Pediatric Auditory Assessment: Using Science to Guide Clinical Practice

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Evidence Based Practice
The conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients by integrating individual clinical expertise with the best available external clinical evidence from systematic research.
Development of Auditory Brainstem

- Axons of auditory nerve grow towards the brain around 16 weeks gestation.
- As axons of the cochlear nerve arrive in the brainstem they interact with the cell bodies to form synaptic connections.
- At the same time more central nuclei in SOC, auditory midbrain and thalamus are forming and connecting.
- Spontaneous axonal growth of ascending and descending pathways are likely driven by signals related to timing and place of connections.
- Later, acoustically driven neural signals will act to consolidate synaptic connections and refine cochleotopic projections.

Development of Auditory Cortex

- When an axon is ready to function, it undergoes a transformation – increasing in size, creating a framework of neurofilaments with the axoplasm, and inducing surrounding glial cells to encircle the axon with a myelin sheath.
- Thus, the presence of neurofilaments is a good indicator of when a neuron is functional.
Development of Central Auditory System
(Moore 2002)

- Human postmortem brain tissues collected from ages 16 weeks gestation through 27 years
- From the 3rd trimester to the fourth postnatal month, mature axons are present only in the most superficial layer of the cortex
- Given that there is no route of transmission of auditory information to the cortex at this stage of development, it is likely that accurate stimulus discrimination of infants less than 5 or 6 months reflects analytical abilities of the brainstem.
Development of Hearing

• When do we first hear?
• Given timelines of development for auditory structures it is likely a fetus will respond to sound around 7 mos gestation

Prenatal Hearing

• The developing fetus has access to sounds that are exogenous (outside the womb) or endogenous (inside the womb)
• The exogenous sounds are highly attenuated
• Though newborns do show signs that they recognize their mother’s voice over other voices
• The idea that infants and children are more intelligent or well-adjusted if they are exposed to music (the Mozart effect) is not substantiated in research
Postnatal Hearing

- Prenatal hearing is not necessary for normal development
- Adopted newborns can and do have strong emotional bonds with their new parents
- Adopted newborns have no trouble learning a language that was NOT spoken by their birth mother

Outer Ear: Infant-Adult Differences

- Development of ear canal ear
- Effective length of ear canal increases from 12 mm to 30 mm
- Angle of TM changes
- Tissue composition of EAC changes
- At ~20 mos, similar to ear canal resonances to that found in adults
Middle Ear Cavity

- Birth to 6 months – length of cavity from the TM to stapes footplate increases
- May contain
  - Mesenchyme
  - Amniotic fluid

Immittance Measures - Infants

- Paradise (1976) demonstrated a poor correlation between tympanometry and otoscopy in infants under 7 mos.
  - 60% of infants with MEE had normal tympanograms - all ears confirmed with myringotomy
- Schwartz & Schwartz (1978) found 80% false-negative rate in myringotomy confirmed cases of MEE in infants <6 mos
- Conversely Keefe et al., 1996 demonstrated that infants may have what appears to be an abnormal 226 Hz tympanogram in a normal ear (false positive)
Probe Tones

- 226 is below the normal adult resonance frequency which is between 650 and 1400 Hz, so the effects of mass and friction are minor.
- The same is not true of the infant so a higher frequency probe tone is recommended.

Reflexes - Infants

- Presence of reflexes in the first few months of life. McCandless and Allred (1978)
  - Only 4% of infants <48 hours had an acoustic reflex using a 220 Hz probe tone.
  - When the probe tone was raised to 660 Hz the number jumped to 89% of infants tested.
- Subsequent studies have shown that acoustic reflexes are more likely to be found using a higher probe (i.e., 660, 100, 1400)
  - Marchant (1986) found sensitivity of 660 Hz tympanogram and 1K Hz reflex was 94%.
  - Bennet (1984) found that 1400 Hz was optimal.
Inner Ear

- Although the structure of the inner ear is adult-like at birth, electrophysiological responses show a broader response to high-frequency sounds.
- Transmission time of the neural response through the auditory brainstem is correlated with young infants’ ability to detect a high-frequency sound – high frequency sounds take longer to travel up the brainstem (Werner et al., 1994).

The Use of Objective Measures For Testing Infants
OAEs in Infants

- OAE amplitude is greatest in infants
  - OAE amplitude increases in infants over the first few days of life (Kok et al, 1992)
  - May be related to changes in external and middle-ear status; clearance of vernix
- Frequency characteristics differ in infants
  - OAE responses contain more robust high-frequency components in infants than in adults
  - Higher noise levels in the lower frequencies may obscure lower frequency OAE components

Auditory Brainstem Response (ABR)

- Stapells et al. (2000) demonstrated high correlations (> .94) between ABR thresholds to .5K, 1K, 2K, and 4K hz air conduction tones and pure tone behavioral thresholds for infants and young children with normal hearing or SNHL
- Equally accurate at predicting thresholds in infants and young children with SNHL
- Bone conduction ABR testing was also accurate
Infant ABR Differs from Adult in All Measurement Parameters

- Morphology consists of 3 instead of 5 peaks
- Absolute and interpeak latencies are longer
- Amplitude are markedly different (robust wave I – infant, robust wave V – adult)
What Accounts For the Differences?

- Wave I prominence because of close approximation to 8th N due to infant head size
- Latency differences because of myelination, cochlear maturation, resolution of middle ear abnormalities (unabsorbed mesenchyme)

Infant Thresholds With ABR

- ~17 dB higher than adults
- Greatest infant-adult difference occurs at 4 KHz for tone pips with no difference at .5 KHz (2-28 wks) – another indication that low frequency hearing is developing first!!
- Confirmed by Sininger & Abdala (1969) with calibrated stimuli – meaning they equated infant and adult SPL in the EAC
P1 – Evoked Response

Cortical Auditory Evoked Response

Latency (msec)

P1

4 µV
P1 as an Indicator of Central Auditory Development

Problems With Behavioral Studies of Auditory Development

- Babies not motivated to perform for researchers
- Not motivated by pay
- Cannot understand verbal questions or respond verbally
- Limited attention spans
- Limited response repertoires
- Inherent variability
Startle Response

- Observed between 60 and 90 dB
- Possible that startle reflex may be absent in normal auditory system
- May have central deafness despite presence of startle reflex
- Reflex highly influenced by physiologic states of hunger and fatigue

Hearing Sensitivity
Tharpe and Ashmead (2001)

- Seven infants (4 girls, 3 boys) tested each month over a 12 month period – started testing at 29 days….before that infants simply slept
- Screened or middle ear disorder (4 infants were excluded because of chronic ME disorder)
- A flashing LED was placed in front of the infant sitting on the parents lap
- A video monitor played “Fantasia” to the left and right of the infant
- Speech noise was used as the stimulus
Tharpe and Ashmead (2001)

![Graph showing threshold estimates by age for all individual test sessions. Thresholds for each subject are designated by unique symbols as shown in the key. The solid line shows the best fitting exponential function for the entire data set, as described in the text.](image1)

![Graph showing mean of threshold estimates for each age range. Error bars designate standard errors.](image2)
Hearing Sensitivity

- Researchers have shown that young infants’ thresholds for detecting sounds are higher than adults and that their ability to separate sounds of different frequencies is immature, particularly at frequencies above 3000 Hz.
- Studies of the acoustical response of the ear of young infants point to the middle ear as a source of immature thresholds in quiet.
- The ME of an infant is less efficient than that of an adult in transmitting sound to the inner ear.
- The efficiency of sound transmission through the middle ear improves considerably in the first year of life (Okabe et al 1988).

Three Stages of Auditory Development

Werner, 2007

- Stage 1 – lasts from full term birth to 6 months of age
  - The ability to encode sound
- Stage 2 – last from 6 months to about 5 years of age
  - The ability to focus on or select features of sounds
- Stage 3 - lasts from 6 years of age to adolescence
  - The ability to use different sound features under changing listening conditions matures
Auditory Development

- The changes in density of the neurofilaments within auditory cortex coincide with improved auditory skills such as perception of sound and speech in noise (Schneider et al., 1989; Elliott, 1979; Hartlet et al., 2000)

How to Measure Hearing Sensitivity in Young Children

- Auditory development and assessment techniques are critically important
  - The accurate and timely assessment of hearing loss is necessary for optimal outcomes (Yoshinago-Itano, Sedey, Coulter & Mehl, 1998)
BOA
Birth to ~ 6 months

• An active response from an infant or toddler passively involved in the task at hand (i.e., cessation of activity)
• Limits include:
  • Rapid habituation to stimuli state of the child
  • What constitutes a response (a very subjective measure)

Wilson, Moore & Thompson, 1976

![Graph showing complex noise signal in dB SPL over age in months for BOA and VRA]
Sources of High Variability

- Wide range of acceptable responses
- Examiner bias
- Infant response dependent on state of arousal
- Infant response dependent upon stimuli used
- Rapid habituation

BOA Should NOT Be Used To:

- Screen hearing
- Estimate hearing thresholds
- Define the settings of hearing aids
BOA is Useful When:

- Reliability of other measures are in question
- OAEs contaminated by otitis media
- ABR contaminated by asynchrony

VRA – 6 to 24 months

- Can be done in a sound field or under headphones
- A reliable head turn towards a sound source. The response must occur at the onset of the stimulus or shortly after
Figure 5.7. Response curves for operant conditioning audiometry. (Reprinted with permission from J. M. Moore et al.: Visual reinforcement of head-turn responses in infants under twelve months of age. *Journal of Speech and Hearing Disorders* 42:328, 1977)
Use of DVD Reinforcers (Schmida et al., 2003)

- 40 children between 12 and 24 months
- Half were tested with VRA using conventional reinforcer (moving chicken)
- Half were tested with VRA using DVD reinforcer (Adventures of Elmo in Grouchland)

Schmida et al., 2003

- On average, 4 more head turns per child using DVD reinforcers over conventional
- DVD reinforcement may allow for additional threshold estimation
- DVD allows flexibility of changing reinforcement for individual child
Lowery et al., (2009)

- 14 infants 7-16 months with normal hearing
- Measured total number of head turns, response consistency, false alarm rate, and sensitivity of each both types of reinforcer

VRA Test Parameters (Tharpe & Ashmead, 1993)

- The majority of children we test will have normal hearing
- Used computer program to run thousands of hearing evaluation simulations
- Examined three factors related to testing infants using VRA
  - Starting level
  - Step size
  - Conditioning
Suggested VRA Protocol

• Starting level of 30 dB
  • This starting level will maximize the number of possible trials based on the idea that the child will have normal hearing

• Step size of 20 down and 10 up

• No conditioning, unless indicated

Summary

• Anatomical development of the peripheral auditory system is complete by 35 weeks gestation

• Central auditory cortex is not complete until early adolescence

• Auditory assessments should reflect child’s capacity and ability to respond
Studies using behavioral and electrophysiological measures demonstrate that auditory development continues well into adolescence.

Important to remember that immature responses reflect immature hearing, not just immature behavior.

Questions?