Lateralization produced by interaural intensive disparities appears to be larger for high- vs low-frequency stimuli

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Abstract: The purpose of this communication is to report the results of a study indicating that a given magnitude of interaural intensive disparity (IID) produced a larger extent of laterality, as measured via an acoustic pointer, for stimuli centered at 4 kHz than for stimuli centered at 500 Hz. The data and their analysis, taken together, suggest that the findings reflect true across-frequency differences rather than being manifestations of response-related factors.

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1. Introduction

Current understanding is that the potency of interaural intensive disparities (IIDs) is largely independent of spectral locus over a very wide range of frequencies. This appears to be true regardless of whether potency of IID is measured in terms of discrimination of changes in IID (see [Grantham, 1984](#); [Yost and Dye, 1988](#)) or in terms of extents of laterality produced by a given IID (see [Yost, 1981](#)). Recently, in the course of conducting a study focused on a different topic, we were surprised to observe measurements of IID-based extents of laterality strongly suggesting that a given magnitude of IID produced a larger extent of laterality for stimuli centered at 4 kHz than it produced for stimuli centered at 500 Hz. This outcome was consistent in that it occurred for all values of IID tested and for each of three listeners. The purpose of this communication is to report the results of a targeted follow-up study. The data obtained affirm our initial observations and suggest that the phenomenon stems from true across-frequency differences in extents of IID-based laterality, rather than being a manifestation of response-related factors.

2. Experiment

2.1 Procedure and stimuli

Extents of laterality were measured for several “target” stimuli while varying their IID. Measurements were obtained from three normal-hearing young adult listeners (one male and two female) via an acoustic pointing task in which the listeners varied the IID of one stimulus (the pointer) so that it matched the intracranial position of a second, experimenter-controlled, stimulus (the target). This procedure has been used previously in several studies (e.g., [Trahiotis and Stern, 1989](#); [Buell et al., 1991](#); [Heller and Trahiotis, 1996](#); [Bernstein and Trahiotis, 2003](#)) and is described fully in [Bernstein and Trahiotis \(1985\)](#). Listeners adjusted the intracranial position of the pointer by rotating a knob. Rotation of the knob produced symmetric changes of the IID (in decibels) of the pointer (i.e., increases in level at one ear and decreases in level at the other ear). The IID adjusted by the listener served as a metric of the intracranial position of the target. An arbitrary and randomly

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chosen value of the IID was inserted in the pointer prior to each match. This served to randomize the initial position of the pointer with respect to the absolute position of the knob. Each sequence of stimuli consisted of three presentations of the target (each separated by 150 ms), a pause of 200 ms, three presentations of the pointer (each separated by 150 ms), and a pause of 600 ms. The duration of target and pointer stimuli was 100 ms including 10-ms $\cos^2$ rise/decay ramps. Target and pointer triads were repeated until the listeners indicated that they had matched the intracranial positions of the target and pointer. Prior to completing a match, listeners had the option of halting, and then restarting, the sequence in order to “check” their adjustments after a period of silence.

Three types of stimuli served as targets: (1) a sinusoidally amplitude-modulated (SAM) tone centered at 4 kHz, having a rate of modulation of 128 Hz, and a depth of modulation of 100%; (2) a 4-kHz-centered “raised-sine” having a rate of modulation of 128 Hz, an exponent (n) of 4.0, and a depth of modulation of 100%; (3) a 200-Hz-wide band of Gaussian noise centered at 4 kHz. Those three targets were chosen because they were shown previously to produce differential potency of interaural *temporal* disparities (ITDs) in terms of both threshold-ITD and ITD-based extent of laterality (e.g., Bernstein and Trahiotis, 1994; 2003; 2009). The motivation was to assess whether the potency of the IID imposed on each of the targets depended upon, in an interactive sense, the salience of the zero-valued *ITD* inherent in stimuli on which only an IID is imposed. The pointer was a 200-Hz-wide band of Gaussian noise centered at 500 Hz and is the same stimulus that has, for decades, served as the pointer in a number of studies from our laboratory employing the acoustic pointing task (see studies cited above). Extents of laterality were measured for each of the targets specified above and in conditions in which the roles of the nominal target and pointer were reversed. That is, in separate conditions, each of the target stimuli specified above served as the pointer and listeners adjusted its IID until it matched the intracranial position of the 200-Hz-wide band of Gaussian noise centered at 500 Hz, which served as the target.

All stimuli were generated digitally using a sampling rate of 20 kHz (TDT AP2), were low-pass filtered at 8.5 kHz (TDT FLT2), and were presented via Etymotic ER-2 insert earphones. The overall level of the target (when presented diotically) was 68 dB SPL; the overall level of the pointer (when presented diotically) was 60 dB SPL. IIDs ranging between -12 and 12 dB, in steps of 4 dB were imposed on the targets via symmetric changes in decibels (i.e., increases in level at one ear and decreases in level at the other ear). Signals destined for the left and right ears were gated coincidentally.

For each stimulus condition, a random process was used to select a value of IID from the set to be tested. Listeners completed three independent matches for that value of IID, after which a new value of IID was chosen (randomly, without replacement). The mean of the magnitude of the IID inserted by the listener to match the diotic targets (IID of 0 dB) served as a “correction factor” and was typically less than 3 dB. The correction factor was subtracted from all of the matching IIDs obtained at each of the other values of target IID. The two stimulus conditions employing the 4-kHz-centered SAM tone (one in which it served as the target, one in which it served as the pointer) were run first, followed by the two conditions employing the 4-kHz-centered noise. The two conditions employing the 4-kHz-centered raised sine were run last. For each of those three high-frequency stimuli, the condition in which it served as the target was run first, followed by the condition in which it served as the pointer. The two conditions were then revisited in reverse order. In the event that the correction factor for a particular run of a stimulus condition was greater than or equal to 5 dB, that run was discarded and was repeated until that criterion was not exceeded. The data reported in the figures represent the mean “corrected” value of IID of the pointer across the six “valid” matches (three from each run) made by each listener for a particular combination of target and IID.

2.2 Results

The filled squares in the top, middle, and bottom panels of Fig. 1 represent the IID of the 500-Hz-centered noise pointer required to make a match when the 4-kHz-centered

Fig. 1. IID of the pointer (in decibels) required to match the intracranial position of the target as a function of its IID. Positive values of IID favored the left ear and negative values favored the right ear. The filled squares in the top, middle, and bottom panels represent the IID of the 500-Hz-centered noise pointer required to make a match when the 4-kHz-centered target stimulus was a SAM tone, a raised-sine, or a Gaussian band of noise, respectively. Each inset depicts an exemplar of the corresponding 4-kHz-centered stimulus. The filled circles in each panel represent the IID required to make a match when the *target* was the 500-Hz-centered noise and *pointer* was one of the afore-mentioned 4-kHz-centered stimuli. Error bars represent ± 1 standard error of the mean. Unfilled circles represent predictions made with the regression lines calculated using the data represented by the filled squares but with the *x* and *y* axes "interchanged" (see text).

target stimulus was a SAM tone, a raised-sine, or a Gaussian band of noise, respectively. Each inset depicts an exemplar of the corresponding 4-kHz-centered stimulus. The filled circles in each panel represent the IID required to make a match when the *target* was the 500-Hz-centered noise and *pointer* was one of the afore-mentioned 4-kHz-centered stimuli. Within each panel, the mean IID of the pointer (taken across the three listeners) is plotted as a function of the IID imposed on the target. Positive values along the ordinate represent values of IID favoring the left ear. Error bars represent ± 1 standard error of the mean. The unfilled circles represent predictions and will be discussed in detail below.

Beginning with the top panel, note that the IID of the 500-Hz-centered noise pointer required to match the intracranial position of the 4-kHz-centered SAM tone (filled squares) target was consistently larger in magnitude than the IID imposed on that target. For example, when the IID of the 4-kHz-centered SAM tone was 8 dB, about 11 dB of IID of the 500-Hz-centered noise was required to make a match. This is the type of outcome that motivated this study because, at face value, it indicates that a given IID produced a greater extent of laterality for the 4-kHz-centered SAM tone than it did for the 500-Hz-centered noise pointer. This result was confirmed quantitatively in that the slope of the best-fit line to the filled squares (forced to pass through the origin) was 1.34, with an associated r^2 of 0.99.

The filled circles represent the data obtained when the roles of the 4-kHz-centered SAM tone and the 500-Hz-centered noise were reversed (i.e., when the 500-Hz-centered noise served as the target). Note that, in this case, the IID of the 4-kHz-centered SAM *pointer* required to match the intracranial position of the 500-Hz-centered noise *target* was consistently smaller in magnitude than the IID imposed on that target. For example, when the IID of the 500-Hz-centered noise target was 8 dB, about 5 dB of IID of the 4-kHz-centered SAM pointer was required to make a match. This result was confirmed quantitatively in that the slope of the best-fit line to the filled squares (forced to pass through the origin) was 0.63, with an associated r^2 of 0.99.

The same general relations are evident in the middle and bottom panels of Fig. 1: (1) pointer-IIDs required to match the intracranial positions of all three types of 4-kHz-centered targets were larger than the IIDs imposed on the targets themselves and (2) the IIDs of the 4-kHz-centered pointers required to match the intracranial position of the 500-Hz-centered noise target were consistently smaller in magnitude than the IIDs of the targets themselves. The best-fit linear regression lines for these two types of 4-kHz targets were 1.24 for the raised-sine target ($r^2 = 0.98$) and 1.27 for the noise target ($r^2 = 0.99$). The best-fit linear regression lines when these two types of 4-kHz-centered stimuli served as pointers were 0.59 for the raised-sine target ($r^2 = 0.94$) and 0.54 for the noise target ($r^2 = 0.98$). Thus, there appears to be no evidence that the potency of the IIDs conveyed by the three types of 4-kHz-centered stimuli was dependent upon, or interacted with, their previously demonstrated differences in terms of potency of *ITD*. This suggests that it was the difference in the center frequencies of the stimuli, *per se* (here, 500 Hz and 4 kHz), that determined the differences observed in the data.

3. Discussion

Consistent with the initial observations that motivated this study, it was found that the IID of a 500-Hz-centered noise pointer required to match the intracranial position of all three 4-kHz-centered targets had to be consistently larger in magnitude than the IID of the target. This outcome, in isolation, appears to be explainable in at least two different ways. First, it could be the case that IIDs conveyed by such types of high-frequency signals are more potent than their counterparts conveyed by a 500-Hz-centered band of noise. Second, it could be the case that IIDs across frequency are equally potent and those data simply reflect some type of factor(s) related to the listeners' use of the manipulandum (the pointing knob).

The purpose of obtaining matches after reversing the roles of the stimuli serving as target and pointer was to determine whether, and, perhaps to what degree, either

interpretation could explain the differences in the data. If response-related factors determined the differences, then one would expect that it would not matter which of the two stimuli served as the pointer and the listener would require the same “larger” value of IID in the pointer to match the intracranial position produced by a given IID of the target. On the other hand, if IIDs conveyed by the high-frequency stimuli really do produce larger extents of laterality than do their counterparts conveyed by the low-frequency stimuli, then one would expect listeners to use *smaller* values of IID conveyed by a high-frequency pointer to match the intracranial position produced by a given IID of a *low-frequency target*. It appears from a visual inspection of Fig. 1 that that is what occurred.

A quantitative analysis of the data supports that explanation. Separately, for each of the three types of high-frequency targets (filled squares in Fig. 1), the best-fitting regression line (through the origin) was computed for two cases: (1) when the IID of the *target* served as the x -variable and the IID of the *pointer* served as the y -variable and (2) when the IID of the *pointer* served as the x -variable and the IID of the *target* served as the y -variable. Each regression line was then used to predict the data for the conditions in which the roles of the high- and low-frequency stimuli were reversed (filled circles in Fig. 1).

Predictions made with the regression lines calculated using “interchanged axes” (shown as the unfilled circles in Fig. 1) were highly accurate. The amounts of variance accounted for¹ by those regression lines were 96% for the SAM tone, 81% for the raised-sine, and 78% for the band of noise. In stark contrast, predictions (not shown) made using the original x and y axes were so inaccurate that more of the variance would have been accounted for by simply using the mean of the data as the sole predictor.

Taken together, the data and their quantitative analysis suggest that IIDs conveyed by high-frequency stimuli really do produce larger extents of laterality than do their counterparts conveyed by low-frequency stimuli. The only caveat is that we cannot, based solely on our own data, rule out the logical (and, to us, highly improbable) notion that some sort of unspecified, response-related factor operates differently across frequency in just such a manner so as to produce the effects we measured.

Some of the data obtained by Yost (1981), who used pure tones as targets, appear to provide support for the interpretation that IIDs conveyed by high-frequency stimuli actually do yield larger extents of laterality than do their counterparts conveyed by low-frequency stimuli. Yost’s listeners indicated the intracranial positions of tonal stimuli containing IIDs by positioning a “linear slide potentiometer” affixed to a drawing of a human head. The listeners’ responses were binned into 21 equal-length sections with the endpoints mapped to values of -10 and 10 . Estimating lateral positions from the lines drawn through the data in Yost’s Fig. 7 (p. 404) revealed that, for an IID of 6 dB favoring the right ear, listeners indicated a position at about 4.8 units toward the right ear when the target was a 500-Hz tone and a position at about 5.9 units toward the right ear when the target was a 5 kHz tone. The ratio of the two positions is 1.23, a ratio quite comparable to those calculated for the data obtained in this study with the 4-kHz-centered targets (filled squares in Fig. 1). For an IID of 6 dB favoring the *left* ear, however, listeners indicated respective positions for the two frequencies that were essentially the same, being about 4.1 and 4.2 units toward the left ear when targets were 500 Hz and 5 kHz tones, respectively. The ratio of those two positions is only 1.02. The left/right differences in the ratios appear to stem from a left/right asymmetry in the data obtained by Yost at 5 kHz. It is an open question whether the relative potency of IID depends upon both the spectral complexity of the stimuli (i.e., pure tones vs more complex stimuli like those employed here) and/or their spectral locus.

The data shown in Fig. 1 reflecting differing extents of laterality obtained at different center frequencies are also interesting in light of the studies cited in the introduction which demonstrate that the *discriminability* of changes in IID is quite uniform as a function of center frequency. This apparent lack of correspondence between IID-based extents of laterality and threshold-IIDs is reminiscent of parallel outcomes found when *ITD* is the independent variable (see Domnitz and Colburn, 1977; Stern and Colburn,

1978, 1985; Heller and Trahiotis, 1996; Trahiotis *et al.*, 2001). These apparently inconsistent outcomes may be reconcilable. Consider that the *resolution* of IIDs or ITDs may be determined by both the magnitude of overall “displacement” of the intracranial image and the underlying “width” or variance of that displacement. Within such a schema, what determines *thresholds* of discrimination is a type of “mean-to-sigma” relation. In contrast, extent of laterality appears to be determined by the “center of mass” or centroid of an intracranial image that is produced by *supra-threshold* values of IID or ITD (see Domnitz and Colburn, 1977 for a detailed explication).

In summary, the data obtained in this study using an acoustic pointing task suggest that there exist true high- vs low-frequency differences in extents of IID-based laterality. In addition, the observed differences in measured extents of laterality do not appear to be a manifestation of response-related factors.

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References and Links

- ¹The formula used to compute the percentage of the variance for which our predicted values of threshold accounted for was $100 \times (1 - [\Sigma(O_i - P_i)^2]/[\Sigma(O_i - \bar{O})^2])$ where O_i and P_i represent individual observed and predicted values of threshold, respectively, and $\bar{O}$ represents the mean of the observed values of threshold (e.g., Bernstein and Trahiotis, 1994).
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