Europe PMC Funders Group
Author Manuscript
Adv Exp Med Biol. Author manuscript; available in PMC 2014 June 24.

Published in final edited form as:
Adv Exp Med Biol. 2013 ; 787: 303–310. doi:10.1007/978-1-4614-1590-9_34.

Measuring the apparent width of auditory sources in normal and impaired hearing

William M Whitmer,
MRC Institute of Hearing Research (Scottish Section), Glasgow Royal Infirmary, Glasgow, G31 2ER

Bernhard U Seeber, and
MRC Institute of Hearing Research, University Park, Nottingham, NG7 2RD, United Kingdom

Michael A Akeroyd
MRC Institute of Hearing Research (Scottish Section), Glasgow Royal Infirmary, Glasgow, G31 2ER

Abstract

It is often assumed that single sources of sound are perceived as being punctate, but this cannot be guaranteed, especially for hearing-impaired listeners. Any impairment that gives a reduction at the periphery in the accuracy of coding fine-scale temporal information must give a slight interaural jitter in the temporal information passed to higher centres, and so would be expected to lead to an effective reduction in the interaural coherence (IC) of any stimulus. This would lead to deficits in locating sounds, but deficits of imprecision, not inaccuracy. In turn, this implies that older hearing-impaired individuals should have a diminished perception of auditory space, affecting their abilities to perceive clear, concise, punctate spatial impressions or to separate sounds by location. The current work tested this hypothesis by using two separate visual-analogy methods to measure auditory source width for broadband sounds. In one method, the listener sketched the auditory image, a visual description task, and for the other, the listener selected the closest one of a set of pre-drawn visual sketches (note that the first is an open-set experiment, whereas the second is a closed-set experiment). We found that older hearing-impaired listeners had increased difficulty in judging changes in interaural coherence, showing a corresponding insensitivity to auditory source width in the visual-analogy tasks.

Keywords

Spatial hearing; hearing impairment; auditory source width; interaural coherence; effects of aging; auditory-visual cross-mapping tasks

1. Introduction

When a sound is coherent, the acoustic information arriving at the two ears is the same. Architectural acoustics studies have shown that these sounds are perceived as punctate

Corresponding author: W. Whitmer, bill@ihr.gla.ac.uk.

Europe PMC Funders Author Manuscripts

images by normal-hearing (NH) listeners. The reflections encountered in most spaces create interaural differences, decreasing the similarity between the sounds reaching the two ears. This can be measured by *interaural coherence* (IC), the normalized peak in the interaural cross-correlation function. The NH listener perceives these less interaurally coherent sounds as broader, more diffuse sounds.[1] While it has been shown across numerous methods that IC affects the width of sounds for normal-hearing listeners (e.g., Keet, 1968), less is known about how it affects the perception of width by older, hearing-impaired (HI) listeners.

There is indirect psychophysical and physiological evidence to suggest that older HI individuals do perceive sound sources differently. In comparisons of the azimuthal localization of broadband sounds, older HI listeners have shown roughly three-fold increases in imprecision – the intrasubject variability or scatter – relative to younger NH groups, though without showing significant changes in location bias (e.g., Lorenzi et al., 1999a & 1999b; Dobreva et al., 2011). Furthermore, the ability to discriminate dichotic from diotic stimuli using supra-threshold interaural time and phase information has been shown to decrease with age (e.g., Hermann et al., 1977; Grose & Mamo, 2010). Physiological examinations of the coding of sound-source location have shown broader tuning and decreased sensitivity along the aged auditory pathway (cf. Ison et al., 2010). This evidence, however, can only *suggest* that there are age and impairment related differences in the spatial percept of sound sources, not *show* these differences.

A recent study by Boyd et al. (2012) has shown that hearing loss can contract the externalization of sounds. Impulse responses from loudspeakers in the front hemifield separated by 30° at a 3-m radius were recorded with and without the listener present. Mixes between the head and no-head impulse responses were convolved with speech, and then the resulting stimuli were presented to younger NH and older HI listeners who were asked to rate the perceived depth on a continuous, semantically anchored egocentric scale. While NH listeners rated sounds to shift from *inside their head* to *at the loudspeakers* with increasing mixes of their individualized impulse response, HI listeners rated sounds to only move from *at their ear* to *in the room*. That is, the older HI listeners' results suggest a reduced perceptual range along the radial dimension.

How these age and impairment changes affect spatial perception can be most easily demonstrated using visual analogies to acoustic space. Licklider and Dzendolet (1948) first reported a visual analogy to the diffuseness of sounds based on IC by mixing three independent noises to the *x*- and *y*-axis inputs of an oscilloscope. Pollack (1960) used this method to visually replicate IC discrimination thresholds (Pollack & Trittipoe, 1959). Plenge (1972) used a visual-description method to demonstrate the varying percept of sound-source size. The stimuli were two independent narrowband noises (400-Hz centre frequency, 300-Hz bandwidth) that were mixed at varying ratios into two channels to vary the IC. The two channels were presented through two loudspeakers in an anechoic chamber to 12 NH listeners who sketched the size of the stimuli onto paper showing the placement of the

[1]The focus here is on the interaural disparities that cause changes in source width, which distinguishes the study of auditory source width from the early twentieth century behaviourist studies of "tonal volume" that examined pure-tone frequency difference limens by means of the assumption that higher frequency tones sound more punctate than lower frequency tones (e.g., Rich, 1916).

loudspeakers, themselves and the walls (i.e., a floor-plan view). Near-diotic stimuli – where the second noise was attenuated more than 25 dB – were drawn as small shapes between the loudspeakers; but when the second noise was attenuated by only 4 dB, the widths of the responses covered the separation of the loudspeakers. Blauert and Lindemann (1986) further explored changes to the size of sketched responses based on the IC. They used pink and bandpass noises presented over headphones. The total proportion of area within the head taken by sketches was measured and analyzed: fully coherent stimuli were drawn significantly smaller than partially coherent stimuli, but partially coherent stimuli, with ICs of 0.25-0.75, did not have significantly different sizes. Partially coherent stimuli were often drawn as two events (just inside the ears) or three events (centre and ears). Using a similar sketching template to Plenge, Martens (1999) demonstrated that the width and envelopment of percussive sounds increased for NH listeners when presented through a two *vs*. one subwoofer system. Merimaa and Hess (2004) used a computerized visual-mapping system for NH listeners to describe the width and envelopment of sounds recorded in anechoic and reverberant rooms. Listeners were instructed to visualize the sound as a circular arc for width judgments, and were able to adjust the radius, angle (extent) and midpoint of the arc on a GUI. The results, given as angular width of the responses, showed significant differences between stimuli, acoustic spaces and listeners.

Nevertheless, a primary issue with demonstrating spatial percepts through visual analogy is that intersubject variability can overwhelm potential perceptual differences. A balance must be struck between having a method that allows the listener to describe their percept of the sound source(s) and a method that constrains extraneous variability to detect changes in that percept. While it is possible to constrain variability through specific instruction, the individual responses can still vary widely (cf. Merimaa & Hess, 2004). A closed-set task, such as establishing similarity through pairwise comparison (Martens, 1999) may also constrain variability, but may not describe the way in which the individual perceives their environment. To illustrate this point, Figure 1 shows numerous but not exhaustive different potential percepts of a given acoustic scenario: a point source directly in front of the listener. Despite being only two-dimensional representations – and schematic representations at that – the possible combinations are overwhelming for any pairwise fixed-level testing design.

To experimentally determine if there were differences in the percept of sound sources between NH and HI listeners, the current study employed two methods of visual analogy: a drawing task and an identification task. In order to reduce variability, emphasis was placed on the apparent width of the stimulus presented over headphones, not the stimulus location. In the drawing or visual description task, listeners drew their representation of sound sources with different interaural coherences and simulated positions onto a pre-drawn schematic of a mannequin head. In the identification task, listeners chose the closest match to their perception of the source from a predefined set of fifteen images representing hypothetically narrow to wide images presented to the left, centre and right.

2. Methods

A group of 21 HI adults matched for hearing loss with ages ranging from 48-77 years were recruited by post. Better ear pure-tone threshold averages ranged from 33-43 dB HL with

Europe PMC Funders Author Manuscripts

asymmetries of 0-10 dB HL. Four NH listeners (2 female), aged 28-41 years with normal hearing based on pure-tone audiometric thresholds between 500-4000 Hz less than 20 dB HL, were also recruited from employees and students of the Institute of Hearing Research. All listeners had participated in an auditory-source-width discrimination task prior to testing, giving them some familiarity with the concept of source width and the stimuli being used in the current tasks.[2]

The stimuli were composed of 500-ms third-octave narrowband noises with octave-spaced centre frequencies from 500-4000 Hz. Each narrowband component was generated using Plenge's symmetric generator method (1972) to reduce variability within each band: two independent noises were independently attenuated, then added and subtracted, respectively, from each other in the left and right channel for the desired IC. In the drawing task, three IC values were tested: 0.6, 0.8 and 1. In the identification task, five IC values were tested: 0.6-1 in 0.1 increments. The broadband stimuli were presented at 75 dB(A) over circumaural headphones. To examine the effect of location and maintain interest throughout the experimental session, the stimuli were presented from three simulated positions (−30, 0 and +30°) and monaurally left or right, randomly chosen on each trial. The ±30° positions were created by applying global ITDs and ILDs of 229 μs and 4.8 dB (being the average values across multiple HRTF databases) to the stimuli.

In the visual description procedure, HI and NH listeners were required to sketch, using a touchscreen, the perceived size of the sound they heard on each trial onto a 450-pixel square image of a mannequin head with an ear-to-ear distance of 360 pixels. Listeners responses were sometimes incomplete, necessitating a recursive sliding or boxcar average to complete shapes. The only additional instructions was that as the experiment was concerned with the size of the sound the listener heard, they were to project any sounds heard to the rear to the front for their response. Each listener was given fully coherent (IC = 1) stimuli with the five locations (L, −30°, 0°, +30° and R) as practice. All listeners then commenced with the experiment, sketching their percept of ten presentations of each of 11 combinations of IC and position (3 IC × 3 positions plus monaural stimuli). Stimuli were presented in random order.

A problem was evident in the visual-description responses for the ±30° stimuli: sketches were constrained by the image of the head. Listeners did not draw images beyond the two ears, so that the area and width were confounded by the centre of the response. As responses for ±30° stimuli were confounded by the visual anchor of the mannequin head, those stimuli were not included in further analysis of the measurement technique. Two of the older HI listeners did not draw shapes at all, only drawing dots to indicate positions (e.g., panel D in Figure 1 above), and three older HI listeners placed left and right positioned stimuli in the opposite hemifield, indicating a possible momentary lapse in understanding the mirror-image aspect of the task. The results of these five listeners were not included in the analysis.

Immediately following the drawing task, HI and NH listeners completed the visual identification task. They were presented with stimuli with ICs of 0.6-1 and simulated

[2]Further details on the methods reported here can be found in Whitmer et al. (2012).

Europe PMC Funders Author Manuscripts

positions of −30, 0 and 30° (no monaural stimuli were used). After each stimulus presentation, a 5 × 3 matrix of images was displayed with 20-pixel high gray bars made of visual noise. The widths of the pre-drawn bars ranged across the five columns from 20-100 pixels in 20-pixel increments based on previously established near-linear relationships between IC and width (cf. Keet, 1968). The positions of the bars across the three rows were at approximately −30°, 0 and +30°. The 15 conditions were presented in a randomized order for each block; after two blocks of practice, listeners completed four test blocks (i.e., a total of 90 trials).

3. Results and Discussion

For the drawing task, the raw results of the 16 HI listeners and four NH listeners are shown in Figure 2; individual sketches were collated into density plots for the 0° stimuli with ICs of 0.6. 0.8 and 1 and the monaural stimuli. Three basic results are clear: (1) changes in IC did not produce noticeably different sized responses for HI listeners, though they did for NH listeners, (2) diotic (IC = 1) stimuli were drawn smaller and narrower by NH listeners relative to HI listeners, and (3) drawing methods varied greatly, especially among HI listeners.

In the identification task, each image of expanding width was assigned a descending IC (1-0.6) based on pilot results. The last four response ICs for each position (−30, 0 and +30°) and IC were averaged for each listener. The raw results for the recognition task are shown in Figure 3. The NH results show a clear change in response selection with increasing IC, and relatively good agreement among listeners. The HI listeners show a clear insensitivity to changes in stimulus IC, with linear-regression slopes near zero. Furthermore, the variability in the mean response for HI listeners varied widely; the average response IC ranged from 0.63 to 0.88, with only a slight tendency towards hypothetically broader (lower IC) images. The mean data in the identification task mirror the mean data in the drawing task: NH listeners judged the least coherent stimuli as significantly wider and the fully coherent stimuli as significantly narrower than HI listeners.

4. Summary

Based on their insensitivity to changes in IC, and the significantly broader width with which they drew diotic (IC = 1) stimuli, older HI individuals do not appear to hear punctate images for binaural sounds. The increased temporal jitter found in the aging auditory pathway (Pichora-Fuller & Schneider, 1991) is manifest in the current results as a reduced sensitivity to changes in interaural coherence; that is, all sound sources are perceived as diffuse images with weaker neural representations of location (Ison et al., 2010). Like many previous studies, these visual-analogy experiments were conducted over headphones for precise control of IC. If these deficits persist in the free field, they could undermine the benefit of source-separation strategies in hearing prostheses, as well as impact our understanding of how the early reflections that change IC can affect HI individuals.

Europe PMC Funders Author Manuscripts

Acknowledgments

The Scottish Section of IHR is supported by intramural funding from the Medical Research Council and the Chief Scientist Office of the Scottish Government.

References

Blauert J, Lindemann W. Spatial mapping of intracranial auditory events for various degrees of interaural coherence. J. Acoust. Soc. Am. 1986; 79:806–813. [PubMed: 3958323]

Boyd A, Whitmer W, Soraghan J, Akeroyd M. Auditory externalization in hearing-impaired listeners: The effect of pinna cues and number of talkers. J. Acoust. Soc. Am. 2012; 131:EL268–EL274. [PubMed: 22423819]

Dobreva M, O'Neill W, Paige G. The influence of aging on human sound localization. J. Neurophysiol. 2011; 105:2471–2486. [PubMed: 21368004]

Grose J, Mamo S. Processing of temporal fine structure as a function of age. Ear. Hear. 2010; 31:755–760. [PubMed: 20592614]

Herman G, Warren L, Wagener J. Auditory lateralization: Age differences in sensitivity to dichotic time and amplitude cues. J. Gerontol. 1977; 32:187–191.

Ison, J.; Tremblay, K.; Allen, P. Closing the gap between neurobiology and human presbycusis: Behavioral and evoked potential studies of age-related hearing loss in animal models and in humans. In: Gordon-Salant, S.; Frisina, R.; Fay, R.; Popper, A., editors. The Aging Auditory System. Springer; New York: 2010. p. 75-110.

de villiers Keet, W. The influence of early lateral reflections on the spatial impression. Proceedings of the Sixth International Congress on Acoustics; Tokyo, Japan. 1968. p. E2-4.

Licklider J, Dzendolet E. Oscillographic scatterplots illustrating various degrees of correlation. Science. 1948; 107:121–124. [PubMed: 17753395]

Lorenzi C, Gatehouse S, Lever C. Sound localization in noise in normal-hearing listeners. J. Acoust. Soc. Am. 1999a; 105:1810–1820. [PubMed: 10089604]

Lorenzi C, Gatehouse S, Lever C. Sound localization in noise in hearing-impaired listeners. J. Acoust. Soc. Am. 1999b; 105:3454–3463. [PubMed: 10380669]

Martens, W. The impact of decorrelated low-frequency reproduction on auditory spatial imagery: Are two subwoofers better than one?. Proceedings of the Audio Engineering Society 16th International Conference of Spatial Sound Reproduction; Rovaniemi, Finland. 1999. p. 67-77.

Merimaa, J.; Hess, W. Training of listeners for evaluation of spatial attributes of sound. Proceedings of the 117th Convention of Audio Engineering Society; San Francisco, California. 2004. Preprint 6237

Pichora-Fuller K, Schenider B. Masking level differences in the elderly: A comparison of antiphasic and time-delay dichotic conditions. J. Speech Hear. Res. 1991; 34:1410–1422. [PubMed: 1787722]

Plenge G. Über das Problem der Im-Kopf-Lokalisation. Acustica. 1972; 26:241–252.

Pollack I, Trittipoe W. Binaural listening and interaural noise correlation. J. Acoust. Soc. Am. 1959; 31:1250–1252.

Pollack I. Identification of visual correlational analysis. J. Exp. Psych. 1960; 59:351–360.

Rich G. A preliminary study of tonal volume. J. Exp. Psych. 1916; 1:13–22.

Whitmer W, Seeber B, Akeroyd M. Apparent auditory source width insensitivity in older hearing-impaired individuals. J. Acoust. Soc. Am. 2012; 132:369–379. [PubMed: 22779484]

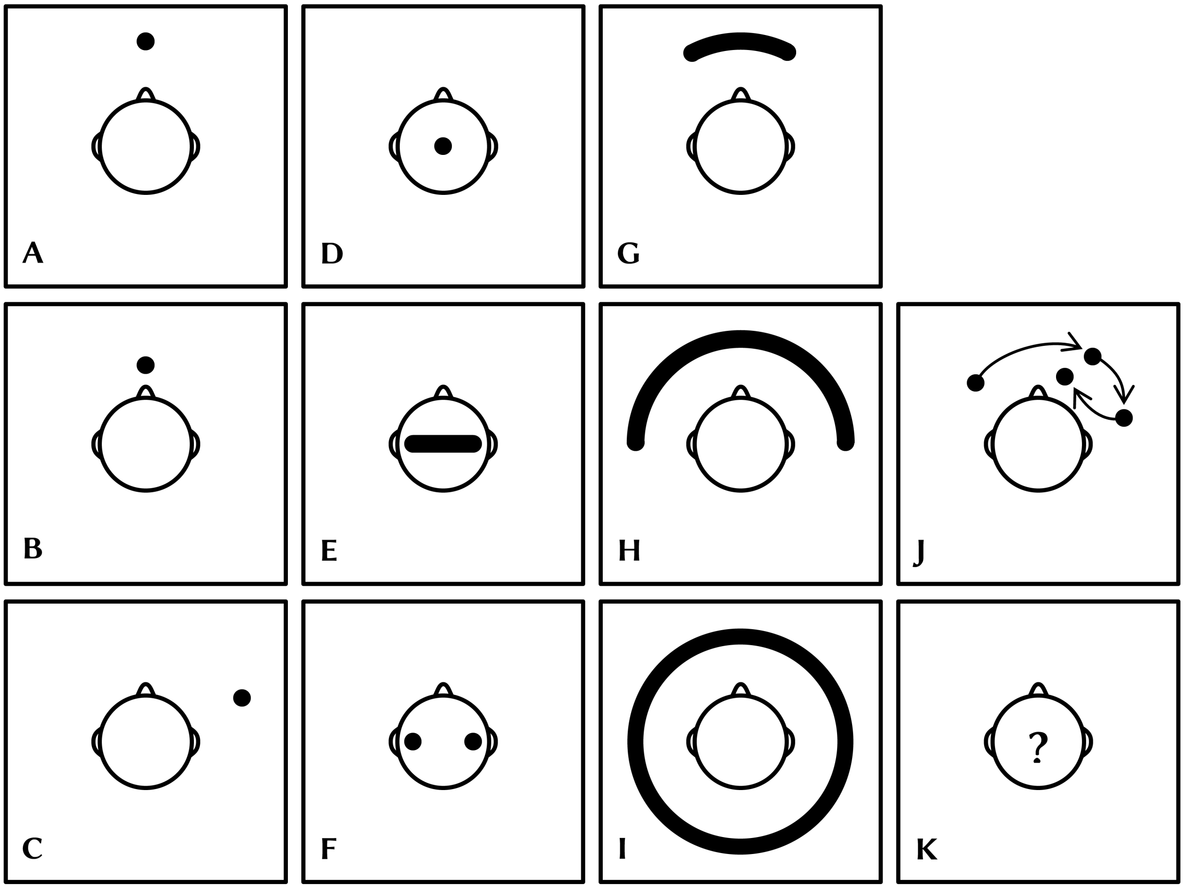

FIGURE 1.

Top-view schematic examples of the potential spatial percepts of an acoustic scene with a point source presented in front of the listener. Panel A shows a punctate percept accurately representing the direction and distance of the acoustic event. Panels B and C show the punctate source perceived at different radial and angular positions (i.e., a localization bias). Panels D-F show intracranial images: a punctate image (D), a broad image (E), and dual images at the two ears (F); headphone presentation without applying proper ear and headphone equalisation would be expected to result in these types of images. Panels G-I show broadened distal images, from slightly broader (G) to stretching across the azimuth (H) to being perceived as all around the listener or fully diffuse (I). Images resembling these could be expected from presentation in a reverberant or multiple-source environment. Panel J shows an unstable spatial percept, with the source location moving, and panel K indicates an indescribable percept.

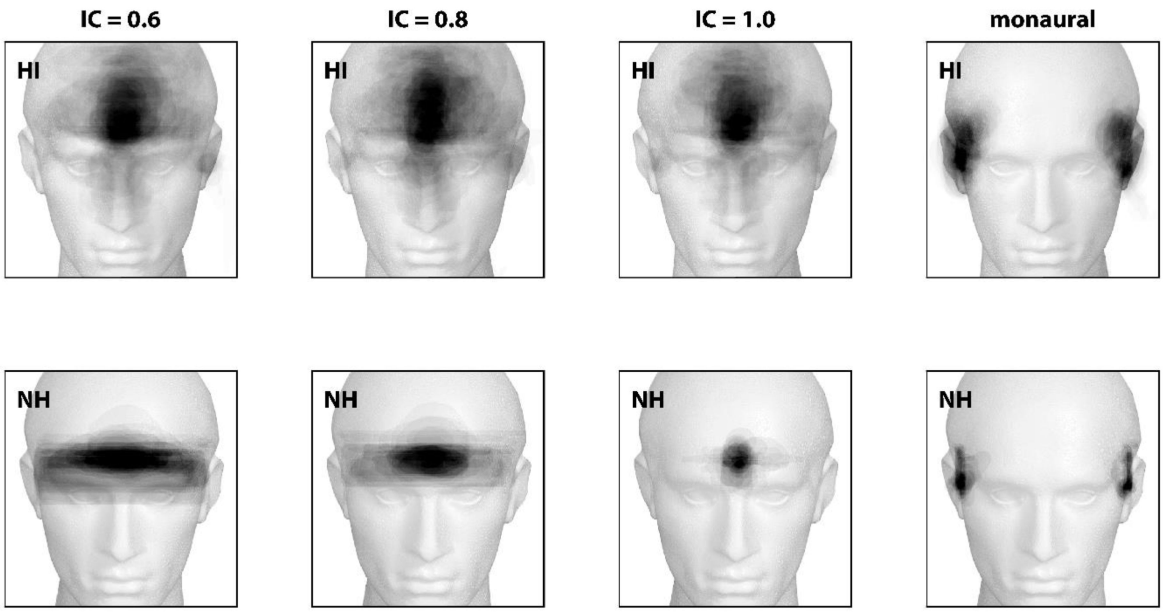

FIGURE 2.
Density plot of drawing experiment responses formed by overlaying all responses for HI (n = 24) and NH (n = 7) participants (rows) and IC (columns) for stimuli presented over headphones with simulated lateral position of 0°. Greyscale indicates frequency, with black being most frequent. The rightmost column shows responses for the monaural stimuli. The mannequin-head image was inverted for contrast during testing. Responses were less affected by IC for HI relative to NH participants.

Europe PMC Funders Author Manuscripts

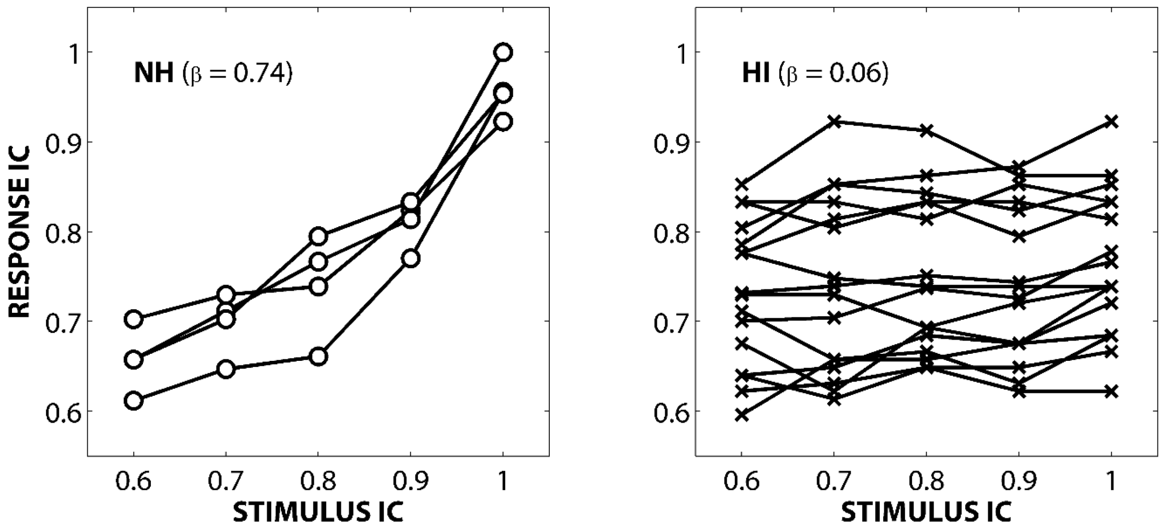

FIGURE 3.

Mean response interaural coherence (IC) of the chosen visual stimulus as a function of stimulus IC for all NH (left panel) and HI (right panel) listeners. The average linear-regression slopes (β) are given for both groups.