Spatial and nonspatial peripheral auditory processing in congenitally blind people

Q C [a], M Z a a X a Z [a],

[a]D a P. , P U . , S a K La a C N . a L a , B N a U . , B , D a P. a I . S a E a , N a N a U . , C a , C a

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a . a a a a 1,2, / . a a 3,4. F a a a . a a a a . a . a . F a , a a . , a a - a a a a a a . a , a , a . a 5. E a a a a a a a a a a - . I a , , a a . a . a a . . a a (. . a) a , . a a A a a a a . a a a a a . . M . . . a a a a - a 4,5. O . T a a a . . . U a a a a a a , D . *et al.* [6] examined the effect of auditory attentional orienting on sound localization. Blind and sighted individuals showed similar attentional cueing effects despite the fact that the former exhibited shorter reaction times (RTs) than the latter when sound sources were placed at far-lateral locations. These results suggest that the improved auditory spatial abilities in blind people are independent of attentional orienting mechanisms. It is not clear, however, whether this conclusion is applicable when attention to nonspatial properties of peripheral sound is concerned.

The purpose of this study is therefore (i) to examine to what extent the processing of spatial and nonspatial properties of auditory stimuli in the periphery is altered in blind adults as compared with sighted adults; (ii) to investigate whether the attentional orienting mechanisms, specifically the mechanisms involving inhibitory processes, are altered by blind adults' general skills in processing spatial and nonspatial properties of the peripheral sound. We used the spatial and frequency cueing paradigms [7] and manipulated the location-based and frequency-based auditory inhibition of return (IOR) concurrently. Congenitally blind and normally sighted but blindfolded study participants were asked to perform spatial (detection and localization) or nonspatial (frequency discrimination) tasks on the same peripheral auditory targets. Both the general response speed and the pattern of IOR effects were then compared between the two groups.

IOR refers to the phenomenon that response to a target after an uninformative peripheral cue is delayed when the target appears at the cued than at an uncued location, if the stimuli onset asynchrony between the cue and the target is longer than 300 ms [8]. IOR is observed not only in the visual domain but also in the auditory domain, and for different properties of auditory stimuli, including location and frequency [7]. In a recent study, we investigated the interaction between location-based and frequency-based IOR effects (Q. Chen, M. Zhang, X. Zhou, in preparation). The cue and the target varied in terms of location and frequency and participants were asked to perform a target detection, localization or frequency discrimination task. Results showed that the patterns of interaction between spatial and nonspatial (frequency) IOR effects varied depending on the task demand. The present study applied these manipulations to both blind and sighted participants and examined whether early visual deprivation alters the spatial and nonspatial processing speed to peripheral auditory stimuli on the one hand and whether the altered perceptual processing speed in blind people changes their higher attentional orienting mechanisms on the other hand.

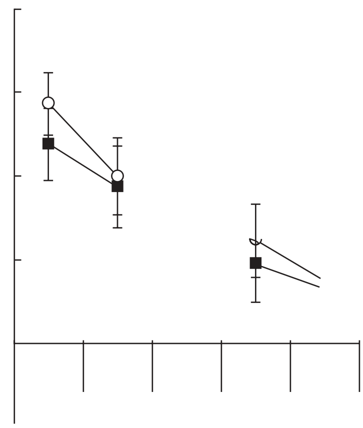
Method

Participants

A total of 57 normally sighted participants and 44 congenitally blind participants were tested, 16 sighted (eight women, age: 22 ± 2.3 years) and 14 blind (seven women, 21 ± 2.5 years) for experiment 1, 18 sighted (nine women, age: 21 ± 1.8 years) and 15 blind (seven women, age: 22 ± 2 years) for experiment 2, and 17 sighted (nine women, 22 ± 2.5 years) and 15 blind (seven women, 23 ± 1.2 years) for experiment 3. The two groups of participants were all right-handed without hearing deficits and were matched on educational level (all second or third-year undergraduate students). Informed consent was obtained from each participant and this study was approved by the Academic Committee of the Department of Psychology, Northeast Normal University, China.

Design and procedures

The three experiments used essentially the same design and stimuli. The cue–target correspondence in location (same vs.



(490 ms) than for sighted participants (594 ms). The interaction between location correspondence and frequency correspondence was significant [F(1,31)=15.34, $P<0.001$], suggesting that the location-based IOR effect when the cue and the target had the same frequency (3 ms) was smaller than the effect when they had different frequencies (31 ms). This interaction also suggested that the frequency-based IOR effect when the cue and the target were presented at the same location (−5 ms) was smaller than the effect when the cue and the target were at different locations (24 ms). Again, there was no three-way interaction (F<1), indicating that the above two-way interaction was manifested in the same way in the two groups of participants (see Fig. 1b).

For experiment 3, the main effects of location correspondence and frequency correspondence were not significant [F(1,30)=1.33, $P>0.1$; F<1]. The main effect of the participant group, however, reached significance [F(1,30)=5.23, $P<0.05$], indicating that the frequency discrimination of the peripheral sound was much slower in blind participants (591 ms) than in sighted participants (509 ms). The interaction between location and frequency correspondences was significant [F(1,30)=11.58, $P<0.005$] (see Fig. 1c). When the cue and the target were at the same location, responses were faster (15 ms) when they had the same frequency than when they had different frequencies. When the cue and the target were at different locations, responses were slower (17 ms) when they had the same frequency than when they had different frequencies. Alternatively, when the cue and the target had the same frequency, responses were faster (21 ms) when they appeared at the same location than when they were at different locations. When the cue and the target had different frequencies, responses were slower (11 ms) when they appeared at the same location than when they were at different locations. The three-way interaction was not significant (F<1), indicating that the above patterns of interaction were the same for the two groups of participants (see Fig. 1c).

Discussion

This study showed that blind participants were much faster than sighted participants at detecting and localizing the peripheral target after the cue while they were much slower at discriminating the frequency of the target. The altered global response speed to spatial and nonspatial information in blind participants, however, was not accompanied by changes in the mechanisms underlying location-based and frequency-based auditory IOR and their interactions. Blind and sighted participants showed exactly the same patterns of auditory attentional cueing effects. The pattern of interaction between location-based and frequency-based IOR in the spatial and nonspatial tasks replicated our previous study with normal individuals (Q. Chen, M. Zhang, X. Zhou, in preparation).

Human auditory information processing can be parceled into spatial ('where') and nonspatial ('what') streams [9–12], resembling the segregation in the visual system [13]. The anterior-ventral stream identifies auditory objects by recognizing spectral and temporal characteristics of auditory input, while the posterior-dorsal stream is responsible for sound-source localization. Early vision deprivation may enhance blind people's auditory processing along the 'where' pathway. For example, Röder *et al.* [5] demonstrated that blind individuals performed better than sighted individuals at localizing peripheral sound, and this superiority was accompanied by the significantly steeper N1 component in electrophysiological recordings. Importantly, the scalp topography of the enhanced N1 in the blind was shifted posteriorly while it was largest over the anterior in the sighted, implying that the 'where' pathway was more activated in blind than in sighted individuals. The present finding of superior performance of blind participants in peripheral detection and localization tasks provides further evidence supporting the enhanced functioning of the 'where' auditory pathway in blind people.

A novel finding in this study is that blind participants were slower than sighted participants in discriminating frequency of the peripheral sound, a finding that differs from earlier studies showing that blind people could perform better in processing 'what' information when the input is from the central space [3]. This discrepancy might be caused by different roles that nonspatial information plays in central and peripheral auditory processing. When the sound is from the periphery, knowing 'where' it comes from is more important for blind people to update the representation of the environment and to avoid danger than knowing 'what' it is. For example, while crossing the road, the most important information for the blind is whether there is a vehicle coming and the direction from which it comes. Knowing what specific type of vehicle is coming is not so crucial. Indeed, anecdotal evidence shows that when blind people do need to know the identity of a stimulus, they usually turn their heads and render the stimulus in the central auditory space. Such ecological practice may have developed to minimize the activation of the 'what' pathway when the sound comes from the periphery. More stringent studies, however, should be carried out to test this suggestion.

Obviously, the alternation of processing speed in the blind is not accompanied by changes in attentional orienting mechanisms, as blind and sighted participants showed exactly the same patterns of attentional cueing effects. This argument is consistent with that of Després *et al.* [6] who also observed the dissociation between general response speed and the pattern of attentional cueing effects in blind people. This argument is also consistent with results of brain imaging studies on auditory processing in blind people [14,15]. These studies found that brain regions responsible for early sensory processing are reorganized to compensate for vision deprivation, such that occipital and temporal cortices are more sensitive to auditory input in blind than in sighted people. For example, a recent positron emission tomography study showed that blind individuals used occipital regions to carry out auditory localization under monaural conditions [16]. No evidence, however, suggests that such reorganizations in cerebral structures and functions involve attentional orienting mechanisms in the parietal cortex and frontal oculomotor regions. In other words, structural and functional reorganizations in the brain, due to vision deprivation, affect perceptual processing in blind people but have no impact upon higher level attentional orienting mechanisms, which can be localized to higher cortices.

Conclusion

Early vision deprivation in blind people enhances the spatial processing but impairs the nonspatial processing of peripheral auditory information. The altered processing speed in the blind, however, is not accompanied by alteration in attentional orienting mechanisms.

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