Navid Shahnaz, Ph.D.
School of Audiology & Speech Sciences
University of British Columbia

Multi-frequency Tympanometry in Infants

There is a need to develop standardized procedures (and criteria) for differentiating OME from sensorineural hearing loss in early infancy. Currently, there are no otoscopic or tympanometric criteria for identification of outer and middle-ear disorders in newborns (Gravel, Marttila, Nerbonne, Nozza, Scott, & Smedley, 1995; Fowler & Shanks, 2002). Physiological measures, such as the auditory brainstem response (ABR), and evoked otoacoustic emissions (EOAE) have the advantage of providing non-invasive, objective, and ear-specific information in newborns who are typically difficult to test behaviourally. The ABR is an electrical response that starts in the inner ear and travels through the auditory nerve to the region of the brain stem and higher auditory areas. The ABR test consists of sounds that are presented to a child's ears through earphones while the child sleeps quietly in a crib or in a parent's arms. The responses are measured through small electrodes taped on the infant's head and then analyzed by computer. EOAEs are acoustic signals generated by the normal inner ear in response to acoustic stimulation. The EOAE test consists of sounds that are presented to a child’s ear through light earphones while the child sleeps quietly in a crib or in a parent’s arms. The responses are measured in the ear canal and then analyzed by a computer.

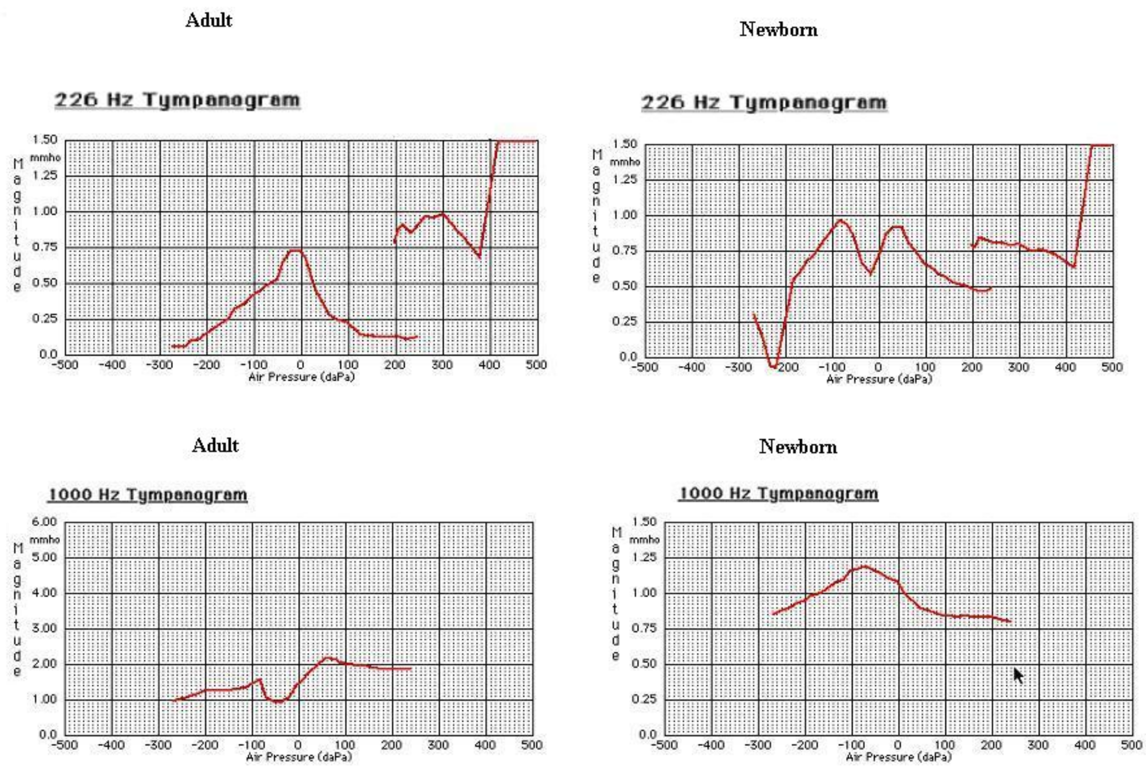
Although ABR and EOAE are widely used in newborn infants screening program, they do not provide diagnostic information in their screening mode. ABR screening does not effectively distinguish between mild sensorineural hearing loss and conductive hearing loss (Hunter & Margolis, 1992). A more complicated “diagnostic” ABR, that compares air-and bone-conduction, can be used effectively to differentiate conductive hearing loss from sensorineural hearing impairment. However, the analysis time and level of expertise that this type of instrumentation demands of the user makes it too difficult, costly, and inappropriate as a screening tool. On the other hand, EOAE cannot differentiate conductive hearing loss from sensorineural hearing loss and is overly sensitive to conductive hearing loss compared to ABR (Hirsch, Codd, & Margolis, 1992; Naeve, Margolis, Levine, & Fournier, 1992; Smurzynski Kim, Jung, Leonard, Kamath, & Rowe, 1992; Zhao, Wada, Koike, & Stephens, 2000). At this time there is considerable interest in developing efficient procedures for separating infants who fail newborn screening (using ABR and/or TEOAE) because the course of medical and audiologic intervention is quite different for conductive and sensorineural impairment. Although temporary in nature, conductive hearing loss, when present early in life, can also have serious consequences for infant health and development.

A very promising physiologic test that could address the need to differentiate conductive hearing loss from sensorineural hearing loss is immittance audiometry. Immittance audiometry is comprised of two tests: tympanometry and acoustic reflexes. In tympanometry, sound is presented while the air pressure is changed within the ear canal. The sound pressure level monitored at the probe tip provides an index of the ease with which acoustic energy flows into the middle-ear system, which is referred to as acoustic admittance (Y). The resulting display is called a tympanogram, which in a normal ear is a bell-shaped curve with a single peak. Standard low frequency tympanometry (220 or 226 Hz) was first conducted with infants under six months of age as early as 1973 (Keith, 1973). However, tympanometric patterns observed in newborn infants do not conform to the classic patterns found in older infants, children, and adults. For example, in infants younger than six months of age with surgically confirmed OME, low frequency tympanograms often appear normal or notched (Hirsch et al., 1992; Margolis et al., 2003; Marchant et al. 1986; Paradise et al., 1976). The unusual characteristics of neonate tympanograms have been attributed to the physiological differences between neonate and adult ears (Himelfarb et al., 1979; Margolis & Hunter, 2000; Sprague et al., 1985). The reasons behind these physiological differences are not quite clear. Newborns' middle ear impedance characteristics are dominated by the effect of mass/resistive elements at low probe tone frequency (Holte et al, 1991; Shahnaz, 2002). This is in contrast with middle ear impedance characteristics in young children and adults which are dominated by the effect of stiffness elements (Shahnaz & Polka, 1997). Therefore, the tympanometric characteristics of neonates are sufficiently different from adults to deserve a unique definition of normal.

The development of multi-frequency tympanometry devices has made it possible to record tympanograms across a wide range of probe-tone frequencies. This technique would also allow the assessment of the relative contribution of stiffness, mass, and resistive elements of the middle ear. To date, the advantage of multi-frequency tympanometry over standard frequency tympanometry has been confirmed in adults for detecting pathologies such as otosclerosis (Shahnaz & Polka, 1997 & 2002) and ossicular discontinuity (Funasaka & Kumakawa, 1988; Hunter & Margolis, 1992; Lilly, 1984; Valvik, Johnsen, & Laukli, 1994). Several studies indicate that the most informative tympanometric recordings in neonates are derived using higher probe tone frequencies (Hirsch et al., 1992; Hunter & Margolis, 1992; Marchant et al., 1986; Rhodes, Margolis, & Hirsch, 1999). Recently, Gliddon and Sutton (2001) reported that failure at a high-frequency probe tone of 660 Hz at the time of birth is one of the best predictors of the presence of OME at eight months of age among SCN babies. Margolis et al. (2003) reported that high-frequency probe tones of 1000 Hz may be an effective tool in identifying OME at two to four weeks of age. Moreover, it has been suggested that significant maturational effect may occur between two to four months of age and could be observed using multi-frequency tympanometry. Therefore, these techniques can be used to assess the age at which the mechanics of newborns middle-ear become more like those of young children and adults.

In a feasibility study performed by Shahnaz (2002) and Polka, Shahnaz,& Zeitoni (2002), thirty ears of sixteen 3-weeks old infants were tested across wide range of frequencies (226 -1000 Hz). All infants, except one, had documented normal hearing using automatic auditory brain-stem response (ABR) for both ears at the time of birth and at 3-weeks of age. The purpose of this pilot project was to seek a consistent pattern in admittance (Y) tympanogram and/or its rectangular components, susceptance (B- the stiffness and mass elements of the middle ear) and conductance (G-the resistive element of the middle ear), to establish a norm. While eighteen ears had multiple peak or irregular tympanometric patterns at conventional low probe tone frequency (226 Hz), 22 ears had a single peak and essentially normal shape tympanogram at 1000 Hz. The results of the newborn infants in this study were then compared to thirty ears of sixteen healthy adults. The tympanometric protocol used in the adult group was similar to the newborn infants. At conventional 226 Hz, tympanograms had a single peak in all adult (100%) ears while 40% of infant ears had single peak patterns. At 1000 Hz admittance tympanograms had a single peak for 74% of infant ears while 22% of adult ears showed single peak patterns. Figure 1 show typical tympanogram obtained at standard low frequency of 226 Hz and extended high frequency of 1000 Hz in an adult and a newborn. Figure 2 illustrates the proportion of a single-peak tympanogram in newborn infants and adults across four different frequencies. As it can be seen in these figures, in the infant ear, tympanograms become simpler in shape as probe frequency increases. This is the reverse of what is found in adult ears, where tympanograms become more complex as probe frequency increases. In other word, at conventional low frequency tympanometry, the adults' middle ear is controlled by elements of stiffness in the middle ear; however, the newborns middle ear is controlled by elements of mass. Because of the dominance of this effect at low frequency, the findings of the current study suggested the importance of higher frequencies in newborns and young infants. This is consistent with recent findings of Margolis et al. (2003). Unfortunately, only a few studies of high frequency tympanometry have been conducted with infants less than 6 months of age, and rarely is hearing loss type confirmed in this work. Moreover, the details of mechano-acoustical properties of infants' middle ear have not been fully explored. Both systematic studies and normative data are badly needed to improve the diagnostic utility of tympanometry in neonates. **See Figures**

Figure 1: Typical tympanograms obtained at standard low frequency of 226 Hz and extended high frequency of 1,000 Hz in an adult and a newborn.



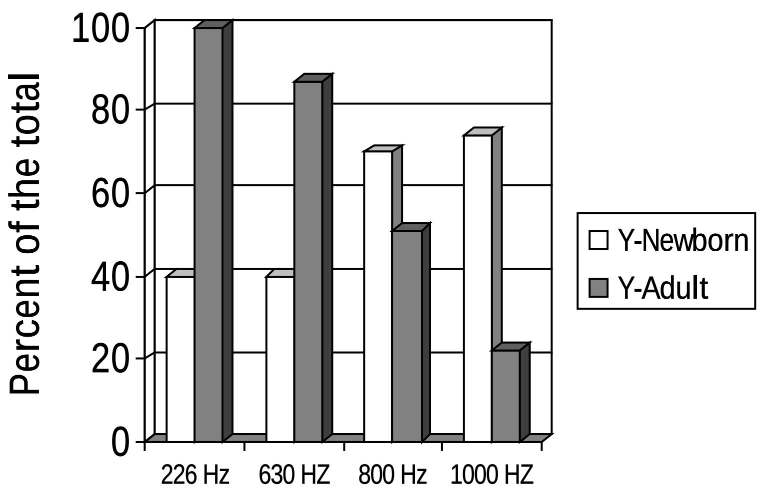


Figure 2: Proportion of single peak admittance (Y) tympanogram in newborn infants and young adults across four different probe tone frequency.