Contralateral Acoustic Effect of Transient Evoked Otoacoustic Emissions in Neonates

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Abstract: Contralateral acoustic stimulation (CAS) has the effect of reducing the amplitude of transient evoked otoacoustic emissions (TEOAE) of the opposite cochlea. This phenomenon is considered to be mediated via the efferent pathway, from the superior olivary complex through the medial olivocochlear system to the contralateral cochlea. The assessment of this suppressive effect provides an objective and noninvasive technique for exploring the function of the efferent auditory system in humans. Two previous studies investigated the suppression effect of TEOAE in newborns and revealed a significant effect in 18 full-term neonates.

In this study, the effect of contralateral acoustic stimulation on TEOAE was investigated in 13 full-term neonates (gestational age, 40–42 weeks). The TEOAE were recorded alternately with and without simultaneous, contralateral white noise. The CAS effect of TEOAE was present in all subjects; a mean of 2.21 dB ± 1.7 (21% ± 9.3%) was found. Our study demonstrated additional support for the functional maturity of the medial olivocochlear efferent system from birth.

Keywords: otoacoustic emission; medial olivocochlear system; neonates; suppression; contralateral acoustic effect; maturation

Hearing from birth (or perhaps even earlier) is crucial for normal language development in a child. From birth, the sensitivity of hearing and frequency selectivity are essential for speech sound perception. The outer hair cells have been proved to enhance sensitivity and fine tuning of the auditory system [1]. Otoacoustic emissions (OAEs) are associated with the mechanical processes of the outer hair cells [2,3]. The efferent auditory pathways, investigated particularly with the olivocochlear bundle (OCB) system that terminates in the cochlea, are involved in these processes. For many years, it was known that the medial component of the OCB synapses extensively on the outer hair cells. Recently, for the first time, acquired knowledge established that transient otoacoustic evoked emissions (TEOAE) facilitated extensive testing of the olivocochlear bundle in awake human beings. A number of studies proved in both humans [4–9] and animals [10–12] the suppression of spontaneous and evoked emissions by contralateral acoustic stimuli, and this effect was termed *suppression effect*, or *contralateral acoustic stimulation* (CAS) effect. The involvement of the OCB in the CAS effect was confirmed.

On the basis of two reports in the literature [13,14], the CAS effect was proved to exist from birth in 18 full-term neonates. Our study adds evidence to the function of the CAS effect from birth in 13 additional babies.

MATERIAL AND METHODS

Subjects

Thirteen normal, healthy, full-term babies (7 male, 6 female) born at The Chaim Sheba Medical Center, Tel Hashomer, were tested. The mean gestational and conceptional ages (measured from the last menstrual cycle) were 40.4 ± 0.7 weeks (range, 40–42 weeks) and 40.7

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± 0.76 weeks (range, 40–43 weeks), respectively. The mean birth weight was 3,447 ± 297 g.

Eleven babies were tested at 24–48 hours after birth, and two more were tested on their third and fifth days. On evaluation, the neonatal physician confirmed that all neonates were normal, with no family history of general or auditory pathology. The neonates had no risk factors for hearing impairment as defined by the Joint Committee on Infant Hearing [15]. The tests were carried out after feeding, during light sleep in a quiet room in the Neonatology Unit.

General Procedure

All neonates passed the TEOAE screening test in both ears before being tested for the CAS effect. The TEOAE screening criteria were reproducibility of more than 50% and a signal-to-noise ratio equal to or greater than 3 dB in three of the four frequency bands: 1.6, 2.4, 3.2, and 4 kHz [16].

One ear of each neonate was tested for the CAS effect, because the entire procedure lasted approximately 1 hour when it was successful. Once this testing was accomplished, the babies usually became restless, and the other ear was impossible to test. The procedure was initiated in more than double the number of babies reported here but could not be completed, as the babies awakened.

The tested ear was chosen arbitrarily according to the side on which the babies were lying in their cribs. The CAS effect was obtained from five right and eight left ears.

The TEOAE Procedure

Click-evoked otoacoustic emissions were recorded and analyzed using the ILO288 Echoport OAE analyzer (Otodynamics, S.L.E. Ltd., Crydon, UK), which was connected to a portable computer (Twin Head 486DX2). A Type E neonatal probe was used.

The Quickscreen mode as proposed in the protocol of newborn testing [17] was used. This mode employs a nonlinear click stimulus of 80 microseconds at a rate of 80 presentations per second. Nonlinear clicks consist of four clicks, the first three being in the same phase and amplitude and the fourth opposite in phase and having a threefold larger amplitude. The summation of four successive responses leaves only the nonlinear component of the otoacoustic response. This stimulus paradigm reduces stimulus artifact, cancels all the linear components of the response, and affects the true amplitude of the emission, thereby rendering difficult the absolute quantification of suppression [18]. We chose this mode for the neonates, taking into account that both emission and noise amplitudes are greater in neonates than in adults [19].

The mean intensity measured at the external ear canal was 69.33 dB **pe** SPL, with an SD of 3.35 dB. For each response, 260 low-noise samples were averaged. As each sample consisted of four successive clicks, the total response was 1,040 stimuli.

A recording window of 2.5–12.5 milliseconds poststimulus was used for analysis. The first 2.5 milliseconds were eliminated to avoid the ringing component of the stimulus. A band-pass of 500–6,000 Hz was employed.

The CAS Effect Procedure

For CAS effect, six successive TEOAE measurements were recorded for each baby, alternately without (three) and with (three) simultaneous contralateral noise. The contralateral acoustic stimulation was a 40-dB HL white noise, generated by a 10D Belton portable audiometer.

The CAS was delivered to the ear by a miniature insert earphone using the same Otodynamics disposable tips used on the type E probe for TEOAE recordings. To avoid its movement, the insert earphone was secured to the ear with surgical tape. Calibration of the insert earphone was carried out with a Brüel-Kjær 2209 sound level meter.

Data Analysis

For each baby, the testing conditions (stimulus intensity and stability, and the number of noisy presentations) and the response measurements (TEOAE amplitudes with and without contralateral noise) were averaged separately for the recordings with and without the CAS. The CAS effect of each neonate was calculated as the difference between the mean TEOAE amplitude *with* CAS and the mean TEOAE amplitude *without* CAS. In a similar manner, the same values were calculated for the entire group. The CAS effect was expressed also as the percentage change between the averaged TEOAE amplitude recorded with CAS and the amplitude recorded without CAS. To calculate this relative difference, the average TEOAE amplitudes were converted from the decibel SPL values calculated by the ILO88 analysis system into micro-Pascal. Student's *t* tests and Pearson correlations were used for statistical analysis.

RESULTS

The means of the recording conditions of the TEOAE without noise and the TEOAE recorded with contralateral noise are presented in Table 1. Results showed no

Table 1. Measurements of Testing Conditions in Newborn Testing (N = 13)

	Stimulus Intensity (dB pe SPL)		**Stimulus Stability (%)**		**No. of Noisy Samples**	
	Without CAS	**With CAS**	**Without CAS**	**With CAS**	**Without CAS**	**With CAS**
Average	70.62	70.29	86.4	86.3	60.5	47.3
SD	2.97	3.54	9	5.2	41.1	28.73
Range	66.3–78.7	65.2–78.6	63.7–96	79.2–92.9	6.3–165	6.8–108

CAS = contralateral acoustic stimulation; SD = standard deviation.

significant differences by paired *t* test between the recordings with and without the CAS in regard to stimulus intensity, stability, and the number of noisy sample measurements.

The average TEOAE amplitude of the entire group *without* contralateral noise (mean ± SD) was 14.38 dB SPL ± 4.78 dB (Figure 1). The average TEOAE amplitude *with* contralateral noise was 12.17 dB SPL ± 4.71 dB.

The CAS effect of the entire group, calculated as the difference between these two means, was 2.21 dB ± 1.7, which was found to be significant by paired *t* test ($t[12] = 4.7$; $p < .001$). The other measurement for these relative differences (i.e., the average of the percentage change of TEOAE amplitude with and without CAS) was 15% (SD, 9.3; range, 3–53%).

Figure 2 shows the individual values of the CAS effect plotted in hierarchy. In 77% of the neonates, the CAS effect was greater than 1 dB; in two cases (15.4%), the effect was less than 0.5 dB.

Two factors were evaluated as being related to the CAS effect. First, no significant correlation was found between the TEOAE amplitude recorded without the contralateral noise and the amount of the CAS effect. Second, despite the small number of subjects, an interesting consideration was assessing whether the neonate's gender or the choice of tested ear (right or left) had any effect either on the TEOAE recordings or on the CAS effect. As described, accomplishing the entire procedure for one ear was difficult; testing both ears of the same neonate was almost impossible. Therefore, when we made a comparison between two ears, we actually compared two different groups of subjects. For both the gender factor (female versus male) and the tested ear factor (right versus left), no significant differences were found either for any of the TEOAE parameters or for the amount of the suppression.

DISCUSSION

The efferent innervation of the cochlea is rich and intriguing. Its peculiar way of synapsing differently with the outer and inner hair cells contributed to the interest of many investigators over the years regarding the functional significance of the efferent system. In the 1960s, an important role in hearing function was ascribed to the efferent olivocochlear bundle [20–24]. As early as 1962, Fex [23,24] claimed an auditory feedback system and connection between the two ears via the efferent system.

In a modest study done in our laboratory, Rubinstein et al. [25] even postulated that normal hearing is the common result of afferent and efferent activity, on the basis of the fact that the compound action potential is increased or decreased by efferent OCB activity. With the tremendous progress in understanding the role and function of the outer hair cells in hearing, significance was attributed also to the efferent role demonstrated by the suppression of the TEOAE.

The results of our study are in agreement with those of Ryan and Piron [13] and Goforth et al. [14]. Average reduction of 2.21 dB in the amplitude of the TEOAE was induced by introducing contralateral noise simultaneously with the TEOAE recording. This magnitude is just a little above the range of 1–2 dB reported in most of the adult studies of the suppression effect. It corresponds to a mean of 21% in our study.

The amount of suppression we found in our testing of the neonate population corresponds to the results of other reports using the linear click in neonate testing:

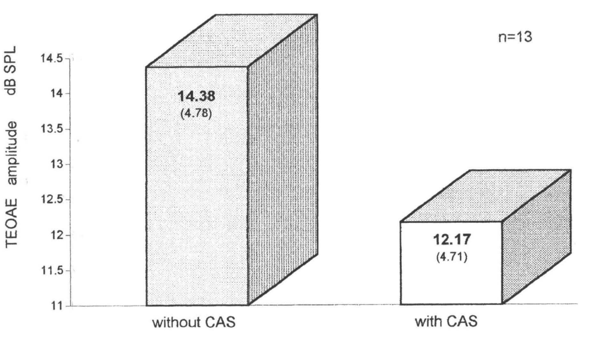

Figure 1. Transient evoked otoacoustic emission amplitudes (in decibels SPL; SD in parentheses) with and without contralateral acoustic stimulation.

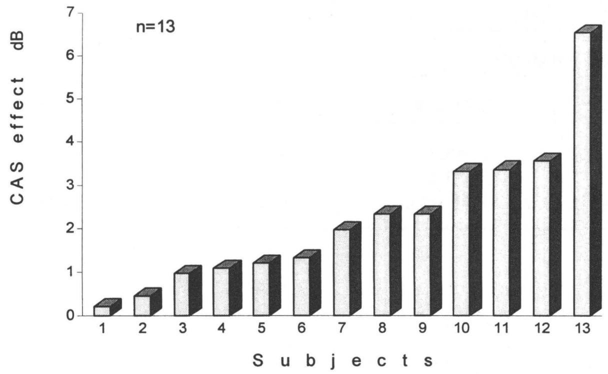

Figure 2. Suppression effect (in decibels): individual data.

Ryan and Piron [13] reported that in most cases, the reduction in amplitude was at least 1.5 dB, and Goforth et al. [14] reported a mean of 2.076 dB in the full-term neonates they tested.

Most authors concur that a large number of inter-subject variations exist in the amount of suppression [5,6,9,18,26]. In this study, it was expressed in high levels of SD and large ranges of the amount of CAS effect (i.e., 0.23–6.53 dB; 3–50%).

Because TEOAE amplitude is widely known to differ greatly among tested ears, we tried to establish the existence of a correlation between the level of emission and the amount of the CAS effect. No significant correlation was found between the amount of the CAS effect and the TEOAE amplitude recorded without contralateral noise. This result agrees with the findings of others [27,28]. Veuillet et al. [6], for example, found no significant differences between two groups of "large" and "small" emission levels. However, Ryan and Kemp [9] claimed that with large TEOAE, the effect can be detected easily, whereas among the smaller TEOAE, detecting the differences above the background noise was difficult.

Evidence of efferent function in the neonates strengthens the importance of this system in the hearing process. Additional new significant dimensions have arisen from findings in Mongolian gerbils, wherein the suppression of the comppound action potential by contralateral noise even preceded the maturation of the otoacoustic emissions [29]. If the same holds true in humans, as demonstrated by Walsh et al. [30] in cats, possibly the OCB is involved even in development.

REFERENCES

1. Ryan AF, Dallos P. The Physiology of the Cochlea. In JL Northern (ed), Hearing Disorders. Boston: Allyn & Bacon, 1996;15–31.
2. Kemp DT, Ryan S, Bray P. A guide to the effective use of otoacoustic emissions. *Ear Hear* 11:93–105, 1990.
3. Probst R, Lonsbury-Martin BL, Martin GK. A review of otoacoustic emissions. *J Acoust Soc Am* 89:2027–2067, 1991.
4. Collet L, Kemp DT, Veuillet E, et al. Effect of contralateral auditory stimuli on active cochlear micromechanical properties in human subjects. *Hear Res* 43:251–262, 1990.
5. Veuillet E, Collet L, Duclaux R. Effect of contralateral acoustic stimulation on active cochlear micromechanical properties in human subjects: dependence on stimulus variables. *J Neurophysiol* 65:724–735, 1991.
6. Veuillet E, Duverdy-Berthlon F, Collet L. Effect of contralateral acoustic stimulation on the growth of click-evoked otoacoustic emissions in humans. *Hear Res* 93: 128–135, 1996.
7. Berlin CI, Hood LJ, Wen H, Szabo P, et al. Contralateral suppression of non-linear click-evoked otoacoustic emissions. *Hear Res* 71:1–11, 1993.
8. Ryan S, Kemp DT, Hinchcliffe R. The influence of contralateral acoustic stimulation on click-evoked otoacoustic emissions in humans. *Br J Audiol* 25:391–397, 1991.
9. Ryan S, Kemp DT. The influence of evoking stimulus level on the neural suppression of transient-evoked otoacoustic emissions. *Hear Res* 94:140–147, 1996.
10. Mountain DC. Changes in endolymphatic potential and crossed olivocochlear bundle stimulation alter cochlear mechanics. *Science* 210:71–72, 1980.
11. Siegel JH, Kim DO. Efferent neural control of cochlear mechanics? Olivocochlear bundle stimulation affects cochlear biomechanical nonlinearity. *Hear Res* 6:171–182, 1982.
12. Puel JL, Rebillard G. Effect of contralateral sound stimulation on the distortion product 2F1-F2: evidence that the medial efferent system is involved. *J Acoust Soc Am* 87:1630–1635, 1990.
13. Ryan S, Piron JP. Functional maturation of the medial efferent olivocochlear system in human neonates. *Acta Otolaryngol* (Stockh) 114:485–489, 1994.
14. Goforth L, Hood LJ, Berlin CI. Efferent suppression of transient-evoked otoacoustic emissions in human infants [abstract]. *ARO* 1997.
15. Joint Committee on Infant Hearing. 1994 Position Statement. *ASHA* 36:38–41, 1994.
16. Vohr BR, White KR, Maxon AB. Effects of exam procedures on transient-evoked otoacoustic emissions (TEOAEs) in neonates. *J Am Acad Audiol* 7:77–82, 1996.
17. Maxon AB, White KR, Behrens TR, Vohr BR. Referral rates and cost efficiency in a universal newborn hearing screening program using transient-evoked otoacoustic emissions. *J Am Acad Audiol* 6:271–277, 1995.
18. Hood LJ, Berlin CI, Hurley A, Wen H. Suppression of Otoacoustic Emissions in Normal Hearing Individuals. In CI Berlin (ed), Hair Cells and Hearing Aids. San Diego: Singular Publishing, 1996;57–72.
19. Bergman BM, Gorga MP, Neely ST, et al. Preliminary description of transient-evoked and distortion-product otoacoustic emissions from graduates of an intensive care nursery. *Am Acad Audiol* 6:150–162, 1995.

20. Desmedt JE. Auditory evoked potentials from cochlea to cortex as influenced by activation of the efferent olivo-cochlear bundle. *J Acoust Soc Am* 34:1478–1496, 1962.

21. Dewson III JH. Efferent olivo-cochlear bundle: some relationships to noise masking and to stimulus attenuation. *J Neurophysiol* 30: 817–832, 1967.

22. Dewson III JH. Efferent olivo-cochlear bundle: some relationships to stimulus discrimination in noise. *J Neurophysiol* 31:122–130, 1968.

23. Fex J. Auditory activity in centrifugal and centripetal cochlear fibers in cats: a study of a feedback system. *Acta Physiol Scand Suppl* 55(189):1–68, 1962.

24. Fex J. Crossed cochlear efferents activated by sound through both ears. *Acta Physiol Scand Suppl* 59:213, 1963.

25. Rubinstein M, Hildesheimer M, Perlstein TP. The influence of efferent fibers on cochlear electrical activity. *J Auditory Res* 16:289–297, 1976.

26. Norman M, Thornton ARD. Frequency analysis of the contralateral suppression of evoked otoacoustic emissions by narrow-band noise. *Br J Audiol* 27:281–289, 1993.

27. Hood LJ, Berlin CI, Hurley A, et al. Contralateral suppression of transient-evoked otoacoustic emission: intensity effects. *Hear Res* 101:113–118, 1996.

28. Zaho F, Merdith R, Stephens SDG, Özçaglar H. Transient evoked otoacoustic emissions with contralateral stimulation in King-Kopetzky syndrome. *J Audiol Med* 6:36–44, 1997.

29. Huang JM, Berlin CI, Cullen Jr JK, Wickremasinghe AR. Development of contralateral suppression of VIIIth nerve compound action potential (CAP) in the Mongolian gerbil. *Hear Res* 78:243–248, 1994.

30. Walsh FJ, McGee J, Liberman MC, et al. Long-term physiological consequences of cutting olivocochlear bundle (OCB) in neonatal animals. *ARO (Midwinter meeting)* 1997. Abstract.