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Masking-Level Difference for Spondaic Words in 2000-msec Bursts of Broadband Noise

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Abstract

One protocol developed for the *Tonal and Speech Materials for Auditory Perceptual Assessment* audio compact disc was the masking-level difference (MLD) for spondaic words in which the words and broadband noise were mixed and recorded at 16 selected signal-to-noise ratios. Four words were recorded at each level. Because it was impossible to monitor the word presentations at negative signal-to-noise ratios, a different paradigm was devised in which the spondaic words were embedded in 2000-msec bursts of noise. Before the materials were finalized for the compact disc, two experiments studied the perceptual characteristics of the paradigm. Experiment I was performed to determine the characteristics of the MLD for spondaic words in 2000-msec bursts of noise at 70 dB SPL. An unexpected finding was that the mean S_0N_0 thresholds were at signal-to-noise ratios 3–4 dB lower than previously reported spondaic word thresholds in continuous broadband noise. Experiment II examined this discrepancy with the spondaic words embedded in continuous noise and in the 2000-msec noise bursts. The results confirmed the 3–4 dB difference between thresholds for the two masker conditions. Based on the pilot data, the spondaic words embedded in 2000-msec bursts of broadband noise at signal-to-noise ratios of 0 dB to –30 dB were recorded on the compact disc in the $S_\pi N_0$ paradigm. In the compact disc trials, which involved 120 subjects with normal hearing, the MLDs for the spondaic words recorded on the compact disc were measured on 60 subjects at each of two noise levels. The mean MLDs were 7.8 dB and 8.8 dB for the 65 and 85 dB SPL noise conditions, respectively, with 90 percent of the MLDs ≥ 5.5 dB for each of the two conditions.

Key Words: Masking-level difference (MLD), noise bursts, S_0N_0, $S_\pi N_0$

The masking-level difference (MLD) refers to the difference between corresponding thresholds in two binaural masking paradigms. Typically, the two masking paradigms, which differ in phase attributes, are termed homophasic and antiphasic. A homophasic condition (e.g., S_0N_0) is one in which the signals in two channels are in phase with one another (S_0) and the noises in two channels are in phase with one another (N_0). Here, the notations S_0 and N_0 denote that the signals (S) in the two channels have no phase difference (i.e., 0°) and the noises (N) in the two channels also have no phase difference (0°). An antiphasic condition (e.g., S_0N_π or $S_\pi N_0$) is one in which either the signals (S_π) or noises (N_π) in the two channels are 180 degrees (π radians) out of phase. Although phase relations other than 180 degrees are used in a variety of experimental conditions, the 180 degree difference produces the maximum effect (Jeffress et al, 1952) and is the condition used in clinical auditory evaluations.

The MLD was described initially in the psychoacoustic literature for pure tones (Hirsh, 1948) and for speech (Licklider, 1948). (See Durlach and Colburn [1978] for a review.) The MLD (S_0N_0 threshold minus $S_\pi N_0$ threshold), which can be 10 to 15 dB for pure tones, is frequency dependent with the largest effects in the lower frequencies (300–600 Hz) and with minimal effects in the frequencies above 1000

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to 2000 Hz (Webster, 1951; Hirsh and Burgeat, 1958; Durlach, 1960). The MLD for speech signals, which is smaller than the MLD for pure tones, is: (1) larger for low-frequency dominated speech signals such as spondaic words than it is for higher-frequency dominated speech signals such as monosyllabic words; and (2) larger for a speech-detection task than for a speech-recognition task (Levitt and Rabiner, 1967; Wilson et al, 1982).

Clinically, the MLD has been suggested as an indicator of lesions that affect the auditory pathways of the brain stem (Noffsinger et al, 1972; Olsen et al, 1976; Quaranta and Cervellera, 1977). Recently, electrophysiologic correlates of the MLD have been observed in the late auditory evoked potentials (Noffsinger et al, 1984; Kavanishvill and Lagidze, 1987; Fowler and Mikami, 1992). Although pure tones produce a larger MLD than do speech signals, there are indications (Noffsinger et al, 1972) that the MLD for speech is more sensitive to auditory abnormalities in the brain stem than is the MLD for pure tones.

The purpose of this paper is to describe the development and evaluation of the MLD paradigm for spondaic words in 2000-msec bursts of broadband noise that is contained on the audio compact disc *Tonal and Speech Materials for Auditory Perceptual Assessment* (track 2, left and right channels). Because of the need to conserve time on the compact disc and because most audiometers can generate the S_0N_0 condition but cannot generate the $S_\pi N_0$ condition, only the $S_\pi N_0$ condition was recorded; the S_0N_0 condition is obtained by splitting the signal from one of the $S_\pi N_0$ channels. Thus, the spondaic words and noise were mixed at various signal-to-noise ratios (S/N) and recorded on the compact disc with the speech out of phase on the two channels and the noise in phase on the two channels. During the initial pilot work, it became apparent that when the words were presented in continuous broadband noise at the more negative signal-to-noise ratios, it was impossible to monitor auditorily the word presentations. The monitoring problem was circumvented by using 2000-msec bursts of broadband noise as the masker. In this paradigm, which permits the tester to monitor the progress of the test even though the words are not heard, the spondaic words were embedded 500 msec into the 2000-msec noise bursts that had 200-msec rise/fall times (see Fig. 1).

Two experiments and the compact disc trials were performed with the spondaic words in the MLD paradigm. The purpose of Experiment I was to obtain normative S_0N_0 and $S_\pi N_0$ thresholds in 2000-msec bursts of broadband noise from young, naive listeners. Based on data from the literature on spondaic words masked by continuous broadband noise (Wilson and Carhart, 1969), the S_0N_0 thresholds obtained in Experiment I were at signal-to-noise ratios that were lower than expected. Consequently, Experiment II was conducted to examine threshold differences between spondaic words embedded in continuous noise and spondaic words embedded in 2000-msec noise bursts. In the compact disc trials, normative S_0N_0 and $S_\pi N_0$ thresholds and the resultant MLDs were obtained from 120 subjects with normal hearing in the 2000-msec bursts of broadband noise at two levels, 65 dB SPL and 85 dB SPL.

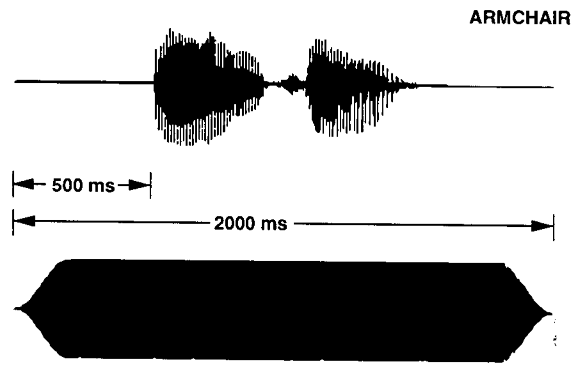

Figure 1 Digitized waveforms of the spondaic word *armchair* (top) and the 2000-msec burst of broadband noise (bottom), which for illustrative purposes are shown as two channels. In the test paradigm, the spondaic word is embedded 500 msec into the noise waveform.

METHOD

The 10 spondaic words that produced the largest MLD (Wilson et al, 1982) were digitized (16-bit; 44,100 samples/sec; 19,800 Hz cut-off with 96-dB/octave rejection) from CID W-1 analog tape recordings provided by Technisonic Studios (St. Louis, MO). The words (*armchair, headlight, horseshoe, hotdog, inkwell, mushroom, northwest, oatmeal, sidewalk,* and *toothbrush*) were edited without a carrier phrase and adjusted in level to peak at 0 VU.

Experiments I and II

For Experiment I, the randomizations were recorded on digital audio tape (DAT) (Sony, Model PCM-2500A) in the $S_\pi N_0$ paradigm with the 10 spondaic words embedded in the noise bursts and with the words 180 degrees out of phase on the two channels. During playback, the $S_\pi N_0$ condition was achieved by routing the two channels from the DAT separately to the two input channels of an audiometer (Grason-Stadler, Model 10) and then to each earphone (TDH-50P encased in P/N 510C017-1 cushions); S_0N_0 was achieved by routing the left channel of the $S_\pi N_0$ condition to both earphones. For Experiment II, the randomizations were recorded with the words on one channel and the broadband noise (continuous or 2000-msec bursts) on the other channel. During playback, the words and noises from the DAT were phase aligned, mixed, and routed to the appropriate earphone through the audiometer. The following criteria/parameters were common to Experiments I and II: (1) 24 different subjects in each experiment; (2) the subjects had pure-tone thresholds at octave frequencies 250 to 8000 Hz of 20 dB HL or better (ANSI, 1989); (3) the broadband noise was presented at 70 dB SPL; (4) the levels of the recorded words were attenuated 2 dB after every fourth word for signal-to-noise ratios from 0 to –36 dB; (5) the subjects were familiarized with the 10 words and had a list of the words throughout testing; (6) the subject responses were verbal; (7) the S_0N_0 condition was always administered before the $S_\pi N_0$ condition; and (8) the S_0N_0 and $S_\pi N_0$ thresholds were computed with the Spearman-Kärber method (Wilson and Margolis, 1983; Finney, 1987).

Compact Disc Trials

One of the recorded $S_\pi N_0$ randomizations used in Experiment I was transferred to the compact disc (track 2). Because of the minimal information provided by the –32 to –36 dB S/N conditions in Experiment II, only the 16 signal-to-noise ratios from 0 to –30 dB were recorded with four words at each level. The compact disc trials were conducted with 60 subjects at each of two noise levels (65 and 85 dB SPL). The 120 subjects with normal hearing are described in Noffsinger et al (1994). As in the two preliminary experiments, the subjects in the compact disc trials were familiarized with the 10 spondaic words and had a list of the words, the responses were verbal, testing for both S_0N_0 and $S_\pi N_0$ started at 0-dB S/N, the S_0N_0 condition preceded the $S_\pi N_0$ condition, and the thresholds were computed with the Spearman-Kärber method.

RESULTS AND DISCUSSION

Experiment I

S_0N_0 and $S_\pi N_0$ thresholds were established for the 10 select spondaic words embedded in 2000-msec noise bursts on 24 subjects. Table 1 lists the mean threshold and MLD data. The mean S_0N_0 threshold was 54.1 dB SPL and the mean $S_\pi N_0$ threshold was 44.5 dB SPL; the mean MLD was 9.5 dB. The unexpected finding was that the mean S_0N_0 threshold was at a signal-to-noise (S/N) ratio 3–4 dB lower than previously reported spondaic word thresholds in continuous broadband noise (e.g., Wilson and Carhart, 1969). In Experiment II, this discrepancy with the S_0N_0 threshold was studied using MLDs from 24 listeners with the spondaic words in two masker conditions: (1) the words embedded in the noise bursts as in Experiment I; and (2) the words embedded in continuous noise.

Experiment II

The individual S_0N_0 and $S_\pi N_0$ threshold data are plotted in Figure 2, with the thresholds in continuous noise depicted on the abscissa and the thresholds in the 2000-msec bursts of noise depicted on the ordinate. As can be seen in the figure, 47 of the 48 threshold comparisons (2 masker conditions by 24 subjects) are displaced to the right of the diagonal line, indicating that the thresholds in continuous noise were at higher sound pressure levels than were the thresholds in the noise bursts. The remaining threshold comparison was at equal sound pressure levels.

The descriptive statistics of the data from Experiment II are listed in Table 2. The relation demonstrated in Figure 2 is reflected in the data in Table 2, with the mean thresholds in the pulsed noise at sound pressure levels 3.8 dB (S_0N_0) and 3.2 dB ($S_\pi N_0$) lower than the mean

Table 1 Mean Thresholds in 2000-msec Bursts of 70 dB SPL Broadband Noise, Mean MLD, and Other Descriptive Statistics for 24 Naive Listeners in Experiment 1

	S_0N_0	$S_\pi N_0$	MLD
Mean (dB SPL)	54.1	44.5	9.5
Mean (dB S/N)	–15.9	–25.5	
SD	1.3	1.6	1.1
Min	51.5	42.5	7.5
Max	57.0	48.5	11.5
Range	5.5	6.0	4.0

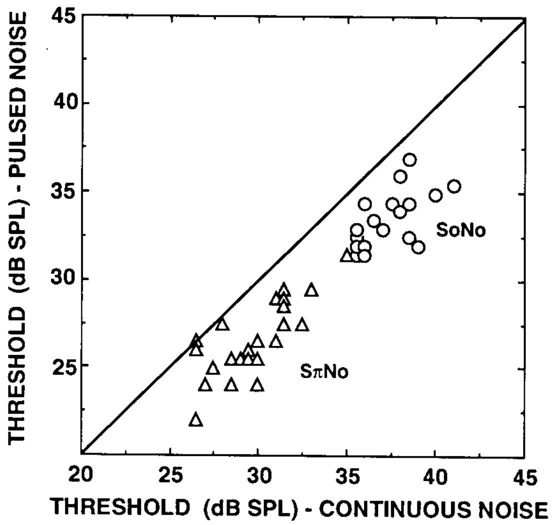

Figure 2 A bivariate plot of the S_oN_o (circles) and $S_\pi N_o$ (triangles) thresholds in continuous noise (abscissa) and in the 2000-msec burst of noise (ordinate) obtained from the 24 subjects in Experiment II.

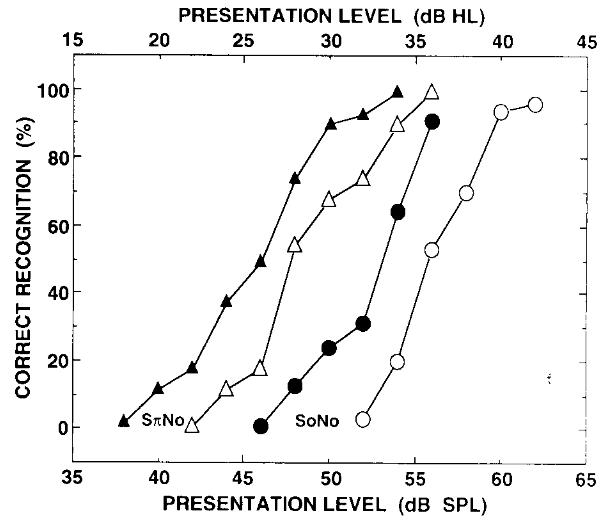

Figure 3 Psychometric functions (n = 24) for the spondaic words presented in continuous noise (open symbols) and in the 2000-msec bursts of noise (filled symbols) in Experiment II. The S_oN_o conditions are depicted with circles, whereas the $S_\pi N_o$ conditions are depicted with triangles.

thresholds in the continuous noise. The mean 57.3 dB SPL S_oN_o threshold in continuous noise (-12.7 dB S/N) is in excellent agreement with other spondaic word threshold data in continuous noise of −12 to −13 dB S/N (Wilson and Carhart, 1969; Konkle and Berry, 1983). The psychometric functions for the four listening conditions are illustrated in Figure 3. The slopes of the functions (interpolated between the 20% and 80% correct points)[1] ranged from 8.6 percent/dB for the two $S_\pi N_o$ conditions to 10.6 percent/dB (pulsed) and 12.5 percent/dB (continuous) for the two S_oN_o conditions. The data in Figures 2 and 3 and in Table 2 demonstrate at equal masker levels better word-recognition performance in the pulsed noise condition than in the continuous noise condition. A possible explanation for this relationship is that the pulsed noise served to define the listening interval for the subjects, thereby reducing the uncertainty associated with the listening task.

Compact Disc Trials

The compact disc trials for the spondaic word MLD were conducted at 65 and 85 dB SPL,[2] with 60 subjects participating at each level. The data from the compact disc trials are

[1]The mean data for the psychometric functions were fit with third-degree polynomials from which the slopes of the functions were calculated. The following equations represent the functions (R^2 = 0.97 to 0.99):

S_oN_o, continuous: $y = 23722 - 1299.2x + 23.513x^2 - 0.14039x^3$;
$S_\pi N_o$, continuous: $y = 4475 - 294.97x + 6.3302x^2 - 0.043908x^3$;
S_oN_o, pulsed: $y = -6803.7 + 423.34x - 8.8673x^2 + 0.062616x^3$; and
$S_\pi N_o$, pulsed: $y = 4399.5 - 303.82x + 6.8501x^2 - 0.049979x^3$.

[2]Because the compact disc was played through the speech channels of the audiometer, the sound pressure level of the noise corresponded to the hearing level of the speech channel that nominally is 20 dB lower than the sound pressure level.

Table 2 Mean Thresholds in 70 dB SPL Broadband Noise (Continuous and 2000-msec Burst Conditions), Mean MLDs, and Other Descriptive Statistics for 24 Subjects in Experiment II

	Continuous Noise			*2000-msec Noise Bursts*		
	S_oN_o	$S_\pi N_o$	*MLD*	S_oN_o	$S_\pi N_o$	*MLD*
Mean (dB SPL)	57.3	49.8	7.5	53.5	46.6	6.9
Mean (dB S/N)	−12.7	−20.2		−16.5	−23.4	
SD	1.5	2.2	1.8	1.5	2.1	1.9
Min	55.5	46.5	3.0	51.5	42.0	4.0
Max	61.0	55.0	10.5	57.0	51.5	11.5
Range	5.5	8.5	7.5	5.5	9.5	7.5

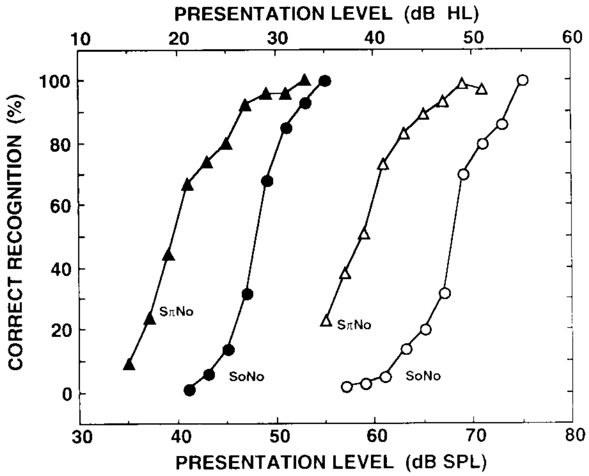

Figure 4 Psychometric functions for the spondaic words presented in the 2000-msec bursts of broadband noise during the compact disc trials. The S_0N_0 functions are depicted with circles and the $S_\pi N_0$ functions are depicted with triangles. The filled symbols represent data with the 65 dB SPL noise level, whereas the open symbols represent data with the 85 dB SPL noise level. Each function represents data from 60 subjects with normal hearing.

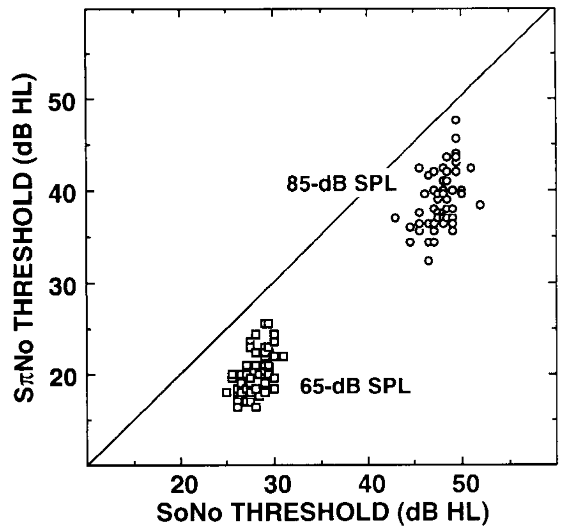

Figure 5 A bivariate plot of the S_0N_0 thresholds and the $S_\pi N_0$ thresholds obtained in 2000-msec bursts of broadband noise at 65 dB SPL (squares) and 85 dB SPL (circles) during the compact disc trials (n = 120).

depicted as psychometric functions in Figure 4, as a bivariate plot of the S_0N_0 and $S_\pi N_0$ thresholds in Figure 5, and as descriptive statistics in Table 3. In Figure 4, the filled symbols represent the data for the 65 dB SPL noise condition, whereas the open symbols represent the data for the 85 dB SPL noise condition. The slopes of the functions[3] in Figure 4 between the 20 and 80 percent correct points ranged from 7.4 percent/dB for the two $S_\pi N_0$ conditions to 8.2 percent/dB for S_0N_0 at the higher level to 11.5 percent/dB for S_0N_0 at the lower level. Several relations among the data in Figure 5 and Table 3 are of interest. First, the S_0N_0 and $S_\pi N_0$ mean thresholds are at −17 dB S/N and −25 dB S/N, respectively, which are in good agreement with the thresholds in pulsed noise from Experiment II. Second, the S_0N_0 mean thresholds reflect the 20-dB difference in the two levels of the noise. Third, as is typically observed with homophasic and antiphasic masking conditions, the variability (standard deviations and ranges) of the $S_\pi N_0$ thresholds is greater than the variability of the S_0N_0 thresholds. Fourth, as the masker level was increased from 65 to 85 dB SPL, there was an increase of about 1 dB in the MLD.

For the two S_0N_0 conditions, 33 or more words of the possible 64 total words presented were recognized correctly by 90 percent of the

[3]The mean data for the psychometric functions were fit with third-degree polynomials from which the slopes of the functions were calculated. The following equations represent the functions (R^2 = 0.97 to 0.99):

S_0N_0 at 65 dB SPL: $y = 11606 - 746.13x + 15.786x^2 - 0.10953x^3$;
$S_\pi N_0$ at 65 dB SPL: $y = -1059.4 + 53.814x - 0.79218x^2 + 0.0035693x^3$;
S_0N_0 at 85 dB SPL: $y = 11322 - 514.45x + 7.6887x^2 - 0.03766x^3$; and
$S_\pi N_0$ at 85 dB SPL: $y = 543.43 - 53.741x + 1.2734x^2 - 0.0085227x^3$.

Table 3 Mean Thresholds in 2000-msec Bursts of Broadband Noise, Mean MLDs, and Other Descriptive Statistics for 60 Subjects at Each of Two Noise Levels in Compact Disc Trials

	65 dB SPL			*85 dB SPL*		
	S_0N_0	$S_\pi N_0$	*MLD*	S_0N_0	$S_\pi N_0$	*MLD*
Mean (dB SPL)	48.0	40.2	7.8	67.9	59.1	8.8
Mean (dB HL)	28.0	20.2		47.9	39.1	
Mean (dB S/N)	−17.0	−24.8		−17.1	−25.9	
SD	1.4	2.4	2.1	1.7	3.0	2.7
Min (dB SPL)	45.0	36.5	3.5	63.0	52.5	2.0
Max (dB SPL)	51.0	45.5	11.5	72.0	67.5	14.0
Range	6.0	9.0	8.0	9.0	15.0	12.0

subjects, which corresponds to thresholds of 29.5 dB HL (49.5 dB SPL) in the 65 dB SPL noise condition and 49.5 dB HL (69.5 dB SPL) in the 85 dB SPL noise condition. For the $S_{\pi}N_0$, 65 dB SPL condition, 46 or more of the words were recognized correctly by 90 percent of the subjects, which corresponds to a 23.0 dB HL (43.0 dB SPL) threshold; for the $S_{\pi}N_0$, 85 dB SPL condition, 47 or more of the words were recognized correctly by 90 percent of the subjects, which corresponds to a 42.5 dB HL (62.5 dB SPL) threshold. Typically, ±2 standard deviations are used to define the normal range; however, because of the bimodal distribution of the MLDs, the 90th percentile was determined for the MLD. For both noise levels, 90 percent of the MLDs were ≥ 5.5 dB. Thus, with the spondaic word materials recorded on the compact disc, MLDs worse than 5.5 dB should be considered abnormal for listeners with normal hearing.

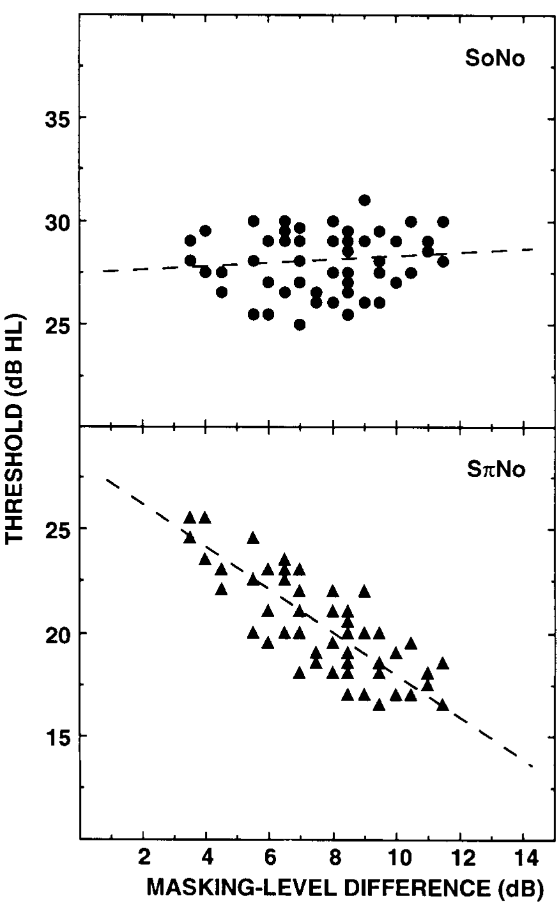

Figure 6 A bivariate plot of the S_0N_0 thresholds (top panel) and the $S_{\pi}N_0$ thresholds (bottom panel) as a function of MLD in the 65 dB SPL broadband noise condition. Data for 60 subjects are displayed.

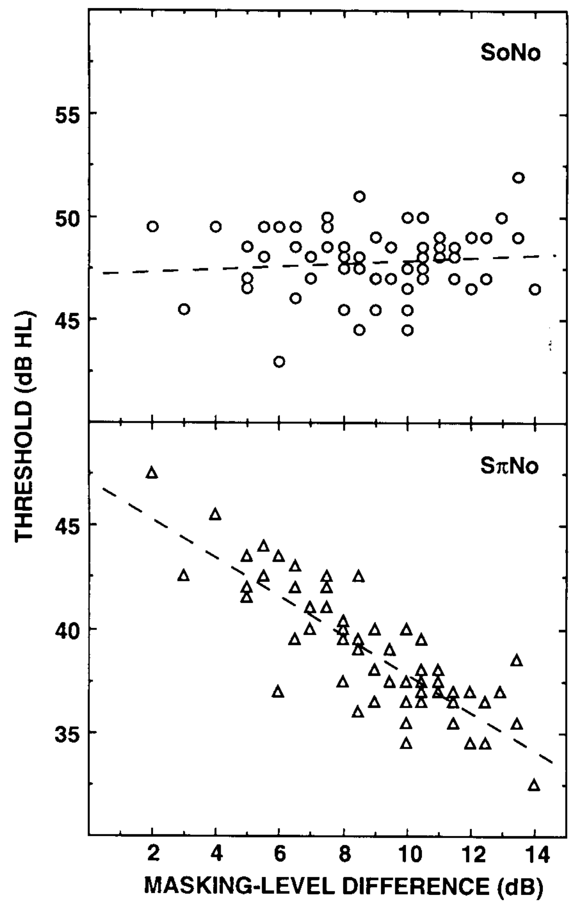

Figure 7 A bivariate plot of the S_0N_0 thresholds (top panel) and the $S_{\pi}N_0$ thresholds (bottom panel) as a function of the MLD in the 85 dB SPL broadband noise condition. Data for 60 subjects are displayed.

A final aspect of the MLD data from the compact disc trials deserves mention. In Figures 6 and 7, the S_0N_0 and $S_{\pi}N_0$ thresholds (ordinate) are plotted as a function of the MLD (abscissa) for the 65 dB SPL and 85 dB SPL noise conditions, respectively. The dashed lines in each panel are the linear regressions used to describe the data.[4] Sixty subject thresholds are plotted, although a few thresholds are superimposed. For both noise levels, the S_0N_0 data in the top panels of the figures are not systematic, which is evidenced by the almost flat regression lines. In contrast to the S_0N_0 data, the $S_{\pi}N_0$ data

[4]The individual S_0N_0 and $S_{\pi}N_0$ thresholds for the 65 dB SPL and 85 dB SPL noise conditions were subjected to linear regression analysis. The following equations represent the functions:

S_0N_0 at 65 dB SPL (R^2 = 0.01): y = 27.433 + 0.073764x;
$S_{\pi}N_0$ at 65 dB SPL (R^2 = 0.66): y = 27.433 – 0.9262x;
S_0N_0 at 85 dB SPL (R^2 = 0.01); y = 47.240 + 0.72395x; and
$S_{\pi}N_0$ at 85 dB SPL (R^2 = 0.69): y = 47.223 - 0.92668x.

in the bottom panels of Figures 6 and 7 demonstrate a systematic inverse relation in that the lower the $S_\pi N_0$ threshold, the larger the MLD. One may speculate from the data in Figures 6 and 7, especially the $S_\pi N_0$ data, that future studies on clinical populations may be able to define abnormal auditory function based on an elevated $S_\pi N_0$ threshold instead of the difference between the S_0N_0 threshold and $S_\pi N_0$ threshold. Based on the current $S_\pi N_0$ threshold data, the 90th percentiles are –22.0 dB S/N for the 65 dB SPL condition and –22.5 dB S/N for the 85 dB SPL noise condition.

The current data from the compact disc trials describe the word-recognition performance of young adults with normal hearing on the MLD paradigm (S_0N_0 and $S_\pi N_0$ thresholds) in which the spondaic words are embedded in 2000-msec bursts of broadband noise. Additional data are needed to define the performance on the MLD task of patients who are older, patients who have peripheral hearing loss, and patients who have various neurologic impairments.

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