Behavioral and Electrophysiological Binaural Interactions in Listeners with Hearing Loss

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INTRODUCTION

The advantages of binaural hearing are well-established in the literature and include improved speech understanding in quiet and in noise, reduced head shadow effect, loudness summation, and localization. Persons with bilateral hearing loss, therefore, typically are fit with two hearing aids (Carter et al., 2001; Erdman & Sedge, 1981); the majority of the literature supports binaural amplification for individuals with bilateral sensorineural hearing loss (e.g., Brooks & Bulmer, 1981; Kobler et al., 2001). Despite the success of binaural hearing aid fittings, however, several studies indicate that 20-30% of individuals with binaural hearing loss choose to wear one hearing aid (e.g., Chung & Stephens, 1986; Kobler et al, 2001). One explanation for the rejection of binaural amplification is binaural interference, which occurs when the signal presented to one ear interferes with the perception of the signal presented to the better ear (Allen et al., 2000; Jerger et al., 1993; Silman, 1995). If binaural interference is problematic for ~25% of listeners with binaural hearing loss, then it is important to have a clinically useful tool for identifying abnormalities in binaural hearing. Binaural processing can be measured behaviorally and electrophysiologically, but little information exists on the relations among these measures in listeners with symmetrical sensorineural hearing loss.

Purpose

The purpose of the present study was to determine the extent to which behavioral measures of binaural processing were related to electrophysiologic measures of binaural processing in listeners with symmetrical hearing with and without hearing loss.

METHODS

Subjects

Thirty-two subjects were enrolled in the study. The subjects were 10 listeners with normal hearing (mean age = 25 ± 2 years) including two males and eight females and 22 listeners with hearing loss (mean age = 62 ±11 years) comprised of male veterans from the VA Medical Center in Mountain Home, TN. The pure-tone thresholds for the listeners with hearing loss can be seen in **Figure 1**.

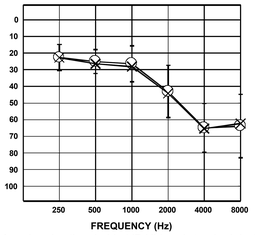

Figure 1. Mean hearing thresholds (dB HL) and standard deviations (right ear only) for subjects with hearing loss.

Words In Noise (WIN)

Thirty-five NU-6 words per list, were presented at 7 signal-to-babble (S/B) ratios ranging from 24-0 S/B (Wilson, 2003). Two lists were presented to the right ear, left ear, and binaurally for a total of 6 different lists presented to each subject. Presentation level was 80 dB HL and subjects repeated the target words.

Dichotic Digits Test (DDT)

The digits 1 to 10 (with the exception of 7) were spoken by a male speaker. The compilation of two- and three-dichotic digit pairs was made by randomly compiling one-pair dichotic digit files. A list of 108 items divided into two lists of 54 stimulus sets were recorded on Version 2.0 of the VA-CD Tonal and Speech Materials for Auditory Perceptual Assessment (1998). Presentation level was 70 dB HL and subjects repeated the digits heard in both ears without regard to order.

Masking Level Difference (MLD)

SoNo (homophasic) and SπNo (anitphasic) stimuli were presented at signal-to-noise ratios ranging from 1-dB S/N to –29-dB S/N in 2-dB decrements (Wilson et al., 2003b). MLDs for 500 Hz were obtained at 70 dB HL with the noise on one channel at a constant level and the tone bursts on the second channel. Subjects responded "yes" if they heard the signal. The MLD threshold was defined as the difference between the SoNo threshold and SπNo threshold.

Middle Latency Responses (MLRs)

Stimulus Parameters. The MLR was recorded in response to a 1000 Hz tone burst generated by the Intelligent Hearing Systems SmartEP System (2.21) and delivered through ER-3A insert earphones. Stimulus duration was 5 ms (2-1-2) presented at 9.7/sec at 78 dB peSPL under three conditions: monaural to the right ear, monaural to the left ear, and binaurally. Stimulus condition order was randomized from subject to subject.

Recording Parameters. Responses were recorded from Ag/AgCl electrodes at Fz (noninverting) and on each ear lobe (inverting) with the low forehead electrode serving as ground. Subjects were seated in a comfortable reclining chair and instructed to sit quietly, but to stay awake. The replicated responses were averaged for the right ear and averaged for the left ear (R, L). The two responses from the binaural recordings were also averaged (BIN). The binaural interaction component (BIC) was calculated as [(R+L)-BIN].

RESULTS AND DISCUSSION

WIN

Listeners with normal hearing scored ~84% correct for monaural and binaural tests. Listeners with hearing loss scored 47% correct for monaural tests, but 55% correct for the binaural test. The monaural WIN performance in both groups was in agreement with Wilson et al. (2003a). The present study was the first data collected on the binaurally presented WIN.

DDT

Listeners with normal hearing revealed no ear advantage (**Figure 2, left**). Listeners with hearing loss, however, showed a clear right ear advantage (**Figure 2, right**). The mean percent correct performance for listeners with hearing loss was as follows: 1-pair AD = 94%, AS = 84%; 2-pair AD = 89%, AS = 74%; and 3-pair AD = 75%, AS = 62%. As the complexity task increased from 1- to 3-digits the performance decreased for listeners with hearing loss. DDT performance was poorer overall and revealed a larger right-ear advantage for the listeners with hearing loss than previous work (Strouse & Wilson, 1999; Wilson & Jaffe, 1996). One possibility for the discrepancy was the greater degree of hearing loss for subjects in the current study compared to previous work.

RESULTS AND DISCUSSION

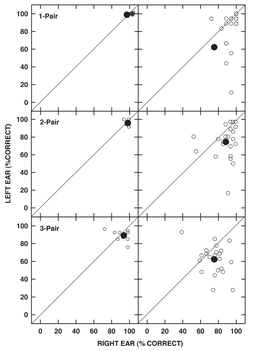

Figure 2. The bivariate plot of percent correct for the right ear (abscissa) and percent correct recognition for the left ear (ordinate) across the three response conditions for individual subjects with normal hearing (left) and individual subjects with hearing loss (right). The solid line represents the line of equality between performance for the right and left ears. The open circles represent individual data and the filled circle represents the group mean score. The open symbols in the graphs were jittered for graphical clarity to avoid superimposition of the datum points for listeners with normal hearing.

MLD

Listeners with normal hearing had a mean MLD of 12.4 dB. The MLD was similar to Wilson et al. (2003b) showing a mean MLD of ~13 dB. Listeners with hearing loss had a mean MLD of 12.3 dB. The MLD shows no effect of high frequency hearing loss (Jerger, et al., 1984). Two of the listeners with hearing loss showed abnormally low MLDs (0 dB and 2 dB), which reflected binaural interference, and were not included in the data analysis.

MLRs

The average peak amplitudes for the MLR are shown in **Table 1**. The BIN was larger than either monaural response. The BIC response for both groups of listeners is shown in **Table 1**. Peak amplitude data for monaural, binaural, and BIC responses were consistent with previously published data (Dobie & Norton, 1980; Kelly-Ballweber & Dobie, 1984).

Table 1. Middle Latency Response peak amplitude measurements

	Na-Pa AS	Na-Pa AD	Pa-Nb AS	Pa-Nb AD	Na-Pa BIN	Pa-Nb BIN	Na-Pa BIC	Pa-Nb BIC
Normal	.61 µV	.62 µV	.57 µV	.64 µV	.91 µV	.80 µV	.23 µV	.19 µV
SNHL	.57 µV	.62 µV	.72 µV	.76 µV	.81 µV	1.02µV	.22 µV	.27 µV

SNHL = sensorineural hearing loss, BIN = binaural, BIC = binaural interaction component

Data Analysis

Electrophysiologic measures. Spearman's rho correlation coefficients (SPSS, version 14.0) revealed significant relations between the MLR and performance on several behavioral tasks (see **Table 2**).

- Listeners with Hearing Loss:
  - The Na-Pa amplitude for the right ear response and for the binaural response accounted for 20% and 26%, respectively, of the variability in the MLD thresholds (**Figure 3**). In addition, the Na-Pa amplitude of the BIC response accounted for 22% of the variability in the MLD thresholds (**Figure 4**) and 24% of the variability in 3-pair DDT performance in the right ear (**Figure 5**).
  - The Na-Pa amplitude for the right ear response and for the binaural response each accounted for ~20% of the variability in performance on the 1-pair DDT in the right ear (**Figure 6**).
  - The Na-Pa amplitude for the binaural response accounted for 25% of the variability in performance on the WIN task presented to the right ear (**Figure 7**).
- The Pa-Nb amplitude for the BIC accounted for 65% of the variability in the 3-pair DDT performance for the left ear in listeners with normal hearing (not shown).

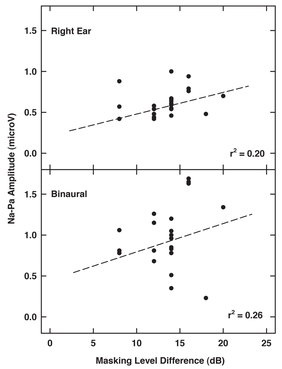

Figure 3. The bivariate plot of masking level difference threshold (abscissa) and amplitude of the Na-Pa (ordinate) for individual subjects with hearing loss. The upper graph shows the response amplitude for signals presented to the right ear and the lower graph shows the response amplitude for signals presented binaurally. The dotted line represents the line of regression. The closed circles represent individual data.

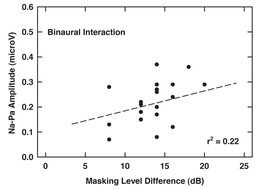

Figure 4. The bivariate plot of masking level difference threshold (abscissa) and amplitude of the Na-Pa for the binaural interaction component (ordinate) for individual subjects with hearing loss. The dotted line represents the line of regression. The closed circles represent individual data.

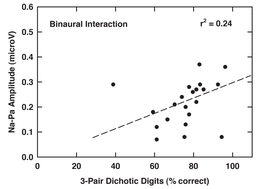

Figure 5. The bivariate plot of percent correct performance on the 3-pair dichotic digits test in the right ear (abscissa) and amplitude of the Na-Pa for the binaural interaction component (ordinate) for individual subjects with hearing loss. The dotted line represents the line of regression. The closed circles represent individual data.

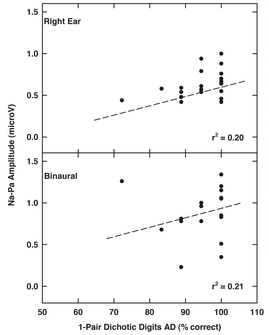

Figure 6. The bivariate plot of percent correct performance on the 1-pair dichotic digits test in the right ear (abscissa) and amplitude of the Na-Pa (ordinate) for individual subjects with hearing loss. The upper graph shows the response amplitude for signals presented to the right ear and the lower graph shows the response amplitude for signals presented binaurally. The dotted line represents the line of regression. The closed circles represent individual data.

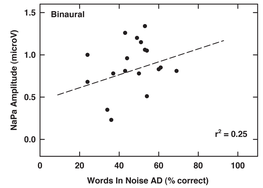

Figure 7. The bivariate plot of percent correct performance on the words in noise task for the right ear (abscissa) and amplitude of the binaurally recorded Na-Pa (ordinate) for individual subjects with hearing loss. The dotted line represents the line of regression. The closed circles represent individual data.

Behavioral measures. Significant relations between several behavioral measures of binaural performance were identified (see **Table 2**). In addition, the MLD thresholds accounted for 26% and 19% of the variability in the right ear performance on the 2-pr DDT and the 3-pr DDT, respectively. **Figure 8** illustrates the correlations between performance on the DDT and the MLD threshold.

Table 2. Spearman correlation coefficients for significant ($p < 0.05$) bivariate relations

	Na-Pa amp AD	Na-Pa amp BIN	Na-Pa amp BIC	WIN AS	WIN AD	WIN BIN	MLD
MLD	r = 0.447, p = 0.037	r = 0.509, p = 0.016	r = 0.464, p = 0.030				
DDT 1-pr AD	r = 0.444, p = 0.039	r = 0.458, p = 0.032		r = 0.538, p = 0.011	r = 0.455, p = 0.033	r = 0.574, p = 0.005	
DDT 2-pr AD							r = 0.507, p = 0.016
DDT 3-pr AD			r = 0.485, p = 0.022				r = 0.440, p = 0.041
WIN AD		r = 0.496, p = 0.019					

MLD = masking level difference, DDT = dichotic digit test, WIN = words in noise, BIN = binaural, BIC = binaural interaction component, r = Spearman correlation coefficient, p = alpha

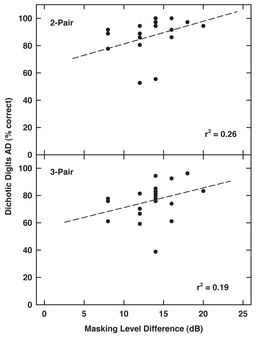

Figure 8. The bivariate plot of percent correct performance on the dichotic digits test in the right ear (ordinate) and masking level difference threshold (abscissa) for individual subjects with hearing loss. The upper graph shows the performance for the 2-pair DDT and the lower graph shows the performance for the 3-pair DDT. The dotted line represents the line of regression. The closed circles represent individual data.

CONCLUSIONS

The purpose of the current study was to determine the extent to which behavioral measures of binaural processing were related to electrophysiologic measures of binaural processing in listeners with symmetrical hearing with and without hearing loss. The current study revealed significant relations between the Na-Pa amplitude and the MLD threshold, performance on the DDT, and performance on a words-in-noise task (WIN; Wilson, 2003). The relationships, though weak, revealed the potential for further investigation into clinically applicable measures of binaural processing. Individuals with symmetrical hearing loss, who find binaural amplification problematic, may have binaural interference that would lead to rejection of amplification. Planned future studies include assessing binaural performance in listeners who prefer monaural amplification.

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