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Phase Effects on the Middle and Late Auditory Evoked Potentials

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Abstract

A masking level difference (MLD) paradigm was used to investigate the presence of an electrophysiologic correlate of the psychoacoustic MLD in the middle and late auditory evoked potentials. In experiment 1, middle latency potentials were recorded in six normal-hearing young adults using vertex and temporal electrode montages. Tone bursts of 500 Hz presented in S_0N_0 and $S_\pi N_0$ conditions produced no threshold differences that were consistent with an MLD. In experiment 2, late latency potential (P_2) thresholds to 500-Hz tone bursts under various phase conditions in noise were measured and compared to behavioral thresholds from the same stimuli. Ten subjects provided behavioral and P_2 thresholds to S_0N_0, $S_\pi N_0$, S_0N_π, $S_\pi N_\pi$, S_mN_0, and S_mN_m conditions. The rank order of behavioral and P_2 thresholds and MLDs was consistent with previous literature on the behavioral MLD. Cortical contributions were confirmed as necessary for the production of the electrophysiologic MLD and, by analogy, the psychoacoustic MLD.

Key Words: Audiometry, auditory cortex, auditory evoked potentials, binaural, hearing

The masking level difference (MLD) for pure tones, described by Hirsh (1948), is a psychoacoustic phenomenon that compares masked auditory thresholds in a number of signal and noise phase conditions. A commonly used paradigm involves the subtraction of the threshold to $S_\pi N_0$ (signal 180° out of phase and noise in phase at the two ears) from the threshold to S_0N_0 (signal in phase and noise in phase at the ears), but other phase combinations of signal and noise also are used. The magnitude of the threshold differences is inversely related to signal frequency (Hirsh, 1948; Hirsh and Burgeat, 1958; Durlach, 1963) and noise bandwidth (Hall and Harvey, 1984) but directly related to signal level (Hirsh, 1948; McFadden, 1968).

Recent attempts have been made to define an electrophysiologic correlate of the MLD using S_0N_0 and $S_\pi N_0$ conditions. These studies have identified MLD-like performance of the late potentials as early as P_1 (Fowler and Mikami, 1992a) but not earlier (Kevanishvili and Lagidze, 1987; Galambos and Makeig, 1992a, b; Fowler and Mikami, 1995). Two studies have addressed the issue of MLD characteristics in the middle latency potentials. Kevanishvili and Lagidze (1987) compared the P_aN_b responses elicited by 60 dB SL (re: S_0N_0) 580-Hz signals in S_0N_0 and $S_\pi N_0$ conditions. The latencies of P_aN_b were not significantly different in these two stimulus conditions and the amplitudes were similar. Galambos and Makeig (1992b) evaluated MLD-like characteristics in the 40-Hz steady-state potential, which occurs in the middle latency epoch between 20 to 120 msec after the stimulus. They found that perceptual changes in monaural and binaural signal-in-noise conditions were unaccompanied by phase coherence changes in the steady-state potentials that would suggest MLD characteristics. Neither study measured electrophysiologic thresholds to the stimuli.

In a study of topographic mapping of the middle latency responses in adult humans, Cacace et al (1990) used both monaural and binaural stimuli. They identified two major components, P_a (29 msec) and P_b (53 msec), from the vertex and a broad third component component, TP_{41} (40–45 msec), over the temporal areas. They found some differences in these components according to stimulus type. P_a was large for all stimuli. P_b was large with binaural and

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right stimulation, and TP_{41} was apparent bilaterally for monaural and binaural stimuli, although it was small on the left with left stimulation. Given these topographic differences in the potentials, it is possible that the temporal component could yield MLD-like characteristics that have not been apparent with the vertical electrode arrays.

Several studies have addressed MLD characteristics in the late auditory potentials. Similar characteristics of the late potential and behavioral MLDs have been demonstrated in terms of frequency distribution (Noffsinger et al, 1984), noise bandwidth (Fowler and Mikami, 1992a), and noise level (Fowler and Mikami, 1992b). In addition, Yonovitz et al (1979) demonstrated S_0N_0–$S_\pi N_0$ threshold differences to clicks in the late potentials.

The present study was designed to extend the characterization of the late-potential MLD by determining if other signal and phase conditions yield the same threshold differences using electrophysiologic techniques as have been shown previously using behavioral techniques. Specifically, most of the psychoacoustic conditions of interest were used by Hirsh (1948). His comparisons were made in the following conditions:

1. tone monaural, noise binaural in phase (S_mN_0);
2. tone monaural, noise binaural out of phase (S_mN_π);
3. tone binaural in phase, noise binaural in phase (S_0N_0);
4. tone binaural out of phase, noise binaural out of phase ($S_\pi N_\pi$);
5. tone binaural in phase, noise binaural out of phase (S_0N_π); and
6. tone binaural out of phase, noise binaural in phase ($S_\pi N_0$).

A hierarchy of thresholds was established for the signal conditions. Thresholds from high to low occurred in the following order for 500-Hz signals: $S_\pi N_\pi$, S_0N_0, S_mN_π, S_mN_0, S_0N_π, and $S_\pi N_0$. Jeffress et al (1956) added a true monaural condition, S_mN_m, because of his expectation that monaural and binaural stimulus conditions should produce different thresholds. This monaural signal condition produced the highest threshold when compared to Hirsh's hierarchy.

The present study had two purposes. First, this study investigated thresholds to stimuli in S_0N_0 and $S_\pi N_0$ conditions to determine if the middle latency response exhibits threshold differences consistent with the MLD in any of several generator orientations. Because previous studies had been unsuccessful in demonstrating MLD–like characteristics in the middle potentials, an initial step size of 5 dB was used to search for MLD characteristics with different generator orientations. If an MLD had been suggested by the 5-dB step sizes, then smaller step sizes and additional stimulus conditions would have been used for a better definition of the MLD. Second, this study extends the description of the MLD–like characteristics in the late latency responses by evaluating MLD conditions other than the common S_0N_0–$S_\pi N_0$. Because the late potential MLD has been recorded using 2-dB step sizes, and because the present focus is on stimulus conditions that yield smaller behavioral MLDs than the S_0N_0–$S_\pi N_0$ condition used previously, 2-dB step sizes were used for experiment 2.

EXPERIMENT 1: MIDDLE LATENCY RESPONSES

Methods

Six normal-hearing adults (mean age = 31 years, range = 26–35 years) served as subjects after signing informed consent forms. All subjects reported a negative history of middle ear disease and had single peaked tympanograms at 226 Hz with peak admittance between ± 100 daPa. Auditory thresholds for octave intervals from 250 to 8000 Hz were ≤ 10 dB HL (re: ANSI, 1989) with interleaving air- and bone-conduction thresholds.

Stimuli were 500-Hz tone bursts (linear envelopes, rise-fall times = 2 msec, plateau = 3 msec) gated at 0° phase and presented at 10.1/sec through matched TDH-39P earphones with MX-41/AR cushions. The noise, which was identical to that used by Fowler and Mikami (1995), had a 3-dB bandwidth of 1800 Hz (200–2000 Hz) and a rejection rate of 115 dB/octave (Rockland Model 751A). The overall noise level was 83 dB SPL, which produced a level per cycle of 50 dB. Responses to the S_0N_0 and $S_\pi N_0$ conditions were recorded in random order. Signals were presented in 5-dB decrements from 100 to 60 peak (p)SPL. These stimuli had previously been shown to elicit a behavioral MLD (Wilson and Fowler, 1987).

Five gold cup electrodes were placed on the neck (CII) and on the scalp (Cz, T3, T4, Fz), ensuring that electrode impedances were < 3000 Ω and ± 1000 Ω between electrode pairs. With Fz as ground, the electrophysiologic responses were recorded simultaneously in the following channels:

(1) T4–CII, (2) T4–T3, (3) Cz–CII, and (4) T3–CII. The nomenclature is based on the 10 to 20 system (Jasper, 1958), and the CII refers to placement on the neck at the vertebral level of C2. The first electrode position for each pair was the noninverting input. These recording channels were chosen to investigate possible MLD characteristics in the vertex and temporal components of middle latency components. Responses were averaged in a 100-msec time window that included a 10-msec prestimulus baseline. Responses were collected with 1000 sweeps per average and a physiologic filter setting of 2 to 250 Hz (Nicolet Pathfinder II). The subjects were awake and sat quietly in a chair in a sound-treated booth during the recording.

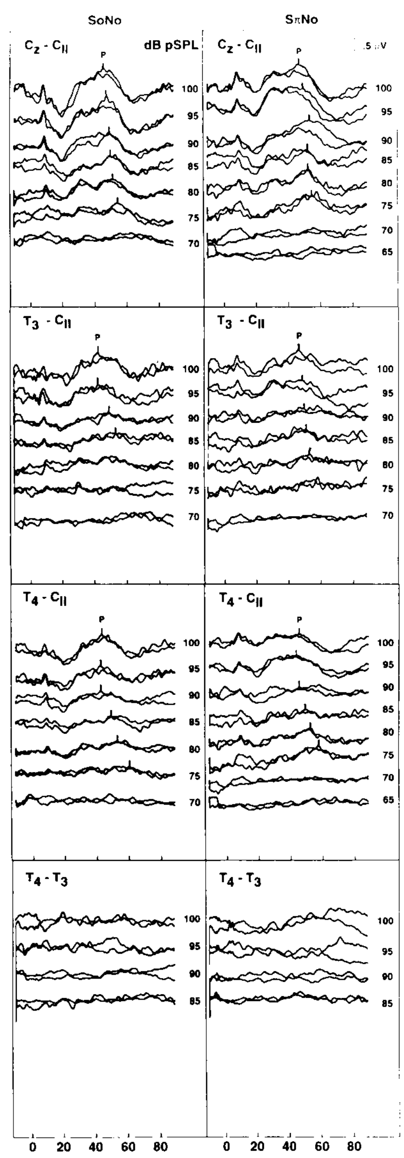

Figure 1 Middle latency (P) responses in one subject to S_0N_0 (left panels) and $S_\pi N_0$ (right panels) conditions for the four recording channels (Cz–CII, top panels; T3–CII, second panels; T4–CII, third panels; T4–T3, fourth panels). The thresholds for all the conditions shown are 75 or 80 dB pSPL, except for the T4–T3 channel in which no response is seen.

Results

Examples of the responses for a typical subject for the middle latency responses are shown in Figure 1. The left panels include responses to S_0N_0 and the right panels include responses to $S_\pi N_0$. The pairs of horizontal panels include the responses from each of the four channels. The P_a and P_b waveforms frequently merged under these masking conditions, yielding a broad waveform. P_b generally predominated at threshold. The major peak in the temporal channels (T3–CII and T4–CII) also generally agreed in latency with the broad P_a–P_b waveform recorded from the vertex. All of these waveforms are labeled P for convenience in Figure 1. The thresholds are marked for each of the conditions and are either 75 or 80 dB pSPL in three of the four channels. For this subject, there were no responses in the T4–T3 channels for signals up to 100 dB pSPL.

For the subject group, middle latency response (P) thresholds were recorded for all six subjects in the Cz–CII channel, for five subjects in the T3–CII and T4–CII channels, and only three (S_0N_0) or two ($S_\pi N_0$) in the T4–T3 channel. The mean thresholds and MLDs with standard deviations for the subject group are given in Table 1. The lack of responses in the horizontal channel suggests that both ears produced similar responses that were effectively canceled in the vector summation of the potentials. Further, no unilateral or asymmetric change in the amplitude or latencies of the potentials was created by the reversal of signal phase in one ear. A one-way analysis of variance

Table 1 Mean Thresholds (in dB SPL) and MLDs (in dB) with Standard Deviations for the Four Channel Middle Latency Responses (P) for the S_0N_0 and $S_\pi N_0$ Conditions

	Cz–CII	*T3–CII*	*T4–CII*	*T3–T4*
S_0N_0	73 (8)	78 (10)	74 (9)	80 (20)
$S_\pi N_0$	74 (6)	77 (8)	76 (8)	87 (10)
MLD	−1 (5)	1 (7)	−2 (6)	*

* N = 2

(ANOVA) for the thresholds for S_0N_0 and $S_\pi N_0$ for the Cz–CII channel indicated no significant difference ($F[1,5] = 0.62$, $p > .05$) and, therefore, no MLD. The S_0N_0 and $S_\pi N_0$ thresholds for the other channels (T3–CII and T4–CII), for which five subjects had thresholds, were within 1 dB for the S_0N_0 and $S_\pi N_0$ conditions, and also produced no significant MLDs.

EXPERIMENT 2: LATE POTENTIALS

Method

Ten normal-hearing young adults (mean age = 29 years, range = 24–43 years) served as subjects after signing informed consent forms. All subjects had normal hearing as defined in experiment 1.

Stimuli were 500-Hz tone bursts (Blackman envelope, rise-fall = 12 msec, plateau = 68 msec) presented through matched TDH-39P earphones in MX-41/AR cushions. Stimuli were presented in random order to minimize the effects of attention in the following six phase conditions: (1) S_0N_0, (2) $S_\pi N_0$, (3) S_0N_π, (4) $S_\pi N_\pi$, (5) S_mN_0, and (6) S_mN_m. The noise had a 3-dB bandwidth of 50 Hz (475–525 Hz) and a rejection rate of 115 dB/octave (Rockland Model 751A). This noise condition previously has been shown to produce a large, reliable MLD for P_2 (Fowler and Mikami, 1992a). Noise was presented continuously at a level of 80 dB SPL, which produced a level per cycle of 50 dB. Signals were presented in 10-dB decrements at high levels and 2-dB decrements near threshold.

Late potentials (P_2) were averaged in a 500-msec window including a 50-msec prestimulus baseline. Responses were collected with 50 sweeps per average (Nicolet Pathfinder II) and a physiologic filter set to 5 to 30 Hz (12 dB/octave rejection rate). Gold cup electrodes were placed on Cz (noninverting input), A2 earlobe (inverting input), and Fz (ground). Electrode impedances were ≤ 3000 Ω and were equal among electrode pairs (± 1000 Ω). Subjects read quietly in a sound-treated booth during the testing. P_2 thresholds were identified by a judge who had no information regarding stimulus condition or level. A judgment of threshold was based on the appearance of responses in two replications of the stimulus condition. Five MLD conditions were derived with the thresholds for each of the signal/noise conditions referenced to the threshold for S_0N_0.

For comparison to the physiologic thresholds, behavioral thresholds to the same stimulus conditions were recorded in the same subjects. The thresholds were recorded in 2-dB steps using a search strategy recommended by ANSI (1978) for the six signal-in-noise conditions. This procedure yields slightly higher thresholds than those measured with a two-interval forced-choice procedure (Marshall and Jesteadt, 1986), but was chosen to verify that the stimuli and 2-dB step size were sufficient to record the behavioral MLDs and, by analogy, the electrophysiologic MLDs.

Results

Figure 2 includes the late potential waveforms for a representative subject, showing P_2 recorded to threshold in the six different stimulus conditions. As seen in this figure, the thresholds

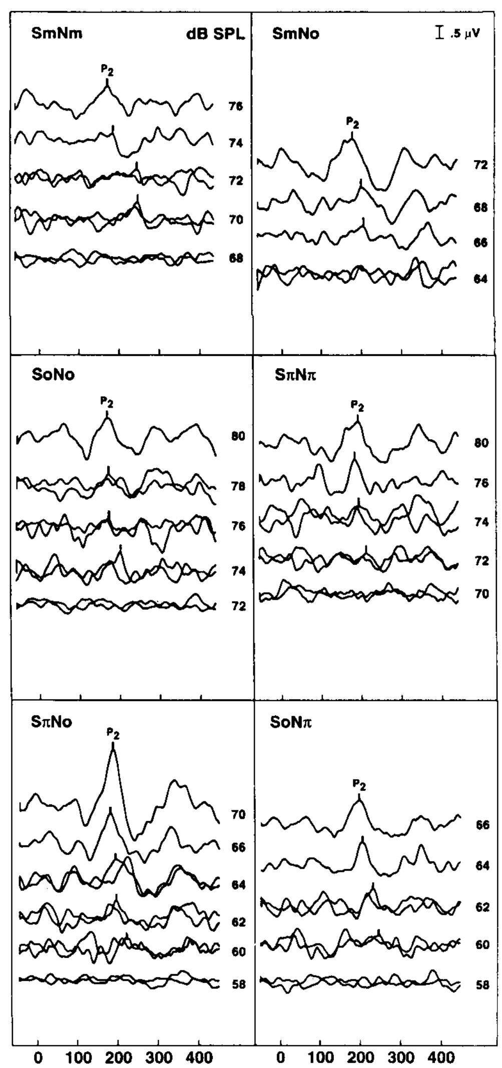

Figure 2 Late latency responses (P_2) in one subject to various stimulus and phase conditions. The thresholds for each condition are marked. MLDs are derived by comparing the thresholds in each condition to the threshold in the S_0N_0 condition (74 dB SPL).

for S_0N_0, $S_\pi N_\pi$ and S_mN_m are 70 to 74 dB SPL, whereas the thresholds for the other stimulus conditions decrease to a low of 60 dB SPL ($S_\pi N_0$ and S_0N_π). The MLDs for this subject, therefore, range from a minimum of 2 dB (S_0N_0–$S_\pi N_\pi$) to a maximum of 14 dB (S_0N_0–$S_\pi N_0$ and S_0N_0–S_0N_π).

The pattern seen in the individual subject was present in the mean data. In Figure 3, each panel shows the behavioral (abscissa) and late latency (ordinate) thresholds for the individual (open circles) and mean (filled squares) for each of the stimulus noise/phase conditions. Table 2 provides the means and standard deviations for the P_2 and behavioral responses for each of the stimulus conditions. The threshold differences between the behavioral and electrophysiologic measures ranged from 0 dB (S_0N_π) to 4 dB ($S_\pi N_\pi$). The rank order of the behavioral and late potential thresholds, highest to lowest, was $S_\pi N_\pi$, S_0N_0, S_mN_0, S_0N_π, and $S_\pi N_0$, which is identical to the rank order reported for behavioral data by Hirsh (1948). The S_mN_m threshold was among the highest for the present behavioral data, the second highest for the late potential data, and not tested by Hirsh. Jeffress et al (1956) reported

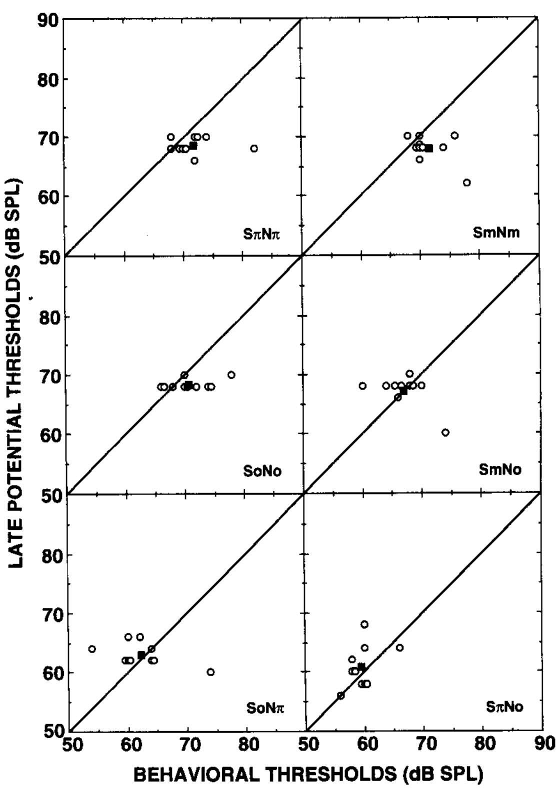

Figure 3 Individual (open circles) and mean (filled squares) thresholds for thresholds (in dB SPL) for the behavioral (abscissa) and P_2 (ordinate) measures for each of the signal noise/phase conditions.

Table 2 Mean Thresholds (in dB SPL) with Standard Deviations for P_2 and Behavioral Responses for the Various Signal and Noise Conditions

	$S_\pi N_\pi$	S_mN_m	S_0N_0	S_mN_0	S_0N_π	$S_\pi N_0$
P_2	72 (4)	71 (2)	70 (4)	66 (3)	63 (5)	59 (2)
Behavioral	68 (1)	68 (1)	68 (1)	68 (1)	63 (2)	60 (3)

S_mN_m, the true monaural condition, as having the highest threshold of the conditions tested.

The thresholds were analyzed with a two-way, two repeated measures ANOVA (Northwest Analytical, 1986) to determine the significance of differences between type of response (P_2 and behavioral) and stimulus condition. A significant interaction between type of response and stimulus condition ($F[5, 45] = 2.53$, $p < .05$) necessitated a post-hoc Newman-Keuls test (Northwest Analytical, 1986) to localize the source of the interaction. A more stringent criterion level (0.01) was used for the post-hoc tests compared to the ANOVA because of the number of comparisons required. The pair-wise comparisons indicated no significant differences in thresholds between the P_2 and behavioral thresholds for any of the signal conditions tested ($p > .01$). The behavioral and late potential thresholds, therefore, showed essentially the same pattern of responses for the signal noise/phase conditions.

The results of the Newman-Keuls test for the comparisons of interest for the P_2 thresholds are shown in Table 3 and the comparisons for the behavioral thresholds are in Table 4. For the P_2 thresholds, S_0N_0, $S_\pi N_\pi$, and S_mN_m thresholds were not significantly different ($p > .01$), whereas, for the behavioral thresholds, S_mN_0 was also not significantly different from the other three conditions. Significantly lower thresholds were

Table 3 Post-hoc Newman-Keuls Test for Significance of Differences among Means for P_2 Thresholds for Each Signal Condition

	$S_\pi N_\pi$	S_mN_m	S_0N_0	S_mN_0	S_0N_π	$S_\pi N_0$
$S_\pi N_\pi$	—	—	—	*	*	*
S_mN_m		—	—	*	*	*
S_0N_0			—	*	*	*
S_mN_0				—	*	*
S_0N_π					—	—
$S_\pi N_0$						—

*p < .01.

Table 4 Post-hoc Newman-Keuls Test for Significance of Differences Among Means for Behavioral Thresholds for Each Signal Condition

	$S_\pi N_\pi$	$S_m N_m$	$S_0 N_0$	$S_m N_0$	$S_0 N_\pi$	$S_\pi N_0$
$S_\pi N_\pi$	—	—	—	—	*	*
$S_m N_m$		—	—	—	*	*
$S_0 N_0$			—	—	*	*
$S_m N_0$				—	*	*
$S_0 N_\pi$					—	—
$S_\pi N_0$						—

*$p < .01$.

achieved for both S_0N_π and $S_\pi N_0$ as compared to thresholds for the homophasic conditions (S_0N_0, $S_\pi N_\pi$, and S_mN_m) for both the behavioral and P_2 methods. The primary difference between the P_2 and behavioral thresholds was in the comparison of the S_0N_π and $S_\pi N_0$ thresholds. These thresholds were significantly different for the P_2 responses, with the $S_\pi N_0$ being 4 dB lower than the S_0N_π thresholds. For the behavioral responses, the 3-dB difference between the S_0N_π and $S_\pi N_0$ thresholds was not statistically significant.

Table 5 shows the means and standard deviations for MLDs derived from differences in thresholds for each of the phase conditions referenced to the S_0N_0 thresholds and includes Hirsh's (1948) data for comparison. In Figure 4, each panel shows the behavioral (abscissa) and late potential (ordinate) MLDs for the individual (open circles) and mean (filled square) data for each of the stimulus/phase conditions referenced to the S_0N_0 condition. The MLDs have the same pattern for the P_2 and the behavioral measurement conditions. The MLD from S_0N_0–$S_\pi N_0$ is approximately 9 dB and is the largest for both behavioral and late potential measures. The second largest MLD for both measures is the S_0N_0–S_0N_π. The only substantial difference between the behavioral and late potential measures is the S_0N_0–S_mN_0 difference, which produced a negligible MLD for the behavioral measures, but a 4-dB MLD for the late potential measures. The P_2 data, in particular, are remarkably similar to those of Hirsh (1948).

Table 5 Mean MLDs (in dB) for the Various Signal-in-Noise Conditions Referenced to S_0N_0 as Determined by the P_2 and Behavioral Methods

	S_0N_0–$S_\pi N_\pi$	S_0N_0–S_mN_m	S_0N_0–S_mN_0	S_0N_0–S_0N_π	S_0N_0–$S_\pi N_0$
P_2	–1	0	4	9	11
Behavioral	–1	0	1	5	7
Hirsh (1948)	–1	DNT	6	9	11

For comparison, the behavioral MLDs obtained for Hirsh (1948) are also given. DNT = did not test.

DISCUSSION

The present study defined additional characteristics that are similar between the MLDs derived from late latency data and behavioral data, and further failed to demonstrate MLD–like characteristics in the middle latency potentials. The late latency data in the present study are consistent with previous studies demonstrating similar characteristics between the P_2 and behavioral measures of the MLD (Yonovitz, et al, 1979; Noffsinger et al, 1984; Kevanishvili and Lagidze, 1987; Fowler and Mikami, 1992 a, b), whereas the absence of a correspondence between the middle latency potentials and the behavioral MLD also confirms earlier findings (Kevanishvili and Lagidze, 1987; Galambos and Makeig, 1992b; Fowler and Mikami, 1995).

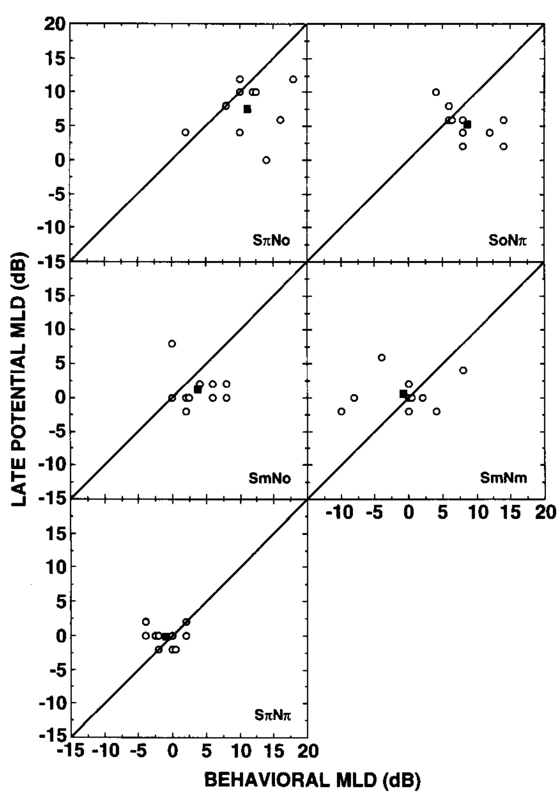

Figure 4 Individual (open circles) and mean (filled squares) MLDs (in dB, referenced to the threshold at S_0N_0) for behavioral (abscissa) and P_2 (ordinate) measures for each signal noise/phase condition.

In addition to using the standard vertical recording orientation, the present study investigated the possibility of MLD–like characteristics in the temporal components of the middle latency responses, as defined by Cacace et al (1990). Both the vertical and temporal components, however, failed to reveal any significant threshold differences between the S_0N_0 and $S_\pi N_0$ conditions that would be consistent with an MLD. The orientation of the middle response generators, therefore, is not the limiting factor in recording the MLD from that epoch. The phase information encoded and maintained by cochlear and brainstem structures (Fowler, 1992; Fowler and Mikami, 1995), therefore, is not broken by the generators of the middle latency responses.

An alternative method that derives the binaural interaction component from the middle latency responses (Dobie and Norton, 1980) does demonstrate binaural interaction at the level of the generators of the middle latency responses. The binaural interaction component paradigm, however, differs from the present paradigm in that it derives a difference potential from the subtraction of summed monaural responses and binaural responses, in essence, comparing amplitude and latency differences in the monaurally and binaurally elicited potentials. This binaural interaction does not indicate threshold differences that are evaluated by varying phase and noise conditions in the present MLD paradigm.

With respect to the late latency responses, the P_2 thresholds from the various stimulus conditions tested agreed with thresholds predicted from the literature on behavioral responses to similar stimulus phase conditions (Hirsh, 1948; Jeffress et al, 1956). Given the differences in recording parameters, the MLDs from the various stimulus conditions that were derived from the P_2 measures were remarkably similar in magnitude to the MLDs derived from the behavioral measures, as was the hierarchy of thresholds to the various signal-in-noise conditions. The encoded phase information from lower structures in the auditory pathways, therefore, is translated to threshold differences cortically by the generators of the late potentials.

Previous studies on auditory evoked potentials have not evaluated responses to the various signal noise/phase conditions that were used in this study. Galambos and Makeig (1992b) compared changes in the steady-state potential, which is essentially derived from the middle latency responses, using four monaural and binaural signal noise/phase conditions that were comparable to S_m, S_mN_m, S_mN_0, and S_0N_0. In the present study, the S_mN_m to S_mN_0 threshold difference was 5 dB and was easily measured in the P_2 thresholds, but was not noted previously in the steady-state potential. As indicated by Galambos and Makeig (1992b) and supported by the present findings, the steady-state potential apparently reflects predominantly middle latency response characteristics with respect to the MLD paradigm.

For psychoacoustic data, Jeffress et al (1956) explained that the highest threshold occurred for the true monaural condition (S_mN_m) because of the difference in critical bandwidths for the monaural and binaural conditions. Consequently, they predicted that the S_mN_m threshold would be 1.5 dB higher than the pseudomonaural condition, S_mN_0. In the present study, the S_mN_m threshold was 5 dB higher than the S_mN_0 threshold, whereas, for the behavioral data, the thresholds were identical. Both of these findings may be related to the relatively large 2-dB step size used for determining thresholds, which contributes to the variability in the threshold measures and may have obscured the small effect that was expected. It is of doubtful practicality to measure the P_2 thresholds in smaller steps than those used in this study.

The critical band concept has been used as an explanation underlying the MLD due to the wider critical band for $S_\pi N_0$ than for S_0N_0. One indication of this difference has been that, in the behavioral MLD, the S_0N_0 signals demonstrate a decibel for decibel increase in thresholds with masker level, whereas the $S_\pi N_0$ thresholds demonstrate a shallower increase (Hall and Harvey, 1984). Similarly, for the late potentials, a shallower slope is achieved with $S_\pi N_0$ conditions than for S_0N_0 conditions (Fowler and Mikami, 1992a). The issue of critical bands has not yet been settled for the late potentials, with one study reporting late potential critical bands comparable to behavioral measures (Keidel and Spreng, 1965) and one study finding no evidence of critical bands in late potentials (Skinner and Antinoro, 1970). Consequently, the effect of critical bands on the late potential MLDs is also unknown. If critical bands are the underlying determinants of behavioral MLDs then it is expected that critical band effects also underlie the late potential MLDs, and could be measured directly in the late latency auditory potentials.

CONCLUSIONS

An MLD paradigm was used to attempt to elicit an electrophysiologic correlate of the psychoacoustic MLD in the middle and late auditory evoked potentials. The middle latency responses did not reveal any threshold differences that would be consistent with an MLD from either vertex or temporal electrode montages. The late latency responses, on the other hand, produced large and reliable MLD characteristics, which were consistent with results from previous studies. The present study extended these findings to include several MLD paradigms that produce small MLDs in psychoacoustic studies, and the magnitude of the MLD recorded from the late latency responses approximated the magnitude of the behavioral MLD recorded in the present study and previously. Translation of the phase code into threshold differences apparently does not occur until the cortex; consequently, cortical contributions were confirmed as necessary for the production of the electrophysiologic MLD and, by analogy, the psychoacoustic MLD.

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