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AUDITORY LOCALIZATION IN NORMAL HEARING ADULTS AND CHILDREN: EFFECTS OF NOISE

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ABSTRACT

Background: Noise has detrimental effects on auditory system and its functioning. Auditory localization (AL), which is the ability to identify the sound source, also deteriorates in presence of background noise. But only limited literature in available on this subject. In this study we investigated differential impact of noise on the auditory cues, interaural level differences (ILD) and interaural time differences (ITD) that helps in AL. Adult-children performance in terms of their AL abilities in presence of noise was also compared. **Method:** Twenty normal hearing adults (NHA; aged 18 to 30 years) and 25 normal hearing children (NHC; aged 7 to 12 years) participated in this study. Each participant was required to complete AL task in four conditions; quiet, soft noise, moderate noise and loud noise. Target stimuli, 500 Hz and 4000 Hz pure-tones, were always presented at 50 dB SPL. Noise intensity in soft noise, moderate noise and loud noise conditions were 40 dB SPL, 50 dB SPL and 60 dB SPL respectively. There were nine loudspeakers arranged in a circular fashion at an angle of 45^o from each other for AL experiment. **Results:** AL performance was analyzed by calculating rmsDOEs (root mean square degree of error) in all the participants for each azimuth (0^{o,} 90^o, 180^o and -90^o) in various conditions (quiet, soft noise, moderate noise and loud noise) at 500 Hz and 4000 Hz. Repeated measures of analysis of variance (RM-ANOVA) showed significant effect of stimulus frequencies, loudspeaker azimuths, noise conditions and groups on AL performance. **Conclusion:** Introduction of noise resulted in poor AL abilities with the noise effect getting worse as noise levels were increased. In all the conditions AL was better for the sound source placed in the frontal plane when compared to medial plane. In-noise localization errors were more for high frequency stimulus in comparison to low frequency. Adults and children performances were significantly different in quiet as well as in noisy conditions.

KEYWORDS: Auditory localization, azimuth, interaural level differences (ILD), interaural time differences (ITD), rmsDOE (root mean square degree of error).

1. INTRODUCTION

Every sound has an origin and every origin a geometric location. In hearing science the ability to locate geometric location of the sound source is called auditory localization (AL). Just like other auditory processes, AL also get affected in the presence of noise but there are only few studies that have investigated the noise impact on AL.[1-4] Good and Gilkey[1] suggested poor AL at lower signal to noise ratio (SNR) with more adverse effect on AL in frontal plane (front/back) when compared to medial plane (right/left). Lorenzi, Gatehouse and Lever[2] found no noise effect on AL at 0 SNR and above regardless of the noise location. AL was degraded at low SNRs. Similar results were also found by Good, Gilkey and Ball.[3]

Auditory cues that help in AL are interaural level differences (ILD) and interaural time differences (ITD)/interaural phase differences (IPD).[5] ILDs are responsible for AL of high frequency sounds while ITDs/IPDs of low frequency sounds.[5] Though previous studies have described the effect of noise on AL but the relative impact of noise on ILD and ITD is not clear. Only Lorenzi, Gatehouse and Lever[2] described the differential effect of noise on ILD and ITD cues in terms of noise azimuth. They found equal effect of noise on ILD and ITD cues when the noise presentation was from 0^o azimuth. ITD cues were less affected when the noise was presented from +/- 90 azimuths in comparison to ILDs. One of the objectives of this study was to investigate in details the differential impact of noise on ITDs and ILDs.

Adult-children differences have been established in task involving speech perception in presence of noise.[6] Some differences have also been suggested between adults and children in terms of AL.[7,8] However, differences in their AL abilities in presence of noise are rarely studied. In one study, Humes, Allen and Bess[4] found higher index of localization error in children when compared to adults. To understand these differences in depth we extended this study to compare AL performances of normal hearing adults (NHA) and normal hearing children (NHC) in presence of noise.

2. METHOD

2.1 Participants
Twenty NHA (aged 18 to 30 years) and 25 NHC (aged 7 to 12 years) participated in this study. All the participants had normal hearing sensitivity, normal middle ear functioning, normal cochlear functioning and no complains of neurological, cognitive or otological problems. Consent was obtained from all the participants before participating in the study. In case of NHC, parents were also asked to sign the consent form.

2.2 Test stimuli
Low frequency (500Hz) and High frequency (4000Hz) pure-tones were used as target stimuli for AL. This study was intended to see the differential effect of noise on ITD and ILD cues and hence the selection of tone was based on the fact that low and high frequency AL is based on the processing of ITD and ILD cues respectively. Target stimuli were generated using Adobe Audition 3.0 software and with 50 ms ramping so to avoid electrical click in the beginning of the stimulus presentation that may cause AL judgement problems. Duration of each target stimulus was 2 second. White noise was used as the background noise.

2.3 Localization set-up
Set-up for AL experiment consisted of nine loudspeakers arranged in a circular fashion at an angle of 45° from each other (Figure 1). Loud speakers (Genelec 8020B speakers) were mounted on Iso-Pod™ (Isolation osition/decoupler™) vibration insulating table stand and were connected to a personal computer with CuBase 6 software (Figure 1) for stimulus and noise presentation. Calibration of loudspeakers was done using a Larson-Davis system 824 (model no. 2540) sound level meter. Stimuli were presented from loudspeakers located at 0°, 90°, 180° and -90° azimuths. At 0° azimuth there was an additional loudspeaker for noise presentation. This loudspeaker was kept a little elevated than the other loudspeaker at 0° azimuth used for presenting stimulus. Loudspeakers located at 45°, 135°, -135° and -45° azimuths were dummy speakers which were used to increase the precision of localization errors.

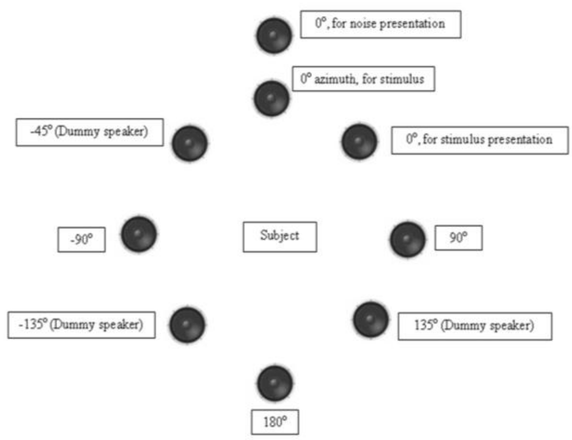

Figure 1: Experimental setup for estimating AL abilities.

2.4 Procedure
Participants were asked to sit in the centre of experimental set-up (in a sound treated room) at a distance of 1 metre from each loudspeaker. Each participant completed AL task in four conditions; quiet, soft noise, moderate noise and loud noise. They were instructed to hear pure-tone stimulus and point towards the location of its source. Target stimuli, 500 Hz and 4000 Hz pure-tones, were always presented at 50 dB SPL. Noise intensity in soft noise, moderate noise and loud noise conditions were 40 dB SPL, 50 dB SPL and 60 dB SPL respectively. In noise conditions, white noise was presented continuously. 500 Hz and 4000 Hz pure-tones were presented in random order in all the four 4 conditions. Randomization of stimuli was done using Random Integer Generator software. In all the conditions, 5 stimuli each of 500 and 4000 Hz were presented from each loudspeaker at 0°, 90°, 180° and -90° azimuth. In total there were 40 presentations in each condition, 20 at 500 Hz and 20 at 4000 Hz. Prior to the start of experiment, during training, two trail stimuli were given from each speaker to make participant familiar to the task and stimuli.

2.5 Analysis
In this study, root mean square of degree of error (rmsDOEs) was calculated in each participant to quantify the AL abilities. For that purpose, first degree of error (DOE) in AL was measured for every trial. Degree of error is the difference in degree between the degree of azimuth of the loudspeaker identified as the source of the stimulus by the participant and the degree of azimuth of the loudspeaker of actual presentation of the stimuli. Following this, rmsDOE was calculated for each azimuth of stimulus presentation in all the conditions. There were 5 trails for each azimuth and therefore five degree of errors was used to calculate rmsDOE for that azimuth. Formula used for calculating rmsDOE was adopted from Letowski and Letowski.[9]

$$\text{rms DOE} = \sqrt{\frac{(DOE)_1^2 + (DOE)_2^2 + (DOE)_3^2 + \ldots + (DOE)_5^2}{5}}$$

Where, $DOE_{1\text{-}5}$= Degree of Error for five trials; and rms DOE = Root mean square degree of Error.

3. RESULTS

rmsDOEs were calculated in all the participants for each azimuth ($0^{o,}$ 90^o, 180^o and -90^o) in various conditions (quiet, soft noise, moderate noise and loud noise) at 500 Hz and 4000 Hz. Repeated measures of analysis of variance (RM-ANOVA) was performed to see the effect of various independent variables (frequency of stimulus, azimuths of loudspeakers, noise conditions and groups) on AL which was the dependent variable in this study. It is to be noted that rmsDOE is calculated as the measure of AL abilities where in higher rmsDOE indicate poor AL abilities and vice-versa.

Results showed a significant effect of noise conditions on AL abilities in both the groups [$F(1.511, 64.973)=414.886$; $p < 0.001$]. As can be seen in figure 2 and 3, rmsDOEs were more in noise conditions when compared to quiet condition and AL abilities got worsen as the noise levels were increased. The two groups were significantly different in quiet condition as well as in noisy conditions [$F(1, 43)=10.868$; $p = 0.002$]. The effect of noise was more adverse in NHC when compared to NHA (Figure 2 and 3). There was a significant group-condition interaction [$F(1.511, 64.973)=3.451$; $p = 0.05$] which on further analysis using pair wise comparison revealed that NHA had similar AL performances in quiet and soft noise condition ($p = 1.000$). All the other conditions were significantly different in NHA and in NHC as per the main effect of condition.

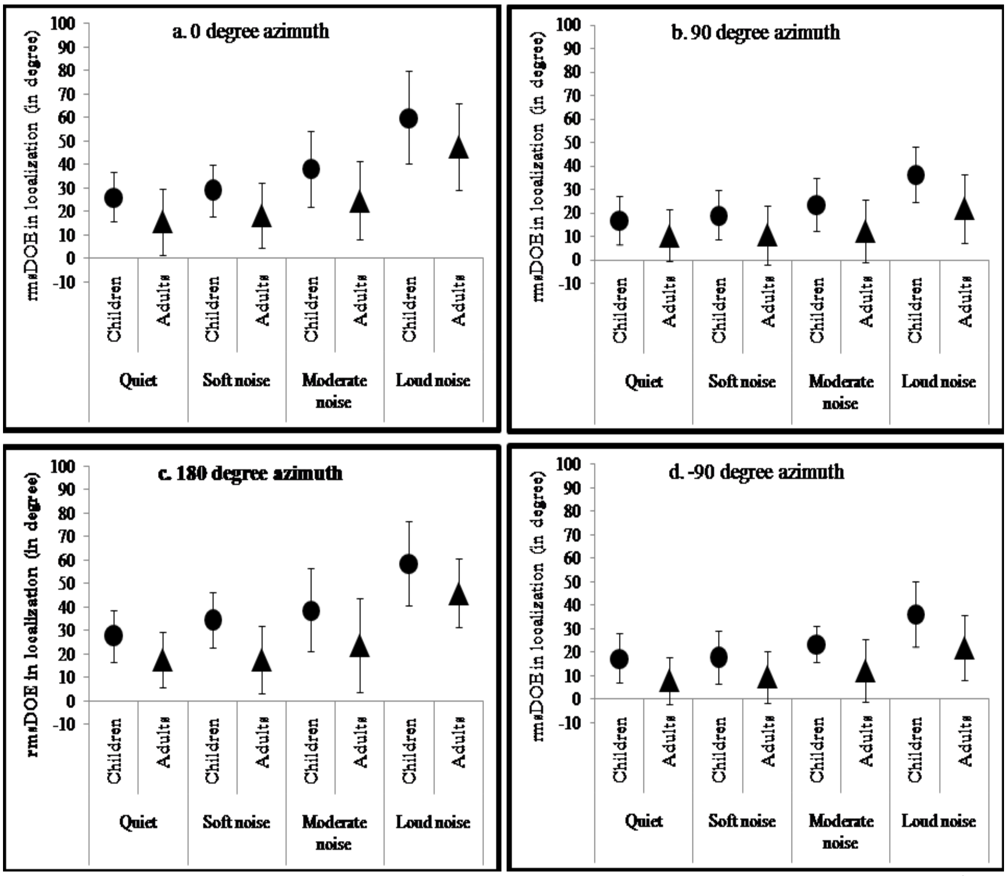

Figure 1: Mean and standard deviation of rmsDOEs in NHC (circles) and NHA (triangles) at 0^o (a)' 90^o (b), 180 (c) and -90^o (d) azimuths in quiet, soft noise, moderate noise and loud noise conditions for 500 Hz pure-tones.

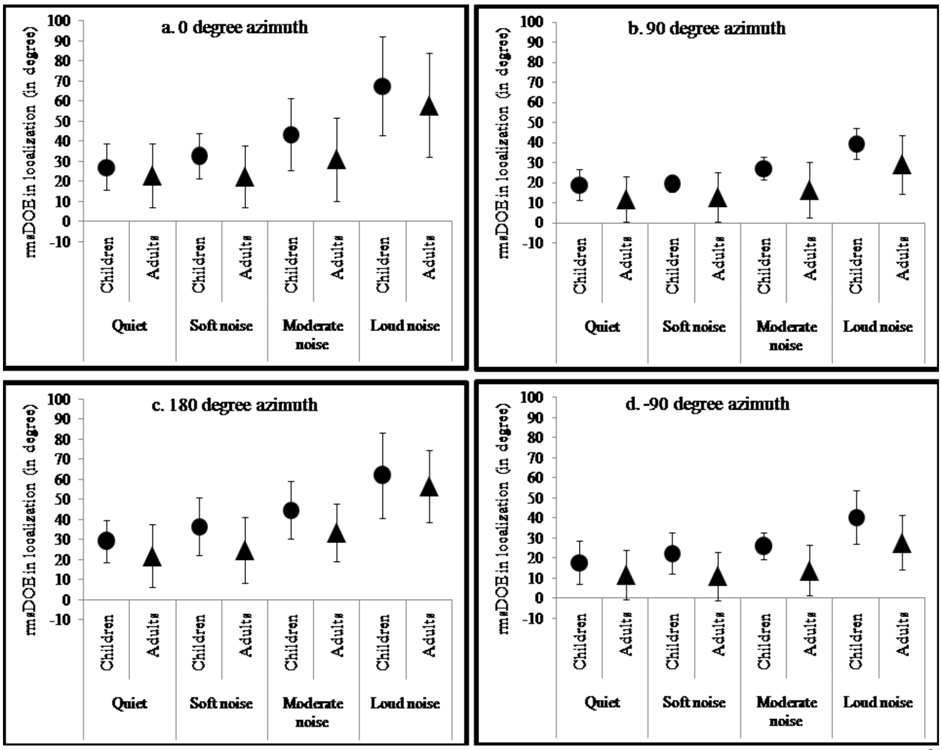

Figure 3: Mean and standard deviation of rmsDOEs in NHC (circles) and NHA (triangles) at 0^o (a), 90^o (b), 180 (c) and -90^o (d) azimuths in quiet, soft noise, moderate noise and loud noise conditions for 4000 Hz pure-tones.

rmsDOEs changes significantly depending upon the loudspeaker azimuth [$F(1.766, 75.949)=130.168$; $p < 0.001$]. Pair wise comparison showed significantly poor AL in frontal plane (front/back; $0^o/180^o$) when compared to medial plane (left/right; $-90^o/90^o$) [Figure 4 and 5]. However, no significant differences were found between 0^o and 180^o ($p=1.000$) & 90^o and -90^o ($p=1.000$) AL abilities. In terms of target stimulus's frequency, ALs at low frequency (500 Hz) was significantly better than the high frequency (1000 Hz) in all the condition in both the groups [Figure 4 and 5; $F(1, 43)=27.741$; $p < 0.001$].

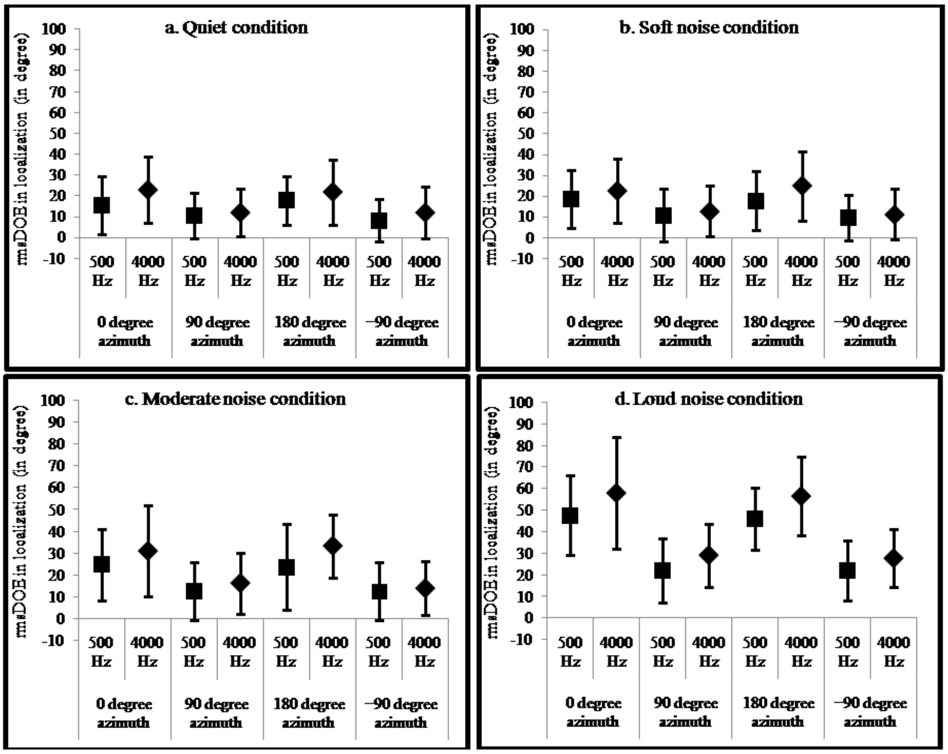

Figure 4: Mean and standard deviation of rmsDOEs at 500 Hz (squares) and 4000 Hz (diamonds) pure-tones in quiet (a), soft noise (b), moderate noise (c) and loud noise (d) conditions at 0^o, 90^o, 180 and -90^o azimuths in NHA.

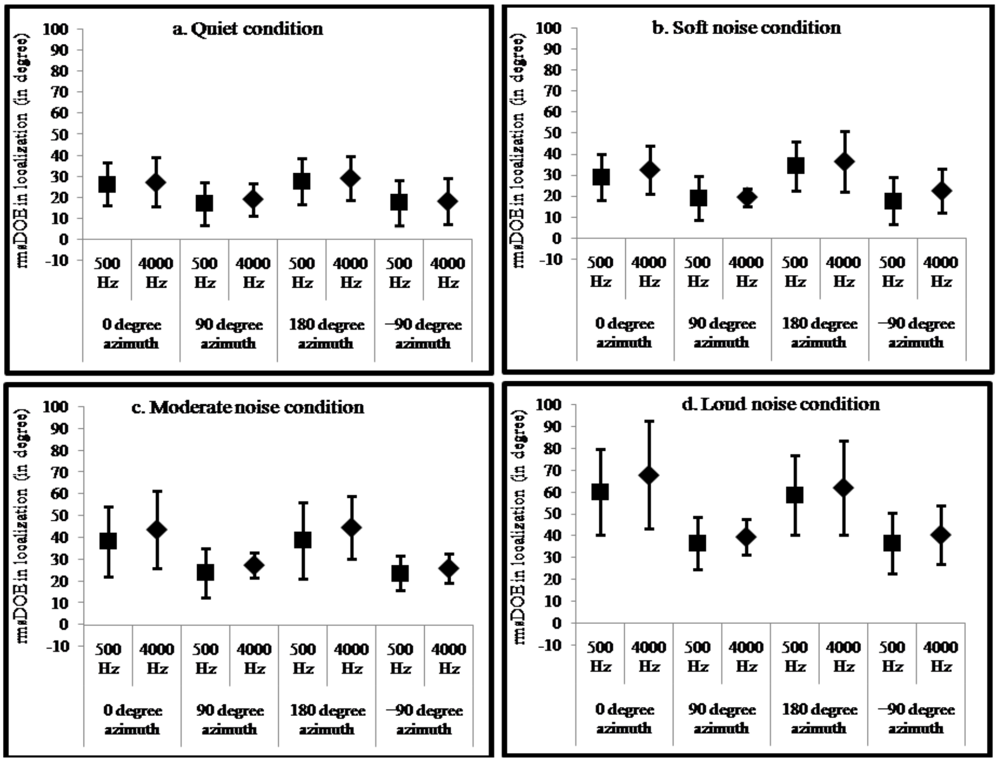

Figure 5: Mean and standard deviation of rmsDOEs at 500 Hz (squares) and 4000 Hz (diamonds) pure-tones in quiet (a), soft noise (b), moderate noise (c) and loud noise (d) conditions at $0^{o,}$ 90^{o}, 180 and -90^{o} azimuths in NHC.

4. DISCUSSION

This study investigated AL abilities in NHA and NHC at 500 and 4000 Hz pure-tone stimuli in quiet and in presence of noise (soft, moderate and loud noise) with target sound source placed at different azimuths ($0^{o,}$ 90^{o}, 180 or -90^{o}). Previous studies have suggested that AL development complete by the age of 6 years.[7,8,10] However in this study NHC demonstrated significantly poor AL abilities when compared to NHA in quiet condition. Reason for this disparity could be the different research methods adopted in this study.

Presence of noise deteriorated AL abilities in both NHA and NHC with the only exception of soft noise condition, in which the adult's performance remained unaffected. AL abilities in both NHA and NHC got worsened with the increase in noise levels, NHC showing greater impact of noise when compared to NHA for any noise condition. These findings were similar to Humes, Allen and Bess.[4] Other inferences for these results can be drawn from the results of speech perception in noise experiments where poorer perception of speech in presence of noise is reported in NHC in comparison to NHA.[6,11,12]

In the classical experiment of localization, Steven and Newman[13] found that localization errors for pure-tones were more prevalent at high frequencies especially above 3000 Hz. Sandel, Teas, Feddersen and Jeffress[14] also observed similar results. These studies have reported different localization abilities at low and high frequency in terms of mean of localization errors, no advanced statistical analysis was performed. Continuous with these results this study has also indicated greater rmsDOEs, indicating poor AL abilities, at 4000 Hz in comparison to 500 Hz in both NHA and NHC in quiet conditions for all the azimuths of signal presentations.

There is discrepancy in literature about the differential effect of noise on AL abilities at low and high frequency stimuli. Humes, Allen and Bess[4] suggested lower AL errors at low frequency (500 Hz) in comparison to high frequencies (4000 Hz). Good and Gilkey[1] & Lorenzi, Gatehouse and Lever[2] found that AL abilities at low and high frequency sounds are equally affected by noise. Results of this study showed greater impact of noise on AL abilities at high frequency in comparison to low frequency. Differential AL abilities at low and high frequency in presence of noise might be related to the processing of localization cues in the presence of noise. AL of low frequencies is based on decoding of ITD cues, while of high frequencies on ILDs.[5] ITD cues are dependent on time difference between two ears and ILD on level of the signal difference. Noise might have masked the smaller intensity level cues between ears and thereby cause a reduction in AL abilities which is dependent on ILDs. Noise also affected ITD cues as higher rmsDOEs were found at 500 Hz in noise conditions but in comparison to 4000 Hz the effect was smaller.

Front-back AL confusions are always evident in literature.[15] Addition of background noise further increases confusion in front-back AL.[1] Continuous with these studies, AL in frontal plane (front-back/ 0^{o}-180^{o}) was found to be poorer in comparison to medial plane (left-right /-90°─90°) in both quiet and noise condition. These findings point towards enhanced AL confusions in presence of noise.

5. CONCLUSIONS

Continuous with the findings of previous studies this investigation also concludes a significant effect of noise on AL. Comparatively the effect of noise was more adverse in NHC when compared to NHA. In either of the groups AL at low frequency was superior to high frequency at various noise levels. Magnitude of error in AL was higher for sound source in the frontal plane in contrast to the medial plane.

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Conflicts of Interest: None.

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