2001

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Recommended Citation

Williams, Kelle, "Validation of an automated algorithm for auditory brainstem response testing" (2001). *Independent Studies and Capstones.* Paper 537. Program in Audiology and Communication Sciences, Washington University School of Medicine. http://digitalcommons.wustl.edu/pacs_capstones/537

VALIDATION OF AN AUTOMATED ALGORITHM FOR AUDITORY BRAINSTEM RESPONSE TESTING

by

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An independent study submitted in partial
fulfillment of the requirements for the degree of

Master of Science in Speech and Hearing

Emphasis in Audiology

Washington University
Department of Speech and Hearing

May 25, 2001

Approved by: David Mason, Ph.D., CCC-A, Independent Study Advisor

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INTRODUCTION

Identification of hearing loss in infants has changed over the years from acquiring behavioral responses to very specific objective measures of the auditory system. Early intervention has also been transformed to include Parent-Infant programs as well as cochlear implants. In 1969 the Joint Committee on Infant Hearing (JCIH) was established to develop better methods of identifying neonatal hearing impairment (Norton et al., 2000). This committee includes the American Academy of Audiology, the American Academy of Pediatrics, the American Speech-Language-Hearing Association, the Council on Education of the Deaf, and the Directors of Speech and Hearing Programs in State Health and Welfare Agencies.

The JCIH recommended in 1972 the use of a registry for neonates who were at a higher than normal risk for hearing loss (Norton et al, 2000). Any newborn who had one or more of the five risk factors would be referred for audiological testing within the first 2 months of life (Vohr et al, 2000). In 1982, the JCIH increased the number of risk factors to seven, and in 1990 it was increased to ten high risk factors. The Healthy People 2000 Initiative, led by the National Institutes of Health, stated that early identification of deafness or hearing loss is a critical factor in preventing or ameliorating language delay or disorder in children who are deaf or hard of hearing, allowing appropriate intervention or rehabilitation to begin while the developing brain is ready (U.S. Department of Health and Human Services, 1990). They set a goal to reduce the average age at which children are identified with hearing loss to no more than 12 months of age by the year 2000. The position statement of the JCIH in 1994 reported that infants with hearing loss should be identified by 3 months of age and should receive intervention by 6 months of age (Arehart, Yoshinaga-Itano, Thomson, Gabbard, & Brown, 1998).

The trend in the United States has moved from newborn hearing screening for infants at risk to a universal screening of all newborns. To date, there are 33 states which have Newborn Hearing Screening Legislation on the books. As more universal newborn hearing screening (UNHS) programs are developed in the United States, controversy remains as to which methods are most efficacious. The JCIH in the year 2000 position statement recommended that physiologic measures be used to detect newborns and very young infants with hearing loss. Auditory brainstem responses (ABRs) and otoacoustic emissions (OAEs), either distortion-product (DPOAE) or transient-evoked (TEOAE), technologies have been the measurements of choice by the JCIH.

A multicenter study sponsored by the National Institutes of Health entitled *Identification of Neonatal Hearing Impairment*, was designed to assess the accuracy of the above three measures. These measures, obtained at or near field, were then related to hearing status which was defined through hearing sensitivity, measured by way of visual reinforcement audiometry (VRA) at 8-12 months.

The ABR is recorded from surface scalp electrodes and is considered a far field representation of evoked electrical activity in the ascending auditory pathways in the brainstem (Mason, Davis, Wood, & Farnsworth, 1998). Sininger et al. (2000) found that the use of ABR with an automated detection algorithm was a reliable method in attaining the hearing status in newborns. They felt there were at least two reasons why a truly objective measure of ABR was necessary for newborn screening: First, the implementation of screening for all newborns requires that nonprofessionals be capable of conducting tests. Secondly, the functioning attributes of any test protocol for newborn hearing screening should be understood. An automated ABR algorithm replaces the subjective interpretations of a tester with an objective probability of a response. This enables the use of less experienced testers, which reduces the costs and variability of the testing (Norton et al., 2000).

Otoacoustic emissions are any sound that originates from the cochlea and can be recorded in the outer ear canal (El-Refaie, Parker, & Bamford, 1996). TEOAEs occur in response to a click or transient auditory stimulus, and are related to the integrity of the outer hair cells of the cochlea. They are said to be present in people with normal cochlear function and a healthy middle ear, and absent in ears with mild or greater degrees of hearing loss (Taylor & Brooks, 2000). The potential advantages of TEOAEs, as stated by Norton et al., are that they are 1) noninvasive, able to be measured, and do not require attaching electrodes; and 2) specific to the peripheral auditory system. The possible disadvantages are 1) internal and external noise may prevent a TEOAE recording; 2) any influences by common conditions in the external or middle ear; and 3) their insensitivity to disorders of the inner hair cells or auditory pathway.

DPOAEs occur in response to total stimuli and also are related to the integrity of the outer hair cells. DPOAEs are recorded when two tones of varying frequency are delivered to the ear. A normal cochlea responds by producing energy at additional frequencies, and these are called *distortion products*. As a measure of auditory function in neonates and infants, Gorga et al. (2000) found that DPOAEs are robust and reliable.

However, results were better when restricting measurements to frequencies at or above 1500 Hz, and testing the newborn when they are in a quiet state versus an "active/alert" or "crying" state.

One of the main objectives of the multicenter study was to compare TEOAEs, DPOAEs, and ABRs for identification of infant hearing impairment. These three tests were assessed on a total of 4911 infants. Sixty-four percent of these infants returned at 8 to 12 months of age for behavioral testing, using visual reinforcement audiometry (VRA). The authors concluded that all three of the neonatal hearing screening tests resulted in low refer rates. Based on the protocol recommended by the National Institutes of Health, refer rates were less than 2%. Norton et al. (2000) summarized their study by stating:

> If the greatest concern of UNHS programs is with referral rates, then a two-stage screening process, starting with OAEs and followed by an ABR only on those infants failing the OAE screening will produce the most favorable results. In the present project, pass rates of 96.6% to 98.0% were observed for a condition equivalent to the above two-stage paradigm. This approach was recommended by the National Institutes of Health (1993) in its Consensus Conference Report. (534)

Currently when calibrating for auditory evoked response equipment, the most common way for describing stimulus intensity level is in reference to normal hearing level for the stimulus (dB nHL). Calibration of the acoustic response is presently done by connecting the earphone to a coupler. Therefore, the purpose of my study is to develop dB nHL values from normal subjects with real ear responses of click stimuli, using an automated algorithm of an ABR screener.

METHODS

Subjects

The majority of the sample came from the graduate program at the Central Institute for the Deaf. The subjects consisted of 15 young adults, 2 males and 18 females, with an average age of 26 years. No selection criteria were used regarding gender, race, or socioeconomic status. Subjects selection was based on willingness to participate and all were required to sign a consent form prior to participating in the study. The study was approved by the Institutional Review Board at Central Institute for the Deaf.

Measurement Procedures

The investigator performed an external ear examination with a standard hand-held otoscope. Visualization of the tympanic membrane along with an unobstructed ear canal categorized all 15 subjects as within normal limits. Tympanometry was performed, and on all cases was recorded a *type A* tympanogram, illustrating normal middle-ear function. Speech audiometry was performed next, beginning with speech-recognition threshold (SRT) using a prerecorded list of spondaic words (CID Auditory Test W-1 on compact disc). Word recognition testing was then performed by using a prerecorded list of phonetically balanced words (CID W-22 on compact disc). Hearing sensitivity was then measured by air conduction and bone conduction using the bilateral Hughson-Westlake method. Results are shown in Table 1:

Subject	SRT (dB HL)	WRS	PTA A/C	PTA B/C
1				
R	0	100%	1.67	0
L	0	100%	0	0
2				
R	0	100%	1.67	1.67
L	0	100%	1.67	1.67
3				
R	0	100%	0	0
L	0	100%	0	0
4				
R	0	100%	1.67	0
L	0	100%	1.67	0
5				
R	10	100%	5	3.3
L	10	100%	3.3	3.3
6				
R	0	100%	3.3	0
L	0	100%	1.67	0
7				
R	0	100%	0	0
L	0	100%	0	0
8				
R	0	100%	0	0
L	0	100%	0	0
9				
R	0	100%	0	0
L	0	100%	0	0
10				
R	0	100%	0	0
L	0	100%	0	0
11				
R	0	100%	3.3	1.67
L	0	100%	3.3	1.67
12				
R	0	100%	1.67	1.67
L	0	100%	1.67	1.67
13				
R	0	100%	0	0
L	0	100%	0	0
14				
R	0	100%	0	0
L	0	100%	1.67	0
15				
R	0	100%	1.67	1.67
L	5	100%	1.67	1.67

Table 1. Results of audiometric testing on 15 young adults.

Using a combined DPOAE and ABR automated screener (AUDIOscreener™) hearing thresholds for clicks were collected. The probe was placed into an ear of each participant. Subjects were asked to respond verbally as to when the stimulus was just audible. Three descending runs of condensation then rarefaction stimulus polarities were presented, followed by three of each in the ascending configuration. The two measures for each condition were recorded and averaged in dB pe SPL and are shown in Table 2:

Subjects	Descending		Ascending	
	Condensation	Rarefaction	Condensation	Rarefaction
1	40.0	40.0	43.3	40.0
2	43.3	45.0	45.0	45.0
3	43.3	43.3	41.7	41.7
4	41.7	43.3	40.0	40.0
5	45.0	45.0	45.0	45.0
6	40.0	40.0	40.0	40.0
7	40.0	40.0	40.0	40.0
8	40.0	40.0	45.0	45.0
9	40.0	40.0	40.0	40.0
10	41.7	41.7	41.7	40.0
11	45.0	45.0	45.0	45.0
12	45.0	45.0	45.0	40.0
13	38.3	40.0	38.3	40.0
14	41.7	40.0	41.7	40.0
15	43.3	45.0	45.0	43.3

Table 2. Descending and ascending results of real ear measures from 15 normal hearing subjects.

Results

Figure 1 illustrates results from the descending condensation trial, which has a range from 38.3 to 45 dB peSPL with a mean of 36.887 and a standard deviation at 2.169. Figure 2 represents the descending rarefaction trial, with a range from 40 to 45 dB peSPL with a mean of 37.220 and a standard deviation at 2.326. Figure 3 shows the ascending condensation condition with a range from 38.3 to 45 dB peSPL with a mean of 37.447 and a standard deviation at 2.430. Figure 4 illustrates the ascending rarefaction condition with a range from 40 to 45 dB peSPL with a mean of 36.667 and a standard deviation at 2.270. Analysis of variance indicates no significant difference in mean threshold values among the two polarities and psychophysical methods.

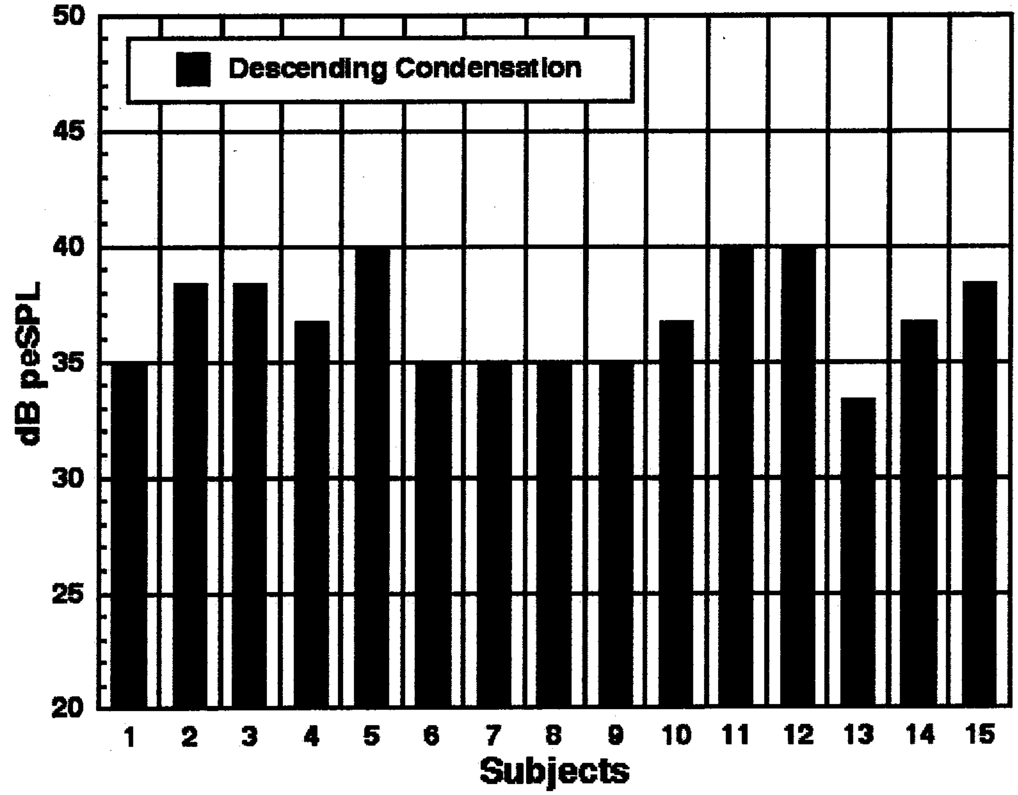


Figure 1. Descending condensation trial with 15 normal hearing subjects.

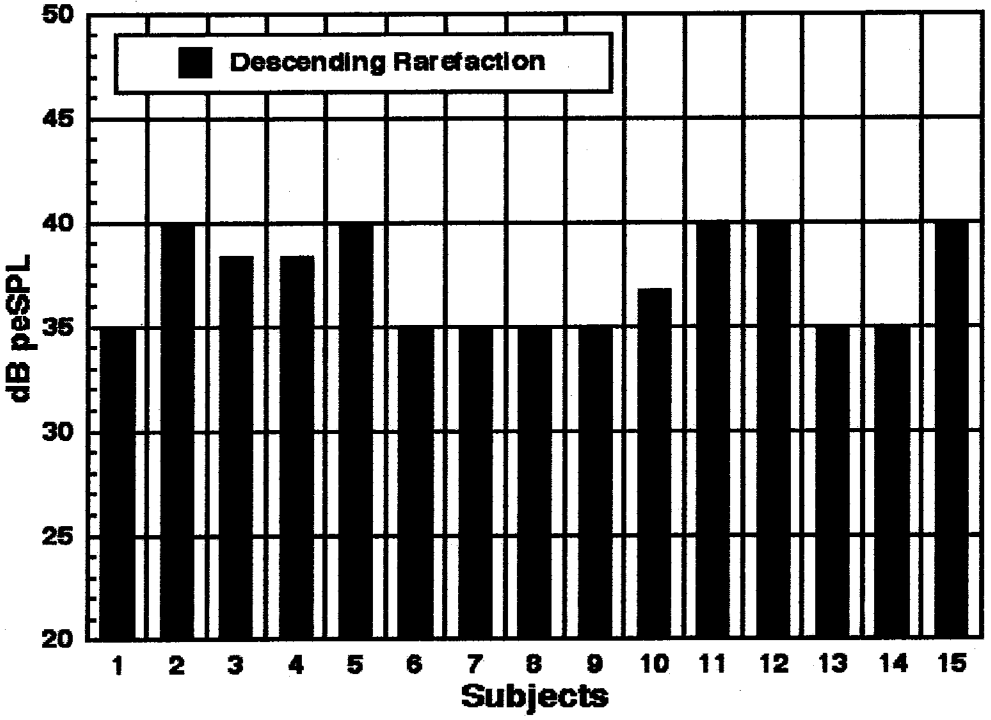


Figure 2. Descending rarefaction trial with 15 normal hearing subjects.

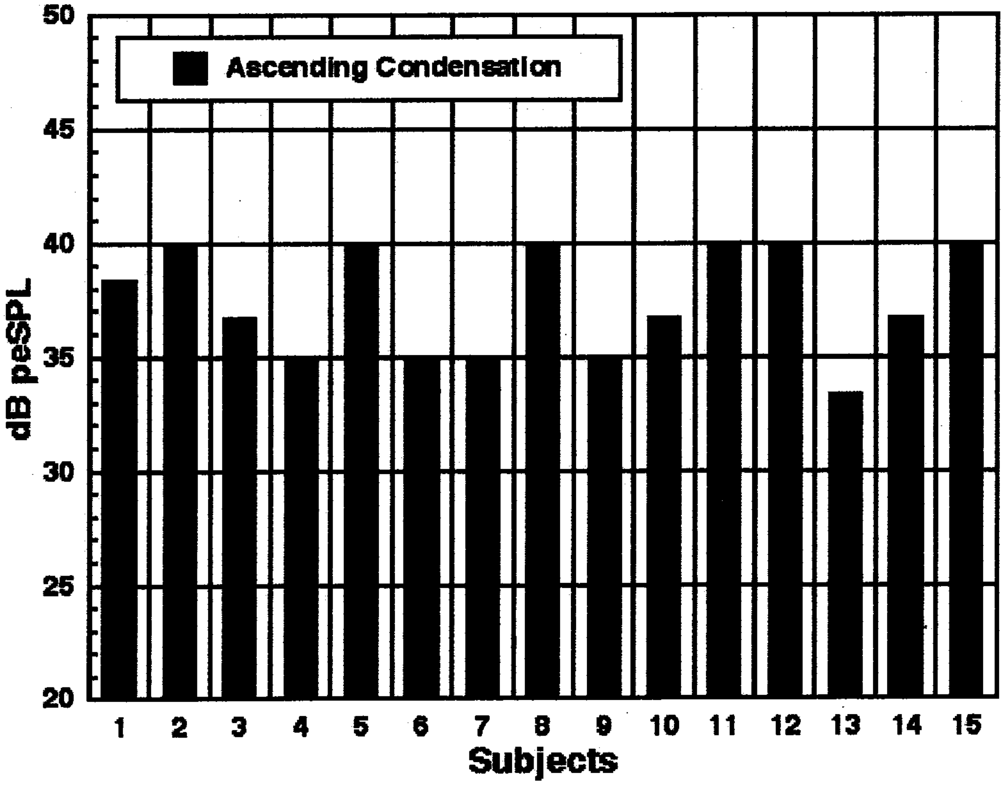


Figure 3. Ascending condensation trial with 15 normal hearing subjects.

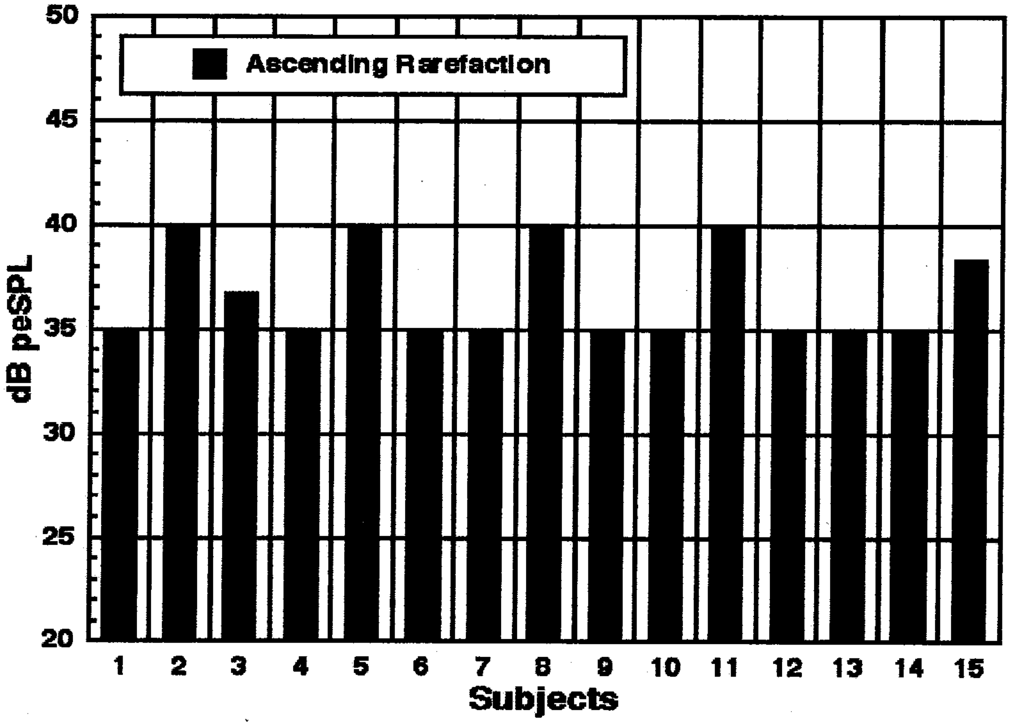


Figure 4. Ascending rarefaction with 15 normal hearing subjects.

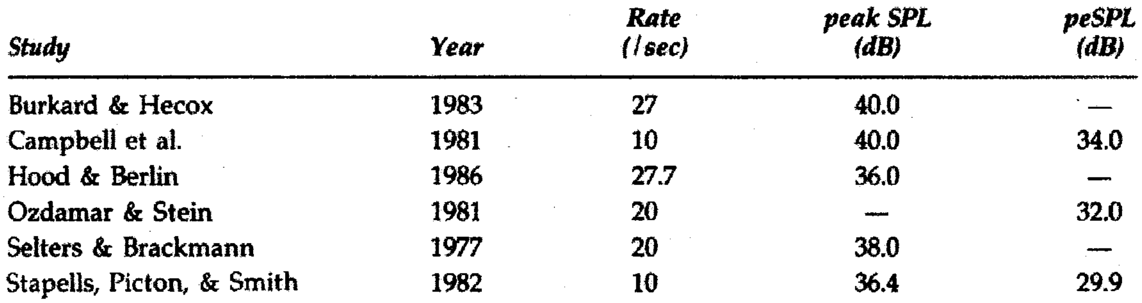
The table below describes the statistics for each of the four conditions and polarities.

Descriptive Statistics

	Desc Cond	Desc Rare	Asce Cond	Asce Rare
Mean	36.887	37.220	37.447	36.667
Std. Dev.	2.169	2.326	2.430	2.270
Std. Error	.560	.601	.627	.586
Count	15	15	15	15
Minimum	33.300	35.000	33.300	35.000
Maximum	40.000	40.000	40.000	40.000
# Missing	0	0	0	0

Table 3. Descriptive statistics for descending and ascending trials of condensation and rarefaction stimulus polarities.

As stated by Hall (1992), the most common practice for describing stimulus intensity level in auditory evoked responses is in reference to normal hearing level for the stimulus (dB nHL). Behavioral threshold levels are determined for a relatively small group of normal hearing adult subjects prior to auditory evoked response measurements. The idea is to find the lowest intensity level of the equipment screen that can be just detected by each subject. And, for most evoked response equipment, "this average is very close to the equipment reading if the measurement is made in a sound-treated room or quiet environment". Based on Hall's study of the relation between dB nHL, dB peak SPL, and dB peSPL, the data from our study falls within this acceptable range. (Table 4).



Study	*Year*	*Rate (/sec)*	*peak SPL (dB)*	*peSPL (dB)*
Burkard & Hecox	1983	27	40.0	—
Campbell et al.	1981	10	40.0	34.0
Hood & Berlin	1986	27.7	36.0	—
Ozdamar & Stein	1981	20	—	32.0
Selters & Brackmann	1977	20	38.0	—
Stapells, Picton, & Smith	1982	10	36.4	29.9

Table 4. Comparison of click-stimulus intensity levels in dB SPL corresponding to 0 dB nHL among selected studies. From *Handbook of Auditory Evoked Responses* by James W. Hall III, 1992.

The results of the ANOVA or analysis of variance is shown in Table 5. These results indicate there is no significant difference between the subjects.

ANOVA Table for Thresholds

	DF	Sum of Sq	Mean Sq	F-Value	P-Val
Column 5	14	226.736	16.195	*	*
Subject(Group)	0	0.000	*		
Category for Thresholds	3	5.396	1.799	1.085	.3658
Category for Thresholds *Subject	42	69.616	1.658	*	*

Reliability Estimates - All Treatments: .897;
Single Treatment: .685

Table 5. Results of ANOVA: Threshold values of subjects with an automated algorithm ABR screener.

Discussion

The results of this investigation clearly show that dB nHL values are easily determined by real ear measures. Utilizing the automated algorithm of the AUDIOscreener™ allowed accurate comparisons of threshold among young normal hearing subjects. The statistical analysis showed no significant variance between subjects and correlated well with published data of click stimulus intensity levels.

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