) [4].

Binaural recordings are a sound recording technique that uses two microphones positioned to mimic human ears, creating a three-dimensional spatial effect. This effect can be achieved by using in-ear microphones or an artificial head. Key elements include:

- HRTF (Head-Related Transfer Function) – A phenomenon describing how the shape of the head, torso, and outer ear affects the perception of sound from different directions.
- ILD (Interaural Level Difference) – The difference in intensity of the received sound between the ears, aiding in source localization.
- ITD (Interaural Time Difference) – The difference in the time it takes for sound to reach each ear, crucial for determining direction [5].

3. CREATION PROCESS

3.1 Type of Audio Material

The fundamental component of the exercises designed to develop the ability to determine and name the direction of sound is appropriately prepared audio material. The recordings were made in two different acoustic environments: an anechoic chamber and a recording studio. Both types of recordings have specific properties that influence the process of spatial perception for the listener.

Record from the Anechoic Chamber at AGH – This is a specially designed space that completely eliminates sound wave reflections, allowing for the recording of direct sound unaffected by the surrounding environment. This type of audio training is more challenging. Listening to such recordings requires focusing solely on subtle directional cues resulting from differences in how sound reaches the listener's ears (e.g., ITD, ILD).

Record from the Music Studio Kotłownia in Kraków – In the acoustic studio, the sound source was recorded along with sound reflections, allowing for a more natural perception of directionality. This type of training is easier. Due to the presence of reflections, reverberation, and other acoustic phenomena occurring in the room, it is easier to determine the location of the sound source, as additional spatial cues support the perception process.

3.2 Exercise Themes

The prepared exercises focus on learning spatial prepositions by applying them to describe the direction of a sound source. The recorded materials enable the creation of multiple audio plays, supporting the training of various prepositions.

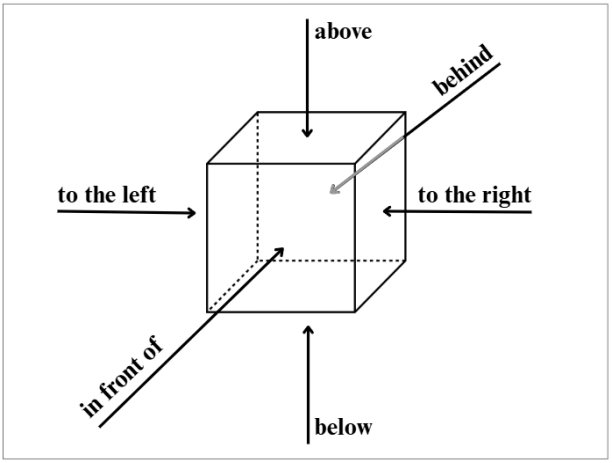

Figure 1. Graphical Representation of Spatial Prepositions.

In the basic version, the participant uses simple prepositions to describe the spatial relationship between themselves and a single sound source, such as: in front of, behind, above, below, to the right, to the left (Fig. 1).

In the more advanced version, two sound sources are introduced, and the participant's task is to simultaneously listen to both and determine their positions in space using previously learned prepositions. Additionally, a new preposition – "between" – is introduced. The difficulty level is further increased by an additional task requiring the participant to identify the second sound source.

The exercises include two main types of sounds:

- For younger children – birdsong,
- For older children – pedestrian crossing signal sound.

The audio materials were sourced from the Soundsnap library [6].

3.3 Recording Setup

The sound recording process was conducted using Soundman OKM II in-ear microphones, connected to a Zoom H6 recorder. These microphones were placed inside the author's ears, which allowed for a natural spatial image of the sound from the listener's perspective.

The sound sources included both pre-recorded signals and naturally produced sounds. Birdsong and pedestrian crossing signals were played in both recording environments using a Genelec 6010A speaker. During the recordings, the person wearing the in-ear microphones rotated relative to the speaker to capture specific sound directions. For example, to record a sound coming from the right side, they positioned themselves with their right shoulder facing the speaker.

Additionally, natural acoustic signals such as whistling, humming, and the sound of unzipping a jacket were included, produced directly by participants during the recording process.

The spoken content delivered to the listener was recorded using a Novox NC-1 microphone.

3.4 Editing

The creation of the complete audio plays involved the use of several editing programs, covering both audio processing and video production.

The basic tool for editing the audio material was the Pro Tools program. In order to preserve the natural sound of the binaural recordings, their content was not interfered with, leaving them in their original form. The information content containing the recorded voice was subjected to basic editing, including:

- Removal of breaths and long pauses,
- Frequency correction using the EQ3 7-Band plugin,
- Signal compression to prevent distortion, using the Dyn3 Compressor plugin.

Additionally, for headphone testing, three sine wave signals corresponding to the musical notes C, E, and G in the first octave (major-minor system) were generated using the Signal Generator plugin. The entire audio material was recorded in PCM and exported to a lossless WAV format, ensuring high-quality sound preservation and allowing for further editing without degradation.

Since the audio dramas are intended for publication on the YouTube platform, it was necessary to prepare appropriate visual materials. All graphic elements, including video thumbnails and illustrations for different parts of the exercises, were designed using Canva. Some images were generated with the built-in AI tool Magic Multimedia.

For final editing, combining audio with graphics, and rendering the finished video files, DaVinci Resolve was used.

3.5 Structure and Format

The audio drama was prepared in two formats:

1. A full-length video
2. An interactive form containing short recordings.

Both formats follow the same structure, including the following elements:

- Information about the type of exercise,
- Message asking you to put on headphones,
- Headphone test – allowing the listener to check whether the left and right headphones are correctly placed,
- Exercise instructions,
- Sounds to be described – in the form version, there is an additional space to mark answers,
- Thank you message and congratulations on completing the audio play,
- Request to submit the completed task for statistical purposes.

The video format is designed for participants who wish to practice independently. Correct answers can be verified by checking the analysis provided in the video description. For those using the interactive form, after submission, they receive the same feedback, including a summary of their results on the last page of the form.

3.6 Data from the Exercises

To evaluate the effectiveness of different types of audio materials in training spatial perception, anonymous participant responses are collected. This data helps assess which recording format is the most effective and should be continued or modified in future exercises.

Additionally, the survey includes open-ended questions, allowing participants to provide feedback and suggest improvements to the structure of the exercises.

In the future, a study involving a group of listeners is planned to verify the effectiveness of the audio dramas in teaching spatial prepositions.

As part of the exercise, data concerning visual perception are also collected. With a sufficiently large participant base, these data may serve to analyze potential correlations between visual and auditory perception. A particularly interesting research question is whether individuals with more significant visual impairments demonstrate enhanced auditory perception and achieve higher scores in tasks involving the identification of sound source direction.

4. SOUNDSCAPES AUDIO PLAYS

The audio plays designed for the training of spatial pronouns represent the second type of materials developed within the project. Their concept was inspired by earlier audio plays based on soundscapes, in which the listener's task is to identify the acoustic environment presented in the recording, answer questions regarding its characteristics, and list and describe the recognized sound sources according to a given scheme. One element of the analysis involves determining the direction where the particular sound is perceived from.

4.1 Analysis of Directional Determination

Assessing the accuracy of indicated sound directions presents certain difficulties, as some sound sources are present throughout the entire recording and change their position, which means that participants may refer to different moments in time. However, there are a few sound sources that occur only briefly and have a defined direction. Referring to Audio Play No. 1, which presents the coastal soundscape of the Baltic Sea, several such sound sources can be identified: the shutter sound of a camera, a dog barking, and the voice of the dog's owner.

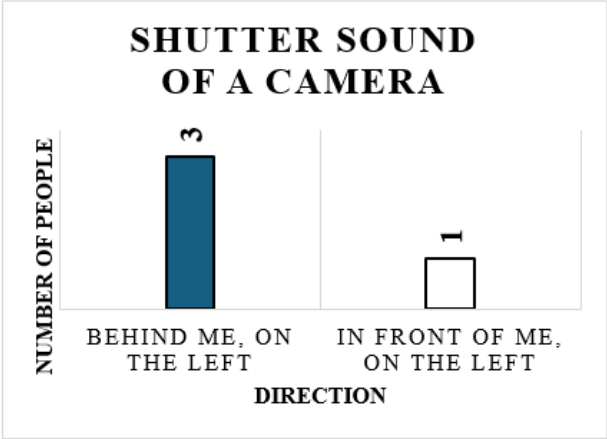

Figure 2. Participants' indication of the shutter sound of camera.

Out of the 71 collected responses, each participant identified a different number of sound sources present in the recording. The sound of the camera shutter was recognized by 4 participants, 3 of whom correctly indicated its direction as "behind me, on the right" (Fig. 2).

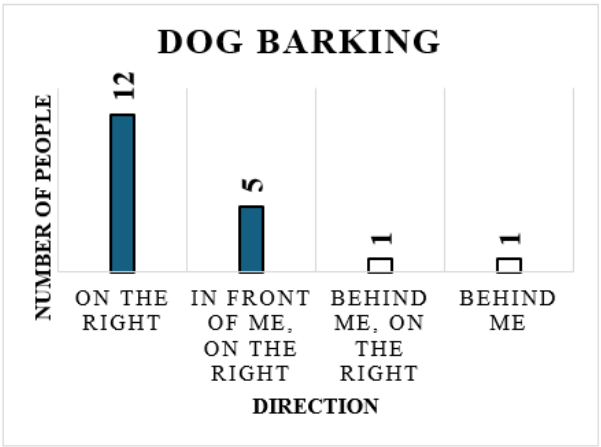

Figure 3. Participants' indication of the dog barking sound.

The barking of a dog was identified by 19 participants. In the recording, the dog appears on the right side and runs straight ahead, passing in front of the listener, still on the right side (two barks audible), which suggests that 17 out of the 19 respondents correctly identified its direction (Fig. 3).

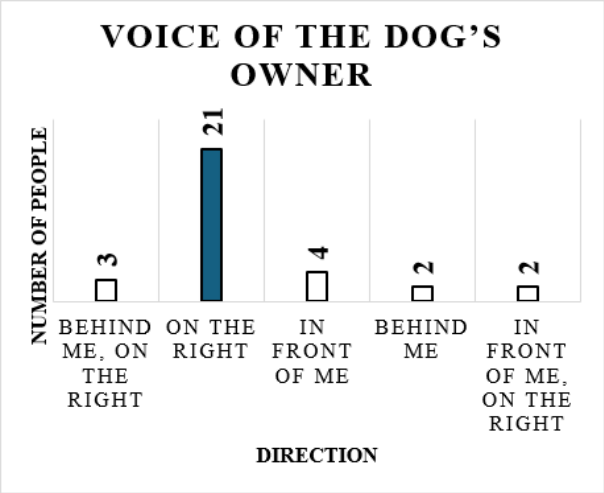

Figure 4. Participants' indication of the voice of the dog's owner.

The dog owner's voice poses a greater interpretative challenge due to its changing position — initially heard on the right side, it then moves behind the dog, giving the impression of moving from behind the listener to the front (Fig. 4). The variation in participants' responses likely stems from this spatial shift. However, none of the respondents indicated the sound source as coming from the left side, which allows us to conclude that, broadly speaking, all participants provided a good assessment of its direction.

For future tests, it may be beneficial to include an additional element — marking the exact moment (in seconds) in the recording when a particular sound source occurs. These preliminary results confirm that listeners of binaural recordings are capable of identifying the sound sources present in the soundscape, as well as determining their direction. These findings support the theoretical assumptions regarding the use of binaural recordings as a tool for training spatial orientation, written in the "Standard for teaching spatial orientation and mobility" [7].

5. POSSIBILITIES AND FUTURE DEVELOPMENT

The recordings were made to create a database of audio plays supporting the training of directional perception. Audio dramas containing birdsong were published, recorded both in an anechoic chamber and in a recording studio. These materials allow for the learning of basic spatial prepositions, such as: behind, in front of, above, below, to the right, to the left, in the context of their actual placement in the sound space.

Further use of the available recordings is planned, as well as completing work on the full set of audio plays supporting the learning of spatial prepositions. In the future, I would like to replace the binaural recordings with ambisonic recordings decoded into binaural format, which would enhance the listening experience for most listeners.

The data will be collecting from participant exercise results will allow for further optimization of the structure of the audio dramas and recording methodologies. Analysis of listeners' responses will help adjust the recording parameters to increase the effectiveness of directional perception training and facilitate the learning of spatial prepositions.

Creating a comprehensive database of such materials may bring significant benefits, particularly in the context of education for children with low vision and blindness. Thanks to the possibility of conducting exercises in home settings, the audio dramas can support the development of spatial orientation and assist in language acquisition, also among sighted children, for whom auditory perception training may be a valuable complement to traditional education.

The project is also being developed to include a sound map, shared in the form of short videos on the YouTube channel *My Friend Sound*. These materials allow listeners to become familiar with the acoustic character of a given location before physically visiting it, which can help combat fear of new spaces. The recordings can also serve as a basis for creating further audio plays based on soundscapes. To date, recordings from 17 locations across different regions of Poland have been published. In the next phase of the project, an application that will enable users to independently plan and organize their auditory training is planned.

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] M. Paplińska, „Przygotowanie dziecka niewidomego do nauki szkolnej", *Cedunis*, cedunis.org.pl (accessed April 1, 2025).

[2] J. Konarska, „Rozwój i wychowanie rehabilitujące dziecka niewidzącego w okresie wczesnego I średniego dzieciństwa", City: Kraków 2010.

[3] R. Piętkowa, "Pojęcie przestrzeni: zarys problematyki", *Język artystyczny*, vol. 3, pp. 39-49, 1985.

[4] M. Fenert, "Orientacja w przestrzeni oraz rozumienie przyimków określających relacje przestrzenne", *Kreatywne Wrota*, kreatywnewrota.pl (accessed April 1, 2025).

[5] J. Blauert, "Spatial Hearing: The Psychophysics of Human Sound Localization", City: Cambridge 1996.

[6] Soundsnap.com (accessed April 1, 2025).

[7] Standard nauczania orientacji przestrzennej i mobilności, City: Warszawa 2022, https://firr.org.pl/wp-content/uploads/2022/04/STANDARD-NAUCZANIA-ORIENTACJI-PRZESTRZENNEJ-I-MOBILNOSCI.pdf (accessed April 1, 2025).