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Effect Of Gender on Auditory Brainstem Response Latencies and Thresholds to Air-And Bone-Conducted Clicks in Newborn Infants

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Abstract

Objective: An examination of gender differences in auditory brainstem response (ABR) wave V latencies and thresholds to air-and bone-conducted clicks was undertaken with newborn infants.

Design: Two hundred and two full-term newborn infants served as participants (i.e., 103 males and 99 females). Wave V latency measures for air- and bone-conducted click stimuli of 30, 45, and 60 dB nHL and 15 and 30 dB nHL, respectively and thresholds to air- and bone-conducted clicks were determined.

Results: Female newborns displayed statistically significant shorter wave V latencies than male newborns for air-conducted click stimuli ($p = .0016$). There were no significant differences in wave V latencies to bone-conducted click stimuli ($p = .11$). Females displayed lower ABR thresholds to both air- and bone-conducted stimuli but the differences did not attain statistical significance ($p = .054$ and $p = .18$ for air- and bone-conducted stimuli, respectively).

Conclusion: The findings of gender disparities in ABR latencies and thresholds to air-conducted clicks may be attributed to either anatomical differences at the periphery or more efficient neural conduction in the auditory nerve and/or brainstem. It was speculated that gender-related differences in bone density or maturation of the skull sutures could affect bone-conducted signal transmission to the cochlea thereby offsetting some inefficiency offered by air-conduction with newborn males. This in turn would minimize gender differences with bone-conducted stimuli.

Key words: auditory brainstem response, latency, threshold, gender.

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Significant effects of age and gender have been evidenced in essentially all dimension of auditory function in adults. For example, hearing sensitivity is significantly better in females than males (e.g., Cooper, 1994; Davis, 1989; Gates, Cooper, Kannel, & Miller, 1990; Jonsson, Rosenhall, Gause-Nilsson, & Steen 1998; Matthews, Lee, Mills, & Dubno, 1997; Kryter, 1983; Leske, 1981; Morrell, Gordon-Salant, Pearson, Brant, & Fozard, 1996; Moscicki, Elkins, Baum, & McNamara, 1985; Pearson, Morrell, Gordon-Salant, Brant, Metter, Klein, & Fozard, 1995; Wiley, Cruickshanks, Nondahl, Tweed, Klein, & Klein, 1998a). Speech recognition in quiet and in competition is also generally superior in females (Dubno, Lee, Matthews, & Mills, 1997; Wiley, Cruickshanks, Nondahl, Tweed, Klein, & Klein, 1998b). Tympanometry indicants also differ among males and females (Blood & Greenberg, 1977; Roup, Wiley, Safady, & Stoppenbach1998; Wiley, Cruickshanks, Nondahl, Tweed, Klein, & Klein, 1996). That is, peak static admittance is greater, acoustic equivalent volume is larger, and tympanometric width is reduced in males. Differences have also been demonstrated between the genders in otoacoustic emissions (OAEs), including both spontaneous and evoked. In general, females display a higher prevalence of spontaneous OAEs (Bilger, Matthies, Hammel, & Demorest, 1990; Lamprecht-Dinnesen et al., 1998; Martin, Probst, & Lonsbury-Martin, 1990; Probst, Coats, Martin, & Lonsbury-Martin, 1986; Strickland, Burns, & Tubis, 1985) and larger amplitudes in both transient evoked (Moulin, Collet, Veuillet, & Morgon, 1993; Robinette, 1992;) and distortion product OAEs (Cacace, McClelland, Weiner, & McFarland, 1996; Dhar, Long, & Culpepper, 1998; Lonsbury-Martin, Martin, & Whitehead, 1997; Moulin et al., 1993). With respect to electrophysiological measures, differences have been documented in early (Aoyagi, Kim, Yokoyama, Kiren, Suzuki, &Koike, 1990; Dehan & Jerger, 1990; Dempsey, Censoprano, & Mazor, 1986; Don, Ponton, Eggermont, & Masuda, 1993, 1994; Mitchell, Phillips, & Trune, 1989; Ponton, Eggermont, Coupland, & Winkelaar, 1993; Sabo, Durrant, Curtin, Boston, & Rood, 1992; Stockard, Stockard, Westmorland, & Corfits, 1979; Trune, Mitchell, & Phillips, 1988) and late evoked potentials (Deldin, Duncan, & Miller, 1994; Golgeli, Suer, Ozesmi, Dolu, Ascioglu, & Sahin, 1999; Hoffman & Polich, 1999; Hymel, Cranford, & Stuart, 1998; Onishi & Davis, 1968; Polich & Hoffman, 1999; Shucard, Shucard, Campos, &

Salamy, 1982; Shucard, Shucard, Cummins, & Campos , 1981; Shucard, Shucard, & Thomas, 1977).

Although gender differences are universally observed, the developmental stages at which these differences are evident vary across indices of auditory function. For example, male and female variances in hearing sensitivity are observed typically after the third decade of life (Jerger, Chmiel, Stach, & Spretnjak, 1993; Kryter, 1983; Pearson et al., 1995; Robinson & Sutton, 1979). Differences in middle ear function are apparent in the third decade of life (Roup et al., 1998). In contrast to gender differences in adulthood, OAE measures differ at birth including spontaneous and (Burns, Arehart, & Campbell, 1992; Bonfils, Francois, Avan, Londero, Trotoux, & Narcy, 1992; Kok, van Zanten, & Brocaar, 1993; Lamprecht-Dinnesen, et al., 1998; Morlet et al., 1996; Strickland et al., 1985) transient evoked OAEs (Kei, McPherson, Smyth, Latham, & Loscher, 1997; Morlet et al.1995, 1996; Newmark, Merlob, Bresloff, Olsha, & Attias, 1997). Concerning electrophysiological measures, it appears that at least for middle and late evoked potentials male and female differences appear in adulthood (see Hall, 1992 for a review). There appears to be less agreement among researchers with respect to the age at which gender differences are evident with the auditory brainstem response (ABR).

Several studies have documented differences in ABR latency and amplitude response measures between the genders in early adolescence (Kjær, 1979; McClelland & McCrea, 1979; Rosenhall, Björkman, Pedersen, & Kall, 1985). On the other hand, there is also evidence to suggest that differences are present in younger male and female children anywhere between the ages of 4 to 11 years of age (O'Donovan, Beagley, & Shaw, 1980; Thivierge & Côté, 1987, 1990). In contrast, others have reported differences as young as 3 to 12 months between male and female infants (Beiser, Himelfarb, Gold, & Shannon, 1985; Maurizi, Ottaviani, Paludetti, Almadori, Pierrie, & Rosignoli, 1988; Mochizuki, Go, Ohkubo, & Motomura, 1983). Findings with newborn males and females are equally as ambiguous. Several camps of researchers did not observe gender differences (Cox, Hack, & Metz, 1981; Durieux-Smith, Edwards, Picton, & MacMurray, 1985; Eldredge & Salamy, 1996; Stockard, Stockard, & Coen, 1983; Stockard et al., 1979; Smyth, Scott, & Tudehope, 1988) while others have (Beiser et al.; Chiarenza, D'Ambrosio, & Cazzullo, 1988; Fujita, Hyde, & Alberti, 1991; Maurizi et al.; Sininger, Cone-Wesson, & Abadala, 1998). In general, studies that have reported differences, absolute wave components have been shorter and wave amplitudes larger with female participants.

To date, two studies examined hearing sensitivity in newborns as estimated by ABR thresholds. Cone-Wesson and Ramirez (1996) investigated threshold differences among the genders with ABR to bone-conducted clicks and 500 and 4000 Hz tone bursts with 60 newborn infants (i.e., 33 males and 27 females). A significant effect of gender was reported ($p < 0.05$). Female participants exhibited lower thresholds for the 4000 Hz stimuli but not for the 500 Hz or click stimuli. Sininger et al. (1998), on the other hand, reported threshold measures in 72 newborn infants to air-conducted clicks and 500, 1500, 4000 and 8000 Hz tonal stimuli. In contrast to Cone-Wesson and Ramirez's data, newborn males were shown to have statistically significant ($p = 0.048$) lower thresholds than females by approximately four dB. Further, greater differences in thresholds were found in the right versus the left ear (cf. 7.45 and 1.56 for the right and left ears, respectively).

An examination of gender differences in ABR measures to both air- and bone-conducted stimuli from the same cohort of newborn infants has not been reported. Toward that end, we sought to explore the effect of gender on ABR thresholds and latencies and in newborn infants to air-and bone-conducted stimuli. Specifically, thresholds to air- and bone-conducted clicks were determined, as well as, wave V latency measures for air- and bone-conducted click stimuli of 30, 45, and 60 dB nHL and 15 and 30 dB nHL, respectively.

Method

Participants

Two hundred and two full-term newborn infants served as participants (103 males and 99 females). They were drawn from previous research projects described elsewhere (Stuart & Yang, 1994; Stuart, Yang, Botea, 1996; Stuart, Yang, & Stenstrom, 1990; Stuart, Yang, & Green, 1994; Stuart, Yang, Stenstrom, & Reindorp, 1993; Yang, Stuart, Mencher, Mencher, & Vincer, 1993; Yang, Stuart, Stenstrom, & Green, 1993; Yang, Stuart, Stenstrom, & Hollett, 1991). Participants were between 38 and 42 weeks gestational age and had birth weights greater than or equal to 2400 g. The mean gestational ages of the female (M = 39.8 weeks, SD = 1.1) and male (M = 39.5 weeks, SD = 1.2) participants were not significantly different [t (200) = -1.89, p = .061]. Also, the mean birth weights of the females (M = 3511 g, SD = 438) and males (M = 3566 g, SD = 484) were not significantly different [t (200) = 0.83, p = .41]. The APGAR scores of all participants were greater than or equal to 8 at one and five minutes. All participants were physically and neurologically normal as judged by neonatal pediatric house staff and were free from risk of hearing loss (Joint Committee on Infant Hearing, 1990).

Apparatus

All participants were tested in a quiet room at the Grace Maternity Hospital, Halifax, Nova Scotia. Background noise assessed with a precision sound level meter (Brüel & Kjær model 2209) with a free-field condenser microphone (Brüel & Kjær model 4145) was approximately 44 dBA. Each participant was tested using either a Nicolet Compact Four or Nicolet Compact Auditory evoked potential system.

ABRs were obtained with click stimuli generated by 100 μs rectangular voltage pulses applied to an insert earphone (Nicolet model TIP-300) and a bone vibrator (Radioear model B70-B). The insert earphone was coupled to an impedance tip adapter (Nicolet model 123-717900) with an infant ear tip (Nicolet model 842-507300). The click stimuli were presented at a rate of 57.7/s with alternating polarity.

Stimulus intensities were calibrated relative to the behavioral thresholds of 13 normal-hearing young adults (*M* = 23.3 years, *SD* = 1.7) who were assessed to have 10 dB HL (American National Standards Institute, 1996) or better pure-tone thresholds at octave intervals from 250 to 8000 Hz. The behavioral thresholds were determined with clicks of 100 μs rectangular voltage pulse, alternating initial phase, and presented at a rate of 10/s (Stapells, Picton, Durieux-Smith, 1982). The reference level (0 dB nHL) for the air-conducted click was 37 dB peak sound pressure as measured in a 2 cm^3 acoustic coupler (Brüel & Kjær model DB-1038) employing a precision sound level meter (Brüel & Kjær model 2209) with a pressure condenser microphone (Brüel & Kjær model 4144). The reference level (0 dB nHL) for the bone-conducted click was 55 dB peak re: 1 μN as measured by the same sound level meter with an artificial mastoid (Brüel & Kjær model 4930). Signal and spectral analyses for both air- and bone-conducted clicks can be found elsewhere (Stuart et al., 1990; Yang & Stuart, 1990).

Procedures

All participants were tested in natural sleep typically following feeding prior to hospital discharge. One hundred and eighty-two participants were tested between 49 and 96 hours postpartum. Twenty participants were tested less than 48 hours postpartum. ABRs to monaural air- and bone-conducted clicks were acquired with stimulation to the left ear of all participants. The presentation of air- and bone-conducted stimuli was counterbalanced between participants. For ABRs to air-conducted clicks, the impedance tip adapter with infant ear tip was placed at the entrance at the infants' external auditory meatus. The bone vibrator was placed in a supero-posterior auricular position for bone-conducted stimulus delivery (Stuart & Yang, 1994; Stuart et al., 1990, 1993; Yang & Stuart, 1990; Yang et al., 1987, 1991, 1993a, 1993b). An elastic band (2.5 x 40 cm) with Velcro (attached on the opposite sides of the two ends) was used to hold the bone vibrator in place. Vibrator-to-head coupling force was adjusted to 425 ± 25 g (absolute boundaries). The coupling force was measured with a hand-held spring scale (Ohaus model 8014) attached to a fine nylon line that was coupled to the bone vibrator. Coupling force was measured at the point the vibrator cleared and became flush with scalp as the vibrator was manually pulled from the head. The spring scale was removed during the recording of the ABR.

Gold-plated cup electrodes consisting of one (noninverting) attached to the high forehead (Fz); one (inverting) attached to the left inferior postauricular area (M_1); and one (common) attached to the right inferior postauricular area (M_2) were employed. Interelectrode impedances were maintained below 5000 Ω. The recorded electroencephalogram was amplified 10^5 and analogue bandpass filtered (30 to 3000 Hz, Butterworth filter with a roll-off slope of 12 dB/octave). Electroencephalogram samples exceeding ± 25 μV were rejected automatically. An analysis time of 15 ms post-stimulus was sampled at 33, 000 Hz.

For determination of ABR thresholds to the air- and bone-conducted clicks, data acquisition began with a starting intensity of 30 dB nHL. Stimulus intensity was decreased in 10 dB steps until an identifiable and replicable wave V peak was no longer attainable. Stimulus intensity was then increased by 5 dB until a replicable wave V was identifiable. Multiple trials were typically obtained at intensities just above and below threshold.

A total of 2048 samples were averaged and replicated for all trials. Replication was defined as two or more wave forms with identifiable wave V peaks within 0.15 ms from one trial to the next. If the wave V component was trough-like, round or bimodal, the last point before rapid negative reflection was identified as the peak (Durieux-Smith et al., 1985). All recordings were stored on floppy diskettes. Responses were analyzed off-line for ABR wave V latencies and thresholds. The presence of the ABR response for threshold required the agreement of two audiologists experienced in ABR testing. Both observers, who were blind to test condition, inspected the waveforms jointly. The lowest stimulus intensity level for air- and bone-conducted stimulus at which a wave V was identifiable and replicable was considered to be the ABR threshold.

Results

Due to the nature of the research procedures that were employed in the set of studies that the participants were drawn from, not all participants underwent testing at all stimulus intensity conditions, with both transducers, or with the threshold search procedures. Consequently, complete data is not available for the whole sample of participants. The number of data observations contributing to mean ABR wave V latencies and mean ABR thresholds to air- and bone-conducted click stimuli as a function of gender are presented in Tables 1 and 2, respectively.

From the available data, ABR wave V latency means and standard deviations to air conducted and bone-conducted click stimuli as a function of stimulus intensity level (dB nHL) and gender were determined and are presented in Figure 1. Means and standard deviations of ABR thresholds to air conducted and bone-conducted click stimuli as a function of gender and postpartum age were also determined and are shown in Figure 2.

To investigate mean ABR wave V latency differences as a function of gender and stimulus intensity level for both air- and bone-conducted click stimuli, separate mixed two-factor analyses of variance (ANOVA) were undertaken. The analyses were performed using the SAS System PROC MIXED (SAS Institute, Version 6.12). This procedure is appropriate for data sets with missing data so long as the missing data are random

(Littell, Milliken, Stroup, & Wolfinger, 1996).[1] Significant main effects of gender [$F\,(1, 200) = 10.27$, $p = .0016$] and intensity [$F\,(2, 141) = 819.10$, $p < .0001$] were found for ABR wave V latency air conducted stimuli. In other words, female participants had significantly shorter ABR wave V latencies to air conducted stimuli versus male participants and as intensity increased wave V latencies decreased. The gender by intensity interaction was not significant [$F\,(2, 141) = 0.32$, $p = .73$]. Since the effect of stimulus intensity on ABR wave V latency has been well established, no additional post-hoc analysis of the main effect of intensity was undertaken.

In contrast, the main effect of gender was not significant [$F\,(1, 182) = 2.53$, $p = .11$] for ABR wave V latencies to bone-conducted stimuli. Similarly, as with the air-conducted stimuli, a significant main effect of intensity [$F\,(1, 100) = 705.65$, $p < .0001$] and a nonsignificant gender by intensity interaction was observed [$F\,(1, 100) = 0.94$, $p = .73$] for ABR wave V latencies to bone-conducted stimuli. Again, as the effect of stimulus intensity on ABR wave V latency has been well established, no additional post-hoc analysis of the main effect of intensity was undertaken.

Between-gender threshold differences for air- and bone-conducted click stimuli were investigated with separate two-factor (i.e., gender and postpartum age) ANOVA performed with SPSS statistical software (SPSS

Inc., Version 8.0). No significant differences were observed for the main effect of gender [F (1, 56) = 3.89, p = .54, η^2 = .065, ϕ = .49] and the age by gender interaction [F (1, 56) = 3.00, p = .089, η^2 = .051, ϕ = .40] while a significant main effect of age was found [F (1, 56) = 47.4, $p < 0.0001$, η^2 = .46] with thresholds for air-conducted click stimuli. The significant age effect with thresholds to air-conducted click stimuli has been previously reported (Stuart et al., 1994). With respect to thresholds to bone-conducted clicks, main effects of gender [F (1, 56) = 1.87, p = .18, η^2 = .032, ϕ = .27], age [F (1, 56) = 0.17, p = .68, η^2 = .003, ϕ = .052] and the gender by age interaction [F (1, 56) = 0.028, p = .87, η^2 = .001, ϕ = .040] were found to be not significant.

Discussion

The present study revealed statistically significant differences in wave V latency between male and female newborn infants for air-conducted click stimuli. That is, female newborns had shorter wave V latencies than male counterparts. Such discrepancy was not observed with wave V latencies to bone-conducted click stimuli between male and female newborns. The findings of shorter wave V latencies to air-conducted click stimuli with newborn females is consistent with previous reports (e.g., Beiser et al., 1985; Chiarenza et al., 1988; Eldredge & Salamy, 1996; Fujita et al., 1991; Maurizi et al., 1988; Sininger et al., 1998). Concordant with the findings of Cone-Wesson and Ramirez (1997) there was no difference between male and female wave V latencies to bone-conducted click stimuli. With respect to ABR thresholds, newborn female infants displayed lower thresholds than their male counterparts to air- and bone-conducted click stimuli. The differences, however, did not attain statistical significance. Contrary to the trend observed with this data, Sininger et al. previously reported that males had statistically significantly lower ABR thresholds to air-conducted tonal and click stimuli. Cone-Wesson and Ramirez observed lower thresholds to bone-conducted stimuli with females versus male newborn infants but only with 4000 Hz tonal stimuli was the difference statistically significant; threshold differences to click stimuli and 500 Hz tonal stimuli were not statistically significanat.[2]

The findings of gender disparities in ABR latencies to air-conducted clicks may be attributed to either anatomical differences at the periphery or more efficient neural conduction in the auditory nerve or brainstem. With respect to the periphery, it has recently been suggested that shorter ABR latencies observed in adult females results from faster cochlear response time leading to better synchronization of the cochlear output (Don, Ponton, Eggermont, & Masuda, 1993, 1994). The faster response is a consequence of a greater basilar stiffness gradient in the female cochlea, concomitant with a cochlea of shorter length versus the male cochlea (Don et al., 1993, 1994; Sato, Sando, & Takahashi, 1991). The parallel findings in newborn and adult females leads one to speculate that differences in cochlear length between males and females may be evident at birth and thus contribute to ABR latency differences at this time. It may also be the case that disparities in middle ear transfer functions (i.e., more efficient transmission in the female middle ear) contribute to higher stimulus levels delivered to the cochlea and consequently evoke shorter wave V latencies. This is purely speculative and studies to date have not explored differences in middle ear function between male and female newborns (e.g., Holte, Margolis, & Cavanaugh, 1991; Keefe, Bulen, Arehart, & Burns, 1993; Keefe, Bulen, Campbell, & Burns, 1994; Keith, 1973, 1975). Further, one could suggest that ear canal volume in females may be smaller and in turn lead to a greater in-situ stimulus level compared to male newborns. Studies to date have not investigated such possible differences between male and female newborns (e.g., Kruger, 1987; Kruger & Ruben, 1987; Sininger, Abdala, & Cone-Wesson, 1997;

Westwood & Bamford, 1992). In light of retrocochlear gender differences contributing to faster ABR wave V latencies among female newborns, greater afferent innervation density has been offered (e.g., Cone-Wesson & Ramirez, 1997; Sininger et al., 1998). There are, however, no published reports to support this speculation.

Gender effects with ABR latency differences in suprathreshold measures are not "paradoxical" with respect to threshold findings to air-conducted clicks reported herein (cf. Sininger et al., 1998). As earlier latencies are typically associated with response to higher stimulus levels one would predict lower thresholds (or at least not greater thresholds) from shorter latencies of suprathreshold ABRs. Sininger et al. found significantly shorter ABR latencies to air-conducted stimuli for females but found significantly lower ABR thresholds in male newborn infants. Although the findings of this study did not reveal significantly lower ABR thresholds in the female participants, the trend approached significance and there was a medium effect size (Cohen, 1988). One possible contributor to differences to ABR thresholds is differences in cochlear active mechanics. Gender differences in cochlear mechanics, as reflected in higher prevalence of spontaneous OAEs (Burns et al., 1992; Bonfils et al., 1992; Kok, et al., 1993; Lamprecht-Dinnesen, et al., 1998; Morlet et al., 1996; Strickland et al., 1985) and transient evoked OAEs of greater amplitudes (Morlet et al., 1996; Newmark et al., 1997), have been suggested as a precursor for better hearing sensitivity in females. The hypothesis of a more suppressive efferent system has also been offered (McFadden, 1993, 1998; McFadden & Pasanen, 1998, 1999; McFadden, Pasanen, & Callaway, 1998). It has been reasoned that prenatal exposure to high levels of androgens among males leads to weaker cochlear amplifiers.

Interestingly, the gender differences evidenced with air-conducted stimuli were not observed in ARB latencies and thresholds with bone-conducted click stimuli. Females did display shorter latencies and lower thresholds, a trend consistent with the air-conducted stimuli, but differences were not statistically significant. A parsimonious explanation would be that gender differences exist in cranial anatomy. As Cone-Wesson and Ramirez (1997) point out gender-related differences in bone density or maturation of the skull sutures could affect bone-conducted signal transmission to the cochlea. It may be the case that the male cranium affords greater signal transmission efficiency to the cochlea. This may offset some inefficiency offered by air-conduction and minimize gender differences with bone-conducted stimuli. This may only be true for middle and low frequency bone-conducted stimuli as Cone-Wesson and Ramirez did find female newborns had significantly lower thresholds to 4000 Hz tonal stimuli. There were no obvious anatomical differences between the participants that could lead to differences in bone-conducted signal delivery in this study (e.g., birth weight and gestation age did not differ between our male and female participants; head circumference was not attained). Although head size is typically smaller in newborn females compared to males (Buda, Reed, & Rabe, 1975; Farkas, Posnick, & Hreczko, 1992; Keen & Pearse, 1988; Meredith, 1971; Moore, Ward, Jones, & Bamford, 1988; Raymond & Holmes, 1994; Waitzman, Posnick, Armstrong, & Pron, 1992), to date, there has been no demonstration of differences in bone density or sutures that would point to signal delivery differences between male and female craniums. (Furuya, Edwards, Alpers, Tess, Ousterhout, & Norman, 1984; Kjær, 1990; Ohtsuki, 1977; Simonson & Kao, 1992).

In summary, the findings of gender disparities in ABR latencies and thresholds to air-conducted clicks may be attributed to either anatomical differences at the periphery or more efficient neural conduction in the auditory nerve or brainstem. It was speculated that gender-related differences in bone density or maturation of the skull sutures could affect bone-conducted signal transmission to the cochlea thereby offsetting some inefficiency offered by air-conduction with newborn males. This in turn would minimize gender differences with bone-conducted stimuli. Further research is warranted to address this speculation.

References

American National Standards Institute (1996). *Specification for audiometers*. (ANSI S3.6-1996). New York: ANSI.

Aoyagi, M., Kim, Y., Yokoyama, J., Kiren, T., Suzuki, Y., & Koike, Y. (1990). Head size as a basis of gender differences in the latency of the brainstem auditory-evoked response. *Audiology, 29,* 107-112.

Beiser, M., Hiemlfarb, M.Z., Gold, S., & Shanon, E. (1985). Maturation of auditory brainstem potentials in neonates and infants. *International Journal of Pediatric Otorhinolaryngology, 9,* 69-76.

Bilger, R.C., Matthies, M. L., Hammel, D. R., & Demorest, M. E. (1990). Genetic implications of gender differences in the prevalence of spontaneous otoacoustic emissions. *Journal of Speech and Hearing Research, 33,* 418-432.

Blood, I., & Greenberg, H.J. (1977). Acoustic admittance of the ear in the geriatric person. *Journal of the American Auditory Society, 2,* 185-187.

Bonfils, P., Francois, M., Avan, P., Londero, A., Trotoux, J., & Narcy, P. (1992). Spontaneous and evoked otoacoustic emissions in preterm neonates. *Laryngoscopes, 102,* 182-186.

Buda, F.B., Reed, J.C., & Rabe, E.F. (1975). Skull volume in infants. Methodology, normal values, and application. *American Journal of Diseases of Children, 129,* 1171-1174.

Burns, E.M., Arehart, K.H., & Campbell, S.L. (1992). Prevalence of spontaneous otoacoustic emissions in neonates. *Journal of the Acoustical Society of America, 91,* 1571-1575.

Cacace, A.T., McClelland, W.A., Weiner, J., & McFarland, D.J. (1996). Individual differences and the reliability of 2F1-F2 distortion-product otoacoustic emissions: effects of time-of-day, stimulus variables, and gender. *Journal of Speech & Hearing Research, 39*, 1138-48.

Chiarenza, G., D'Ambrosio, G., & Cazzullo, A. (1988). Sex and ear differences of brain-stem acoustic evoked potentials in a sample of normal full-term newborns. Normative study. *Electroencephalography and Clinical Neurophysiology, 71,* 357-366.

Cohen, J. (1988). *Statistical power analysis.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Cone-Wesson, B., & Ramirez, G. (1997). Hearing sensitivity in newborns estimated from ABRs to bone-conducted sounds. *Journal of the American Academy of Audiology, 8,* 299-307.

Cooper, J.C. (1994). Health and Nutrition Examination Survey of 1971-75: Part I. Ear and race effects in hearing. *Journal of the American Academy of Audiology, 5,* 30-6.

Cox, S., Hack, M., & Metz, D. (1981). Brainstem-evoked response audiometry: Normative data from the preterm infant. *Audiology, 20,* 53-64.

Davis, A.C. (1989). The prevalence of hearing impairment and reported hearing disability among adults in Great Britain. *International Journal of Epidemiology, 18,* 901-907.

Dehan, C., & Jerger, J. (1990). Analysis of gender differences in the auditory brainstem response. *Laryngoscope, 100,* 18-24.

Deldin, P.J., Duncan, C.C., & Miller, G.A. (1994). Season, gender, and P300. *Biological Psychology, 39,* 15-28.

Dempsey, J., Censoprano, E., & Mazor, M. (1986). Relationship between head size and latency of the auditory brainstem response. *Audiology, 25,* 258-262.

Dhar, S., Long, G.R., & Culpepper, N.B. (1998). The dependence of the distortion product 2f1-f2 on primary levels in non-impaired human ears. *Journal of Speech, Language, & Hearing Research, 41,* 1307-18.

Don, M., Ponton, C., Eggermont, J., & Masuda, A. (1993). Gender differences in cochlear response time: An explanation for gender amplitude differences in the unmasked auditory brain-stem response. *Journal of the Acoustical Society of America, 94,* 2135-2148.

Don, M., Ponton, C., Eggermont, J., & Masuda, A. (1994). Auditory brainstem response (ABR) peak amplitude variability reflects individual differences in cochlear response times. *Journal of the Acoustical Society of America, 96,* 3476-3491.

Dubno, J.R., Lee, F.S., Matthews, L.J., & Mills, J.H. (1997). Age-related and gender-related changes in monaural speech recognition. *Journal of Speech, Language, & Hearing Research, 40,* 444-52.

Durieux-Smith, A., Edwards, C., Picton, T.W., & MacMurray, B. (1985). Auditory brainstem responses to clicks in neonates. *Journal of Otolaryngology*, *4* (Suppl. 14), 12-18.

Eldredge, L., & Salamy, A. (1996). Functional auditory development in preterm and full term infants. *Early Human Development, 45,* 215-228.

Farkas, L.G., Posnick, J.C., & Hreczko, T.M. (1992). Anthropometric growth study of the head. *Cleft Palate-Craniofacial Journal, 29*, 303-8.

Fujita, A., Hyde, M., & Alberti, P. (1991). ABR latency in infants: Properties and applications of various measures. *Acta Oto-Laryngologica, 111,* 53-60.

Furuya, Y., Edwards, M.S.B., Alpers, C.E., Tess, B.M., Ousterhout, D.K., & Norman, D. (1984). Computerized tomography of cranial sutures . Part 1: Comparison of suture anatomy in children and adults. *Journal of Neurosurgy, 61,* 53-58.

Gates, G.A., Cooper, J.C., Kannel, W.B., & Miller, N.J. (1990). Hearing in the elderly: The Framingham cohort, 1983-1985. *Ear and Hearing, 11,* 247-256.

Golgeli, A., Suer, C., Ozesmi, C., Dolu, N., Ascioglu , M., & Sahin O. (1999). The effect of sex differences on event-related potentials in young adults. *International Journal of Neuroscience, 99,* 69-77.

Hall, J.W., III. (1992). *Handbook of auditory evoked potentials*. Needham Heights, MA: Allyan and Bacon.

Hoffman, L.D., & Polich, J. (1999). P300, handedness, and corpus callosal size: gender, modality, and task. *International Journal of Psychophysiology, 31,* 163-74.

Holte, L., Margolis, R.H., & Cavanaugh Jr., R.M. (1991). Developmental changes in multifrequency tympanograms. *Audiology, 30, 1*-24.

Hymel, M.R., Cranford, J. L., & Stuart, A. (1998). Effects of contralateral speech competition on auditory event-related potentials recorded from elderly listeners: A brain map study. *Journal of the American Academy of Audiology, 9,* 385-397.

Jerger, J., Chmiel, R., Stach, B., & Spretnjak, M. (1993). Gender affects audiometric shape in presbycusis. *Journal of the American Academy of Audiology, 4,* 42-49.

Joint Committee on Infant Hearing (1990). 1990 position statement. *Asha*, *33* (Suppl. 5), 3-6.

Jonsson, R., Rosenhall, U., Gause-Nilsson, I., & Steen B. (1998). Auditory function in 70- and 75-year-olds of four age cohorts. A cross-sectional and time-lag study of presbyacusis. *Scandinavian Audiology, 27,* 81-93.

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,* 2617-38.

Keefe, D.H., Bulen, J.C., Campbell, S.L., & Burns, E.M. (1994). Pressure transfer function and absorption cross section from the diffuse field to the human infant ear canal. *Journal of the Acoustical Society of America, 95,* 355-71.

Keen, D.V., & Pearse, R.G. (1988). Weight, length, and head circumference curves for boys and girls of between 20 and 42 weeks' gestation. *Archives of Disease in Childhood, 63*, 1170-2.

Kei, J., McPherson, B., Smyth, V., Latham, S., & Loscher, J. (1997). Transient evoked otoacoustic emissions in infants: effects of gender, ear asymmetry and activity status. *Audiology, 36,* 61-71.

Keith, R.W. (1973). Impedence audiometry with neonates. *Archives of Otolaryngology, 97,* 465-467.

Keith, R.W. (1975). Middle ear function in neonates. *Archives of Otolaryngology, 101,* 376-379.

Kjær, M. (1979). Differences in latencies and amplitudes of brainstem evoked potentials in subgroups of a normal material. *Acta Neurologica Scandinavica, 59,* 72-79.

Kjær, I. (1990). Ossification of the human fetal basicranium. *Journal of Craniofacial Genetics and Developmental Biology, 10,* 29-38.

Kok, M.R., van Zanten, G.A., & Brocaar, M.P. (1993). Aspects in spontaneous otoacoustic emissions in healthy newborns. *Hearing Research, 69,* 115-123.

Kruger, B. (1987). An update on the external ear resonance in infants and young children. *Ear and Hearing, 8*, 333-336.

Kruger, B., & Ruben, R.J. (1987). The acoustic properties of the infant ear. A preliminary report. *Acta Oto-Laryngologica, 103,* 578-85.

Lamprecht-Dinnesen, A., Pohl, M., Harmann, S., Heinecke, A., Ahrens, S., Muller, E., & Riebandt, M. (1998). Effects of age, gender and ear side on SOAE parameters in infancy an childhood. *Audiological Neurootolaryngology, 3,* 386-401.

Leske, M.C. (1981). Prevalence estimates of communicative disorders in the U.S.: Language, hearing and vestibular disorders. *Asha, 23,* 229-237.

Littell, R.C., Milliken, G.A., Stroup, W.W., & Wolfinger, R.D. (1996). *SAS System for mixed models.* Cary, NC: SAS Institute Inc.

Lonsbury-Martin, B. L., Martin, G. K., & Whitehead, M. L. (1997). Distortion product otoacoustic emissions. In M. S. Robinette & T. J. Glattke (Eds.), *Otoacoustic emissions: clinical applications* (pp. 98-100). New York: Thieme.

Matthews, L.J., Lee, F.S., Mills, J.H., & Dubno, J.R. (1997). Extended high-frequency thresholds in older adults. *Journal of Speech, Language, & Hearing Research, 40,* 208-214.

Martin, G., Probst, R., & Lonsbury-Martin, B. L. (1990). Otoacoustic emissions in human ears: Normative findings. *Ear and Hearing, 11*, 106-120.

Maurizi, M., Ottaviani, F., Paludetti, G., Almadori, G., Pierri, F., & Rosignoli, M. (1988). Effects of sex on auditory brainstem response in infancy and early childhood. *Scandinavian Audiology, 17,* 143-146.

McClelland, R., & McCrea, R. (1979). Intersubject variability of the auditory-evoked brain stem potentials*. Audiology, 18,* 462-471.

McFadden, D. (1993). A speculation about the parallel ear asymmetries and sex differences in hearing sensitivity and otoacoustic emissions. *Hearing Research, 68,* 143-151.

McFadden, D. (1998). Sex differences in the auditory system. *Developmental Neuropsychology, 14,* 261-298.

McFadden, D., & Pasanen, E.G. (1999). Spontaneous otoacoustic emissions in heterosexuals, homosexuals, and bisexuals. *Journal of the Acoustical Society of America,105,* 2403-2413.

McFadden, D., & Pasanen, E.G. (1998). Comparison of the auditory systems of heterosexuals and homosexuals: click-evoked otoacoustic emissions. *Proceedings of the National Academy of Sciences of the United States of America, 95,* 2709-13.

McFadden, D., Pasanen, E.G., & Callaway, N.L. (1998). Changes in otoacoustic emissions in a transsexual male during treatment with estrogen. *Journal of the Acoustical Society of America, 104,* 1555-1558.

Meredith, H.V. (1971). Human head circumference from birth to early adulthood: racial, regional, and sex comparisons. *Growth, 35*, 233-251.

Mitchell, C., Phillips, D., & Trune, D. (1989). Variables affecting the auditory brainstem response: Audiogram, age, gender and head size. *Hearing Research, 40,* 75-86.

Mochizuki, Y., Go, T., Ohkubo, H., & Motomura, T. (1983). Development of human brainstem potentials and gender differences from infants to young adults. *Progress in Neurobiology, 20*, 273-285.

Moore, W.M., Ward, B.S., Jones, V.P., & Bamford, F.N. (1988). Sex difference in fetal head growth. *British Journal of Obstetrics and Gynaecology, 95,* 238-42.

Morlet, T., Perrin, E., Durrant, J.D., Lapillonne, A., Ferber, C., Duclaux, R., Putet, G., & Collet, L. (1996). Development of cochlear active mechanisms in humans differs between gender. *Neuroscience Letters, 220,* 49-52.

Morlet, T., Lapillonne, A., Ferber, C., Duclaux, R., Sann, L., Putet, G., Salle, B., & Collet L (1995). Spontaneous otoacoustic emissions in preterm neonates: prevalence and gender effects. *Hearing Research, 90,* 44-54.

Morrell, C.H., Gordon-Salant, S., Pearson, J.D., Brant, L.J., & Fozard, J.L. (1996). Age- and gender-specific reference ranges for hearing level and longitudinal changes in hearing level. *Journal of the Acoustical Society of America, 100,* 1949-67.

Moscicki, E.K., Elkins, E.F., Baum, H.M., & McNamara, P.M. (1985). Hearing loss in the elderly: An epidemiologic study of the Framingham heart study cohort. *Ear and Hearing, 6,* 184-190.

Moulin, A., Collet, L., Veuillet, E., & Morgon, A. (1993). Interrelations between transiently evoked otoacoustic emissions, spontaneous otoacoustic emissions and acoustic distortion products in normally hearing subjects. *Hearing Research, 65,* 216-233.

Newmark, M., Merlob, P., Bresloff, I., Olsha, M., & Attias, J. (1997). Click evoked otoacoustic emissions: Inter-aural and gender differences in newborns. *Journal of Basic and Clinical Physiology and Pharmacology, 8,* 133-139.

O'Donovan, C.A., Beagley, H.A., & Shaw, M. (1980). Latency of brainstem response in children. *British Journal of Audiology, 14,* 23-29.

Ohtsuki, F. (1977). Developmental changes of the cranial bone thickness in the human fetal period. *American Journal of Physical Anthropology, 46,* 141-153.

Onishi, S., & Davis, H. (1968). Effects of duration and rise time of tone bursts on evoked V potentials. *Journal of the Acoustical Society of America, 44,* 582-591.

Pearson, J.D., Morrell, C.H., Gordon-Salant, S., Brant, L.J., Metter, E.J., Klein, L.L., & Fozard, J.L. (1995). Gender differences in a longitudinal study of age-associated hearing loss. *Journal of the Acoustical Society of America, 97,* 1196-1205.

Polich, J., & Hoffman, L.D. (1998). P300 and handedness: on the possible contribution of corpus callosal size to ERPs. *Psychophysiology, 35,* 497-507.

Ponton, C., Eggermont, Coupland, S., & Winkelaar, R. (1993). The relationship between head size and auditory brain-stem response interpeak latency maturation. *Journal of the Acoustical Society of America, 94,* 2149-2158.

Probst, R., Coats, A. D., Martin, G. K., & Lonsbury-Martin, B. L. (1986). Spontaneous, click- and toneburst-evoked otoacoustic emissions form normal ears. *Hearing Research, 21*, 261-274.

Raymond, G.V., & Holmes, L.B. (1994). Head circumferences standards in neonates. *Journal of Child Neurology, 9*, 63-6.

Robinette, M. (1992). Clinical observations with transient evoked otoacoustic emissions with adults. *Seminars in Hearing, 13,* 23-36.

Robinson, D.W., & Sutton, G.J. (1979). Age effect in hearing – A comparative analysis of published data. *Audiology, 18,* 320-334.

Rosenhall, U., Björkman, G., Pedersen, K., & Kall, A. (1985). Brain-stem auditory evoked potentials in different age groups. *Electroencephalography and Clinical Neurophysiology, 62,* 426-430.

Roup, C.M, Wiley, T.L., Safady, S.H., & Stoppenbach, D.T (1998). Tympanometric screening norms for adults. *American Journal of Audiology, 7,* 55-60.

Sabo, D., Durrant, J., Curtin, H., Boston, J., & Rood, S. (1992). Correlations of neuroanatomical measures to auditory brain stem response latencies. *Ear and Hearing, 13 ,* 213-222.

Sato, H., Sando, I., & Takahashi, H. (1991). Sexual dimorphism and development of the human cochlea. Computer 3-D measurement. *Acta Oto-Laryngologica, 111,* 1037-1040.

Shucard, D.W., Shucard, J.L., Campos, J.J., & Salamy, J.G. (1982). Some issues pertaining to auditory evoked potentials and sex-related differences in brain development. *Brain and Language, 16*, 342-347.

Shucard, D.W., Shucard, J.L., Cummins, K.R., & Campos, J.J., (1981). Auditory evoked potentials and sex-related differences in brain development. *Brain and Language, 13,* 91-102.

Shucard, D.W., Shucard, J.L., & Thomas, D.G. (1977). Auditory evoked potentials as probes of hemispheric differences in cognitive processing. *Science, 197,* 1295-1298.

Simonson, T.M., & Kao, S.C. (1992). Normal childhood developmental patterns in skull bone marrow by MR imaging. *Pediatric Radiology, 22,* 556-559.

Sininger, Y., & Abdala, C. (1996). Hearing threshold as measured by auditory brainstem response in human neonates. *Ear and Hearing, 17,* 395-401.

Sininger, Y., Abdala, C., & Cone-Wesson, B. (1997). Auditory threshold sensitivity of the human neonate as measured by the auditory brainstem response. *Hearing Research, 104,* 27-38.

Sininger, Y., Cone-Wesson, B., & Abdala, C. (1998). Gender distinctions and lateral asymmetry in the low-level auditory brainstem response of the human neonate. *Hearing Research, 126*, 58-66.

Smyth, V., Scott, J., & Tudehope, D. (1988). Auditory brainstem evoked response inter-peak latencies in very low birthweight infants. *International Journal of Pediatric Otohinolaryngology, 16,* 69-76.

Stockard, J., Stockard, J., Westmoreland, B., & Corfits, J. (1979). Brainstem auditory-evoked responses: Normal variation as a function of stimulus and subject characteristics. *Archives of Neurology, 36,* 823-831.

Stockard, J., Stockard, J., & Coen, R. (1983). Auditory brain stem response variability in infants. *Ear and Hearing, 4, (1),* 11-23.

Stapells, D.R., Picton, T.W., & Durieux-Smith, A. (1982). Normal hearing thresholds for clicks. *The Journal of the Acoustical Society of America*, *72*, 74-79.

Strickland, A. E., Burns, E. M., & Tubis, A. (1985). Incidence of spontaneous otoacoustic emissions in children and infants. *Journal of the Acoustical Society of America, 78*, 931-935.

Stuart, A., & Yang, E.Y. (1994). Effect of high-pass filtering on the neonatal auditory brainstem response to air- and bone-conducted clicks. *Journal of Speech and Hearing Research*, *37*, 475-479.

Stuart, A., Yang, E.Y., & Botea, M. (1996). Neonatal auditory brainstem responses recorded from four electrode montages. *Journal of Communication Disorders, 29,* 125-139.

Stuart A, Yang EY, Stenstrom R. (1990). Effect of temporal area bone vibrator placement on auditory brainstem response in newborn infants. Ear Hear 11:363-369.

Stuart, A., Yang, E.Y., & Green, W.B. (1994). Neonatal auditory brainstem response thresholds to air- and bone-conducted clicks: 0 to 96 hours postpartum. *Journal of the American Academy of Audiology*, *5*, 163-172.

Stuart, A., Yang, E.Y., Stenstrom, R., & Reindorp, A.G. (1993). Auditory brainstem response thresholds to air and bone conducted clicks in neonates and adults. *The American Journal of Otology*, *14*, 176-182.

Thivierge, J., & Côté, R. (1987). Brain-stem auditory evoked response (BAER): Normative study in children and adults *Neurophysiology, 68,* 479-484.

Thivierge, J., & Côté, R. (1990). Brain-stem auditory evoked response: Normative values in children. *Electroencephalography and Clinical Neurophysiology, 77,* 309-313.

Trune, D., Mitchell, C., & Phillips, D. (1988). The relative importance of head size, gender and age on the auditory brainstem response. *Hearing Research, 32,* 165-174.

Waitzman, A.A., Posnick, J.C., Armstrong, D.C., & Pron, G.E. (1992). Craniofacial skeletal measurements based on computed tomography: Part II. Normal values and growth trends. *Cleft Palate-Craniofacial Journal, 29,* 118-128.

Westwood, G.F., & Bamford, J.M. (1992). Probe-tube microphone measurements with very young infants. *British Journal of Audiology, 26,* 143-151.

Wiley, T.L., Cruickshanks, K.J., Nondahl, D.M., Tweed, T.S., Klein, R., & Klein, B.E.K (1996). Tympanometric measures in older adults. *Journal of the American Academy of Audiology, 7,* 260-268.

Wiley, T.L., Cruickshanks, K.J., Nondahl, D.M., Tweed, T.S., Klein, R., & Klein, B.E.K. (1998a) Aging and high-frequency hearing sensitivity. *Journal of Speech, Language, & Hearing Research, 41*, 1061-7102.

Wiley, T.L., Cruickshanks, K.J., Nondahl, D.M., Tweed, T.S., Klein, R., & Klein, B.E.K. (1998b). Aging and word recognition in competing message. *Journal of the American Academy of Audiology, 9,* 191-198.

Yang, E.Y., Stuart, A., Stenstrom, R., & Green, W.B. (1993). Test-retest variability of the auditory brainstem response to bone-conducted clicks in newborn infants. *Audiology*, *32*, 89-94.

Yang EY, Stuart A, Stenstrom R, Hollett S. (1991). Effect of vibrator to head coupling force on the auditory brain stem response to bone conducted clicks in newborn infants. Ear Hear 12:55-60.

Yang, E.Y., Stuart, A., Mencher, G.T., Mencher, L.S., & Vincer, M.J. (1993). Auditory brain stem responses to air- and bone-conducted clicks in the audiological assessment of at-risk infants. *Ear and Hearing*, *14*, 175-182.

Foot Note

[1]No effect sizes are provided as the SAS System PROC MIXED does not generate them.

[2]Cone-Wesson and Ramirez (1997) did not report post-hoc analysis of their gender effect threshold data (see Figure 2, p. 302). Dr. Cone-Wesson graciously provided the data set for further analyses. Statistically significant lower thresholds were found with the female newborns with the 4000 Hz tonal stimuli [t (18) = -2.57, p = .019] but not with the 500 Hz tonal [t (18) = = -0.38, p = .71] or click [t (18) = -0.44, p = .66] stimulus.

Table 1

Number Of Data Observations Contributing To Mean ABR Wave V Latencies As A Function Of Stimulus Intensity Level (dB nHL) And Gender (n = 202).

		Gender	
		Male	Female
	Intensity		
Air- Conduction	30	103	99
	45	29	22
	60	48	46
Bone-Conduction	15	48	54
	30	93	91

Table 2

Number Of Data Observations Contributing to Mean ABR Thresholds To Air- And Bone-conducted Click Stimuli As A Function Of Gender and Postpartum Age (n = 202).

	Gender	
	Male	Female
Air- Conduction		
Less Than 48 Hours	9	11
Greater than 48 Hours	23	17
Bone Conduction		
Less Than 48 Hours	9	11
Greater than 48 Hours	23	17

Figure Captions

Figure 1. Mean ABR wave V latencies (ms) to air- and bone-conducted click stimuli as a function of stimulus intensity level (dB nHL) and gender. Error bars represent plus/minus one standard deviations of the mean.

Figure 2. Mean ABR thresholds (dB nHL) to air- and bone-conducted click stimuli as a function of gender and postpartum age. Error bars represent plus one standard deviation of the mean.