

BRIEF REPORT

The Effect of Otitis Media With Effusion on Infants' Detection of Sound

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The purpose of this study was to obtain a preliminary estimate of how otitis media with effusion affects the hearing sensitivity of infants. An observer-based method was used to estimate detection thresholds for 1000- or 4000-Hz tones for infants diagnosed with otitis media by a physician and for control infants. These preliminary results suggest that otitis media with effusion produces a mild to moderate hearing impairment in infants and that it may affect the developmental course of auditory sensitivity in the first year of life.

hearing auditory sensitivity otitis media auditory development

Otitis media with effusion refers to the condition in which infection or dysfunction of the middle ear leads to fluid accumulation in the middle ear cavity. It has been estimated that 75-85% of all infants have at least one episode of otitis media during the first 2 years of life (e.g., Gravel, McCarton, & Ruben, 1988); as many as 25% of infants develop recurrent or persistent otitis media. Recent careful studies indicate that recurrent or persistent otitis media is associated with degraded binaural hearing and sound localization (e.g., Hall, Grose, & Pillsbury, 1995), difficulty understanding speech in noise (e.g., Gravel & Wallace, 1992), and distractibility in school (e.g., Roberts et al., 1989) even when middle ear function is normal at the time of testing. Delays in language acquisition have also been reported (e.g., Friel-Patti & Finitzo, 1990). Some, but not all, of these effects dissipate by about 4 years of age (Gravel & Wallace, 1992; Hall et al., 1995; Roberts, Burchinal, Davis, Collier, & Henderson, 1991).

Models of the effects of otitis media on development posit that the intermittent deprivation of auditory input during bouts of otitis media disrupts normal perceptual development, and that the resulting perceptual deficits, in turn, disrupt language development and academic performance. Otitis media is held to be particu-

larly harmful when it occurs during infancy. This general model is supported by recent studies (e.g., Gravel, Wallace, & Ruben, 1995; Roberts, Burchinal, & Campbell, 1994). The degree of hearing loss experienced by infants during bouts of otitis media, however, has not been well quantified (but see Gravel et al., 1995). Moreover, the hearing loss experienced by infants may not be predictable from observations of older children, because infants' middle ears are immature (e.g., Keefe, Bulen, Arehart, & Burns, 1993). Considering the central role that hearing loss during infancy plays in models of the effects of otitis media on development, it would be helpful to establish the degree of hearing loss that occurs during bouts of otitis media during infancy. Furthermore, because many cases of otitis media in infants are asymptomatic, it would be useful for those who study perceptual development during infancy to have an idea of the range of hearing levels that could be represented in their apparently healthy subjects.

The purpose of this study was to obtain a preliminary estimate of the hearing loss occurring during bouts of otitis media during infancy at 1000 and at 4000 Hz, based on infants' behavioral response to sound. Pure-tone thresholds provide the accepted measure of auditory sensitivity in audiology and psychoacoustics, and they can be readily compared to thresholds of older children or adults. These frequencies were chosen because sensitivity in this frequency range is known to be affected by otitis media, because these frequencies fall within humans' most sensitive hearing range and because infor-

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mation in this frequency range is critical to speech, particularly consonant, perception (Katz, 1994). Pure-tone thresholds are highly correlated with thresholds for speech in adults (Katz, 1994), and apparently in infants (Nozza, Wagner, & Crandell, 1987). Finally, considerable development in thresholds at these frequencies occurs during infancy; it would be reasonable to ask whether development is similar in infants with otitis media.

Twenty-seven "referred" infants were recruited from a local pediatric practice within 24 hours after otoscopic diagnosis of otitis media. The diagnosis was made using a form and criteria developed by Yankelowitz et al. (1991). This sample included infants who were diagnosed during routine well-baby visits, considered "silent" or asymptomatic cases of the disorder. An age-matched comparison group of 25 infants not under treatment for otitis media with effusion (OME) with no more than two prior episodes of OME was recruited from the lab's general subject pool list. No subject with risk factors for hearing loss, preterm birth or complications at delivery, or medical conditions besides otitis media was included. The average age at first threshold was 34.6 weeks ($SD = 8.8$; range 13 to 50 weeks) for referred infants and 33.3 weeks ($SD = 8.4$; range 16 to 49 weeks) for comparison infants. Screening tympanometry¹ was performed on all subjects at each test session, and an admittance peak of at least 0.2 mmhos between -200 and +50 daPa was considered a "pass." All of the comparison infants passed the tympanometric screen. The participating pediatricians, though not specialists in pediatric otology, had considerable experience in the diagnosis of otitis media in infants, and in combination with tympanometry, their examinations were expected to be very effective in identifying cases of otitis media. Note that inaccuracies in diagnosis would tend to make the mean differences between diagnostic categories smaller; thus the present results may set a lower limit on the degree of hearing loss experienced by infants with otitis media.

The pure tones were digitally generated, 500 ms in duration, with 16 ms rise and fall times. They were presented to the infants through an Etymotic insert earphone, held in place in the ear canal with a foam ear tip. The right ear was tested except that the left ear of referred infants

with a unilateral left ear effusion and of their age-matched comparison infants was tested. The stimuli and progress through the experiment were controlled by a computer. Testing was carried out in a double-walled sound booth.

The general goal in data collection was to obtain a threshold at 1000 Hz and at 4000 Hz from each infant at two time points about 2 weeks apart. The average test-retest interval actually achieved was 21 days for referred infants. It was expected that otitis media would resolve in about 50% of infants in this time period (Roland et al., 1989). Data were obtained from 22 referred infants fewer than 5 days after diagnosis and from 1 referred infant 8 days after diagnosis. Few infants would be expected to show improvement in fewer than 5 days; by 8 days, about 25% might show some improvement (Roland et al., 1989). A comparison infant was scheduled to be tested at approximately the same ages as each referred infant, although scheduling and other constraints usually made an exact match impossible. The average test-retest interval for comparison infants was 15 days.

Three procedures ensured that the observer was blind to the condition of the infant's middle ears when threshold data were collected. The parent was asked not to reveal to the individual observing the infants' behavior whether the infant had been referred by a pediatrician or from the subject pool list. The ear to be tested, but not the referral source, was indicated on an information sheet prepared for each test session by the second author, who did not test infants. Tympanometry was not performed until the end of the test session.

The observer-based psychoacoustic procedure was used to estimate thresholds (for details see Werner, 1995). An observer began trials, watched the infant from outside the test booth, and judged whether 6 repetitions of a tone or no tone had been presented to the infant during each trial. The infant's behavior was the only information upon which the observer could base these judgments. The observer received feedback on each trial. The infant was reinforced for responding to the tone by the 4-s activation of a mechanical toy whenever the observer gave a "tone" judgment on a tone trial, but in no other case. The infant and observer were trained to an 80% correct criterion for a tone at 80 dB SPL.

Threshold was then estimated using an adaptive procedure: The level decreased if the observer was correct on 2 consecutive trials, and the level increased if the observer was incorrect on a single trial. The session continued until the direction of level change "reversed" 8 times. The average level of the tone at the last 6 reversal points was taken as the threshold.

For the purposes of analysis, infants were placed into three diagnostic categories. Referred infants who failed tympanometry at the first test session comprised the OME+ group. Referred infants who passed tympanometry at the first test session comprised the OME? group. Comparison infants, all of whom passed tympanometry, comprised the OME- group. At the initial test, the numbers of thresholds obtained at 1000 and at 4000 Hz were 11 and 8 for the OME+ group, 4 and 5 for the OME? group, and 17 and 8 for the OME- group, respectively. At retest, the corresponding numbers were 6 and 4 for the OME+ group, 6 and 4 for the OME? group, and 11 and 8 for the OME- group.

Average initial-test threshold for the three groups at 1000 Hz and at 4000 Hz are shown in Figure 1. The average threshold of the OME+ group was 15 dB higher than that of the OME- group at 1000 Hz, and about 30 dB higher at 4000 Hz. Because some, but not all, infants had thresholds at both 1000 and 4000 Hz, analyses were completed separately at each frequency. An analysis of variance of threshold was performed with diagnostic group as a factor and age as a covariate. The effect of diagnostic group was significant for both frequencies [1000 Hz: $F(2, 28) = 3.38, p = .048$; 4000 Hz: $F(2, 17) = 7.14, p = .006$]. Tukey HSD comparisons indicated that at 1000 Hz, the OME+ group had higher thresholds than either the OME? or OME- group, $p < .05$ for both cases. At 4000 Hz, the difference between the OME+ and OME- groups was significant, $p = .002$, but the difference between the OME+ and OME? group was only marginally significant, $p = .07$. The thresholds for the OME- group may appear high, but they are similar to thresholds we have previously obtained from infants using the same psychophysical procedure (e.g., Werner & Bargones, 1991). There is no reason to think that the psychophysical procedure would have differentially affected the thresholds of infants in different diagnostic groups.

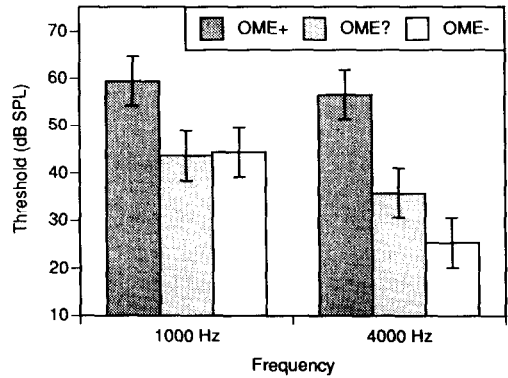


Figure 1. Average threshold for three diagnostic groups at 1000 and 4000 Hz. Error bars represent ± 1 standard error.

A more accurate estimate of the degree of hearing loss associated with otitis media with effusion might be made on the basis of within-subject comparisons. For the present purposes, a threshold is considered to have changed when the difference between test and retest thresholds was greater than 3 dB. Infants who passed tympanometry on the first test and failed tympanometry on retest exhibited an average threshold increase of 12.8 dB (SEM = 7.1 dB; $n = 2$) at 1000 Hz and of 19.9 dB (SEM = 8.1 dB; $n = 2$) at 4000 Hz. Three of the 4 infants in this category had higher thresholds at retest, and the threshold of the fourth did not change. Similarly, infants who failed tympanometry on the first test and passed tympanometry on retest exhibited an average threshold decrease of 15.1 dB (SEM = 7.4 dB; $n = 3$) at 1000 Hz and of 24.2 dB (SEM = 5.7; $n = 4$) at 4000 Hz. Five of the 7 infants in this category had lower thresholds on retest than on the initial test, one infant had a higher threshold, and the threshold of the last infant did not change. Infants with the same tympanometry outcome at test and retest exhibited threshold changes averaging 2.8 dB at 1000 Hz (SEM = 8.8 dB; $n = 14$) and 5.2 dB at 4000 Hz (SEM = 9.0 dB; $n = 7$). Because the number of infants in each of these cells was small, tests of significance were not performed. However, it is noteworthy that the threshold change seen within individual infants with a change in middle ear status is similar to the mean difference between infants in different diagnostic groups at

the initial test. It should also be noted that in older children, hearing loss can vary even during a bout of otitis media, so it is not surprising that some infants' thresholds changed between test and retest in a direction not predicted by their tympanogram.

The regression of threshold on age was calculated for infants in the OME+ and OME- groups. Only thresholds at time points when the infant failed the tympanometry screen were included for the OME+ group. The thresholds of the OME- infants decreased with age (1000 Hz: $t(24) = -1.613$, $p = .06$; 4000 Hz: $t(8) = -1.943$, $p < .05$), and they decreased at a somewhat faster rate at 4000 Hz (.9 dB/wk) than at 1000 Hz (.5 dB/wk). This pattern is consistent with that observed in earlier studies (Olsho, Koch, Carter, Halpin, & Spetner, 1988). Thresholds decreased only slightly with age for the OME+ group at both 1000 and 4000 Hz (about .2 dB/wk), and in fact, the regression was not significant (both $p > .5$). This pattern suggests that threshold development in infants with middle ear disorders cannot readily be described by the normal developmental "curve" shifted up the conductive hearing loss, at least in this small sample.

The results of this preliminary study show that the hearing loss associated with otitis media with effusion could be on the order of 15–30 dB, depending on the infant's age and the acoustic frequency. This hearing loss is evident in both between group and within individual comparisons. The size of the hearing loss is about the same as that reported for older children (e.g., Katz, 1994) and for the click-evoked ABR (e.g., Gravel et al., 1995), and a level reduction of this magnitude produces a significant decrement in infants' speech discrimination performance (Nozza, 1987). The observation that the hearing loss associated with OME could be greater at 4000 than at 1000 Hz among infants is consistent with a report by Roberts et al. (1995). It would be extremely interesting if future results confirm that otitis media affects the course of threshold development.

FOOTNOTE

1. In tympanometry, a probe tip is held against the entrance to the ear canal. A low-frequency tone is played into the ear canal through the probe. The admittance of the

tympanic membrane is calculated from the sound waveform recorded in the ear canal by a microphone in the probe, as the air pressure in the ear canal is simultaneously varied. The expectation is that when the air pressure in the ear canal matches the pressure in the middle ear cavity, the admittance of the tympanic membrane will be highest. In other words, the maximum amount of sound will be transmitted into the middle ear when the pressure on the two sides of the tympanic membrane is equal. The admittance of the tympanic membrane will be lower when the pressure in the ear canal is either higher or lower than the pressure in the middle ear cavity. A plot of admittance as a function of pressure is called a tympanogram. The peak of the tympanogram will occur when the ear canal pressure equals the middle ear pressure. Generally the peak is around 0 daPa. The difference between the minimum and maximum admittance is called the static admittance; it reflects the function of the middle ear under the ideal condition. When there is fluid in the middle ear, the admittance of the tympanic membrane is low and the tympanogram does not have a peak. Although tympanometry and otoscopy do not always agree, a "flat" tympanogram is considered a good indicator of middle ear effusion. Shanks et al. (1988) provide a more detailed tutorial on tympanometry.

AUTHORS' NOTES

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REFERENCES

- Friel-Patti, S., & Finitzo, T. (1990). Language learning in prospective study of otitis media with effusion in the first two years of life. *Journal of Speech and Hearing Research*, 33, 188–194.
- Gravel, J.S., McCarton, C.M., & Ruben, R.J. (1988). A prospective study of otitis media in infants

- born at very low birthweight. *Acta Otolaryngologica*, 106, 516–521.
- Gravel, J.S., & Wallace, I.F. (1992). Listening and language at 4 years of age: Effects of early otitis media. *Journal of Speech and Hearing Research*, 35, 588–595.
- Gravel, J.S., Wallace, I.F., & Ruben, R.J. (1995). Early otitis media and later educational risk. *Acta Otolaryngologica*, 115, 279–281.
- Hall, J.W., III, Grose, J.H., & Pillsbury, H.C. (1995). Long-term effects of chronic otitis media on binaural hearing in children. *Archives of Otolaryngology - Head and Neck Surgery*, 121, 847–852.
- Katz, J. (Ed.). (1994). *Handbook of clinical audiology* (4th ed.). Baltimore: Williams & Wilkins.
- Keefe, D.H., Bulen, J.C., Arehart, K.H., & Burns, E.M. (1993). Ear-canal impedance and reflection coefficient in human infants and adults. *Journal of the Acoustical Society of America*, 94, 2617–2638.
- Nozza, R.J. (1987). Infant speech-sound discrimination testing: Effects of stimulus intensity and procedure model on measures of performance. *Journal of the Acoustical Society of America*, 81, 1928–1939.
- Nozza, R.J., Wagner, E.F., & Crandell, M.A. (1988). The binaural release from masking for a speech sound in infants, preschoolers, and adults. *Journal of Speech and Hearing Research*, 31, 212–218.
- Olsho, L.W., Koch, E.G., Carter, E.A., Halpin, C.F., & Spetner, N.B. (1988). Pure-tone sensitivity of human infants. *Journal of the Acoustical Society of America*, 84, 1316–1324.
- Roberts, J.E., Burchinal, M.F., Collier, A.M., Ramey, C.T., Koch, M.A., & Henderson, F.W. (1989). Otitis media in early childhood and cognitive, academic and classroom performance of the school-aged child. *Pediatrics*, 83, 477–485.
- Roberts, J.E., Burchinal, M.R., & Campbell, F. (1994). Otitis media in early childhood and patterns of intellectual development and later academic performance. *Journal of Pediatric Psychology*, 19, 347–367.
- Roberts, J.E., Burchinal, M.R., Davis, B.P., Collier, A.M., & Henderson, F.W. (1991). Otitis media in early childhood and later language. *Journal of Speech and Hearing Research*, 34, 1158–1168.
- Roberts, J.E., Burchinal, M.R., Medley, L.P., Zeisel, S.A., Mundy, M., Roush, J., Hooper, S., Bryant, D., & Henderson, F.W. (1995). Otitis media, hearing sensitivity, and maternal responsiveness in relation to language during infancy. *Journal of Pediatrics*, 126, 481–489.
- Roland, P.S., Finitzo, T., Friel-Patti, S., Brown, K.C., Stephens, K.T., Brown, O., & Coleman, J.M. (1989). Otitis media: Incidence, duration, and hearing status. *Archives of Otolaryngology - Head and Neck Surgery*, 115, 1049–1053.
- Shanks, J.E., Lilly, D.E., Margolis, R.H., Wiley, T.L., & Wilson, R.H. (1988). Tympanometry. *Journal of Speech and Hearing Research*, 53, 354–377.
- Werner, L.A. (1995). Observer-based approaches to human infant psychoacoustics. In G.M. Klump, R.J. Dooling, R.R. Fay, & W.C. Stebbins (Eds.), *Methods in comparative psychoacoustics* (pp. 135–146). Boston: Birkhauser Verlag.
- Werner, L.A., & Bargones, J.Y. (1991). Sources of auditory masking in infants: Distraction effects. *Perception and Psychophysics*, 50, 405–412.
- Yankelowitz, S., Gravel, J.S., Wallace, I., & Karma, P. (1991). A clinical research form for use in the documentation of middle ear effusion. *Ear and Hearing*, 12, 296–298.