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Gender Differences Among Newborns on a Transient Otoacoustic Emissions Test for Hearing

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*The purpose of this study was to examine gender differences with regard to cochlea sensitivity as measured by the transient evoked otoacoustic emissions hearing screening procedure. During this test, a sudden burst of sound is presented at between 78 and 83 dB SPL which stimulates the entire basilar membrane. This in turn excites the outer hair cells in the cochlea and causes an echo-type response which is recorded by a microphone in a probe placed in the ear canal. This test is used to screen for peripheral hearing loss. Subjects (*N *= 350) for this project were healthy, full-term newborns (38–42 weeks gestation) in the first 48 hours of life who had bilaterally passed the transient evoked otoacoustic emissions (TEOAE) screening test. Male (*n *= 170) and female (*n *= 180) infants were selected randomly from all babies born during a 3-month period who met the criteria at a large birthing hospital. Responses to TEOAE stimuli were recorded at 1.6 kHz, 2.4 kHz, 3.2 kHz, and 4.0 kHz. The responses were recorded as decibel levels indicating a signal-to-noise ratio. These decibel levels were used in a three-way ANOVA with repeated measures comparing gender, ear, and frequency level. Results indicated significant differences due to gender (female hearing more sensitive than male) and frequency (least sensitive hearing recorded at 1.6 kHz, most sensitive hearing recorded at 3.2 kHz). A significant two-way interaction indicated that differences in hearing sensitivity between genders increased as the frequency increased.*

Current research in the use of musical stimuli to create an environment conducive to homeostasis among premature infants and

hospitalized newborns has revealed overwhelmingly positive effects. Data gathered from these studies support the use of music therapy techniques to reduce the length of hospitalization (Caine, 1992; Standley, in press), calm infants (Moore, Gladstone, & Standley, 1994), reduce behaviors indicating stress (Caine, 1992), temporarily increase oxygen saturation levels (Cassidy & Standley, 1995; Collins & Kuck, 1991; Standley & Moore, 1995), improve the frequency and strength of non-nutritive sucking (Standley, 1997), and increase the tolerance of sensitive infants to multi modal stimulation (Standley, in press).

One startling outcome has emerged in three studies suggesting a possible gender effect with regard to the effects of music. Data from two studies indicate that premature *female* infants engaged in experimental music therapy treatment were discharged from the hospital 11 days sooner than their premature female control peers (Caine, 1992; Standley, in press). The difference between experimental and control premature *male* infants was negligible. One other study reported a gender difference with regard to type of aural stimuli successful in reducing heart rate among 6-month old infants (Kagan & Lewis, 1965). Females responded to more complex aural stimuli (music) yet males responded to less complex stimuli (single tone). While many music therapy studies report an effort to balance groups on the basis of gender, the majority do not report analysis of gender as an independent variable.

Hearing and interpreting sounds progress through the mechanical processing which takes place in the outer, middle, and inner ears, and through the intricate conversion into electrical-chemical energy in the cochlea, transfer to the brain via synapses in the auditory nerve, and finally reception by and interpretation within the temporal lobes of the brain. Therefore, the cause(s) of apparent differences between male and female responses to aural stimuli is difficult to pinpoint. At any point in this complex process, males and females could develop differently. Identifying differences between genders with regard to peripheral hearing (that part of the hearing process which takes place prior to and up to the conversion of mechanical sound into electrical-chemical energy) would provide a first step in identifying variables that might influence responses to musical stimuli.

Two types of hearing screenings are commonly used to test the effectiveness of the hearing system in newborns. The auditory

brain stem response (ABR) screens for neural hearing ability—that is the ability of the auditory nerve to deliver electrical impulses to the brain. Because sound waves must travel through the outer, middle, and inner ear in order to reach the brain stem, this test also screens for peripheral hearing. The ABR involves presenting click-like stimuli through a probe inserted in the ear canal, and measuring the electrical impulses as they travel up the brain stem via electrodes attached to the scalp. Research using the ABR as a dependent measurement tool on newborns (Cone-Wesson & Ramirez, 1997; Eldredge & Salamy, 1996) suggests that females are more sensitive to aural stimuli than are males.

The transient evoked otoacoustic emissions test (TEOAE) is another commonly used screening test. Similar to the ABR, sudden click-type noises are presented through a probe placed in the ear canal. In the TEOAE, very brief sounds produced by the probe almost instantaneously trigger movement in the outer hair cells of the cochlea (i.e., transiently evoked, or TE). This movement produces mechanical energy within the cochlea that is transmitted back through the middle ear and tympanic membrane. There it is converted to an acoustic signal in the ear canal. This acoustical signal is an otoacoustic emission (OAE). Unlike the ABR, the probe in the ear canal also functions as a microphone which detects and records these OAEs. OAEs only occur in a normal cochlea with normal hearing. Given that no measurement of brain activity is recorded, this test screens for peripheral hearing loss only—that is preneural hearing. However, in comparison to the ABR it is faster, less invasive, and more readily assesses a wider frequency range (800 Hz to 4.0 kHz as compared to 1 kHz to 3.2 kHz). Results from TEOAE research with 2-month old infants (Kei, McPherson, Smyth, Latham, & Lascher, 1997) and preterm neonates (Morlet et al., 1995) indicate that female infants respond more sensitively than male infants, and suggest a right ear advantage in the processing of auditory signals. It is thought that gender difference on OAE test results (Morlet et al., 1996) and ABR results (Don, Ponton, & Eggermont, 1993) can be, in part, attributed to an intersex difference in cochlear length, with the male cochlea being longer than female (Hall, 2000).

Evidence exists that characteristics of male and female brains differ during fetal development. Research with newborns is a critical aspect of exploring gender differences on many measurement

scales, because environmental conditioning has not had a chance to take place. The success of music therapy with infants is dependent upon a functioning hearing mechanism. Given the suggestion that musical stimuli be presented "using the minimum decibel level necessary to cause the desired effect" (Cassidy & Ditty, 1998, p. 78) it seems important to test the ability of the cochlea to respond to soft sounds. Music intensity levels affect the outer hair cell function, which is precisely what is measured by the TEOAE. Without a data-based standard protocol for presenting musical stimuli to infants (Cassidy & Ditty, 1998) and the recent conclusions that gender may play a role in the effectiveness of music therapy techniques, the possible relationship between gender and hearing development must be explored. Therefore, the purpose of this study is to further examine gender and ear differences with regard to cochlea sensitivity and address the development of a standardized protocol for music therapy interventions with male and female infants.

Method

In most states, state law requires that every infant born in a hospital be screened for potential early detection of hearing loss. With the exception of the state of Alabama, this "universal screening" is practiced throughout the southern United States (http://www.asha.org). Therefore, the subject pool for this study consisted of all infants (N = 1,685) born at a large southern hospital during a 3-month time period. All infants considered for inclusion in this project were healthy, full-term newborns (38–42 weeks gestation) in the first 48 hours of life and had bilaterally passed the transient evoked otoacoustic emissions (TEOAE) hearing screening test. From this group, 350 infants were randomly selected as subjects. This resulted in 170 male and 180 female infants.

The TEOAE hearing screening test was used in this study to collect data. The TEOAE presents a fast series of click-like noises through a probe placed in the ear canal. Standard protocol for the TEOAE test requires these sounds be presented at a stimulus intensity level of between 78 and 83 dB SPL. This level was established to obtain a response from an individual with hearing approximately 30 dB HL or better. The ear responds to the clicks by returning sound to the ear canal, somewhat like an "echo." The intensity of this sound is measured in amplitude across the frequency spectrum of 1.6 kHz to 4.0 kHz. A minimum of 50 samples unaf-

fected by noise must be collected for accurate test results. Cochlear function is assumed for frequencies for which TEOAEs are present with an amplitude greater than or equal to 3 dB above the noise floor for each frequency band. The louder the returned sound or "echo" in the ear canal, the more sensitive the hearing may be at any given frequency. The decibel levels indicating the signal above the noise ratio were the data used in statistical analysis.

Results

A three-way Analysis of Variance with repeated measures comparing the between variable of subject gender (male or female), and the within variables of ear (right or left), and frequency (1.6 kHz, 2.4 kHz, 3.2 kHz, and 4.0 kHz) was completed on the TEOAE data. Results indicate a significant difference due to the main effects of gender, $F(1, 348) = 6.3$, $p = .0125$, and frequency, $F(3, 1044) = 221.92$, $p < .0001$. Females had significantly higher signal-to-noise ratios ($M = 13.19$ dB) than males ($M = 12.05$ dB). Hearing was least responsive at 1.6 kHz ($M = 8.5$ dB), and most responsive at 3.2 kHz ($M = 15.07$ dB). Responses at 2.4 kHz ($M = 13.69$) and at 4.0 ($M = 13.27$ dB) were similar. There was no significant difference due to ear, $F(1, 348) = 3.8$, $p = .051$. Right ear ($M = 12.37$ dB) and left ear ($M = 12.88$ dB) responses were statistically similar.

There also was a significant two-way interaction between frequency and gender, $F(3, 1044) = 5.21$, $p = .0014$. Figure 1 displays this interaction in graphic form. Males and females follow the same pattern in responses across 1.6 kHz, 2.4 kHz, and 3.2 kHz. At the highest frequency, males were less responsive than at 2.4 kHz whereas females were more responsive. Genders had similarly low responses at 1.6 kHz (M difference = .39 dB). This difference became greater at each subsequent decibel level (M difference at 2.4 kHz = .57 dB; M difference at 3.2 kHz = 1.28 dB; M difference at 4.0 kHz = 2.32 dB). There were no other significant two-way nor a significant three-way interaction.

Discussion

Data from this study support previous research in finding a difference in hearing sensitivity due to gender (Cone-Wesson & Ramirez, 1997; Don et al., 1993; Eldredge & Salamy, 1996; Kei et al., 1997; Morlet et al., 1995, 1996). These data extend previous findings by observing TEOAE results of healthy newborns rather than

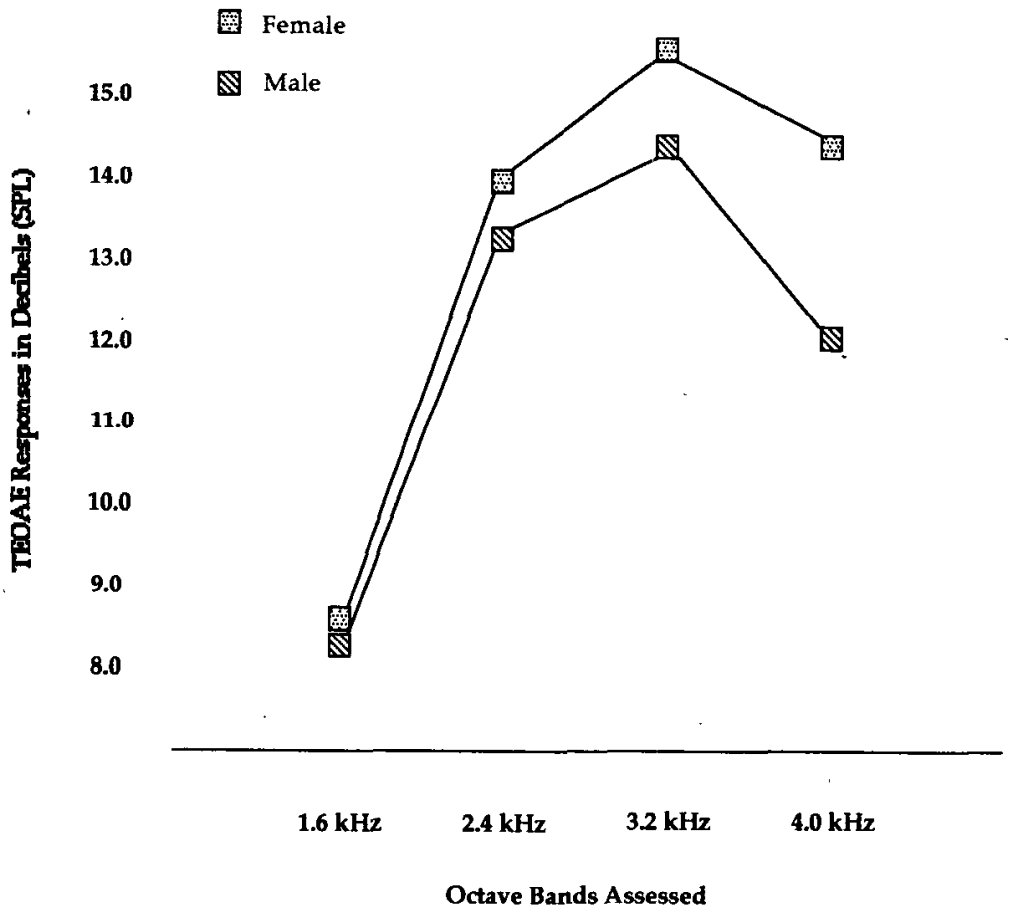

FIGURE 1.
Interaction between genders across frequencies

premature infants (Morlet et al., 1995) or 2-month old infants (Kei et al., 1997). The advantage of female over male newborns in response to high frequencies is clearly evident. The higher the frequency, the greater the advantage. Data in this study from the TEOAE can be interpreted as an indication that the outer hair cells of female newborns respond more sensitively than those in male newborns. Questions arise as to why this occurs and the implications for music therapy.

Prior research indicated that in adults, there is a difference in cochlea length, with males having longer cochlea than females (Hall, 2000). It has been suggested that the shorter cochlea may result in faster response time and better synchronization of the neural pathways (Don et al., 1993). There are clear data to support a mechanical/physiological difference in hearing between genders

which may begin to explain the differences found between male and female infants in response to music. The fact that female infants have enjoyed greater benefits from music therapy than male infants, paired with a difference in hearing sensitivity, brings up the possibility of a relationship between them.

It is evident that in the pursuit of standardized music therapy protocol for the presentation of stimuli to premature and term infants, gender must be considered. While the clinical importance of the significant differences between male and female infants on the TEOAE may be unclear (mean differences were subtle), based on the data presented in this paper consideration should be given to protocols that differ between genders. Future research should explore the possibility that increasing the decibel level of aural stimuli or boosting higher frequencies for male infants may result in responses for males that are more like the responses from their female peers. While the frequency bands observed in this project are above the fundamental frequencies performed in most musical situations, they are present in timbral differences among instruments. When considering prior research (Kagan & Lewis, 1965), it might be that male newborns respond more desirably to different music (different timbres, pitch levels, etc.) than female newborns.

It appears that answers to some of these questions regarding physiological differences between genders are relatively easy to answer given the prevalence and sophistication of hearing screening. What is more difficult and costly to determine is brain response to and interpretation of musical stimuli. In the end, it may not matter to the music therapist *why* gender differences occur, but rather how to counteract the apparent disadvantage present in the male hearing system. Future research in controlled environments should compare infant gender differences in responses to music presented across a range of decibel levels, timbres, and styles in order to determine effective protocol for music therapy.

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