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Impact of unilateral hearing loss on sound localization

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Abstract

The impact of unilateral hearing loss on the localization of horizontal plane sound sources ipsilateral and contralateral to the side of the unimpaired ear was examined. Normal-hearing listeners judged the direction of six loudspeakers, separated by 30° and arrayed frontally or laterally on the right side with the right or left ear occluded. The benefit of massed practice over three sequential days was assessed. For the frontal loudspeaker array, azimuthal discrimination on the occluded side was poor but only 30% of sounds were perceived to come from the unoccluded side. For the right lateral array, when the ipsilateral ear was unoccluded, front and back were rarely confused. Accuracy mainly decreased for speakers close to the midline axis, front and back. When the contralateral ear was unoccluded responses were biased toward the rearmost speaker. Practice did not improve performance. The findings were discussed within the context of military operations. They support the need for job-specific hearing standards.

Keywords: Unilateral hearing loss; Directional hearing; Military medicine

1. Introduction

Asymmetrical hearing loss is not uncommon in military personnel, particularly those in combat arms trades (e.g., infantry) who use small-calibre weapons regularly [1–4]. Generally, hearing is worse in the ear on the side opposite the shoulder that supports the firearm. Since situational awareness is critical in field operations, it is important to characterize deficits in auditory perception that may result from unilateral impairment. The present study determined the extent to which imposed unilateral hearing loss affected frontal and lateral horizontal plane sound localization ability, and whether observed performance decrements might be reduced with massed practice in the short-term.

It is well understood that the ability to localize the source of sound in space depends on the encoding of both binaural cues (interaural differences in time-of-arrival and intensity of sound at the two ears) and spectral cues provided by the pinnae of the ears [5]. Binaural cues enable discrimination of azimuth angles within and between left and right sides of space. Spectral cues primarily enable elevation discrimination within the cone-of-confusion, including the special case of discrimination of front from rearward speakers in horizontal arrays. Spectral cues operate optimally for frequencies above 4 kHz [6]. In studies of monaural localization, typically normal-hearing subjects are made unilaterally deaf by inserting an earplug in one ear, and covering the pinna of that ear with a muff. The question of interest is whether these subjects have the ability to localize using only the spectral cues provided by the pinna of the unoccluded ear. Wightman and Kistler [7] have argued that even with the plug and muff in place, subjects may have some residual hearing on the occluded side, giving rise to binaural cues. They caution that reducing the level of the stimulus to ensure monaural hearing may have the undesirable effect of also diminishing spectral cues provided by the unoccluded ear.

Many studies of monaural sound localization have been conducted over the past 25 years. Outcomes were highly dependent on the frequency and bandwidth of the sound to be localized [8,9], the orientation of the speaker array,

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whether horizontal or vertical [10], and the amount of practice given subjects [11]. In a classic study, Oldfield and Parker [12] tested blindfolded subjects with the right ear occluded on their ability to discriminate among speakers arrayed laterally on the left side from 0° to 180°, and elevated between −40° and +40°. A white noise stimulus ensured that subjects would have access to the high frequencies required for the operation of pinnae-based spectral cues. Subjects were able to distinguish front from back on the unoccluded side with only a slight decrement in performance. However, auditory space was compressed to between 30° and 150°, with large azimuthal errors for loudspeakers close to the median plane. Elevation discrimination appeared to be unrelated to azimuthal accuracy and was largely unaffected.

In a study of learning effects, Musicant and Butler [13] demonstrated a significant advantage of massed over distributed practice, one session of 60 trials vs one trial a day for 60 days, on the discrimination of a lateral array of speakers on the side of the unoccluded ear. They concluded that massed practice led to an enhanced central representation of auditory space. In a later study, Slattery and Middlebrooks [14] evaluated the benefit of long-term practice by comparing the performance of normal-hearing sighted subjects, monaurally and binaurally, and unilaterally impaired patients, using a horizontal array of speakers positioned at azimuth angles between −160° and 160°. Normal-hearing subjects listening with one ear plugged showed displacements of about 30° toward the unoccluded ear. No practice effect was observed in the short-term over a 24-h period. The patients showed a range of capability, some with near normal outcomes, indicating the possibility of complete adaptation in the long-term. Long-term adaptation has also been demonstrated in animal models. King et al. [15] found that auditory localization in the adult ferret improved after several months of monaural occlusion, although not to the level observed before plugging.

In the present study of monaural hearing, the discrimination of loudspeakers in horizontal frontal and right lateral arrays was studied separately, so that the utilization of binaural cues and binaural and spectral cues in combination, respectively, could be evaluated. A comparison was made of listening with the unoccluded ear on the side ipsilateral and contralateral to the speakers. The benefit of massed practice over consecutive days was also assessed.

2. Experimental design

The study protocol was approved by the Defence Research and Development Canada Human Research Ethics Committee. Normal-hearing men and women, aged 18–35 years, were eligible to participate. Normal hearing was defined as hearing thresholds no greater than 15 dB HL in each ear and an interaural difference in threshold no greater than 10 dB at 0.5, 1, 2 and 4 kHz [16]. The latter constraint was included to minimize a possible bias in sound localization due to an existing asymmetry in hearing. Previous studies have demonstrated that there is a decrease in the accuracy of sound localization with age, starting in the mid 1930s [17]. However, no gender effects have been identified [18]. All subjects were right-handed to avoid confounding by possible differences in laterality of brain function. All had no difficulty seeing at close range and were tested without blindfolding. Research has shown that deprivation of sight results in performance decrements in sound localization [19].

Subjects were tested individually while seated in the centre of a double-walled, semi-reverberant sound proof booth (IAC Series 1200) with inner dimensions of 3.5 (L) × 2.7 (W) × 2.3 (H) m. This facility models listening in a small office [20]. Sound localization ability was assessed using two different arrays of six loudspeakers (frontal and right lateral) in the horizontal plane. For the frontal array the loudspeakers were positioned 30° apart at the following azimuth angles: 285° (−75), 315° (−45), 345° (−15), 15°, 45° and 75°, relative to the straight ahead (0°). The loudspeakers for the right lateral array were positioned at 15°, 45°, 75°, 105°, 135°, and 165° (see Fig. 1). The speakers in each array were chosen to be either right/left or front/back symmetric to enable an assessment of reversal errors across the midline and interaural axes of the head. Previous research in normal-hearing subjects has shown that front/

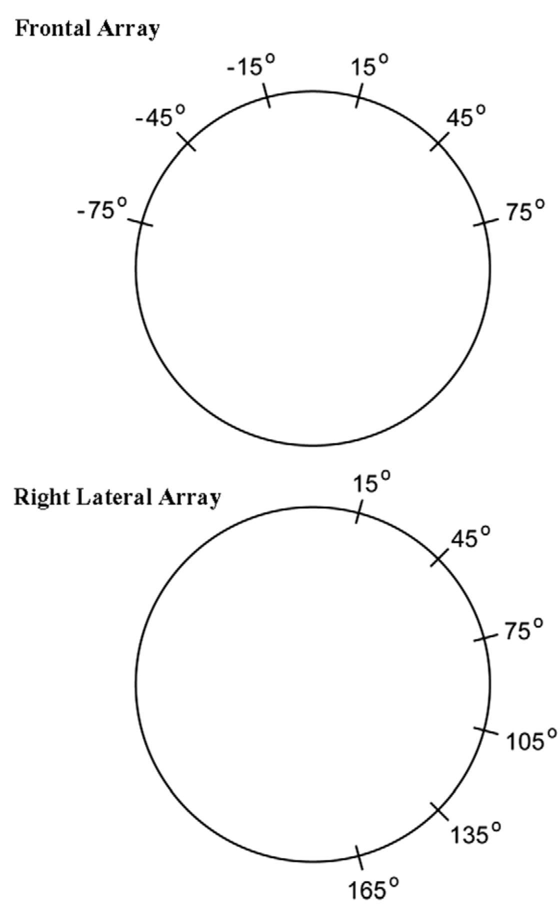

Fig. 1. The two arrays. Top and bottom illustrations show the frontal and right lateral arrays, respectively.