Original Paper

School-Age Outcomes in Preterm Children Born with Risk Factors for Hearing Loss: Contralateral Suppression of Transient Evoked Otoacoustic Emissions

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Key Words

Medial olivocochlear system • Contralateral suppression • Auditory efferents • Outer hair cells • Cochlea • Spontaneous otoacoustic emissions • Preterm infant

Abstract

We investigated the effect of contralateral suppression of linear transient evoked otoacoustic emissions (TEOAEs) in 16 preterm children born with risk factors for hearing loss. We evaluated those children, together with a control group of term children, at 8–10 years of age. The magnitude of the TEOAE suppression effect in both ears was significantly smaller in the preterm children than in the term children ($p < 0.05$). There is increasing evidence of adverse school-age outcomes (including hearing loss) in preterm children. Such outcomes can interfere with the school performance of those infants. The TEOAE suppression effect seems to be a promising early marker of hearing outcomes in preterm infants.

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Introduction

The increasing concern over learning difficulties in preterm children raises the need to diagnose sensory deficits or disorders (or a combination of the two) that can have a negative impact on the skills involved in the learning process, in which hearing plays a relevant role. When individuals develop problems in auditory processing rather than in auditory sensitivity, finding the source of the problem and establishing an early diagnosis are major challenges. Early identification of individuals at risk for developing auditory processing disorders allows the most appropriate approach to be selected and applied in a timely manner.

Longitudinal studies have shown that learning difficulties are more common in preterm children than in term children. The survival of increasingly premature infants poses the challenge of giving back to families and society children that are able to fully develop their affective, cognitive, and productive potential. The risk factors for developing neurobehavioral deficits include the presence of markers of white matter damage, principally periventricular leukomalacia, low gestational age, low birth weight, and chronic lung disease [Lorenz, 2001; Adams-Chapman and Stoll, 2006; Stahlmann et al., 2009].

Gestational age and weight at birth, as well as the type and severity of complications during fetal life, including hearing impairment, are risk factors for neonatal morbidity. Hearing impairment might be related to the peripheral auditory system, as well as to auditory processing disorders.

Although the relationship among auditory processing disorders, language disorders, and learning disabilities are complex, comorbidity is common; in particular, many children with learning and reading disabilities present with temporal processing deficits [Cestnick and Jerger, 2000; Bailey and Snowling, 2002; Breir et al., 2003; Billiet and Bellis, 2011].

Studies aimed at improving the objectivity of the evaluation of children with auditory processing disorders have focused on the use of electrophysiological parameters as a complement to behavioral tests. Middle- and long-latency auditory evoked potentials, as well as suppression of otoacoustic emissions (OAEs), have shown promise as early diagnostic parameters when considered in conjunction with auditory processing activities [Burgueti and Carvallo, 2008; Durante and Carvallo, 2008; Schochat et al., 2010].

Generated by normal nonlinear mechanisms within the cochlea, OAEs are thought to be the result of motile activity by the outer hair cells, which are innervated by the efferent nerve fibers of the olivocochlear bundle [Dallos, 1992; Rasmussen, 1946]. The combination of contralateral acoustic stimulation and transient evoked otoacoustic emissions (TEOAEs) allows the study of sound-evoked olivocochlear feedback and therefore of the efferent cochlear innervation. It has been shown that efferent activation can reduce TEOAE levels. This effect is known as TEOAE contralateral suppression [Berlin et al., 1994; Veuillet et al., 1999] and is already present at term neonates [Durante and Carvallo, 2002].

The presence of risk factors for hearing loss (as determined by newborn hearing screening) seems to be related to reduced efferent auditory pathway function, with a reduced inhibitory effect on outer hair-cell functioning [Durante and Carvallo, 2008], which could affect the development of auditory processing. Minimal TEOAE suppression effect was also reported by other authors: Angeli et al. [2008], who evaluated children with learning difficulties; Muchnik et al. [2004] and Sanches and Carvallo [2006] who evaluated children with auditory processing disorder; Lalaki et al. [2011] who evaluated individuals with tinnitus; and Yalçinkaya et al. [2010] who studied children with auditory listening problems associated with receptive and expressive language delay.

Infants with known risk factors for late hearing loss, progressive hearing loss, or both, should have periodic audiometric follow-up examinations until they reach the age of 3 years. The periodicity and number of re-evaluations can be stipulated on the basis of the severity

Table 1. Distribution of risk factors for hearing loss (n = 16)

Risk factors for hearing loss	n	%
Birth weight <1,500 g	8	50
Ototoxic drug use >7 days	8	50
Low Apgar scores	4	25
Mechanical ventilation >5 days	2	12.5

of each case. For children in whom newborn hearing screening reveals the presence of risk factors for hearing loss, at least one follow-up appointment, at 24–30 months of age, is recommended [JCIH, 2007; Lewis et al., 2010]. However, the use of OAE suppression to determine, in an objective manner, whether the efferent auditory pathways are functioning in neonates would allow early identification of children at risk for auditory processing disorder, which in turn would allow the appropriate measures to be taken in a timely manner.

The objective of the present study was to contribute to a better understanding of the effect of suppression of TEOAEs. To that end, we evaluated school-age outcomes in preterm children born with risk factors for hearing loss (as determined by newborn hearing screening).

Methods

Approval for this study was granted by the local ethics committee (Protocol No. CEP FCMSCSP 277/09). Written informed consent was obtained from the parent or guardian of each child tested in this study.

Subjects

We obtained data related to 52 children. All of the children who were invited to participate in the present study had normal hearing test results (including pure tone audiometry, speech audiometry, and tympanometry), presented with no neurological or psychiatric syndromes or disorders (exclusion criteria), and met the following inclusion criteria:

- Control group (n = 36) – born at term without risk factors for hearing loss; no history of hearing impairment; no learning disabilities; no language disorders; in the 8–10 year age bracket; and enrolled in a public school in the central region of the city of São Paulo, Brazil.
- Study group (n = 16) – having been treated at the preterm infant follow-up outpatient clinic of a teaching hospital in the city of São Paulo, Brazil; having been an extremely premature infant; having at least 1 risk factor for hearing impairment (as determined by newborn hearing screening); and being in the 8–10 year age bracket.

The mean birth weight was $1,497 \pm 379$ g, and the mean gestational age at birth was 32.2 ± 2.8 weeks. The risk factors for hearing loss found in the study sample are described in table 1.

Procedures

The tests were performed in a sound-treated booth, the TEOAEs being recorded by an Echoport Plus ILO292 OAE analyzer (Otodynamics Ltd, Hatfield, UK) coupled to a laptop running the program Echoport Plus ILO292, version 5.61 (Otodynamics Ltd). A UGS TEOAE probe (Otodynamics Ltd) and a response time window of 4–20 ms were used. In all children, the TEOAEs were recorded in linear mode, with and without contralateral stimulation. For all tests, the clicks were delivered at a peak equivalent sound pressure level (SPL) of 60–65 dB, and a total of 100 sweeps were recorded for both ears.

Table 2. Distribution of means and standard deviations of TEOAE (in decibels SPL), with and without contralateral stimulation, and suppression by response or signal-to-noise ratio, ear, and group

Ear	TEOAE		Group	
			control	study
Right	response	without CS	11.0 ± 4.8	10.3 ± 7.7
		with CS	9.8 ± 5.1	9.2 ± 8.1
		suppression	1.2 ± 1.0	0.7 ± 0.8
	SNR	without CS	4.3 ± 5.7	3.8 ± 6.4
		with CS	2.7 ± 6.3	2.9 ± 6.5
		suppression	1.8 ± 1.5	0.9 ± 1.4
Left	response	without CS	8.9 ± 6.1	9.4 ± 6.0
		with CS	7.7 ± 6.7	8.6 ± 6.5
		suppression	1.2 ± 1.1	0.5 ± 0.7
	SNR	without CS	4.4 ± 6.9	3.8 ± 5.7
		with CS	2.1 ± 7.7	2.6 ± 6.1
		suppression	2.3 ± 2.2	1.2 ± 1.7

CS = Contralateral stimulation; SNR = signal-to-noise ratio.

The TEOAEs were registered on channel A, which is the linear click channel. Contralateral stimulation consisted of continuous broadband white noise at 60 dB SPL, delivered through channel B of the OAE analyzer and presented by a general purpose probe (insert earphone; Otodynamics Ltd).

All subjects were tested bilaterally. After the two probes were in place, TEOAEs were recorded in alternating blocks (with and without contralateral stimulation).

Data Analysis

For each test, TEOAE contralateral suppression was measured in dB, and the data obtained were categorized by group (control or study), ear (right or left), and type of measurement (total response or signal-to-noise ratio). The degree of TEOAE contralateral suppression was determined by subtracting the TEOAE level obtained with contralateral stimulation from that obtained without contralateral stimulation.

Measurements and Statistical Analysis

The statistical analyses were carried out at the FCMSCSP Center for Applied Statistics. We employed descriptive and inferential statistics (the Mann-Whitney test). Analysis of variance showed that the measurements with and without contralateral stimulation for the two groups, ears, and genders were equivalent in terms of the intensity of the stimulus and stability ($p \geq 0.5$). For all tests, we used a descriptive level of significance of 0.05 (5%) in order to reject the null hypothesis.

Results

As can be seen in table 2, in terms of TEOAE response or the signal-to-noise ratio (either with or without contralateral stimulation), there were no significant differences between the control and study groups ($p > 0.2$).

Fig. 1. TEOAE contralateral suppression levels in right and left ears by type of response (total response and signal-to-noise ratio, SNR) and group (control and study).

By group, ear, and type of response, TEOAE contralateral suppression levels presented considerable interindividual variability (fig. 1). However, the TEOAE suppression effect (total response and signal-to-noise ratio) were significantly reduced in the right and left ears in the study group. In the study group, the TEOAE suppression effect was found to be significantly reduced in both ears. For TEOAE contralateral suppression, the total response was 1.24 ± 0.08 dB in the control group and 0.63 ± 0.09 dB in the study group ($p < 0.05$), whereas the signal-to-noise ratio was 2.05 ± 0.08 dB and 1.01 ± 0.09 dB, respectively ($p < 0.04$).

Discussion

The principal finding of the present study was that the TEOAE contralateral suppression effect was significantly reduced, at school age, in preterm children born with risk factors for hearing loss ($p < 0.05$).

An increasing number of studies have investigated the impact of preterm birth on child and adult development. This is due to the fact that preterm infants often require intensive care unit (ICU) admission. In the ICU, such infants undergo various interventions, such as treatment of infections, respiratory support, and nutritional support, all of which result in increased survival.

As the number of preterm infants who survive their ICU stay increases, so does the concern over the increasing number of children who present with learning difficulties. Perinatal complications can have an impact on the social, academic, and professional lives of individuals who were preterm infants. Therefore, measures should be taken in order to reduce the impact of those complications and eliminate (or at least reduce) the potential differences between individuals who were preterm infants and those who were term infants.

In preterm birth, multiple factors influence neuromaturation and can lead to numerous neurodevelopmental disabilities and neurological disorders, as well as to altered central nervous system processing [Allen et al., 2011]. The impact of preterm birth on hearing is attributable to a high prevalence of risk factors for hearing loss among preterm infants, including very low birth weight, prolonged ICU stay, and ototoxic drug use. It seems that preterm birth also has an impact on auditory development; studies have shown that, at school age, preterm children present with worse auditory processing test results than do term children [Fortes et al., 2007; Gallo et al., 2011].

The medial olivocochlear system can be objectively evaluated by measuring OAE suppression. Pickles [1988] conducted studies that raised the first hypotheses regarding the

functions of the medial olivocochlear system. According to the author, the medial olivocochlear system discriminates signals in noise, provides protection against acoustic trauma, controls the mechanical state of the cochlea, and plays a role in auditory attention. Minimal or absent OAE suppression is often associated with difficulties in sound localization, lateralization, recognition, and discrimination, as well as with auditory figure-ground discrimination and auditory neuropathy [Berlin et al., 1994; Veuillet et al., 1999; Abdala et al., 2000; Kumar and Vanaja, 2004; Muchnik et al., 2004; Sanches and Carvalho, 2006; Yalçinkaya et al., 2010].

Suppression of OAEs by competing noise constitutes a promising clinical tool, because it plays a significant role in the evaluation of cochlear status and of mechanisms involving the central auditory system. It is an objective, noninvasive procedure that allows the differential diagnosis of auditory processing disorders.

A study conducted by Durante and Carvalho [2008] showed that neonates with risk factors for hearing loss and extremely low TEOAE suppression values should be referred for hearing evaluation by means of electrophysiological measurements (auditory evoked potentials). The typical TEOAE suppression behavior observed in the risk group suggested that the auditory inhibitory function of the medial olivocochlear system was reduced in those infants and might indicate a risk for developing auditory processing disorders. Although preliminary, these results are similar to those of other studies, which showed that reduced OAE suppression is a strong marker of auditory processing disorders [Veuillet et al., 1999; Kumar and Vanaja, 2004; Muchnik et al., 2004; Sanches and Carvalho, 2006; Yalçinkaya et al., 2010], and can support the testing of infants at risk of developing abnormal efferent function [Morlet et al., 2004].

There is increasing evidence of adverse school-age outcomes (including hearing loss) among preterm children [Lorenz, 2001; Adams-Chapman and Stoll, 2006; Stahlmann et al., 2009; Stephens and Vohr, 2009; Allen et al., 2011]. This underscores the need to monitor the auditory development of such children until they reach school age in order to prevent such outcomes from interfering with their school performance.

New neuroimaging techniques and analytical tools are contributing to the understanding of neurologic sequelae of preterm birth by providing microstructural evidence of injury sustained by the preterm brain [Myers and Ment, 2009] and can aid in the study of auditory processing.

Although the present study was limited by the small sample size, these preliminary results suggest that reduced efferent system function, as measured by the amount of TEOAE contralateral suppression, seems to be common in preterm children at school age and underscore the TEOAE suppression effect as a promising early marker of outcome in preterm infants.

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Disclosure Statement

None of the authors has any conflict of interest.

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