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Informational masking release in children and adults

Joseph W. Hall III[a)], **Emily Buss**, and **John H. Grose**
Department of Otolaryngology/Head and Neck Surgery, University of North Carolina School of Medicine, Chapel Hill, North Carolina 27599

Abstract

This study assessed informational masking and utilization of cues to reduce that masking in children aged 4–9 years and in adults. The signal was a train of eight consecutive tone bursts, each at 1 kHz and 60 ms in duration. Maskers were comprised of a pair of synchronous tone-burst trains, with randomly chosen frequencies spanning 200–5000 Hz, with a protected region 851–1175 Hz. In the reference condition, maskers were eight bursts in duration, with a fixed frequency within intervals. Experiment 1 tested two monotic masking release conditions: within-interval randomization of masker burst frequency and the introduction of leading masker bursts. Experiment 2 examined masking release in which the signal was presented to one ear and masking components were presented to both ears (masker components in the contralateral ear were 10 dB higher than those in the ipsilateral ear). Both adults and children demonstrated a significant informational masking effect, with children showing a larger effect on average. Both groups also showed significant release from masking in the two monotic conditions, although children received somewhat less benefit from the masking release cues. The binaural condition supported a moderate release from informational masking in adults, but resulted in *increased* informational masking in children.

I. INTRODUCTION

Previous investigations have shown that stimulus components well separated in frequency from a sinusoidal target signal can cause large masking effects when the spectral composition of the remote masker varies randomly on a trial-by-trial basis (e.g., Neff and Callaghan, 1987; Neff and Green, 1987; e.g., Watson, 1987; Neff and Callaghan, 1988; Lutfi, 1990; Leek *et al.*, 1991; Kidd *et al.*, 1994; 2002; Richards *et al.*, 2002; Kidd *et al.*, 2003). Such effects are usually referred to as informational rather than energetic masking because they do not appear to depend upon the excitation of peripheral sensori-neural elements associated with the signal frequency. Informational masking is of particular interest because of its potential to provide insights about auditory processing of complex and variable sounds that occur in natural settings.

There is a small body of research suggesting that informational masking is particularly large in young listeners. For example, Werner and Bargones (1991) showed that infants experienced appreciable masking arising from spectral components two octaves above the signal frequency. This result was interpreted in terms of nonsensory masking in the infants. Informational masking is also relatively large in young children. When tested using maskers having trial-by-trial frequency variability, preschool and school-aged children often showed more informational masking than adults (Allen and Wightman, 1995; Oh *et al.*, 2001; Wightman *et al.*, 2003).

The present study is concerned primarily with release from informational masking. Studies by Neff (1995) and by Kidd and colleagues (Kidd *et al.*, 1994; Arbogast *et al.*, 2002) have shown that informational masking in adults can be reduced substantially by the introduction of

a) Electronic mail: jwh@med.unc.edu.

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stimulus cues thought to promote the perceptual segregation of the signal from the masking stimulus. For example, informational masking can be reduced by providing cues that influence perceptual segregation via auditory streaming, spectro-temporal coherence, and binaural spatial separation (Kidd *et al.*, 1994; Arbogast *et al.*, 2002). In general, informational masking can be reduced by the introduction of stimulus features that make the signal sound different or separate from the masker (Durlach *et al.*, 2003a; 2003b). The study of release from informational masking is important because it may provide clues about auditory processes that enable listeners to separate attended signals from complex, dynamic acoustical maskers.

Whereas psychoacoustical experiments indicate that children are especially prone to informational masking, the ramifications that this may have for hearing are not clear. One reason for this is that little is currently known about the extent to which children experience release from informational masking with the introduction of segregation cues. If such release is robust in children, then informational masking effects in real environments, where multiple sound source segregation cues often exist (e.g., Bregman, 1990; e.g., Yost, 1991), may not be of particular significance. There is some evidence that release from informational masking in children may not be particularly robust. A recent study by Wightman *et al.* 2003 indicated that children in the age range of approximately 4–13 years showed less release from masking than adults when the masker was presented to the nonsignal ear; in this case, the segregation cue was presentation of the signal and masker to opposite earphones, a manipulation that could result in masking release via differential lateralization of the signal and masker. Whereas this stimulus manipulation resulted in essentially total release from masking in adult listeners, it resulted in essentially no release for the younger children and only partial release for many of the older children.

The purpose of the present investigation was to study the development of release from informational masking further. Experiment 1 explored developmental effects for release from informational masking using monaural sound segregation cues related to onset asynchrony and spectro-temporal coherence. Previous studies on adult listeners (Kidd *et al.*, 1994) have shown that such manipulations can result in significant release from informational masking. At the outset, it was hypothesized that children would show relatively poor benefit from monotic cues to informational masking. This hypothesis is consistent with the findings of reduced efficacy of binaural cues to masking release reported by Wightman *et al.* 2003.

II. EXPERIMENT 1

A. Methods

1. Stimuli—The conditions used here were based on the multiburst paradigm of Kidd *et al.* 1994. In this paradigm, the signal was a train of eight bursts of a 1000-Hz pure tone, each burst 60 ms in duration including 10-ms $\cos^2$ ramps. These bursts were concatenated, with no interburst gaps, resulting in a total signal duration of 480 ms. The condition associated with the largest informational masking in this paradigm is referred to as a *multiburst-same* (MBS) stimulus. Here, the masker was comprised of two trains of eight, 60-ms tone bursts that were synchronous with the signal bursts. For each observation interval, the frequency for the bursts in each of the trains was randomly selected from a range 200–5000 Hz. Within this range, there was a “protected” frequency region, extending from 851–1175 Hz, from which random masker picks were excluded. The purpose of the protected region was to limit the influence of energetic masking. Once selected, the frequency of each masker train remained constant over the observation interval. An example of a signal-present stimulus in the MBS condition is illustrated in Fig. 1 [panel (A)], with the tone bursts represented by dashed lines and gray regions indicating the range of possible masker frequencies.

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There were also two masking conditions incorporating cues for perceptual segregation of the signal and masker components. After Kidd *et al.* 1994, one of these employed a perceptual segregation cue related to spectro-temporal coherence, and is referred to as the *multiburst-different* (MBD) condition. Here, the masker was again composed of two trains of stimuli, each comprised of eight 60-ms bursts. However, in this MBD stimulus, the frequency within each of the two trains varied randomly from burst to burst (over the ranges 200–851 and 1175–5000 Hz). Thus, as illustrated in Fig. 1 [panel (B)], the frequency components within each of the two masker trains varied randomly over the course of the eight bursts, while the frequency of the signal remained fixed over the course of the eight bursts. Kidd *et al.* 1994 speculated that masking release in the MBD condition resulted from a perceptual process in which the spectro-temporal constancy of the signal allowed its segregation from the set of randomly varying masker components.

The second masking release condition employed a temporal onset asynchrony cue. Here, the signal and masker were the same as for the MBS masker except that the masker began two bursts prior to the signal onset. In this case, the masker was comprised of ten 60-ms bursts, with the frequency within each train remaining constant across the ten bursts. An example of a signal-present stimulus in the *fringed*-MBS condition is shown in Fig. 1 [panel (C)]. The assumption was that, if spectral components possess temporal asynchrony, they should be easier to separate perceptually (Bregman and Pinker, 1978;Dannenbring and Bregman, 1978;Darwin, 1984). Note that, when the signal bursts were present, they were synchronous with the masker bursts, and that the asynchrony in this paradigm was with respect to the masker burst train beginning earlier than the stimulus burst train. This stimulus bears some resemblance to a masking release condition used by Kidd *et al.* 1994, where signal bursts were presented synchronously with alternate masker bursts. It also shares similarities with the “masker first” technique used by Richards *et al.* 2004, where a pretrial cue of masker alone resulted in release from informational masking.

Sound generation was performed digitally, in the time domain, using an array processor (TDT, APOS), with the signal and masker played out via separate channels of a digital-to-analog converters (TDT, DD1) at a rate of 20 kHz. The level of each channel was adjusted via a programmable attenuator (TDT, PA4). Each channel was antialias filtered at 7 kHz (Kemo, VBF8), summed (TDT, SM3), and played to the left channel of a Sony MDR V6 earphone.

2. Procedures—Stimuli were presented in blocks of three-alternative, forced-choice trials, and responses were tracked adaptively using a 3-up, 1-down paradigm (Levitt, 1971). An initial step size of 8 dB was reduced to 4 dB after the first reversal, and to 2 dB after the second reversal. The adaptive track included six total reversals, with the track result estimated as the average level at the final four reversals. An adaptive track typically consisted of 25–30 trials. Three such track estimates were obtained, and a fourth was performed if the first three estimates varied by more than 3 dB. Data reported below were the average of all track estimates obtained for a particular condition. Thresholds were obtained first for the eight-burst signal presented in quiet. This threshold in quiet was then used to set the signal level for the remaining conditions of the experiment. In the masking conditions, the signal level was maintained at 30 dB SL (with regard to the threshold in quiet), and the level of the masker was changed adaptively to estimate the masked threshold. The maximum masker level allowed by the software was 83 dB SPL, but very few tracks reached this maximum, so this constraint had minimal impact on the results presented here. Each listener first completed the MBS condition and then completed one of the two masking release conditions.

There were two versions of experimental procedure. In the version used with the younger children (under 7.5 years of age), pictures on a video monitor signaled the listening intervals, and the children responded by pointing to the picture associated with the signal. The

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experimenter entered the response and visual feedback was provided via the action of an animated figure, for example, a frog turning into a prince (e.g., Veloso *et al.*, 1990). In a second version, older children and adults received visual cues of listening intervals, entered responses, and received visual feedback via a handheld response box. Whereas it is possible that use of different methods with the younger children could have introduced differences into the data, our own pilot work using a wide range of experimental paradigms has suggested that these two methods most effectively maintain attention of these very different populations.

3. Listeners—All listeners had pure-tone detection thresholds of 20 dB HL or better at octave frequencies from 250 to 8000 Hz (ANSI, 1996). None had a history of chronic ear disease, and none had a known history of otitis media within a 3-year period preceding testing. There were 30 child listeners (11 females and 19 males), ranging in age from 4.5 to 9.0 years, with a mean age of 6.6 years. Because previous research suggested a developmental effect in the pre-school years, effort was made to recruit children in this age range. The 12 children under 6.0 years of age will be referred to as the *preschool* group. There were 20 adult listeners (13 females and 7 males), ranging in age from 19 to 33 years, with a mean age of 24.5 years. All listeners were paid for participation and provided data in 1–2 sessions lasting no more than 1 h each.

Each listener was assigned to one of the two masking release conditions. In the conditions examining masking release for the MBD manipulation, there were 11 adults and 13 children. In the conditions examining the temporal fringe manipulation, there were 9 adults and 17 children. The reason for restricting each listener to only one of the masking release conditions was to limit the possibility that susceptibility to informational masking in one set of conditions might become unstable due to exposure to other condition sets. Pilot data on a small number of adult listeners suggested that such instability was a possibility. Although we wished to reduce the possibility of such instability in performance, we wanted to be able to measure any instability in susceptibility to informational masking that might occur within the conditions completed. For that reason, each listener completed a final set of thresholds in which the MBS condition was repeated. This allowed us to determine whether, during the course of testing, the listener might have learned strategies that reduced informational masking in the baseline condition.

B. Results and discussion

Thresholds for detection in quiet were significantly lower for the adults than for the children by 5.3 dB ($t_{46.6}$ =5.3;p<0.001). For the children, the threshold in quiet ranged from 1.8 to 22.8 dB SPL, and for adults the threshold in quiet ranged from −1.0 to 8.3 dB SPL. Because the signal level at threshold in quiet varied, the signal level used in the masking conditions, set at 30 dB *re*: detection in quiet, also varied.

The top two panels of Fig. 2 plot results for experiment 1, with listeners in the MBD group shown in the top panel and listeners in the fringed-MBS group shown in the middle panel. The bottom panel shows results for experiment 2 (see below). In each panel, the masker levels at threshold for the initial MBS condition and the masking release condition are plotted in dB SPL as a function of age. In examining the masked thresholds, bear in mind that, because the signal level was fixed at 30 dB SL and the masker level was varied, a relatively lower masker level at threshold reflects relatively greater masking. A low masker level at threshold is expected in the MBS condition, consistent with a large informational masking effect, and higher masker level at threshold is expected in the MBD and fringed-MBS conditions, consistent with a release from masking. One striking feature of the present data is the enormous range of individual differences. Such variance is often noted in studies of informational masking (Neff and Dethlefs, 1995). In the MBS condition of the present study, the masker level at threshold spanned approximately 45 dB within the adult group, whereas the variation

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in this condition was less among the children (approximately 28 dB). In contrast, variability was very high among the children in the MBD and fringed-MBS conditions, whereas variability was relatively low for the adults in these conditions. Because of the gross differences in variability between groups, nonparametric methods were used to examine group differences and some within-group differences in the statistical tests reported below. Nonparametric tests were used in cases where the Levene's test of equality of variances (Levene, 1960) indicated unequal variances.

1. Developmental results for informational masking—Among the children, the masker levels at threshold in the MBS condition were uniformly low, with most points falling between 10–40 dB SPL, indicating appreciable informational masking. This is somewhat in contrast to the adults, where some listeners showed low masker levels at threshold (10–40 dB SPL), but others tolerated considerably higher masker levels (up to 72 dB SPL). Thus, compared to adults, children showed informational masking that was larger and more consistent (see Fig. 2). Masker levels at threshold in the initial MBS baseline condition were significantly better for adults than children (see Table I). In the MBD group, the adult MBS threshold was 19 dB better (Mann-Whitney $U=20.0$; $p=0.002$), and in the fringed-MBS group, the adult MBS threshold was 16.5 dB better (Mann-Whitney $U=38.0$; $p=0.03$). This developmental effect is consistent with previous work showing more informational masking in pre-school and young school-aged children than adults (Allen and Wightman, 1995;Oh *et al.*, 2001;Wightman *et al.*, 2003). The fact that this difference is modest when contrasted with the individual variability within listener group, which was on the order of 50 dB for adults and 30 dB for the children, should be taken as evidence that the children were only somewhat more susceptible to informational masking than adults.

The wide range of adult results in the MBS conditions allows identification of adults with baseline informational masking comparable to the child listeners: a subset of 70% of the adults had masker levels at threshold below 40 dB SPL in the initial MBS condition, comparable to those of the typical child listener (8 of 11 adult listeners in the MBD group and 6 of 9 adult listeners in the fringed-MBS group). This division is indicated by the dashed horizontal lines in Fig. 2, and will be referred to again below in the statistical analyses assessing amount of masking release.

2. Developmental results for release from informational masking—In the adults, both monaural release conditions consistently improved performance in all listeners who had appreciable informational masking in the MBS baseline condition. Adults showing very little informational masking release were presumably already performing near ceiling in the baseline condition. Children, on the other hand, did not benefit uniformly from the release manipulations. In one extreme case, performance of an 8-year-old child deteriorated substantially in the fringed-MBS condition (see Fig. 2), a result that replicated with additional data collection several days after the first session. Despite this nonuniformity, the performance of most children tended to improve in both of the release conditions.

Of primary interest here was whether children differed from adults in terms of the amount of release from informational masking. One coarse way in which this was assessed was simply in terms of the masker level at threshold in the masking release conditions. The Mann-Whitney *U* nonparametric test indicated that children had significantly lower (poorer) masker levels at threshold than adults in both of the monaural informational masking release conditions. In the MBD condition, this difference was 28.6 dB ($U=22$;$p=0.03$), and in the fringed-MBS condition it was 17.4 dB ($U=31$;$p=0.02$) (see Table I). Note that in this comparison, all of the adults (even those who showed very little informational masking in the baseline condition) were included. The comparison of informational masking release between adults and children is complicated somewhat by this fact, as the adults who did not show much informational masking in the

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baseline condition could not show much release from masking (ceiling effect). One general observation is that, for the adult listeners who did demonstrate low masker levels at threshold in the baseline condition, the masker levels at threshold increased substantially for the release condition in every case. In contrast, there were some cases among the children where the masker levels at threshold remained low in the release condition. We therefore performed statistical assessment of group differences in release from informational masking comparing children and the subset of 70% of adults who showed comparable baseline informational masking. Masking release was defined as the difference in the masker level at threshold between the first block of MBS and the monaural release condition, either MBD or fringed-MBS. Mean masking release is shown in Table I. In the MBD condition, the average masking release was 17.1 dB greater for the adults than for the children. This difference was significant (U=22;p=0.03). In the fringed-MBS condition, the average masking release was 12.4 dB greater for the adults than for the children. This difference was not significant (U=31;p=0.18). In order to confirm that children actually showed a significant masking release in both masking release conditions, Wilcoxon signed ranks tests were performed in which the initial masker level at threshold in the MBS condition was compared to the masker level at threshold in the masking release condition (either MBD or fringed-MBS). These tests indicated significant masking release for the children in both the MBD condition (z=2.5;p=0.01) and the fringed-MBS condition (z=3.2;p=0.001).

Three brief comments regarding the above statistical outcomes are in order. For each, recall that the statistical outcomes pertain to the subset of adults who showed substantial informational masking in the initial MBS baseline. The first comment pertains to the fact that the children achieved a masking release that was not statistically different from that of the adults in the MBS/fringed-MBS comparison, but achieved significantly less masking release than the adults in the MBS/MBD comparison. A feature of the data that is in line with this outcome is that, whereas many children performed like the adults in the fringed-MBS condition, fewer did so in the MBD condition (cf. Fig. 2). For example, in the fringed-MBS condition, the worst adult masker level at threshold was approximately 60 dB SPL, and over half of the children achieved a masker level at threshold that was as good or better than this value. In the MBD condition, the worst adult masker level at threshold was approximately 70 dB SPL, and only 3 of 13 children achieved a masker level at threshold that was as good or better than this value. Overall, these results support a tentative interpretation that children in the age range investigated here are more likely to show adult-like levels of masking release for cues related to temporal asynchrony than for cues related to spectro-temporal coherence. The second comment pertains to the finding that adults and children did not differ significantly in terms of masking release in the MBS/fringed-MBS comparison. It is nevertheless clear that, whereas all adults showed masking release here, some of the children did not. The third comment pertains to the finding that children showed a significant release from masking for both of the monaural cues investigated here. Examination of Fig. 2 reveals that this result must be interpreted with care, as there were instances, for both cues, where individual children showed little or no masking release.

Comparisons of *preschool* and *young school-aged* children yielded mixed evidence regarding a difference in informational masking release between these groups. For the children who listened to the MBD release condition, 3 of 6 *preschool* children had the smallest masking release obtained in this condition (just 1–2-dB improvement), but 2 of 6 had a masking release above the mean for the child group (36-and 43-dB improvement). For the children who listened to the fringed-MBS release condition, 5 of 6 of the *preschool* children had masking release above the mean for the child group, and the remaining child had a release just 1 dB less than the mean. These results, while inconclusive, suggest that any difference between *preschool* and *young school-aged* children in ability to make use of the MBD and fringed-MBS cues for

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informational masking release is highly listener dependent, and may be more pronounced in, or restricted to, the MBD manipulation.

3. Developmental results related to learning—Because the MBS baseline condition was run both before and after the masking release condition, these data can be used to estimate changes in performance with listening experience. Such a change could result from exposure to the masking release condition, additional exposure to the baseline condition itself, or central factors unrelated to the particular stimuli encountered (e.g., fatigue or general familiarity with testing procedures). The mean MBS results and standard deviations appear in Table I. In statistical tests of change in the MBS result for the adults, only those listeners with a masker level at threshold below 40 dB for the first estimate were included. Children showed relatively consistent intersubject variability across the estimates for the first and second MBS conditions, so change in masker level at threshold was assessed using a t-test. In contrast, adults showed high intersubject variability in the second MBS condition, so the nonparametric Wilcoxon test was used to assess change in performance here. For the MBD release group, there was no significant change in performance over the two MBS conditions for either group (t_{11}=0.2; p =0.84 for children and Z=1.4; p=0.16 for adults). For the fringed-MBS group, both groups showed significant change. The adults improved in the second MBS estimate (Z=2.0;p=0.04), while the children showed a small but significant decrease in performance (t_{16}=3.3; p =0.005). These differences are shown in Fig. 3, with individual data in filled, narrow bars (ordered by age) and mean data in unfilled, wide bars. As with the initial MBS condition, adults had better thresholds than children for the second MBS condition (see Table I) both in the MBD group (Mann-Whitney U=20.0; p=0.004), and in the fringed-MBS group (Mann-Whitney U=5.5; $p < 0.001$).

There is no evidence that sensitivity of the children in the baseline condition improved over the course of testing. For adults, however, exposure to the fringed-MBS release condition improved thresholds. It is not obvious why the performance in the MBS condition improved for the adults in the context of the fringed-MBS condition but not in the context of the MBD condition. It is possible that the improvement within the fringed-MBS context is related to the fact that stimuli are quite similar between the MBS and the fringed-MBS conditions. These conditions are identical (except for the leading masker bursts in the fringed-MBS condition), and it is possible that this facilitated the transfer of strategies learned in the fringed-MBS condition to the final MBS condition. A very different strategy may be utilized in the MBD condition, perhaps involving spectral variations that are absent from the MBS condition. A caveat to this interpretation is that the observed differences may have arisen from individual differences between the randomly assigned listener samples comprising the two groups of adults.

III. EXPERIMENT 2

Whereas experiment 1 examined the ability of children to make use of monaural cues to reduce informational masking, Wightman *et al.* 2003 studied the ability of children to make use of binaural cues related to sound lateralization. In that study, the informational masking condition involved signal and masker presentation to a single ear, and the informational masking release condition involved signal presentation to one ear and masker presentation to the opposite ear. This manipulation eliminated informational masking in adults, reduced or eliminated informational masking in some school-age children, but had little or no effect on performance of the preschool children. In some contrast, the present experiment 1 indicated little evidence of a consistent difference between the preschool and school-aged children. Overall, experiment 1 (where monaural cues for masking release were employed) showed more evidence for release from informational masking in younger children than in the study of Wightman *et al.* 2003 (where cues for masking release were binaural in nature). Several aspects of the methods of

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the Wightman *et al.* study differed substantially from those of experiment 1, making comparisons across the monaural and binaural conditions problematic. The most obvious was that there was no masking energy in the signal ear in the masking release condition of the Wightman *et al.* study. Furthermore, stimuli in the Wightman *et al.* study were presented at a steady level for the 360-ms presentation interval, rather than bursting on and off, and the signal level was adjusted to obtained threshold, rather than the masker level adjustment used here. Finally, each listening interval was preceded by a signal cue in the Wightman *et al.* study. Because of the large differences in method between studies, we decided to run a binaural condition that shared features with both the current experiment 1 and the study of Wightman *et al.* The intent was to examine whether developmental effects for release from informational masking may be relatively pronounced for binaural spatial hearing cues related to interaural intensity differences.

A. Methods

1. Stimuli—In an initial implementation of this experiment, stimuli were identical to those in the MBS condition of experiment 1, with the exception that, whereas the signal was presented to the left ear only, masker components were presented diotically. This was similar to a previous approach by Kidd *et al.* 1994, where a release from informational masking was presumably due to the fact that the signal was lateralized to one ear, and the masker was lateralized to the midline. Our initial data using this method showed masking release that was relatively unreliable, so we modified the approach such that the masker components in the contralateral ear were presented at a level 10 dB higher than the masker components presented in the ipsilateral ear (masker frequencies and phases were identical). The rationale for this modification was to enhance the difference between the lateralized images of the signal versus the masker. This will be referred to as the *binaural* condition. As pointed out above, this masking release condition was like the MBS condition of experiment 1, except that masker components were presented to both ears. The condition was intended to be akin to the release condition in the Wightman *et al.* 2003 study, in that the masker stimuli were manipulated in such a way as to promote lateralization of the masker to the ear contralateral to the signal.

2. Procedures—The procedures for experiment 2 were identical to those of experiment 1, with the exception that the maximum level of the ipsilateral masker was reduced from 83 dB SPL (experiment 1) to 73 dB SPL.

3. Listeners—Listeners participating in this experiment were demographically quite similar to those participating in experiment 1. All had pure-tone detection thresholds of 20 dB HL or better at octave frequencies from 250 to 8000 Hz (ANSI, 1996), and none had a history of chronic ear disease. There were ten child listeners, ranging in age from 6.1 to 10.2 years, with a mean age of 8.2 years. There were ten adult listeners, ranging in age from 18 to 28 years, with a mean age of 22.3 years. All listeners were paid for their participation and provided data in 1–2 sessions lasting no more than 1 h each. None of the listeners in experiment 2 had previously participated in any psychophysical studies of informational masking, including those performed in experiment 1.

B. Results and discussion

Thresholds for detection in quiet were significantly lower for the adults than for the children by 5.5 dB (t_{18} =2.3;p=0.03). The bottom panel of Fig. 2 plots the masker level at threshold (ipsilateral ear) for the first block of MBS and the binaural block as a function of listener age.

1. Developmental results for informational masking—As in experiment 1, the initial MBS condition was associated with uniformly poor performance for the children (large informational masking), and a range of results among the adult listeners. Masker levels at

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threshold in the initial MBS baseline condition (see Table I) were higher (better) for the adults than for the children, but the probability value (U=25.5;p=0.06) did not reach statistical significance (α=0.05). As in experiment 1, there was a wide range of adult performance in the MBS condition, allowing identification of adults with baseline informational masking comparable to the child listeners: a subset of 80% of the adults had masker levels at threshold below 40 dB SPL, comparable to those of the typical child listener.

2. Developmental results for release from informational masking—Among the adults, the binaural manipulation improved performance in some of the listeners who had appreciable informational masking in the MBS baseline condition (see the bottom panel of Fig. 2). Children, on the other hand, showed a consistent lack of masking release, with most even showing additional masking in the binaural condition. Overall, the adults showed significantly higher (better) masker levels at threshold in the binaural condition than did the children (see Table I). The Mann-Whitney U nonparametric test indicated that children had significantly lower (poorer) masker levels at threshold than adults in the binaural condition (U=2.0;p<0.001). Paired t-tests were performed to compare the initial MBS and binaural conditions. For the adults, this was performed on the 80% of the listeners who showed baseline informational masking comparable to that for the children (see Fig. 2). The tests showed a significant improvement in performance for the adults (t_7 =4.7; p =0.002) and a significant decline in performance for the children (t_9 =4.3; p =0.002). We note that, if some of the children had demonstrated a masking release in the binaural condition, we would have tested younger children to explore differential effects of age (the youngest child in this experiment was 6.1 years of age). Among the children tested, there was no significant correlation between age and the amount of increased masking in the binaural condition (r=0.03;df =8;p=0.93).

The present results, where children actually showed a masking increase in the condition designed to result in masking release, contrast with the results of experiment 1 where children typically showed a decrease in masking in the masking release condition. This indicates that the ability of children to take advantage of masking release cues depends strongly upon the type of cue available. The present results indicate that a lateralization cue based upon interaural intensity differences was not utilized well by the children tested here.

In comparing the present binaural results to those of Wightman *et al.* 2003, it might seem incongruous that, whereas some of the children showed masking release in the Wightman *et al.* study, none of the children did so in the present study. It is possible that this difference is related to the overall salience of the cue for masking release in the different paradigms. In the Wightman *et al.* study, it is clear that the masking release cue in the binaural condition was highly salient among the adults, as there was essentially no informational masking among adults in that condition. In the present study, it can be inferred that the masking release cue in the binaural condition was less salient, as some of the adults continued to show substantial masking here. Thus, the failure of any of the children in the present study to show masking release in the binaural condition may be related to the relatively modest salience of the cue for masking release. The results of the present study are in general agreement with the conclusions of Wightman *et al.*, in that children were relatively poor in achieving benefit from the spatial hearing cue.

3. Developmental results related to learning—As in experiment 1, the change in performance in the MBS condition was quantified as the difference in the masker level at threshold between the first and second estimates for MBS condition, and only the subset of adults with thresholds below 40 dB for the first estimate was included. The mean results appear in Table I. Although the change in the MBS threshold was greater for the adults than for the children, the change was not significant for either group (t_7 =0.99; p=0.35 for the children and Z=−1.54; p=0.12 for the adults). As with the initial MBS condition, adults had better thresholds

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than children for the second MBS condition (see Table I), but the difference was not statistically significant (Mann-Whitney U=25.0; p=0.06).

4. Relation between informational masking and threshold in quiet, assessed across experiments 1 and 2—In both of the experiments of this study, it was found that the children had higher thresholds in quiet than the adults. Although not directly related to the main aims of the study, a question of interest is whether there was a relationship between the threshold in quiet and the masker level at threshold in the MBS condition. A *negative* relationship (high threshold in quiet associated with a low masker level at threshold) might be expected on the grounds that a high threshold in quiet will occur for poor listeners, and poor listeners may not be able to tolerate high masker levels in the MBS condition. On the other hand, a *positive* relationship (high threshold in quiet associated with a high masker level at threshold) might be expected on the grounds that a high threshold in quiet will result in the signal being presented at a relatively high SPL in the MBS condition (30 dB SL), therefore requiring a relatively high SPL masker level to mask it. A correlation performed on the data of the children of both experiments (40 children total) supported the latter expectation (r=0.61; df=38; p<0.001). Because children had higher thresholds in quiet than adults, this correlation would suggest a bias toward lower informational masking in the MBS condition for children than adults (the higher thresholds in quiet for the children being associated with higher masker levels at threshold in the MBS condition). Nevertheless, the results of this study showed significantly *more* informational masking in the children than the adults in the MBS condition. This is likely due to the fact that, among adults, interlistener variability in informational masking overshadowed factors related to the threshold in quiet. This is supported by the observation that the correlation between threshold in quiet and the masker level at threshold in the MBS condition was not significant (r=0.24; df=28; p =0.20) among the 30 adults tested in experiments 1 and 2.

IV. GENERAL DISCUSSION

A key strength of the present approach was that we were able to identify subsets of adults who showed informational masking that was comparable to that demonstrated by the children, thereby allowing reasonable tests of potential developmental differences in release from informational masking. The present results indicated no significant difference between adults and children for informational masking release related to temporal asynchrony (although there were several individual cases in which children did not show masking release here), and indicated significantly smaller masking release in children for cues related to spectro-temporal coherence (although most children achieved substantial masking release here). In general, there were remarkable individual differences in the ability of children to achieve masking release in the monaural conditions examined. These individual differences appeared to be related only poorly to age across the children tested here. The results of the present study indicate that the ability to achieve informational masking release from lateralization cues related to interaural intensity differences may develop relatively late. This result is consistent with previous results from Wightman *et al.* 2003, where children often continued to show considerable informational masking even when the masker was moved to the ear contralateral to the signal. Overall, these results suggest that children have a relatively poor ability to benefit from informational masking release cues that hinge upon the differential lateralizations of the signal and masker. In experiment 2, the binaural cue did not result in release from informational masking in any of the children, but instead resulted in a significant increase in masking in this group. Although the methodologies differed between experiment 2 and the Wightman *et al.* study, both studies used manipulations that would tend to isolate the percepts of the signal and maskers to opposite ears. The manipulation in the present study was less radical than in Wightman *et al.*, where the masker was physically absent from the signal ear in the masking release condition. Taken as a whole, the available results suggest that the development of the use of cues related to informational masking release is highly dependent upon the type of cue under investigation.

As Wightman *et al.* 2003 noted, caution should be used in generalizing results obtained in highly constrained laboratory conditions to more natural listening situations. For example, even though the results obtained to date show poor performance by children on masking release tasks that are associated with sound lateralization (listening via earphones), it is possible that such deficits would not occur in tasks involving sound localization in real environments, where the available cues are more natural than those occurring in highly controlled but unnatural earphone studies. In this regard, it should be kept in mind that a developmental effect associated with a particular type of cue might be related to a multitude factors, one of which is the context in which the cue (monaural or binaural) is presented. For example, in segregating sound sources in real environments, children might be adept in using spatial hearing cues in combination with the other cues that often occur in concert (e.g., cues related to harmonicity and/or onset asynchrony), but may be less efficient than adults when required to use isolated cues for sound segregation in less natural listening conditions.

It should also be cautioned that results indicating late development of the ability to use binaural cues in release from informational masking do not mean that children are generally poor in using binaural cues for masking release, even in the context of highly controlled laboratory experiments. For example, the results of several experiments indicate that children have adult-like masking-level differences (MLDs) (Hirsh, 1948) in a relatively broadband masking noise by age 5–6 years (Hall and Grose, 1990; Grose *et al.*, 1997).

V. CONCLUSIONS

Results of experiment 1 suggest that children aged 4–9 years can make use of monaural cues associated with informational masking release, though at a somewhat reduced level when compared to adults with similar amounts of baseline informational masking. There was some suggestion that the ability to achieve masking release may develop earlier for the cue of temporal asynchrony than for the cue of spectro-temporal coherence. Results from experiment 2 showed that children approximately 6–10 years of age failed to show a masking release (and actually showed increased masking) when interaural level differences were provided that would tend to lateralize the signal and masker to opposite ears. Development of the ability to achieve masking release from informational masking under highly controlled conditions depends strongly upon the kind of cue under study.

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References

Allen P, Wightman F. Effects of signal and masker uncertainty on children's detection. J Speech Hear Res 1995;38:503–511. [PubMed: 7596115]

ANSI. ANSI S3.6–1996, "Specification for Audiometers". American National Standards Institute; New York: 1996.

Arbogast TL, Mason CR, Kidd G Jr. The effect of spatial separation on informational and energetic masking of speech. J Acoust Soc Am 2002;112:2086–2098. [PubMed: 12430820]

Bregman, AS. Auditory Scene Analysis: The Perceptual Organisation of Sound. Bradford Books, MIT Press; Cambridge, MA: 1990.

Bregman AS, Pinker S. Auditory streaming and the building of timbre. Can J Psychol 1978;32:19–31. [PubMed: 728845]

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Dannenbring GL, Bregman AS. Streaming vs fusion of sinusoidal components of complex waves. Percept Psychophys 1978;24:369–376. [PubMed: 750985]

Darwin CJ. Perceiving vowels in the presence of another sound: Constraints on formant perception. J Acoust Soc Am 1984;76:1636–1647. [PubMed: 6520301]

Durlach NI, Mason CR, Kidd G Jr, Arbogast TL, Colburn HS, Shinn-Cunningham BG. Note on informational masking. J Acoust Soc Am 2003a;113:2984–2987. [PubMed: 12822768]

Durlach NI, Mason CR, Shinn-Cunningham BG, Arbogast TL, Colburn HS, Kidd G Jr. Informational masking: Counteracting the effects of stimulus uncertainty by decreasing target-masker similarity. J Acoust Soc Am 2003b;114:368–379. [PubMed: 12880048]

Grose J, Hall J, Dev M. The MLD in children: Effects of signal and masker bandwidths. J Speech Lang Hear Res 1997;40:955–959. [PubMed: 9263958]

Hall JW, Grose JH. The masking-level difference in children. J Am Acad Audiol 1990;1:81–88. [PubMed: 2132590]

Hirsh IJ. Influence of interaural phase on interaural summation and inhibition. J Acoust Soc Am 1948;20:536–544.

Kidd G Jr, Arbogast TL, Mason CR, Walsh M. Informational masking in listeners with sensorineural hearing loss. J Assoc Res Otolaryngol 2002;3:107–19. [PubMed: 12162362]

Kidd G Jr, Mason CR, Arbogast TL, Brungart DS, Simpson BD. Informational masking caused by contralateral stimulation. J Acoust Soc Am 2003;113:1594–1603. [PubMed: 12656394]

Kidd G Jr, Mason CR, Deliwala PS, Woods WS, Colburn HS. Reducing informational masking by sound segregation. J Acoust Soc Am 1994;95:3475–3480. [PubMed: 8046139]

Leek MR, Brown ME, Dorman MF. Informational masking and auditory attention. Percept Psychophys 1991;50:205–214. [PubMed: 1754361]

Levene, H. Robust tests for equality of variances. In: Olkin, I.; Ghurye, SG.; Hoeffding, W.; Madow, WG.; Mann, HB., editors. Contributions to Probability and Statistics: Essays in Honor of Harold Hotelling. Stanford University Press; Stanford, CA: 1960.

Levitt H. Transformed up–down methods in psychoacoustics. J Acoust Soc Am 1971;49:467–477. [PubMed: 5541744]

Lutfi RA. How much masking is informational masking. J Acoust Soc Am 1990;88:2607–2610. [PubMed: 2283433]

Neff DL. Signal properties that reduce masking by simultaneous, random-frequency maskers. J Acoust Soc Am 1995;98:1909–1920. [PubMed: 7593915]

Neff, DL.; Callaghan, BP. Simultaneous masking by small numbers of sinusoids under conditions of uncertainty. In: Yost, WA.; Watson, CS., editors. Auditory Processing of Complex Sounds. Erlbaum, Mahwah; NJ: 1987.

Neff DL, Callaghan BP. Effective properties of multicomponent simultaneous maskers under conditions of uncertainty. J Acoust Soc Am 1988;83:1833–1838. [PubMed: 3403798]

Neff DL, Dethlefs TM. Individual differences in simultaneous masking with random-frequency, multicomponent maskers. J Acoust Soc Am 1995;98:125–134. [PubMed: 7608391]

Neff DL, Green DM. Masking produced by spectral uncertainty with multicomponent maskers. Percept Psychophys 1987;41:409–415. [PubMed: 3601622]

Oh EL, Wightman F, Lutfi RA. Children's detection of pure-tone signals with random multitone maskers. J Acoust Soc Am 2001;109:2888–2895. [PubMed: 11425131]

Richards VM, Huang R, Kidd G Jr. Masker-first advantage for cues in informational masking. J Acoust Soc Am 2004;116:2278–2288. [PubMed: 15532659]

Richards VM, Tang Z, Kidd GD Jr. Informational masking with small set sizes. J Acoust Soc Am 2002;111:1359–1366. [PubMed: 11931313]

Veloso K, Hall JW, Grose JH. Frequency selectivity and comodulation masking release in adults and in six-year old children. J Speech Hear Res 1990;33:96–102. [PubMed: 2314089]

Watson, CS. Uncertainty, informational masking, and the capacity of immediate auditory memory. In: Yost, WA.; Watson, CS., editors. Auditory Processing of Complex Sounds. Erlbaum; Mahwah, NJ: 1987.

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Werner L, Bargones J. Sources of auditory masking in infants: Distraction effects. Percept Psychophys 1991;50:405–412. [PubMed: 1788029]

Wightman FL, Callahan MR, Lutfi RA, Kistler DJ, Oh E. Children’s detection of pure-tone signals: Informational masking with contralateral maskers. J Acoust Soc Am 2003;113:3297–3305. [PubMed: 12822802]

Yost WA. Auditory image perception and analysis: The basis for hearing. Hear Res 1991;56:8–18. [PubMed: 1769927]

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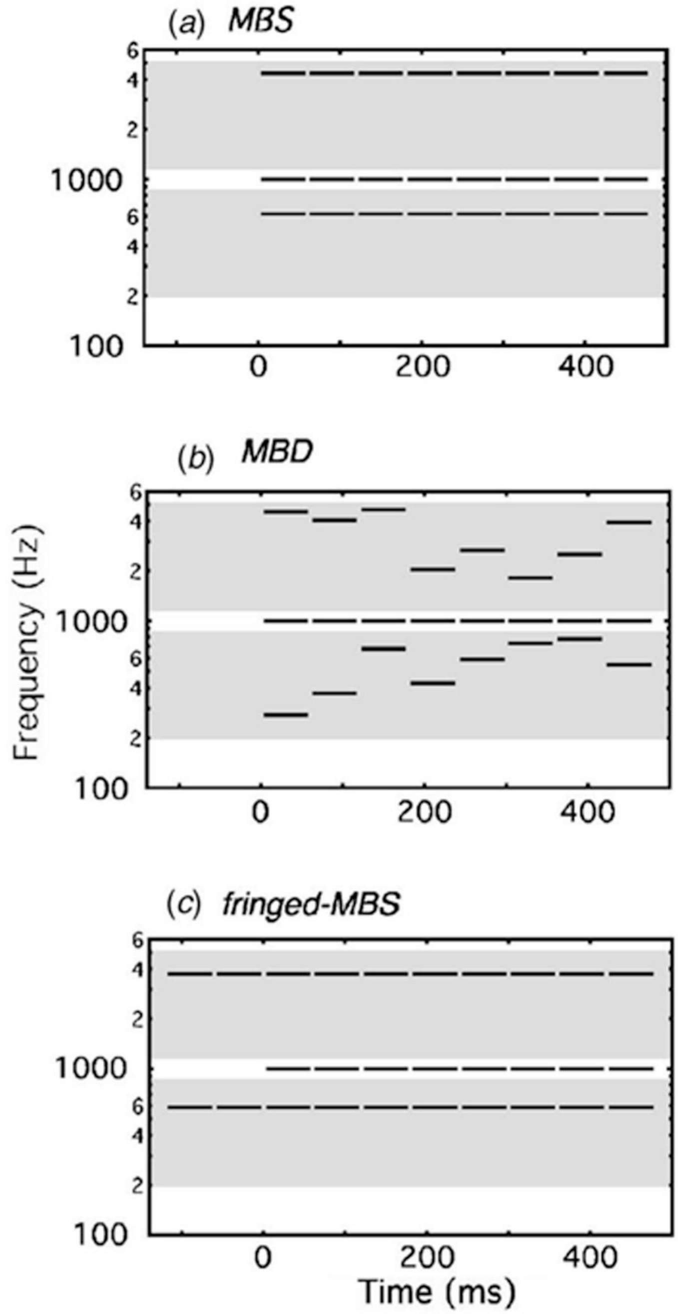

FIG. 1.
Stimulus schematic for experiment 1.

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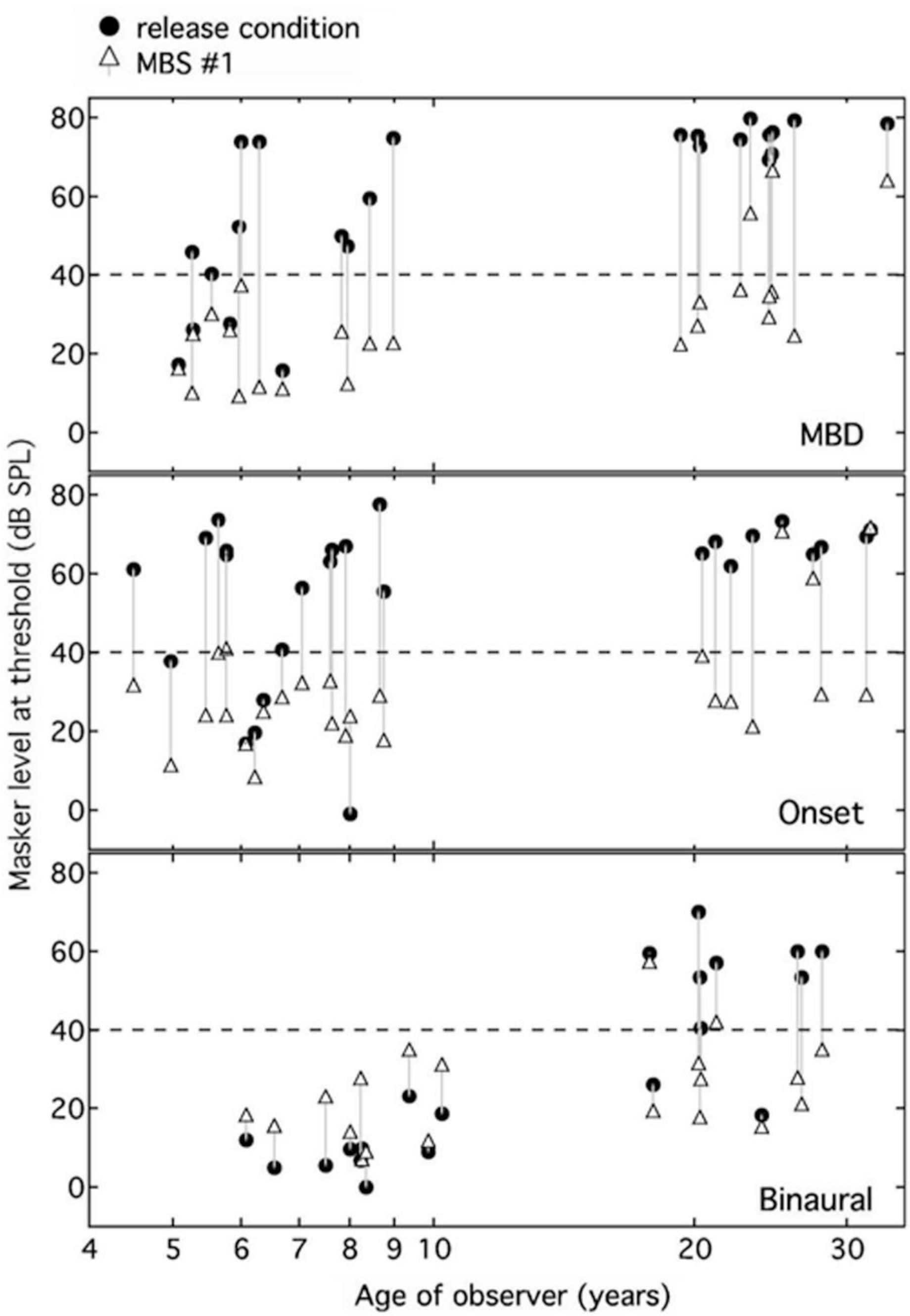

FIG. 2.
Masker level at threshold is plotted in dB SPL as a function of age for individual listeners. The dashed line indicates the (approximate) maximum sensitivity achieved by child listeners in the *multiburst-same* (MBS) condition. The top, middle, and bottom panels are associated with the MBD (13 children, 11 adults), fringed-MBS (17 children, 9 adults), and binaural (10 children, 10 adults) conditions, respectively.

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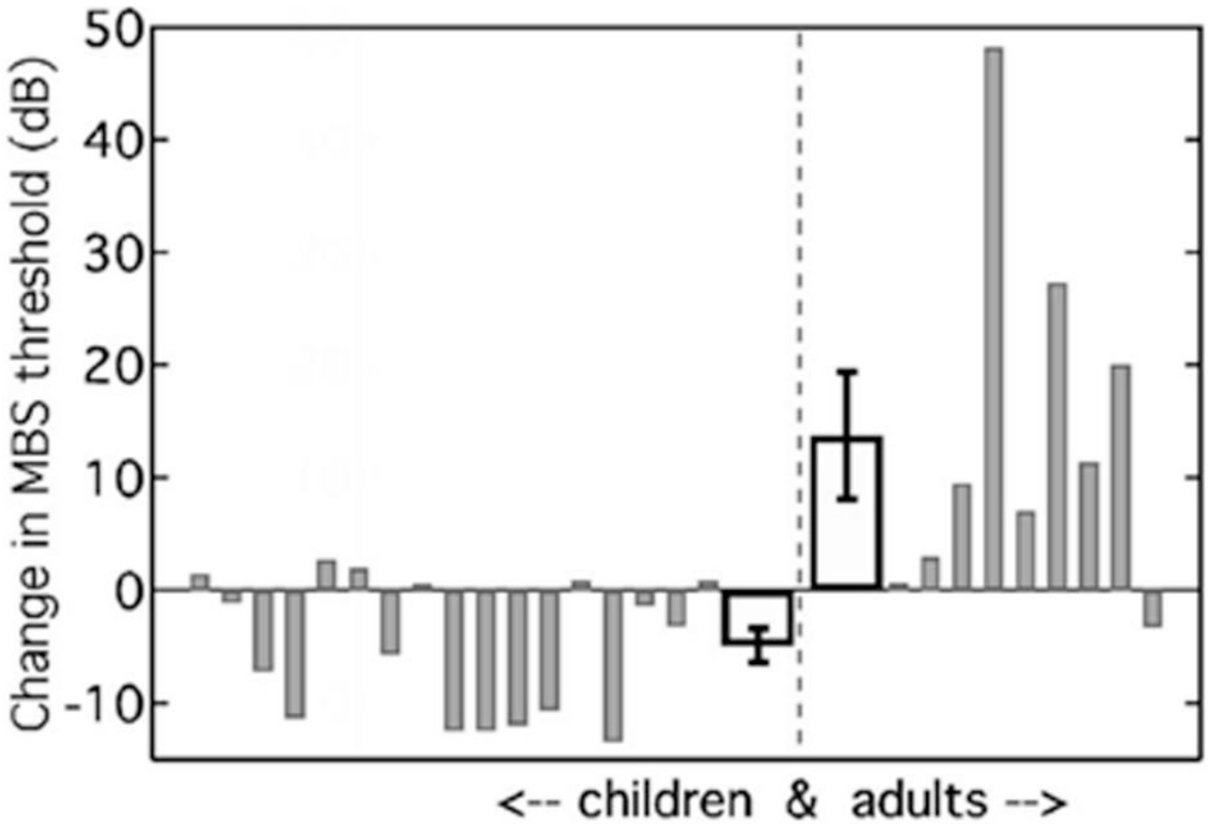

FIG. 3.
Individual (narrow, filled bars) and average (wide, unfilled bars) results for the change in the masker level at threshold between the first and second estimates for the MBS condition. The data are from the listeners in the fringed-MBS group of experiment 1. The error bars show plus and minus 1 standard error of the mean.

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TABLE I

Masker levels at threshold (dB SPL) and masking release (dB) for experiments 1 and 2. Standard deviations are in parentheses. The "matched adult" data are for the subset of adults who obtained a masker level at threshold of 40 dB or lower in the initial MBS condition (comparable to children). Values connected by dashed lines are instances where child performance was significantly worse than for adults (comparisons are between children and all adults for the masker levels at threshold and between children and matched adults for masking release). A single asterisk denotes masking release that was statistically significant. The double asterisk denotes significant *increase* in masking.

MBD cue, Expt. 1	***n***	**Adult 11**		**Child 13**		**Matched adult 8**
MBS (1st est)		39.1 (15.7)	-------------	20.1 (8.9)		30.5 (5.3)
MBD		75.3 (3.3)	-------------	46.7 (20.5)		74.2 (3.1)
MBS (2nd est)		44.9 (19.7)	-------------	20.8 (12.0)		35.0 (11.7)
Masking release				26.6* (20.7)	-------------	43.7* (7.3)
Fringe cue, Expt. 1	*n*	9		17		6
MBS (1st est)		41.8 (19.9)	-------------	25.3 (9.0)		29.1 (5.8)
Fringed-MBS		67.9 (3.5)	-------------	50.5 (22.7)		66.9 (2.9)
MBS (2nd est)		55.6 (17.7)	-------------	20.5 (9.5)		46.7 (11.7)
Masking release				25.3* (20.7)		37.7* (7.4)
Binaural cue, Expt. 2	*n*	10		10		8
MBS (1st est)		29.6 (12.9)		19.4 (9.6)		24.6 (7.1)
Binaural		49.9 (16.4)	-------------	10.0 (6.7)		47.8 (17.9)
MBS (2nd est)		41.4 (20.7)		22.0 (9.9)		36.4 (20.3)
Masking release				−9.4** (7.0)	-------------	23.2* (13.8)