Tohoku J. Exp. Med., 2003, **200**, 129–135

Effects of Contralateral Noise on the Measurement of Auditory Threshold

Tetsuaki Kawase, Masaki Ogura, Toshinori Sato, Toshimitsu Kobayashi and Yôiti Suzuki[1]

Department of Otolaryngology, Head and Neck Surgery, Tohoku University Graduate School of Medicine, Sendai 980-8574, and
[1]*Research Institute of Electrical Communication, Tohoku University, Sendai 980-8577*

Kawase, T., Ogura, M., Sato, T., Kobayashi, T. and Suzuki, Y. *Effects of Contralateral Noise on Measurement of Auditory Threshold.* Tohoku J. Exp. Med., 2003, **200** (3), 129–135 —— It is well known that sound presented in the contralateral ear can elicit the activity of the olivocochlear (OC) efferent. In the present study, the effects of the addition of contralateral noise on the psychophysical measurements of auditory thresholds were investigated in human subjects with normal hearing. The results obtained in the present study indicate that the addition of contralateral noise at a level of only 20 or 30 dB sound pressure level (SPL) may cause a significant elevation of the auditory threshold in the mid-frequency area (usually 2–3 dB). When the level of contralateral noise was elevated, the elevation of the auditory threshold tended to be larger and the affected frequency area became wider. Although other factors that elevate the auditory thresholds, such as cross-talk effects and the acoustic reflex of the middle ear muscles, may be involved in the above-mentioned paradigm, especially when higher levels of contralateral noise are used, it is important to know the degree of OC-mediated threshold elevation in usual audiometric measurement. ——— audiometry; masking noise; olivocochlear efferent; suppression

Efferent innervation from the brainstem to the cochlea is known as the olivocochlear bundle (OCB), which consists of two major components: unmyelinated lateral olivocochlear (LOC) and myelinated medial olivocochlear (MOC) neurons (Warr and Guinan 1979). LOC neurons originate in the lateral part of the superior olivary complex and primarily project to the inner hair cell area. On the contrary, MOC neurons originate in a more medial part of the superior olivary complex and exclusively innervate to the outer hair cells (OHCs) (Warr and Guinan 1979; Guinan et al. 1983). Although the practical role of these systems is not fully understood, it is well known that the activation of the MOC system suppresses the response of

Received May 30, 2003; revision accepted for publication July 23, 2003.
Address for reprints: Tetsuaki Kawase, Department of Otolaryngology, Head and Neck Surgery, Tohoku University Graduate School of Medicine, 1-1 Seiryomachi, Aoba-ku, Sendai 980-8574, Japan.
e-mail: kaw@mail.cc.tohoku.ac.jp

afferent auditory neurons via olivocochlear (OC) effects on OHC (Brown et al. 1983). As one of the effective triggers of the activation of MOC neurons, it is well known that sound presented in the contralateral ear can elicit the activity of the OC efferent neurons, and suppress the response of the auditory nerve fibers as well as otoacoustic emissions (OAEs) (Fex 1962; Cody and Johnstone 1982; Liberman 1988; Warren and Liberman 1989; Collet et al. 1990; Veuillet et al. 1991; Moulin et al. 1993).

In the present study, the effects of contralateral noise on the psychophysical measurements of auditory thresholds were investigated in normal human subjects. It may be regarded as an extraordinary situation that noise is added in the contralateral ear during signal perception. However, we routinely use such a paradigm in clinical audiometric measurement, especially in the measurement of bone conduction thresholds. In that sense, it seems to be important to know the magnitude of the effects of the addition of contralateral noise on the auditory thresholds in humans.

Materials and Methods

Effects of contralateral noise on threshold measurement

Audiometric measurements were conducted in five ears of four healthy subjects (1 male and 3 females). No pathologic findings of the tympanic membrane were observed by inspection. Standard tonal audiometry showed no elevation of pure-tone thresholds (within 20 dB healing level [HL] HL at all tested frequencies). Auditory thresholds under various conditions of contralateral noise were examined. A schematic paradigm for the presentation of the test signals is shown in Fig. 1. Tone bursts (duration of 50 milliseconds, rise-fall time of 5 milliseconds) at six frequencies (250, 500, 1000, 2000, 4000 and 8000 Hz) were used as probe tones, and a broadband noise (BBN) burst (duration of 500 milliseconds, rise-fall time of 5 milliseconds) was applied to the contralateral ear (contra-noise). The probe tone to be masked was presented 450 milliseconds after the onset of the contra-noise.

Focusing on the frequency of 2000 Hz in which the largest effects were obtained in the above-mentioned measurements, the effects of

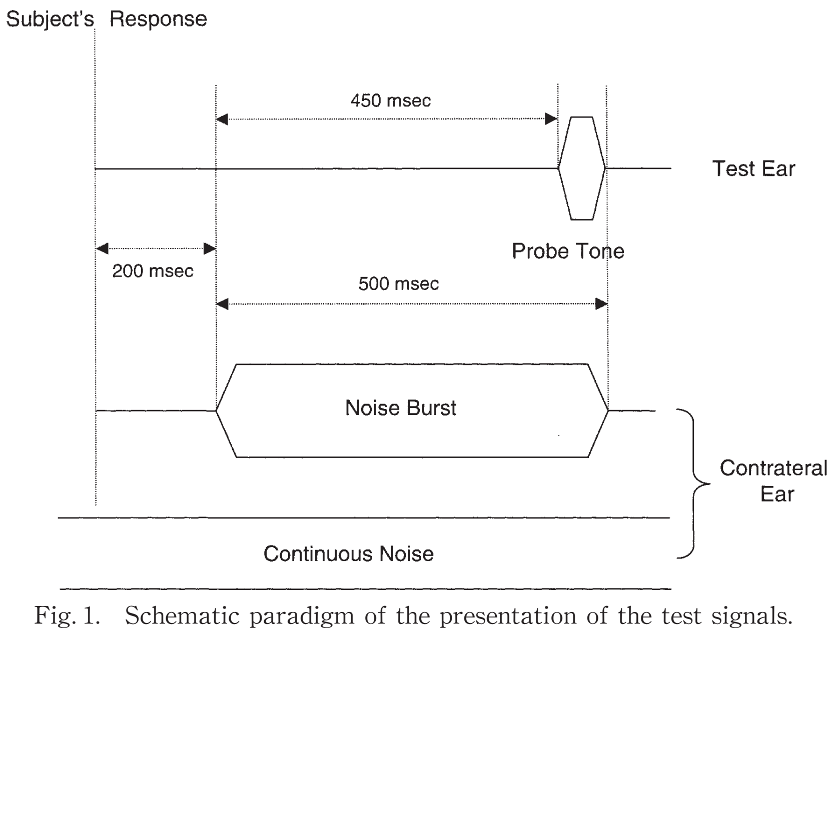

Fig. 1. Schematic paradigm of the presentation of the test signals.

three additional types of contra-noise were examined in two cases: a continuous BBN, a continuous narrow band noise (NBN) at 2000 Hz and a 2000 Hz-NBN burst (duration of 500 milliseconds rise-fall time of 5 milliseconds). The 2000 Hz-tone burst was used as a probe tone. When the continuous noise was used as a contra-noise, a probe tone was presented 650 milliseconds after the subject's response, while in the case that a 2000 Hz-NBN was used as contra-noise, the signal and contra-noise were presented in the same fashion as for the BBN (Fig. 1). Moreover, to determine the effect of direct masking, the masked threshold for the probe tone at 2000 Hz was examined for the presentation of a 2000 Hz-NBN burst together with a signal in the ipsilateral ear instead of the contralateral ear.

The thresholds were determined by a randomized maximum likelihood sequential procedure (RMLSP) (Takeshima et al. 2001), an adaptive method for the estimation of auditory sensitivity. In this method, the sound level of the next stimulus is determined randomly within a certain range centered at the sound level that yields the maximum likelihood calculated from the subject's responses, in contrast with the "original" maximum likelihood sequential procedure (MLSP), in which the next stimulus is simply determined as the highest level of likelihood (Hall 1968; He et al. 1998).

The generation of the stimulus and the sampling of the listener's responses, as well as the execution of the RMLSP method, were conducted by means of an IBM-compatible computer. Tones were produced by a programmable generator (TDT WG2, DD1) and an attenuator (TDT PA4 in series), and were presented after mixing (TDT SM3). The subjects were asked to judge whether the stimulus of the probe tone was audible or not. After selection of the response by the subject by means of a response button, the next set of stimuli was presented after a delay of 200 milliseconds.

To determine the level of next stimuli, the logistic function was assumed to be a psychometric function for calculating the likelihood in the run. Our psychometric function was in the form of

$$PF\ (X;\ M;\ S;) = 1/(1+\exp\{(M\text{-}X)/S\} \qquad (1)$$

X: the level of the stimulus in decibels
M: the mean of the logistic (the point where the logistic function has a value of 0.5)
S: S.D. corresponding to the slope of psychometric functions

The stimuli covered a range of 30 dB (±15 dB) in 1-dB steps. The "threshold" was defined as the track point on the psychometric function corresponding to a correctness level of 50% (Levitt 1971) using the method of maximum likelihood after 50 trials.

Measurement of DPOAEs

To assess the magnitude of sound-evoked OC-effects, the effects of contralateral BBN on the level of distortion products otoacoustic emissions (DPOAEs) at 2f1-f2 were measured using a measurement system from Etymotic Research (earphone: ER-2; microphone: ER-10B; IBM PC-based DSP board: Ariel DSP 16+; software: CUBDIS, version 2.4, Mountainside, NJ, USA). Equilevel primaries (L1=L2=55 dB) at a frequency ratio of f2/f1=1.2 were used. A BBN at 50 dB sound pressure level (SPL) was used for the sound presented to the contralateral ear. Eight ears from four healthy subjects were studied.

All parts of the present study were performed in accordance with the guidelines of the Declaration of Helsinki.

RESULTS

In Fig. 2, average threshold shifts caused by the addition of contralateral BBN burst are plotted as a function of the frequency of the probe tone. The addition of contra-noise at a level of only 20 or 30 dB SPL caused a signifi-

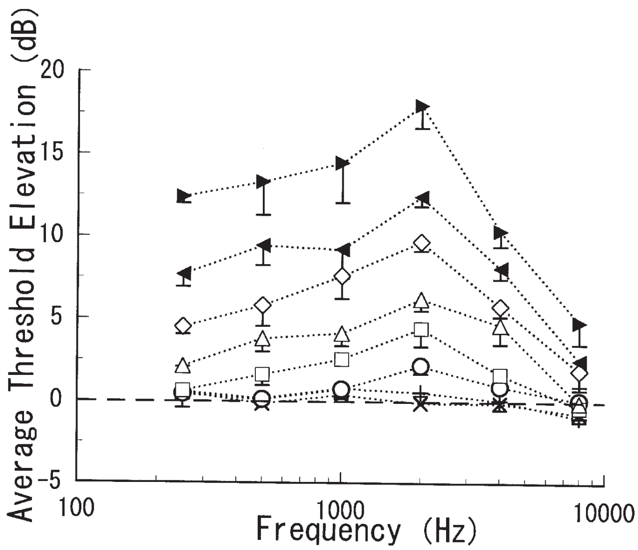

Fig. 2. Effects of contralateral BBN burst on the auditory thresholds.
Average threshold shifts caused by the addition of contralateral BBN bursts are plotted with standard errors as a function of the frequency of the probe tone. (Contra Noise Level: ··×··, 10 dB SPL; ··+··, 20 dB SPL; ··○··, 30 dB SPL; ··□··, 40 dB SPL; ··△··, 50 dB SPL; ··◇··, 60 dB SPL; ··◀··, 70 dB SPL; ··▶··, 80 dB SPL)

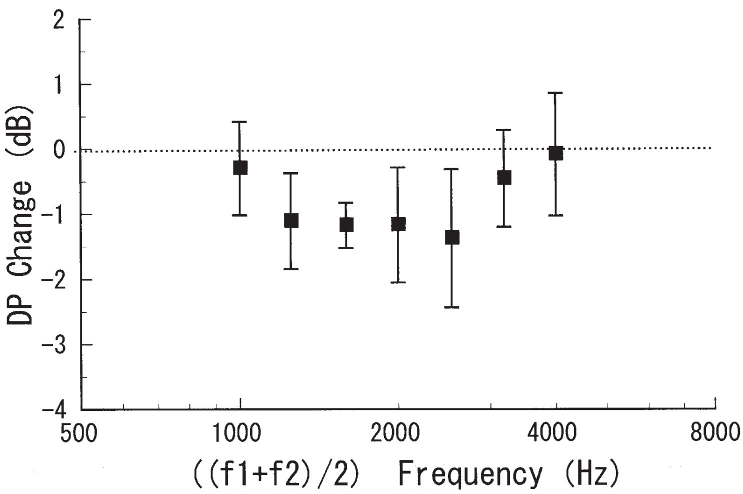

Fig. 3. The effects of contralateral continuous BBN on the level of DPOAEs ($n=8$ ears).
Average changes of the level of DPOAEs caused by the addition of contralateral BBN (continuous) are plotted as a function of the frequency of (f1+f2)/2.

cant elevation of the auditory threshold in the mid-frequency area. When the level of contra-noise was elevated, the elevation of the auditory threshold tended to be greater and the affected frequency area became wider especially to toward the lower frequecy.

On the other hand, in Fig. 3, average depressions of the level of DPOAEs caused by the addition of contralateral BBN (continuous) are plotted as a function of the frequency of (f1+f2)/2. DPOAEs in the mid-frequency area were depressed by the addition of contralateral continuous BBN. The frequency region in which a large effect of contralateral noise on DPOAEs

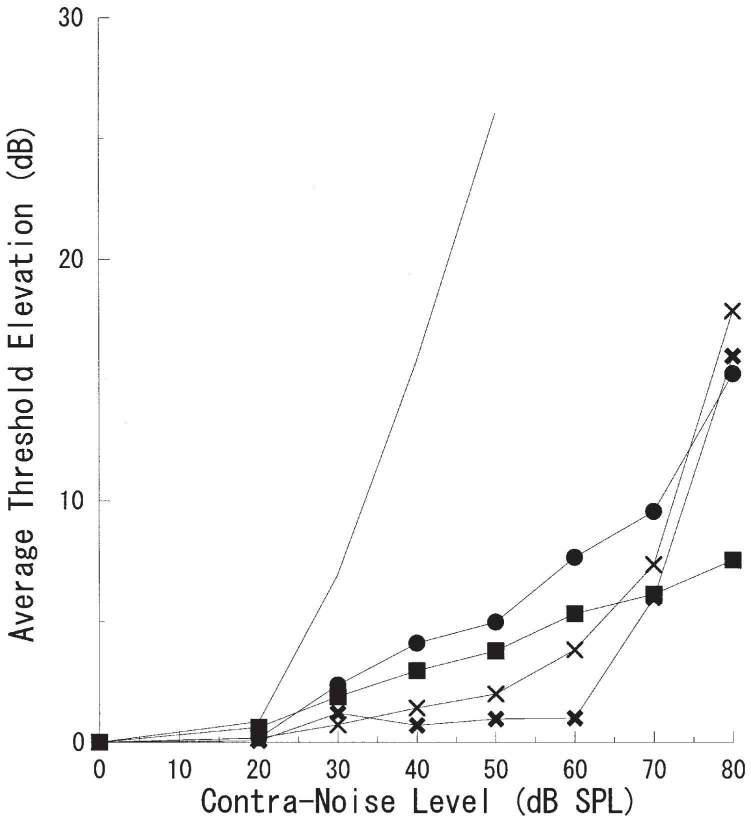

Fig. 4. Threshold elevation as a function of presented noise level: effects of different types of noise presentation.
The elevations of the threshold for a 2000 Hz probe tone were examined in several conditions of noise presentation: (1) a contralateral BBN burst (●), (2) contralateral continuous BBN (■), (3) a contralateral 2000 Hz-NBN burst (×), (4) contralateral continuous 2000 Hz-NBN (✖) and (5) an ipsilateral 2000 Hz-NBN burst (thin line).

was observed appeared to be similar to that obtained in threshold measurements.

In Fig. 4, the elevation of the threshold for a 2000 Hz probe tone is compared among the following conditions: a contralateral BBN burst, contralateral continuous BBN, a contralateral 2000 Hz-NBN burst, contralateral continuous 2000 Hz-NBN and an ipsilateral 2000 Hz-NBN burst. Data shown in the figure are averaged data from 2 ears. When the presented level of contra-noise was relatively low (less than 60 dB SPL), the effects of contralateral BBN on the threshold elevation were larger than those of NBN, and the effects of continuous conditions were smaller than those of burst conditions. The functions of the threshold elevation caused by the contra-noises were relatively linear as long as the presented level was low. However, the functions became steeper when the presented level of contra-noise was higher.

The slope of the function for higher-level contralateral NBN was similar to that of ipsilateral masking by NBN.

Discussion

In audiometric measurement, we routinely apply masking noise contralaterally to prevent subjects from hearing the test tone by the contralateral ear (cross-hearing). However, such contralaterally applied noise can affect the threshold measurement in the test ear due to at least three factors: overmasking, contraction of the middle ear muscle (MEM) and OC effects. As is known, when the level of contra-noise is too high (usually greater than about 50 dB above threshold for NBN), cross-hearing of the contra-noise can occur (overmasking) (Goldstein and Newman 1994). The MEM can also contract in response to a relatively loud sound, and this may reduce the sensitivity for the low frequency tone (Møller 1965; Borg 1972; Borg et al. 1984). The threshold of the acoustic reflex of the MEM is about 70–75 dB SPL for BBN and about 90–95 dB SPL for tones or narrow band stimuli (Gelfand 1984). On the other hand, the threshold of the OC-reflex is known to be very low. Sensitive efferent units can respond to sound at a level below 10 dB SPL, and the OC-mediated suppressive effect is especially remarkable when broad-band stimuli are applied (Liberman 1988; Warren and Liberman 1989). Therefore, it appears that the threshold elevations caused by the relatively low level (below 60 dB SPL) of contralateral BBN (shown in Fig. 2) is mainly due to the OC-mediated effects. Actually, the frequency area in which remarkable effects were observed for threshold measurements is similar to that obtained in the contra-noise effects on DPOAEs; this is thought to be related to the OC effects on OHCs. On the other hand, when a higher level of contralateral noise was applied (70–80 dB SPL), MEM effects were possibly involved, especially in the low frequency area.

As shown in Fig. 4, the effects of contralateral BBN were larger than those of NBN. Moreover, when the effects of continuous noise are compared with those of burst noise, the threshold elevations of the latter were greater than those of the former. These findings are consistent with the known characteristics of the OC system: it has been known that the OC-mediated suppressive effects are larger for broadband stimuli than those for tone (Warren and Liberman 1989) and that the OC-mediated effects activated by the contra-noise are greatest at the beginning of the noise presentation, and gradually decrease with time (Wiederhold and Kiang 1970; Kujawa et al. 1993; Sridhar et al. 1995; Liberman et al. 1996; Sasaki et al. 2000). On the contrary, based on the resemblance to the ipsilateral masking function, the effects of 2000 Hz NBN at the level over 70 dB SPL appeared to show the cross-hearing effects of contralaterally presented noise.

Therefore, findings of the present study suggest that the effects of contralaterally presented masking noise in routine audiometry would be considerably small as long as continuous NBN is used at an appropriate level (cross-hearing does not occur). On the other hand, when a BBN is used as a masker (as in the case of speech test, etc.), OC-effects should be considered to some degree (5–10 dB SPL).

Acknowledgments

This study was supported by grants from the Ministry of Education, Science and Culture (Grants-in-Aid for Scientific Research [B] 11557123 and [C] 11371668).

References

Borg, E. (1972) Acoustic middle ear reflexes: A sensory-control system. *Acta Otolaryngol.,* Suppl. **304**, 1–34.

Borg, E., Counter, S.A. & Rosler, G. (1984) Theories of middle ear muscle function. In: *The Acoustic Reflex*, edited by S. Silman, Academic Press, Orlando, pp. 63–99.

Brown, M.C., Nuttall, A.L. & Masta, R.I. (1983) Intracellular recordings from cochlear inner hair cells: Effects of stimulation of the crossed olivocochlear efferents. *Science*, **222**, 69–72.

Cody, A.R. & Johnstone, B.M. (1982) Acoustically evoked activity of single efferent neurons in the guinea pig cochlea. *J. Acoust. Soc. Am.*, **72**, 280–282.

Collet, L., Kemp, D.T., Veuillet, E., Duclaux, R., Moulin, A. & Morgon, A. (1990) Effect of contralateral auditory stimuli on active cochlear micromechanical properties in human subjects. *Hear Res.*, **43**, 251–262.

Fex, J. (1962) Auditory activity in centrifugal and centripetal cochlear fibers in cat. *Acta Physiol. Scand*., **55**, Suppl. 189, 2–68.

Gelfand, S.A. (1984) The Contralateral acoustic-reflex threshold. In: *The Acoustic Reflex*, edited by S. Silman, Academic Press, Orlando, pp. 137–186.

Goldstein, B.A. & Newman, C.W. (1994) Clinical masking: A descision-making process. In: *Handbook of Clinical Audiology*, edited by J. Katz, Williams and Wilkins, Baltimore, pp. 109–131.

Guinan, J.J., Warr, W.B. & Norris, B.E. (1983) Differential olivocochlear projections from lateral vs. medial zones of the superior olivary complex. *J. Comp. Neurol*., **221**, 358–370.

Hall, J.L. (1968) Maximum-likelihood sequential procedure for estimation of psychometric functions. *J. Acoust. Soc. Am*., **44**, 370.

He, N., Dubno, L.R. & Mills, J.H. (1998) Frequency and intensity discrimination measured in a maximum-likelihood procedure from young and aged normal-hearing subjects. *J. Acoust. Soc. Am*., **103**, 553–565.

Kujawa, S.G., Glattle, T.J., Fallon, M. & Bobbin, R.P. (1993) Contralateral sound suppresses distortion product otoacoustic emissions through cholinergic mechanisms. *Hear. Res*., **68**, 97–106.

Levitt, H. (1971) Transformed up-down procedures in psychoacoustics. *J. Acoust. Soc. Am*., **49**, 467–477.

Liberman, M.C. (1988) Response properties of cochlear efferent neurons: Monaural vs. binaural stimulation and the effect of noise. *J. Neurophysiol*., **60**, 1779–1798.

Liberman, M.C., Puria, S. & Guinan, J.J. (1996) The ipsilaterally evoked olivocochlear reflex causes rapid adaptation of the 2f1-f2 distortion product otoacoustic emission. *J. Acoust. Soc. Am*., **99**, 3572–3584.

Moulin, A., Collet, L. & Duclaux, R. (1993) Contralateral auditory stimulation alters acoustic distortion products in humans. *Hear Res*., **65**, 193–210.

Møller, A.R. (1965) An experimental study of the acoustic impedance of the middle ear and its transmission properties. *Acta Otolaryngol*., **60**, 129–149.

Sasaki, N., Kawase, T., Ogura, M. & Takasaka, T. (2000) The time-course of the contralateral sound effects on the level of distortion product otoacoustic emissions. *Tohoku J. Exp. Med*., **191**, 71–78.

Sridhar, T.S., Liberman, M.C., Brown, M.C. & Sewell, W.F. (1995) A novel cholinergic "slow effect" of efferent stimulation on cochlear potentials in the guinea pig. *J. Neurosci*., **15**, 3667–3678.

Takeshima, H., Suzuki, Y., Fujii, H., Kumagai, M., Ashihara, K., Fujimori, T. & Sone, T. (2001) Equal-loudness contours measured by the randomized maximum likelihood method sequential procedure. *Acustica*, **87**, 389–399.

Veuillet, E., Collet, L. & Duclaux, R. (1991) Effect of contralateral acoustic stimulation on active cochlear micromechanical properties in human subjects: dependence on stimulus variables. *J. Neurophysiol*., **65**, 724–735.

Warr, W.B. & Guinan, J.J. (1979) Efferent innervation of the organ of Corti: two separate systems. *Brain Res*., **173**, 152–155.

Warren, E.H. & Liberman, M.C. (1989) Effects of contralateral sound on auditory-nerve responses. I. Contributions of cochlear efferents. *Hear Res*., **37**, 89–104.

Wiederhold, M.L. & Kiang, N.Y.S. (1970) Effects of electrical stimulation of the crossed olivocochlear bundle on single auditory nerve fibers in cat. *J. Acoust. Soc. Am*., **48**, 950–965.