The Effect of Otitis Media With Effusion on Complex Masking Tasks in Children

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Objective: To determine whether there is a relationship between the presumed complexity of auditory processing and the time course of recovery of auditory function in children with a history of otitis media with effusion (OME).

Design: Longitudinal testing over a 1-year period following insertion of tympanostomy tubes in clinical and control groups.

Subjects: A total of 34 children with a history of OME were tested. Twenty-five were tested both just before the placement of tympanostomy tubes and on up to 3 separate occasions (1 month, 6 months, and 1 year) after the placement of the tubes. With subject attrition, there were 27, 16, and 10 listeners at the 1-month, 6-month, and 1-year tests, respectively. An age-matched control group of 29 children was tested.

Methods: The comodulation masking release (CMR) paradigm was used to measure the ability of the listener to detect a signal in a noise background composed of a simple (1 amplitude modulation pattern) or more complex (2 amplitude modulation patterns) masking background.

Results: Children with a history of OME had reduced masking release before and 1 month after insertion of tympanostomy tubes for both the simple and complex CMR tasks. After surgery, the CMR results for simple task was not significantly different from that in controls by 6 months, but CMR for the complex task remained significantly reduced even 1 year after surgery.

Conclusion: Our results suggest a slower recovery of auditory function for more complex auditory tasks in children with a history of OME.


OME ASPECTS of complex auditory perception appear to be measurably affected by a history of otitis media with effusion (OME). For example, binaural auditory perception, as measured by the masking-level difference (MLD),1 is often reduced in children with a history of OME, even when thresholds in quiet have been normal for some time.2-5 There is also evidence that some relatively complex monaural processes involving signal analysis in background noise are impaired in those with a history of OME. For example, speech recognition in various masker backgrounds is often poor in persons with a history of OME.6-9 There is also evidence that a history of OME can affect comodulation masking release (CMR), which depends on an across-frequency analysis of temporal envelope information10-13 and is obtained when the masking noise has a temporal fluctuation pattern that is correlated across frequency. In a random masking noise, in which the modulation pattern is uncorrelated across frequency, energy components away from the signal frequency do not significantly affect the masking of a pure-tone signal; masking is accomplished primarily by the noise components within a relatively narrow region around the signal frequency: the critical band or auditory filter. However, when the level of the noise in one spectral region modulates coherently with noise components in other spectral regions, the noise energy outside the auditory filter centered on the signal frequency can produce a release from masking. This type of monaural masking release is reduced in children with a history of OME, although time course for recovery of CMR after restoration of normal hearing thresholds is more rapid than for the MLD.14

Thus, a history of OME can be associated with a reduced ability to detect or recognize a signal in a competing background noise. However, other psychoacoustical data indicate that the relationship between a history of OME and the ability to hear signals in background noise

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SUBJECTS AND METHODS

SUBJECTS

The control group consisted of 29 children (age range, 5.0-11.7 years; mean, 8.4 years). The listeners in this group had no history of ear disease and had air conduction thresholds that were 15-dB hearing loss (HL)\(^{18}\) or better for octave frequencies between 250 and 8000 Hz. The experimental group was composed of 34 children (age range, 5.3-11.9 years; mean, 7.4 years) who had a history of OME. Only subjects having a documented hearing loss of 25-dB HL or worse at 2 frequencies between 250 and 2000 Hz and type B tympanograms were included in the experimental group. In these subjects, hearing thresholds were measured on at least 2 occasions over a period of several months before the placement of tympanostomy tubes. In addition, the presence of OME was documented via otoscopy performed by an otolaryngologist. The parents of most subjects in the experimental group reported that the children had experienced several ear infections, but specific documentation on the number and severity of the bouts was generally not available. Twenty-five of the children with OME were tested both just before the placement of tympanostomy tubes and on as many as 3 separate occasions (1 month, 6 months, and 1 year) after the placement of the tubes. The intent of the presurgery test was to provide information about the relative performance between children with normal hearing and children with hearing loss related to OME for the same nominal masker level. This provided some indication of the disadvantage experienced by children with OME-related hearing loss. Nine of the children did not receive a test before surgery but participated in postsurgery testing. With subject attrition, there were 27, 16, and 10 listeners in the 1-month, 6-month, and 1-year tests, respectively. In 2 cases, subject attrition occurred because children experienced recurrence of OME. The children with normal hearing were tested on only 1 occasion. After surgery, air conduction thresholds for children in the OME group were 15-dB HL or better for octave frequencies between 250 and 8000 Hz. Audiometric pure-tone thresholds were obtained using the descending Hughson-Westlake method.\(^{19}\)

CONDITIONS AND STIMULI

The 1000-Hz pure-tone signal was 400 milliseconds in duration, including the 50-millisecond cosine\(^2\) rise/fall time. An inverse fast Fourier transform incorporating a sampling rate of 11.025 kHz and buffer size of 2 discrete points was used to create the noise stimuli.\(^{17}\) This resulted in maskers with approximately 0.08-Hz frequency resolution that, on cyclical output, had an overall periodicity of approximately 11.89 seconds. Noise stimuli were played through a 20-bit digital-to-analog converter and low-pass filtered at 4 kHz. The signal was created digitally and played out via a 16-bit digital-to-analog converter. Stimuli were delivered to the left ear via headphones (Sony model MDR V6, Sony Corporation, Tokyo, Japan).

Two baseline masking conditions were used to obtain the basic CMR effect. In an OSB condition, a 20-Hz-wide noise band was centered on the signal frequency (1000 Hz). In the other baseline condition, additional 20-Hz-wide comodulated flanking bands (FBs) were centered on 400, 600, 800, 1200, 1400, and 1600 Hz. Comodulation masking release was taken as the OSB threshold minus the threshold with the 6 comodulated bands added. Two further experimental conditions used not only the OSBs and FBs described above, but also either 2 or 8 codeviant bands. In the situation with 2 codeviant bands, a pair of 20-Hz-wide codeviant bands centered on 900 and 1000 Hz were used. In the second codeviant band condition, the 20-Hz-wide codeviant bands were centered on 300, 500, 700, 900, 1100, 1300, 1500, and 1700 Hz. The masker level was 50-dB/Hz sound pressure level for all the conditions except for the OSB. In the OSB condition, the spectrum level was 1.4 dB lower (48.6 dB/Hz) due to an error in calibration that was constant throughout the study. This would result in an expected decrease in the magnitude of the derived CMRs by 1.4 dB. Schematic representations of the stimuli spectra used in the various conditions are shown beside the corresponding data in Figure 1 and Figure 2.

PROCEDURE

Data were collected using a 3-alternative, forced-choice, adaptive strategy incorporating a 3-down 1-up stepping rule that estimated the 79.4% correct point on the psychometric function.\(^{20}\) In this procedure there were 3 observation intervals, the signal being present in only 1, at random. Following 3 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 2 reversals in level direction, and further reduced to 2 dB after the next 2 reversals. A threshold run was stopped after 8 reversals, and the average of the final 4 reversals was taken as the threshold for the run. Visual feedback was provided to the subject after each response. At least 2 estimates were collected per condition, with an additional 1 or 2 estimates collected if the difference between the first 2 exceeded 3 dB. The final threshold for a condition was determined as the average of the 2 to 4 estimates. Intrasubject variability was relatively low: approximately 90% of thresholds were calculated from 2 estimates.

A video display was used in the threshold estimation procedure. Before the test began, the child had a choice of fish, rocket ships, balloons, or robots that were used as visual stimuli to mark the 3 observation intervals. 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 2 threshold tests.

is not completely straightforward and can be strongly task dependent. For example, the masked threshold for a pure tone presented in a relatively broadband, random noise is usually not different between controls and children with a history of OME. This finding implies both normal frequency selectivity\(^{15,16}\) and normal processing efficiency\(^{18}\) in children with a history of OME. It is perhaps noteworthy that the detection of a monaural signal in random masking noise does not depend on either across-ear or across-frequency analyses, and probably requires
less complex auditory processing than that associated with auditory masking release (CMR or MLD) or speech perception in noise.

The present study tested the hypothesis that the time course for the recovery of normal auditory function may be related to the complexity of the task. We know already that the simple detection of a tone in random noise does not appear to be affected by OME, but in the presumably more complex CMR case, performance remains abnormal for several months following the restoration of normal audiographic findings. Given this result, it is of interest to determine whether still larger and more enduring effects of OME might be found for more complex monaural psychoacoustic conditions. This would help to establish the generality of the problem of analyzing signals in noise, and tie the magnitude of effect and recovery of function to the presumed complexity of the underlying auditory processing. One example of a relatively complex monaural task involves the simultaneous processing of more than 1 apparent auditory source, as represented by 2 unique modulation patterns carried by 2 sets of noise bands. We used such a task in adults and children with no history of ear disease. In that paradigm, CMR for a set of comodulated noise bands was disrupted by the presence of 2 further bands (termed codeviant bands) that were comodulated between themselves, but not with the noise band centered on the signal (on-signal band [OSB]) and its comodulated flanking bands. The resulting reduction in CMR may be due in part to difficulty in segregating the 2 codeviant bands from the comodulated set. It is found that CMR can be substantially restored by extending the number of codeviant bands from 2 to 8. We hypothesized that increasing the number of codeviant bands clearly defines a second auditory source that can be effectively segregated from the original comodulated set. This paradigm would appear to be appropriate for the study of relatively complex monaural processing in children with a history of OME.

### RESULTS

#### COMPARISONS BETWEEN CONTROL AND OME GROUPS

Individual data for all conditions of the experiment, plotted as a function of age, are summarized in Figures 1 and

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Figure 1. Individual thresholds as a function of listener age. Each column corresponds to a separate test session; each row corresponds to a particular masking condition (see schematics at far right). Individual results are shown for the control group in the presurgery test; the 95% prediction intervals for the control group are replotted in the columns showing postsurgery data. OME indicates otitis media with effusion; OSB, on-signal band; and SPL, sound pressure level.
2. The solid lines bound the 95% prediction interval around the regression line for the control group. In the panels showing the postsurgery results, the data points from the control group are not shown, but the prediction intervals are replotted to aid identification of abnormal results from the OME group. Note that masked thresholds (Figure 1) generally improved with increasing age. The correlations between age and threshold, averaged over all masked threshold conditions, were −0.53 (P < .05) and −0.39 (P < .05) for the control and experimental groups, respectively. The CMR measures (Figure 2) showed no significant correlations with age for either group. The lack of an age effect for CMR is consistent with previous results.

2.2. Results

Results were examined in terms of analysis of covariance or analysis of variance. For analyses involving masked thresholds, an analysis of covariance was used (with age as the covariate). Considering first the OSB data, analyses of covariance indicated that the groups did not differ significantly for any of the tests. For the cases involving comodulated bands, the thresholds of the OME group were significantly higher than normal on the presurgery test (F[1,51] = 25.1; P < .05), but not on any of the postsurgery tests. For the cases involving 2 codeviant bands, the OME group had significantly higher thresholds than normal only on the 1-year test (F[1,37] = 5.2; P < .05). The effect of OME on threshold was most pronounced and consistent for the cases involving 8 codeviant bands: the OME group had significantly higher thresholds on the presurgery test (F[1,51] = 12.8; P < .05), the 1-month test (F[1,54] = 8.0; P < .05), the 6-month test (F[1,43] = 5.7; P < .05), and the 1-year test (F[1,37] = 13.5; P < .05).

Because there was no correlation between CMR and age, simple analyses of variance were performed (Figure 2). For the cases in which only comodulated bands were used, the CMRs of the OME group were significantly reduced on the presurgery test (F[1,52] = 39.1; P < .05) and on the 1-month test (F[1,55] = 4.6; P < .05), but were not significantly reduced on the remaining tests. For the cases involving 2 codeviant bands, CMRs for the OME group were significantly reduced on the presurgery test (F[1,52] = 9.5; P < .05) and the 1-year test (F[1,38] = 5.0; P < .05). Again, the effect of OME was most consistent over time for the cases involving 8 codeviant bands. In this situation, CMR for the OME group was significantly reduced on the presurgery test (F[1,52] = 22.1; P < .05), the 1-month test (F[1,55] = 14.3; P < .05), the 6-month test (F[1,44] = 21.3; P < .05), and the 1-year test (F[1,38] = 7.6; P < .05).

It is also of interest to consider the percentage of subjects with a history of OME for whom the CMR magnitudes were below the normal prediction interval. For the cases involving no codeviant bands, there were 32% subjects on the presurgery test, 22% on the 1-month test, 12% on the 6-month test, and 18% on the 1-year test. For the cases involving 2 codeviant bands, these figures were 12% on the presurgery test, 15% on the 1-month test, 12% on the 6-month test, and 18% on the 1-year test. For the cases in which 8 codeviant bands were used, these fig-

Figure 2. Individual comodulation masking release data (CMR) as a function of listener age. See the legend to Figure 1 for an explanation of column, row, and abbreviation descriptors.

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ures were 40% on the presurgery test, 44% on the 1-month test, 41% on the 6-month test, and 54% on the 1-year test.

EFFECTS RELATED TO MAGNITUDE OF HEARING LOSS

We determined the correlation between the presurgery hearing loss in the signal ear and CMR for the various conditions. For this purpose, the audiogram was summarized as the pure-tone average for 500, 1000, and 2000 Hz. In the presurgery test, the correlation was not significant for the cases involving 2 (r = -0.25) or 8 (r = -0.11) deviant bands, but was significant (r = -0.53; P < .05) for the cases with no deviant bands. We also determined the correlations between the presurgery hearing loss and CMRs obtained in the postsurgery tests to evaluate whether a simple relationship could be found between the magnitude of the hearing loss and the postsurgical CMR. No significant correlations were found between presurgery audiogram findings and CMR for any of the postsurgery CMR conditions.

Our results support the theory that OME influences distinct auditory abilities differently, and that the temporal course of recovery can differ greatly across abilities. In agreement with previous results, 2,3 the simple monaural detection of a pure tone in a narrowband noise was not significantly affected in children with a history of OME, either at the time of hearing loss or after the audiogram findings had returned to normal. Also in agreement with previous findings, 4 simple CMR (no deviant bands present) was sometimes reduced during and shortly after hearing loss, but was usually normal by 6 months after the return of normal audiometric hearing. The new finding of the present study is that the recovery of normal performance is more protracted for the condition in which all deviant bands are present. The results for this condition are reminiscent of our previous findings 5 that indicated a recovery of normal MLD performance that often took from 1 to 2 years (and sometimes longer) after the recovery of normal hearing.

The hypothesis of the present investigation was that longer periods of recovery of auditory function might be associated with the complexity of the analysis required for the function. This hypothesis was supported to the extent that performance was not affected for the task that was conceptually the most simple (detection of a tone in a single band of noise) and was affected the most and for the longest duration for the task that was conceptually the most complex (detecting a tone in a complex noise background in which 2 independent patterns of modulation were present simultaneously). One interpretation of these findings is that for complex auditory analyses to be efficient, the central auditory system must be able to develop consistent strategies for analyzing peripheral information. A prerequisite for such development might be a relatively constant internal representation of auditory information given a constant physical input. In cases of chronic OME, a constant physical stimulus may result in different patterns of auditory information, depending on the current state of the hearing loss. As long as the chronic OME condition persists, the establishment of optimally efficient strategies of auditory analysis may be forestalled. Once the OME condition has resolved, the auditory system can begin operating on a more reliable relationship between physical input and the auditory representation of the input. This stable relationship may allow an optimization of auditory analysis, a process that may take longer for relatively complex analyses. Our results suggest that analyses requiring the processing of multiple patterns of modulation may recover relatively slowly in children with a history of OME.

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COMMENT

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