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Spatial Localization of Sound in the Late-Blind During Spatial Bisection Task and Minimum Audible Angle Task

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Abstract

Objectives: Our objective was to assess the spatial localization of sound in both minimum audible angle task and spatial bisection task in the azimuthal plane in late blind subjects.

Methods: A total of ten late blind individuals and eight normal sighted blindfolded controls performed the spatial bisection task and minimum audible angle task.

Results and Conclusion: The late blind performed as good as the controls in both the tasks. The late blind would have had intact vision in their developmental years, enabling development of the ability to spatially localize sound. These results support the cross sensory calibration hypothesis that vision calibrates spatial localization of sound while the sensory system is still maturing.

Keywords: *Spatial bisection task, Minimum audible angle task, late blind, Cross sensory calibration*.

Introduction

Blind people rely on other forms of sensory inputs like hearing in order to perceive and orient themselves to the environment they live in, largely by distinguishing and localizing the plethora of sounds they hear.

So, a question arises as to whether this increased dependence on the auditory system can lead to its enhancement or whether the lack of vision can affect the development of other senses. Before attempting to answer this question, an essential consideration is of the frame of reference that is used to localize sounds. The frame of reference is defined as the means of representing the location of entities in space[1]. The two dominant ones are egocentric and allocentric frames of reference. The egocentric frame uses the subject as the centre of the environment whereas the allocentric frame is centred either on external objects or the environment itself. [2, 3]

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The "Sensory compensation hypothesis" suggests that loss of vision leads to compensatory enhancement in other sensations, such as somatosensory or auditory in the egocentric frame of the listener.[4,5] Experiments have shown that the blind display more accurate localization in the peripheral auditory space.[6] Also, improved accuracy in sound localization has been reported even after blindfolding normal-sighted adults for just 90 minutes.[7] Further, spatial hearing tasks have been shown to elicit activation within the visual cortex of blind individuals, providing support to the model of cross modal neuroplasticity in the cortex.[8,9,10,11,12]

This view is opposed by the "Perceptual deficit hypothesis" which advocates that early visual experience has a profound influence on auditory learning and so, a deficiency in vision during development can impair spatial representation.[13] The calibration of auditory representation of space, in particular, is dependent on the visual feedback. This suggests that people born blind may develop cognitive spatial deficits in hearing especially in the allocentric frame of reference. Gori et al. showed that the performance of congenitally blind individuals was severely impaired in a spatial bisection task as compared to sighted individuals. In this task, the participants were required to indicate, out of the three presented sounds, whether the second was closer in space to the first or the third sound.[14, 15, 16]

It was noted that the ability of late blinds in localizing sounds in the allocentric frame had not been tested before. Keeping with these observations, it was hypothesised that late blinds would localize sounds as good as sighted controls in an allocentric frame, attributable to the normal uninterrupted feedback of the visual system on auditory learning, just like sighted controls.

Aims and Objective

To compare the ability of spatial localization of sounds in the late blind with normal sighted blindfolded controls by the methods of spatial bisection task and minimum audible angle task.

Subjects, Materials and Method

Subjects:

Ethical approval was obtained from the Institutional ethical committee as part of a larger Indian Council of Medical Research (ICMR) short term studentship project. Ten late blind (onset of blindness after 16 years) young adults of either gender were recruited from a recreational centre for the blind and eight normally sighted individuals who were age and gender matched were recruited from the staff of Bangalore Medical College and Research Institute to serve as controls.

Inclusion Criteria:

Only subjects who gave informed consent to participate in the study were included. For blind subjects, the informed consent was administered in Braille and they gave their consent with their left thumb impression.

Only subjects defined as 'Blind' (categories 4 and 5, World Health Organization classification) were included in the study.

The hearing threshold of all the subjects had to conform to the normal range and this was tested by audiometry.

Exclusion Criteria:

The subjects were requested to bring their medical reports and those with cognitive and neurological deficits were excluded.

Subjects with any other acute or chronic diseases were excluded.

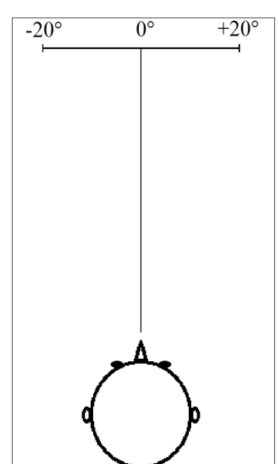
Materials:

The Audiometer mobile application 'Hearing Test version 1.1.2' (by developer: hearingtest@e-audiologia.pl), calibrated according to the default headphones of the phone was used.

The horizontal array of speakers was placed on a table 150 cm away from the height-adjustable chair where the subject was seated. An angle of 2° was maintained between adjacent speakers such that 21 speakers covered the total angular range of +20° to -20° with respect to the position of the subject. The speakers were Generic Passive 5Volt-Speaker modules, compatible with the Arduino microcontroller board. 'Arduino' is an open-source platform based on easy-to-use hardware and software that provides a programming tool, Arduino IDE (Integrated Development Environment), for writing code and uploading it to the Arduino board and was used in the study. The duration of sound production and intervals between successive sounds were programmed in the IDE software on the laptop to which the microcontroller was connected.

Methodology

All the experiments were performed in an anechoic room. First, the procedure was thoroughly explained to the subjects and any doubts were adequately clarified. The sighted controls were blindfolded.



Experimental Setup

A. Spatial Bisection Task

For this task, the subject was made to sit on a chair facing the array of speakers placed horizontally, 150cm away. The array of speakers was adjusted such that it was at the same height as the ears of the subject and the subject faced the centre of the array (0°). Three sounds each having a frequency of 1500 Hertz and lasting 75 milliseconds were played. The first sound was played from the first speaker at -20° to the subject's left. 500 milliseconds later the second sound was played from any one of the speakers from -18° to +18°. And after an interval of 500 milliseconds, the third and final sound was played from the last speaker at +20° to the subject's right. Then the subject had to indicate verbally whether the second sound seemed closer to the first sound (in which case "Left" was the correct response) or to the last sound ("Right" was the correct response). This concluded one trial. Thirty such trials were performed for each subject with the position of the second sound changing every time. The data recorded for each trial included (A) The angle at which the second sound was presented and (B) Whether the response of the subject was correct or incorrect with respect to the second sound being closer in space to the first or third sounds.

B. Minimum Audible Angle Task

In this task, the same setup was used as for the spatial bisection task. Here, two sounds 75 milliseconds long were presented successively with a 500 milliseconds interval. On the first trial, both the sounds were played from the central speaker (0°). Then the subject was required to indicate whether the two sounds seemed to come from the same location. Then, the first sound was played from the central speaker (0°), and the second sound from a speaker just adjacent to the central speaker (2°) and the question repeated and the response recorded. The trials were repeated with successive increase in angular distance of the second sound (2°, 4°, 6°, 8°) from the central speaker till the subject was able to distinguish the two sounds sources as separate and that angle was recorded as the Minimum Audible Angle. 5 sets of such trials were performed on each side of the central speaker alternately for each subject.

Statistical Analysis

Descriptive statistics were done and presented as Mean ± Standard deviation (SD). Inferential statistics for the spatial bisection task was done using Chi-square test and by independent t test for minimum audible angle task. A Graph was plotted using Microsoft Excel. P-value less than 0.05 was considered to be significant.

Observations and Results

Table 1: Descriptive Statistics for age and gender matching of the subjects

	Late blind n = 10	**Controls n = 8**	**P-value**
Age (in years)	27 ± 3	27 ± 1	P = 0.86
Gender (M : F)	7 : 3	5 : 3	P = 0.8625

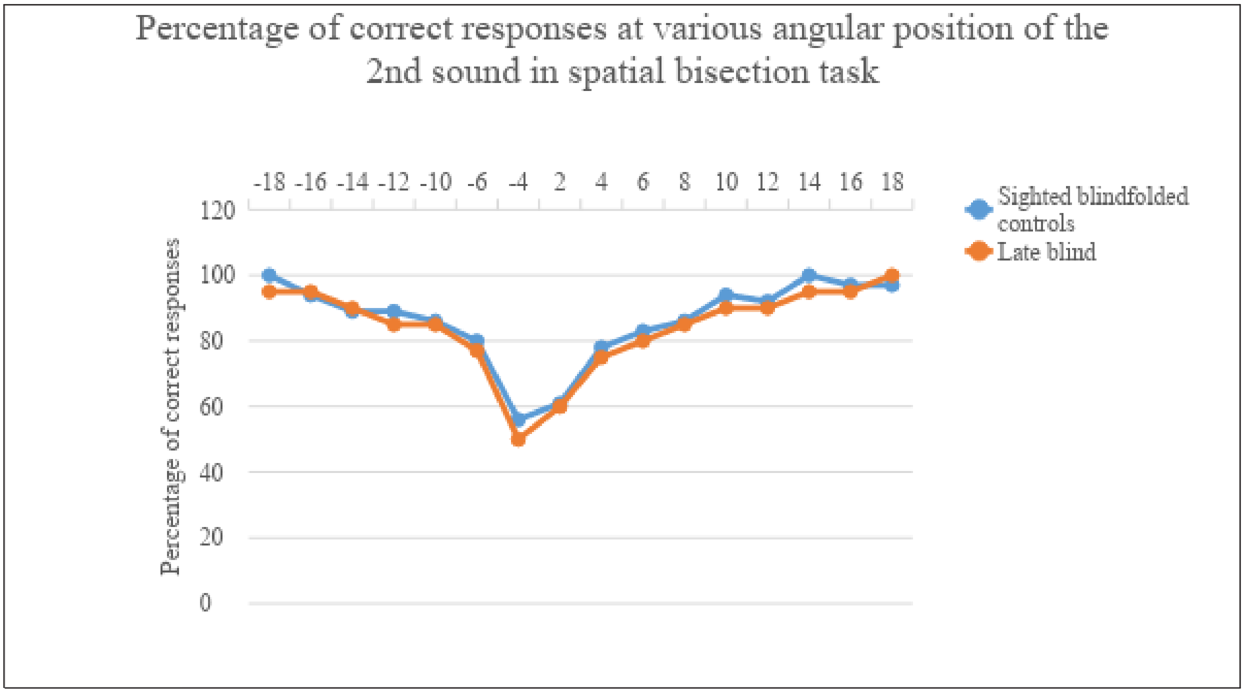
Table 2: Mean and Standard Deviation (SD) of the number of correct responses out of 30 trials per subject in the spatial bisection task

	Late blind n = 10	**Controls n = 8**	**P-value**
Number of correct responses (Mean ± SD)	26 ± 4	27 ± 2	P = 0.524
Percentage of correct responses	86%	89%	

Table 3: Comparison of proportion of right to wrong responses in the two groups for Spatial Bisection task

	Late blind n = 10	**Controls n = 8**
Number of correct responses	258	214
Number of wrong responses	42	26
Total	300	240

Chi-Square = 0.94, P-Value =0.3323



Graph 1: Percentage of correct responses at each angular position of the second sound in spatial bisection task

Table 4: Shows the minimum angular separation of the 2 sounds to be recognized as 2 distinct sound in minimum audible angle task.

	Late blind n = 10	**Controls n = 8**	**P-Value**
Minimum audible angle (left of the central speaker) (Mean ± SD) (in degrees)	4 ± 1	3 ± 1	P = 0.159
Minimum audible angle (right of the central speaker) (Mean ± SD) (in degrees)	4 ± 2	3 ± 1	P = 0.328
Minimum audible angle (mean of both sides) (Mean ± SD) (in degrees)	4 ± 1	3 ± 1	P = 0.230

Results

Table 1 shows the Mean ± Standard Deviation of ages, and the Male to Female ratios of the subjects in the 2 groups. The mean age was not significantly different between the 2 groups. The proportions of the genders were compared using Chi-Square test and the P-value was found to be insignificant.

Table 2 shows the Mean ± Standard Deviation of the number of correct responses of the subjects in the 2 groups in the spatial bisection task. The late blind and control group showed a mean of 26 and 27 correct responses respectively. The next row shows the percentage of correct responses.

Table 3 shows the proportion of correct to wrong responses in the 2 groups for spatial bisection task. Of the total of 300 trials in the late-onset blind subjects (30 trials each for 10 subjects), 258 were correct and 42 were wrong. Of the 240 trials in the sighted blindfolded controls, (30 trials for 8 subjects), 214 responses were right and 26 responses were wrong. Chi-Square test showed a significance of P=0.94. That means that the two groups were not significantly different from each other.

Graph 1 is plotted with the results of the spatial bisection task. While the X-axis of the graph denotes the angular position of second sound, the Y-axis shows the percentage of correct responses for the corresponding position. The graph shows that the accuracy is highest (100%) at the extreme positions of the second sound at ±18° when the second sound is closest to the first or third sounds and it is easiest to perform the spatial bisection task. The accuracy gradually reduces to 80% at ±6°. The accuracy drops to 50% at -4° when the second sound is close to the central speaker.

Table 4 shows the performance of the subjects in the minimum audible angle task. We observed that that there was no significant difference between the 2 groups.

Discussion

Mechanism of spatial localization of sound: A person determines the direction where the sound is coming from by two principal means. For frequencies below 2 kiloHertz, the time lag between the entries of sound into the two ears, known as Interaural Time Difference (ITD), is used to localize the sound. For frequencies above 2 kiloHertz, the shadowing effect of the head creates increasingly sizable differences in the intensity of the sounds at the two ears called as Interaural Level Difference (ILD). So, this mechanism is utilised for frequencies higher than 2 kiloHertz. The time lag mechanism discriminates direction more accurately than the intensity mechanism as it is only dependent on the exact interval of time between the signals and not on extraneous factors. Hence the sounds presented in our study were of the frequency of 1500 Hertz to enable better localization.[17]

Cross sensory calibration hypothesis states that when the sensory system is developing, the faster and more accurate system calibrates the other systems. Vision being faster and more accurate than hearing, calibrates spatial localization of sound during the developing years. Studies have shown that owls reared with distorted vision due to prisms attached to their eyes showed biases in sound localization. The spatial bisection task is based on the allocentric frame of reference. The study of Gori et al in this frame showed that early blind performed poorly in this task. The late blind were defined as those who develop complete blindness only after 16 years of age. During their childhood, their vision would have calibrated the spatial localization of sound. Hence we hypothesised that late blind must be similar in performance to normal controls. This had not been examined before our study. In accordance with this, our results show that they could perform the spatial bisection task as good as the sighted blindfolded controls.[18]

Strengths and limitations: Adequate age and gender matching ensured that sighted blindfolded controls were similar to the late blind in those aspects that would have otherwise been confounding factors. The use of Arduino microcontroller board ensured faster and more accurate testing.

The performance of spatial bisection by late blind in the vertical plane can be explored in further studies.

Conclusion

We found that the late blind performed as good as controls in the spatial bisection task and minimum audible angle task. This can be attributed to the intact vision of late blind during their developmental years which enables the calibration of the spatial localization of sounds, providing support to the cross sensory hypothesis.

Conflict of Interest: Nil

Source of Funding: Nil

Ethical approval: Obtained as part of Indian Council of Medical Research (ICMR) Short Term Studentship project from the Institutional Ethical Clearance Committee.

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References

1. Kosslyn SM. Seeing and imagining in the cerebral hemispheres: a computational approach. Psychol Rev. 1987 Apr;94(2):148–75.
2. Klatzky RL. Allocentric and egocentric spatial representations: Definitions, distinctions, and

interconnections. In Springer; 1998. p. 1–17.

3. Voss P. Auditory spatial perception without vision. Frontiers in Psychology. 2016;7.
4. Wan CY, Wood AG, Reutens DC, Wilson SJ. Congenital blindness leads to enhanced vibrotactile perception. Neuropsychologia. 2010 Jan;48(2):631–5.
5. Nilsson ME, Schenkman BN. Blind people are more sensitive than sighted people to binaural sound-location cues, particularly inter-aural level differences. Hearing Research. 2016 Feb;332:223–32.
6. Voss P, Lassonde M, Gougoux F, Fortin M, Guillemot J-P, Lepore F. Early-and late-onset blind individuals show supra-normal auditory abilities in far-space. Current Biology. 2004;14(19):1734–8.
7. Lewald J. More accurate sound localization induced by short-term light deprivation. Neuropsychologia. 2007 Mar 25;45(6):1215–22.
8. Burton H. Visual cortex activity in early and late blind people. The Journal of neuroscience. 2003;23(10):4005–11.
9. Leclerc C, Saint-Amour D, Lavoie ME, Lassonde M, Lepore F. Brain functional reorganization in early blind humans revealed by auditory event-related potentials. Neuroreport. 2000;11(3):545–50.
10. Gougoux F, Zatorre RJ, Lassonde M, Voss P, Lepore F. A functional neuroimaging study of sound localization: visual cortex activity predicts performance in early-blind individuals. PLoS Biol. 2005;3(2):e27.
11. Collignon O, Vandewalle G, Voss P, Albouy G, Charbonneau G, Lassonde M, et al. Functional specialization for auditory–spatial processing in the occipital cortex of congenitally blind humans. Proceedings of the National Academy of Sciences. 2011;108(11):4435–40.
12. Voss P, Lepore F, Gougoux F, Zatorre RJ. Relevance of spectral cues for auditory spatial processing in the occipital cortex of the blind. Frontiers in psychology. 2011 Mar 28;2:48.
13. Wanet MC, Veraart C. Processing of auditory information by the blind in spatial localization tasks. Perception & Psychophysics. 1985 Jan 1;38(1):91–6.
14. Gori M, Sandini G, Martinoli C, Burr DC. Impairment of auditory spatial localization in congenitally blind human subjects. Brain. 2014 Jan;137(Pt 1):288–93.
15. Gori M, Sandini G, Burr D. Development of visuo-auditory integration in space and time. Multisensory Perception and Action: psychophysics, neural mechanisms, and applications. 2012;28.
16. Vercillo T, Burr D, Gori M. Early visual deprivation severely compromises the auditory sense of space in congenitally blind children. Developmental psychology. 2016;52(6):847.
17. Grothe B, Pecka M, McAlpine D. Mechanisms of Sound Localization in Mammals. Physiol Rev. 2010 Jul 27;90(3):983.
18. Gori M, Sandini G, Martinoli C, Burr D. Poor haptic orientation discrimination in nonsighted children may reflect disruption of cross-sensory calibration. Current Biology. 2010 Feb 9;20(3):223-5.