The Masking-Level Difference in Children

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Abstract

The masking-level difference (MLD) was investigated in children aged 3.9 to 9.5 years and in an adult control group in order to examine the development of the MLD with age. A three-alternative forced-choice adaptive tracking procedure was used for all listeners. MLDs were determined for a 500-Hz pure-tone signal presented in a 300-Hz-wide masking noise centered on 500 Hz, where both interaural time and amplitude cues were present, and in 40-Hz-wide maskers centered on 500 Hz, where either amplitude (MLDΔa) or time (MLDΔt) cues were present. The masking noise level was fixed at 60 dB/Hz SPL. For the 300-Hz-wide masker, the MLDs of the children increased in magnitude up until the age of 5 or 6 years. For the 40-Hz-wide maskers, the MLDs of the 5- and 6-year-old children were still somewhat below adult values. It is possible that these differences between adults and children are related to the development of the peripheral/brainstem auditory system. By this interpretation, the MLD might be small in young listeners because the interaural time and amplitude cues underlying the MLD are coded with relatively poor precision.However, it is perhaps more likely that these differences are coded precisely in the peripheral auditory system, but that more central auditory processes are relatively inefficient in extracting the interaural information.

Key Words: Masking-level difference, binaural hearing, children, psychoacoustics

The present study investigated the masking-level difference (MLD)(Hirsh, 1948) in children aged between approximately 4 and 9 years. The MLD depends on the ability of the auditory system to process relatively subtle interaural difference cues of time and amplitude. Whereas the anatomic stage of processing most critical for the MLD may have its locus at the level of the superior olivary complex (the most peripheral site of human binaural interaction), the MLD also hinges on more peripheral auditory processing and has been found to be reduced in cases where the probable site of lesion was conductive (Hall and Derlacki, 1986; Quaranta and Cervellera, 1974), cochlear (Hall et al, 1984; Jerger et al, 1984; Quaranta and Cervellera, 1974), or neural/brainstem (Hannley et al, 1983; Noffsinger et al, 1972). The MLD may therefore have importance as a gauge of peripheral/brainstem auditory development.

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The literature presently available does not offer a completely clear account of the effect of subject age on the magnitude of the MLD. Sweetow and Reddell (1978) tested children 4 to 12 years of age, using both a 500-Hz pure-tone signal and a speech signal. The authors found that the MLD did not differ significantly between adults and children (MLDs for speech were between approximately 6 and 8 dB, and MLDs for a 500-Hz pure tone were between approximately 9 and 10 dB for both adults and children). Whereas these results indicated no effect of age on the MLD, no analysis of the MLD within the 4- to 12-year-old age group was reported; the primary intent of the study was to determine the value of the MLD in identifying children with perceptual disorders, rather than to determine the effect of age on the MLD. A subsequent study by Roush and Tait (1984) investigated the MLD for a 500-Hz pure-tone signal in children aged 6 to 12 years. MLDs of the children ranged between 10 and 14 dB. Although the primary purpose of the study was, again, not related to the development of binaural hearing, the results indicated no significant change of MLD within this age range.

A study intended more directly to investigate the effect of age on the MLD was reported by Nozza (1987). This study compared the MLD performance of adult and infant listeners, using a 500-Hz pure-tone signal. The results indicated significantly smaller MLDs for infant listeners as contrasted with the adult control group. A later MLD study (Nozza et al, 1988), using a speech signal, compared MLDs for infants, preschoolers (aged 3.5 to 4.5 years), and adults. The results showed that MLDs increased with increasing age across the three groups tested. However, Nozza et al argued that the difference between adults and preschoolers was eliminated when level of stimulation was taken into account. The three groups were initially compared using a relatively low fixed masker pressure spectrum level of 35 dB. Because the MLD increases with increasing masker level over low spectrum levels (McFadden, 1968), and because the thresholds in quiet of their listeners improved somewhat as a function of increasing age, Nozza et al contended that the MLD may have increased as a function of increasing age due to the relatively higher sensation level of the masking noise with increasing age of the subject. When adults were retested at lower masking pressure spectrum levels (15 and 25 dB/Hz) in an attempt to adjust for their relatively lower thresholds in quiet, smaller MLDs were found than for the 35 dB/Hz spectrum level. In interpreting the effect of masker presentation level, Nozza et al concluded that the difference between adults and infants remained significant, but that the difference between adults and preschoolers did not.

The primary purpose of the present study was to determine more clearly the effect of subject age on the MLD for a 500-Hz pure-tone signal, investigating an age range from about 4 to 9 years. In order to minimize any contribution of masker level to the results, a masker pressure spectrum level of 60 dB was used, well above the pressure spectrum level of approximately 30 dB where the MLD asymptotes (Hall and Harvey, 1984; McFadden, 1968). In addition to investigating the MLD for a pure tone in noise, where binaural difference cues of both time and amplitude are available, the present study also determined the MLD under conditions where only interaural time cues, or only interaural amplitude cues, were available. Thus a secondary purpose of the present study was to determine the effect of subject age on sensitivity to each of the two types of interaural difference cues that potentially contribute to the MLD.

METHOD

Subjects

There were 10 adult subjects, aged 19 to 35 years (mean = 26.3 years), who served as controls for the children. These subjects had hearing thresholds within normal limits and had no history of ear disease. Twenty-six children, also without history of hearing loss, participated. The ages of the children ranged from 3.9 to 9.5 years (mean = 5.6 years.)

Stimuli

In the first MLD test, the masking noise was an interaurally in-phase (No), 300-Hz-wide noise band centered on 500 Hz. The 500-Hz pure-tone signal was either interaurally in phase (So) or 180° out of phase (Sπ). Under these test conditions, an So signal resulted in no binaural difference cues, and an Sπ signal resulted in interaural difference cues of both time and amplitude. The stimuli in the second MLD test were derived such that sensitivity to interaural differences of time and amplitude could be assessed independently. A 40-Hz-wide narrowband noise centered on 500 Hz was used as both the signal and masker. In the baseline (NoSo) condition, the noise band was added to itself, in phase, during the signal interval. For the stimuli used to investigate the cue of interaural amplitude difference, the signal was presented in phase with the masker in one ear and 180° out of phase with the masker in the other. For the ear receiving the in-phase masker the effect of the signal was to increase the amplitude of the masker (due to summation), whereas for the ear receiving the out-of-phase masker the effect of the signal was to decrease the amplitude of the masker (due to cancellation). Thus there was an interaural amplitude difference cue, but no interaural time difference cue. The MLD derived from this condition will be referred to as the MLDΔa. In the procedure examining the interaural time difference cue, the Sπ signal had the same waveform as the masker but was delayed by 500 μs (90° at 500 Hz) with respect to the masker. NoSπ stimulation under this circumstance resulted in some amount of amplitude increase in both ears, but because that amount was the same in each ear, no interaural amplitude difference cue was introduced. This signal did, however, introduce an interaural time difference cue, as it effectively advanced the phase of the masker in one ear, while retarding the phase of the masker in the other. The MLD derived from this condition will be referred to as the MLDΔt. Due to time constraints, only 16 of the 26 children participated in this MLD test.

The signal was always 400 ms in duration and had a 50-ms cosinusoidal rise/fall time. All stimuli were presented binaurally over TDH 49 earphones. Stimulus timing and response collection were controlled by an IBM AT microcomputer. The masking stimuli were presented at a level of 60 dB Hz SPL. The MLD was determined by subtracting the NoSπ threshold from the NoSo threshold.

Procedure

Data were collected using a three-alternative, forced-choice, three-down one-up adaptive strategy estimating 79.4 percent detection threshold (Levitt, 1971). In this procedure there were three observation intervals, the signal being present in only one, at random. Following three correct responses in succession, the level of the signal was reduced; following a single incorrect response, the level of the signal was increased. An initial step-size of 8 dB was reduced to 4 dB after the first two reversals in level direction and was further reduced to 2 dB after the next two reversals. A threshold run was stopped after eight reversals, and the average of the final four reversals was taken as the threshold for the run. Visual feedback was provided to the subject after each response. At least two estimates were collected per condition, with an additional one or two estimates collected if the difference between the first two exceeded 3 dB. The final threshold for a condition was determined as the average of the two to four estimates.

The forced-choice task made use of a video display to encourage motivation on the part of the children. At the beginning of a threshold run, the child had a choice of fish, rocketships, or balloons, which were used as visual stimuli to mark the three observation intervals. For example, three fish were presented on the screen, and each in sequence opened its mouth. During one of these intervals, at random, the signal was presented. The child selected the interval judged to contain the signal. If the selection was correct the fish left the screen by means of a dropped hook, while if the selection was wrong the correct fish wiggled its tail. An experimenter observed the child to confirm that attention remained on the screen throughout the threshold run. If the child's attention did not appear to be on the display, the experimenter had the option of suspending stimulus presentation while the attention of the child was directed back to the video screen. Each trial was initiated by the subject. A 5- to 10-minute rest/play interval was given after every threshold run. Audiometric pure-tone thresholds at 500 Hz were obtained for each ear, using the descending Hughson-Westlake method (Carhart and Jerger, 1959).

RESULTS

The average NoSo and NoSπ thresholds for the adult listeners, along with the average MLDs for the 300-Hz- wide and 40-Hz-wide masking noise band conditions are shown in the top portion of Table 1. Audiometric thresholds

TABLE 1 Average NoSo and NoSπ Thresholds, MLDs for the 300-Hz-Wide and 40-Hz-Wide Masking Noise Conditions, and Thresholds in Quiet at 500 Hz

	300-Hz-Wide Masker			40-Hz-Wide Masker					Quiet
	NoSo	NoSπ	MLD	NoSo	NoSπa	NoSπt	MLDΔa	MLDΔt	THR
Adult	78.3	63.6	14.7	72.7	64.4	64.0	8.3	8.7	4.5
	(1.1)	(1.2)	(0.8)	(1.9)	(3.7)	(4.4)	(1.9)	(2.1)	(3.9)
Child	81.4	68.5	12.9	77.0	73.8	75.1	3.2	1.9	9.2
	(2.6)	(4.5)	(2.2)	(4.4)	(6.7)	(7.0)	(3.4)	(4.4)	(4.4)

NoSo and NoSπ thresholds are in dB SPL, MLDs are in dB, and thresholds in quiet are in dB HL. Standard deviations are shown in parentheses.

at 500 Hz are also shown. Standard deviations are shown in parentheses. For the Δt and Δa MLDs (40-Hz-wide masking noise), the NoSo baseline was the same: the threshold for the in-phase addition of the 40-Hz-wide band added to itself. The MLD for the 300-Hz-wide masker was approximately 15 dB and showed low intersubject variability. The MLDs for the 40-Hz-wide noise band were approximately 8 dB for both the Δa and Δt cues, but intersubject variability was rather large for each of these MLDs. The magnitudes of the MLDs for adults are in general agreement with those reported in earlier studies (Hall and Derlacki, 1988; Jeffress and McFadden, 1971).

Average data for the children are shown in the bottom portion of Table 1. In this manner of data presentation, within-group trends among the children are ignored. As can be seen, the MLD in the 300-Hz-wide masking noise was slightly smaller for the children than for the adults. A t-test showed this difference to be significant ($t=2.4$; $df=34$; $p<0.05$). MLDs for the narrowband masking noise (Δa and Δt) were more clearly smaller for the children than for the adults. The t-tests for both MLDΔa ($t=4.3$; $df=24$; $p<0.01$) and MLDΔt ($t=4.6$; $df=24$; $p<0.01$) indicated that the MLDs for children were significantly smaller than those of adults.

The 300-Hz masker MLD data of the children are shown as a function of age in Figure 1. The shaded region depicts the 95 percent confidence interval for the adult listeners. The figure shows that whereas much of the data from the young listeners fell within the adult range, there was a trend for the MLD to increase as a function of increasing age. The correlation between age and MLD for the 300-Hz-wide noise band was 0.65 ($df=24$; $p<0.001$). The partial correlation between MLD and subject, controlling for the threshold in quiet at 500 Hz, was 0.64. Inspection of Figure 1 indicates that the correlation between subject age and MLD was due largely to the change in MLD magnitude over the age range from 4 to 6 years. In order to quantify this trend, separate correlations were determined in which only children less than 6 years old were included, and in which only children more than 5 years old were included. The correlation for the younger group was 0.75 ($df=15$; $p<0.001$); the correlation for the older group was 0.36 (not significant). These analyses indicate that the MLD increases as a function of increasing age, but only up to an age of about 5 or 6 years.

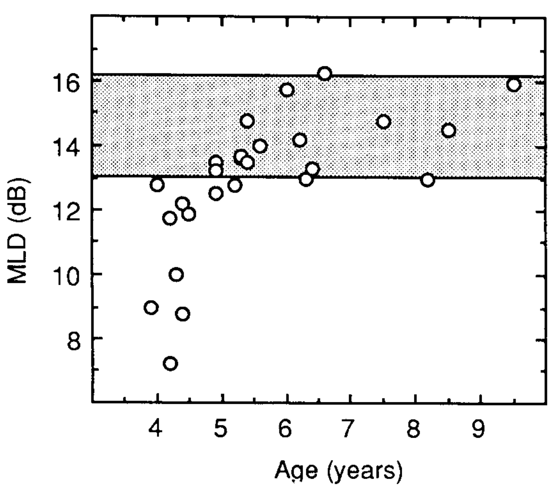

Figure 1 MLD for the 300-Hz-wide masker as a function of subject age. The 95 percent confidence interval for the adult listeners is shown by the shaded region.

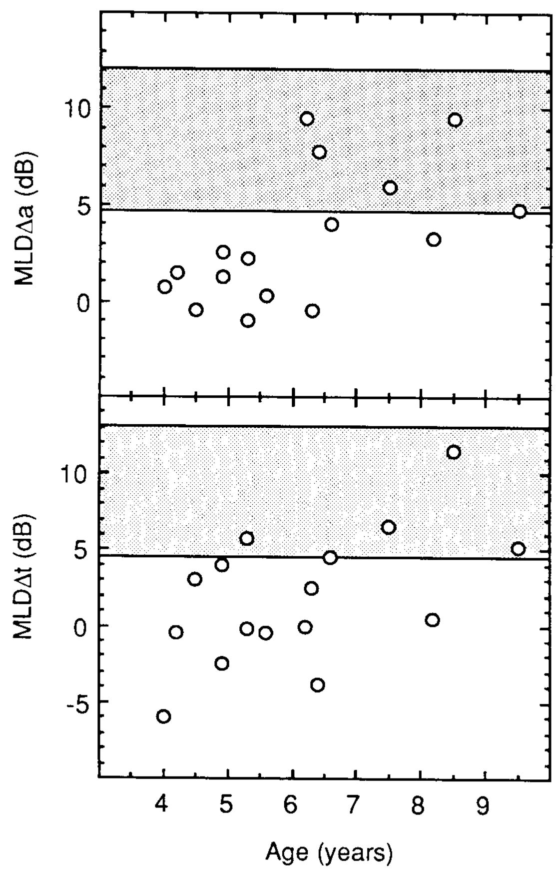

Figure 2 MLDs for the 40-Hz-wide maskers as a function of subject age for the Δa (top panel) and Δt (bottom panel) cues. The 95 percent confidence interval for the adult listeners is shown by the shaded region.

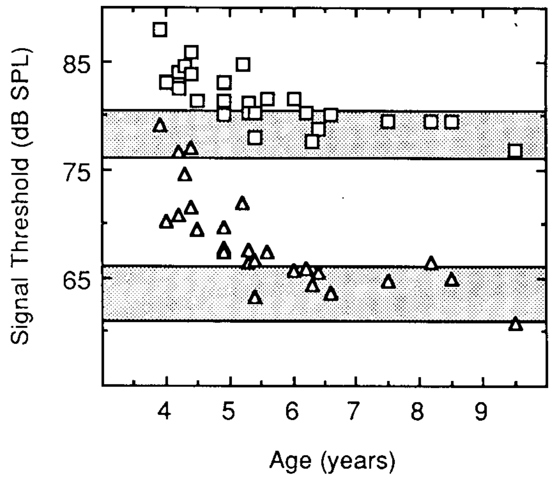

Figure 3 NoSo (squares) and NoSπ (triangles) thresholds as a function of subject age for the 300-Hz-wide masking noise.

Figure 2 shows MLDs as a function of subject age for the Δa (top panel) and Δt (bottom panel) cues. The trend of increase in MLD with increasing subject age is again apparent, although here the increase of MLD with subject age was more gradual than for the 300-Hz-wide masker, and there were more 5- and 6-year-old listeners showing MLD values below the adult limits. The correlation between age and MLD was 0.58 (df=14; $p<0.01$) and 0.56 (df=14; $p<0.05$) for the MLDΔa and MLDΔt, respectively. In order to assess the impression that the MLDs had reached adult values by age 5 or 6 for the 300-Hz-wide masker, but not for the 40-Hz-wide maskers, a repeated measures analysis of variance was performed on the 5- and 6-year-old listeners and the adults. This analysis indicated a significant effect of group ($F_{1,15}=47.8$; $p<0.001$), reflecting the relatively smaller MLDs for the children; a significant effect of MLD type ($F_{2,30}=76.3$; $p<0.001$), reflecting the relatively smaller MLDs for the 40-Hz-wide maskers; and a significant group by MLD-type interaction ($F_{2,30}=8.8$; $p<0.001$). Post hoc analysis indicated that this interaction was due to the fact that the two age groups did not differ for the 300-Hz-wide masker, but that the MLDs of the 5- and 6-year-old children were significantly smaller than those of the adults for the 40-Hz-wide masker.

It should be noted that some of the MLDs for the 40-Hz-wide maskers were negative. In the case of MLDΔa, this was negligible, the MLDs never being more negative than about 1 dB; however, for the MLDΔt case, three of the MLDs were negative by more than 2 dB. This is due to the different way in which the signal adds to the masker in the NoSo and NoSπ conditions. In the NoSo condition, the noise is added to itself, in phase, resulting in a relatively great increment in energy. However, in the NoSπ case, the noise is added to itself with a 90° phase shift, resulting in a relatively smaller energy increment (i.e., for a given threshold, a greater absolute signal energy is required in the NoSπ case as compared to the NoSo case). Thus a negative MLD is possible, even though the actual energy increment is smaller in the NoSπ case.

Finally it should be pointed out that the masked thresholds were, in general, higher for the children than for the adults (see Table 1). Figure 3 shows scattergrams plotting NoSo and NoSπ thresholds against subject age for the 300-Hz-wide masking noise. The associated correlations were -0.72 (df=24; $p<0.001$) and -0.74 (df=24; $p<0.001$) for NoSo and NoSπ thresholds, respectively. Figure 4 shows similar data for the 40-Hz-wide noise stimuli. The corre-

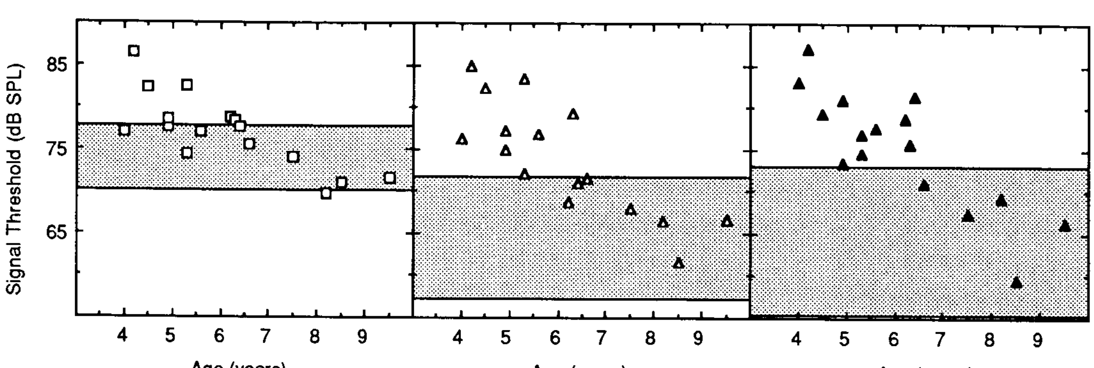

Figure 4 NoSo (squares, left panel), NoS$\pi\Delta a$ (open triangles, middle panel) and NoS$\pi\Delta t$ (filled triangles, right panel) thresholds as a function of subject age for the 50-Hz-wide masking noise.

lations between age and masked threshold were −0.78 (df=14; $p<0.01$), −0.81 (df=14; $p<0.01$), and −0.84 (df=14; $p<0.01$) for the NoSo, NoSπ (Δa cue), and NoSπ (Δt cue) stimuli, respectively.

DISCUSSION

Pure-Tone Signal Added to 300-Hz-Wide Noise Masker

The present results indicate that the MLD for a 500-Hz pure-tone signal presented in noise increases slightly as a function of age. In the present data, the improvement of MLD with subject age is clearest over the age range from 4 to 5 or 6 years. It is unlikely that the present MLD effects are related to stimulus presentation level for the following three reasons: (1) the thresholds in quiet among the present subjects were only slightly higher for the younger subjects; (2) the correlation between MLD and subject age remained significant when the factor of threshold in quiet was partialled out; and (3) the presentation level for the masking noise was well above that at which MLD magnitude approaches asymptote (Hall and Harvey, 1984; McFadden, 1968). The change of MLD size as a function of age is likely, therefore, to be related to factors other than presentation level. Viewed along with the earlier results of Nozza et al (1988), it would appear that the MLD is of reduced magnitude in infancy and does not reach a developmental maximum until an age of approximately 5 to 6 years.

We can only speculate on the factors that account for the improvement in MLD in the age range of 4 to 5 or 6 years. Perhaps the most straightforward explanation is that the peripheral/brainstem auditory processes assumed to account for the MLD are not developmentally mature until an age of 5 or 6 years. However, it is prudent also to consider more complex explanations that depend more upon central auditory processing. For example, Nozza et al (1988) noted that poor MLD performance of infants might be explained either by peripheral factors (such as incomplete myelinization) or by some sort of central "criterion" factor. Whereas a myelinization hypothesis may be feasible for infants, it is unlikely to apply to 4-year-old listeners (Reinis and Goldman, 1980). The forced-choice procedure used in the present study is largely criterion free, at least in terms of controlling for "conservative" or "liberal" decision strategies. However, a related, presumably central, factor that might account for the age effect has been termed "processing efficiency." For example, Patterson (1976) noted that the monaural detection of a tone in noise is determined essentially by (1) the frequency selectivity of the auditory system, and (2) processing efficiency. The former refers to the ability of the peripheral auditory system to improve the signal-to-noise ratio by filtering out noise components distal to the signal frequency; the latter refers to the ability of the central auditory system to process the cue for signal detection (probably related to an increase in stimulus energy), and extract the signal from the noise that the auditory system has failed to remove by peripheral filtering. In the case of the MLD, it is likely that the cues for detection are quite different in the NoSo and NoSπ conditions. In the NoSo case, as in monaural detection, the cue for signal detection is probably based largely on the energy increase due to the signal. However in the NoSπ case, detection is probably concerned primarily with the coding of binaural difference cues, although energy increase may also be an important factor (McFadden, 1975). Although there is no a priori reason why processing efficiency for both types of signal cues (NoSo and NoSπ) would not reach developmental maturity at about the same time, it would not be unreasonable to assume that the processing of binaural difference cues is more complex and could mature somewhat later in the developmental process. The present results would be consistent with an interpretation that processing efficiency for both NoSo and NoSπ detection improves over the ages 4 to 6 years, but that the processes accounting for NoSπ detection mature slightly later.

A related hypothesis that might explain the poor MLD performance of our youngest subjects is related to the growth of neural excitation in the NoSo and NoSπ masking cases as a function of the signal level. For example, Nozza et al (1988) pointed out that the reduced MLDs of infants may be related to a loudness growth phenomenon described by Townsend and Goldstein (1971). The latter authors showed that, at levels above masked threshold, the loudness of a NoSo signal increased more steeply than that of a NoSπ signal, resulting in a decreased "MLD" for suprathreshold signals. The masked thresholds (both NoSo and NoSπ) of infants (Nozza et al, 1988) and young children (present study) are higher than those of adults;

therefore the detection thresholds of these listeners correspond to levels for which the suprathreshold MLDs of adults are relatively small (Townsend and Goldstein, 1971). This would be consistent with the present finding of a relatively small MLD for our younger listeners.

The results of a recent study (Hall and Grose, 1990) comparing monaural frequency selectivity in adults and children is consistent with the above interpretation. In this study, a notched-noise masking procedure (Patterson, 1976) was used to measure frequency selectivity. In this method, frequency selectivity is measured in terms of the magnitude of the difference between signal threshold in a noise with no notch, and signal threshold in a noise with a spectral notch centered on the signal frequency. We will refer to this as the no-notch/notch difference score. Results showed that 4-year-old children had higher masked thresholds than adults both in the no-notch case and in the notch case. However, their thresholds were relatively higher in the notch case, consistent with an interpretation of relatively poor frequency selectivity. This result was in agreement with previous findings by Allen et al (1989). Hall and Grose speculated that this result might be related to the growth of neural excitation as a function of increasing signal level. Key to their interpretation was the fact that the growth of loudness was found to be considerably more steep in the no-notch noise than in the notched noise. Their explanation of the reduced no-notch/notch difference score of the children was based on the assumptions that (1) the relatively high thresholds of the children in the no-notch condition was due to poor processing efficiency, e.g., the necessity of a large amount of excitation at signal threshold; and (2) the comparatively higher threshold of the children in the notch case was due to a relatively shallow growth of neural excitation in the notched-noise masker. Thus, by this account, the low no-notch/notch difference score of the 4-year-old children was due to poor processing efficiency, or the need for a relatively great amount of signal-related excitation at masked threshold. In support of this interpretation, Hall and Grose found that the no-notch/notch difference score was not different between adults and 4-year-old children when masking conditions were used in which the growth of loudness was similar in the no-notch and notched masking noises. If a method could be used in which the growth of loudness was similar for NoSo and NoSπ presentation, then it might be found that the MLDs of young listeners would be comparable to those of adults. Unfortunately, we are aware of no stimulus conditions under which loudness growth would be theoretically similar for NoSo and NoSπ presentation.

40-Hz-Wide Noise Signal Added to 40-Hz Wide Noise Masker

Interpretation of the results where the signal was a narrowband noise added to a narrowband noise masker is slightly more involved. Here the MLDs for both Δa and Δt continued to increase over a wider age range than for the 300-Hz-wide masker. This result is somewhat puzzling. The MLD for a pure-tone signal presented in noise presumably depends on sensitivity to either interaural time differences, interaural amplitude differences, or to both kinds of interaural differences. Thus, if by age 5 or 6 the MLD for a tone presented in noise is comparable to that for adults, then it would follow that the MLD for either the Δt cue or the Δa cue (or to both types of cue) would also be comparable to adult values; however, this is apparently not the case. One possible explanation for these results is that children, more than adults, require the simultaneous presence of both interaural amplitude and time cues for good binaural performance.

Another possibility is what might be termed an auditory "figure/ground" issue. In detecting an Sπ pure tone in a 300-Hz-wide No noise background, the tone is heard as being off midline and stands out as being different from the background noise both in terms of its pitch and its timbre. When the signal and masker are identical narrow bands of noise, the Sπ signals again result in binaural difference cues that are associated with off-midline perception; however, neither a pitch nor timbre cue is available (since the signal has the same pitch and timbre as the masker), and the signal may not be heard out as readily from the masking noise. Under this circumstance, the binaural difference cue alone (without concomitant pitch and timbre cues) may be too subtle to allow good performance for the young listener. Both of the above hypotheses assume that cues for detection are available in the peripheral auditory system of the young children, but that detection is limited by the performance of a relatively central auditory process. This is suggested because detection performance for an Sπ pure tone presented in masking noise is probably determined by the same binaural difference cues; yet performance in the latter case is better than that in the case where the signal and masker are the same narrowband noise.

CONCLUSIONS

The results of the present study support the following conclusions:

1. The MLD for a pure-tone signal presented in a 300-Hz-wide masking noise increases in magnitude over the ages of approximately 4 to 5 or 6 years.
2. The smaller MLDs for subjects under 5 or 6 years is probably not related to the threshold in quiet and masking noise level. One possibility is that the differences in MLD noted with subject age are related to the development of the elements of the peripheral/brainstem auditory system which are thought to be critical for the processing of the interaural difference cues on which the MLD is based. However, it is perhaps more likely that the developmental differences are related more closely to central auditory processing.
3. The MLDΔa and MLDΔt for a narrowband noise signal continued to be slightly smaller than adult values even for 5- and 6-year-old listeners. Presumably, this was not due to a reduced ability to code interaural differences of time and level, as such a disability should also be associated with reduced MLDs for the 300-Hz-wide masker. The reduced MLDs may instead be related to a reduced ability of the central auditory system to interpret the information on binaural difference cues that are available in the auditory brainstem.

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