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Evaluating Factors Affecting Audiologists' Diagnostic Performance in Auditory Brainstem Response Reading: Training and Experience

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***Abstract*—**This study aims to determine if audiologists' experience characteristics in ABR (Auditory Brainstem Response) reading is associated with their performance in interpreting ABR results. Fifteen ABR traces with varying degrees of hearing level were presented twice, making a total of 30. Audiologists were asked to determine the hearing threshold for each of the cases after completing a brief survey regarding their experience and training in ABR administration. Sixty-one audiologists completed all tasks. Correlations between audiologists' performance measures and experience variables suggested significant associations ($p < 0.05$) between training period in ABR testing and audiologists' performance in terms of both sensitivity and accuracy. In addition, the number of years conducting ABR testing correlated with specificity. No other correlations approached significance. While there are relatively few significant correlations between ABR performance and experience, accuracy in ABR reading is associated with audiologists' length of experience and period of training. To improve audiologists' performance in reading ABR results, an emphasis on the importance of training should be raised and standardized levels and period for audiologists training in ABR testing should also be set.

***Keywords*—**ABR, audiology, performance, training, experience.

I. Introduction

HEARING loss is a wide spread problem, that adversely impact up on the child' language and social development [1]. About 9% (32 million) of the population with hearing loss are children. It is estimated that in every 1000 neonates and infants, approximately 0.5 to five have a hearing loss that can occur due to congenital or acquired factors in early childhood [2]. Hearing loss delays the process of language acquisition, reducing the individual's ability to communicate with others, which can adversely affect academic performance and employment opportunities [3]. Early identification and early intervention for hearing loss is known to limit its impact on individuals' lives [4]. Hearing impaired children who receive intervention and hearing rehabilitation before six months of age may be able to develop language to similar abilities as children with normal hearing levels [3], [5], [6].

ABR is one of the evoked potentials used to assess the function of the brainstem and is currently considered the most effective method for the early detection of hearing loss [7]. The impact of technical aspects of ABR testing on clinical outcomes has been widely investigated. Stimulus parameters such as frequency [8], phase [9], rate [10], intensity [11] high-pass filter and rise-fall time [12] have all been found to impact upon ABR results. Variability among audiologists in the interpretation of ABR traces has also been addressed previously [13]-[18]. However, little is known about the relationship between diagnostic performance and audiologists' training and experience. Two studies have commented on the relationship between audiologists' experience and consistency in reading ABR results [13], [15]. While both of the studies found that more experience in reading ABR traces is linked with greater consistency and better agreement between audiologists, only small samples were included (eight and four, respectively). Therefore, the current study aims to evaluate if diagnostic performance is associated with reader training and experience through investigating sensitivity, specificity and accuracy of 61 audiologists presented with 30 ABR test cases.

II. Materials and Methods

A. Ethical Approval

This study received ethics review board approval and the need for patient consent was waived. Participation by audiologists was voluntary and there were no inducements for participation.

B. Participants

93 audiologists who routinely perform ABR testing were recruited for the study. The only requirements for participation were that the audiologists conduct ABR testing as part of their clinical work. Audiologists' knowledge and experience in ABR testing were collected through the survey. Audiologists had no time restriction to complete reading the cases and anonymity was maintained for all participants. 61 out of the 93 participants interpreted all of the cases, making a completion rate of 65%. Only those participants who completed all responses were included in the present analyses.

C. ABR Cases

15 de-identified 4 kHz ABR traces were collected. All ABR

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results were from infants who were referred for threshold ABR testing as a result of failing the local newborn hearing-screening program. At the time of ABR testing, all infants were aged less than 12 weeks (using corrected age where premature). The 15 selected traces consisted of three with normal estimated hearing level (upper limit of 25 dBnHL (Decibel Normal Hearing Level) at 4 kHz) and 12 with different degrees of hearing loss ranging from mild to profound, including one with no ABR response. Degree of hearing loss was based upon Goodman's scale of classification (1965). The order of tracing acquisition of the ABR and any repeated waveforms were removed on purpose to eliminate any clue about the threshold and single traces only were provided at each intensity level. Participants were aware of the stimulus frequency (4 kHz), age of infant at time of assessment and intensities assessed.

D.ABR Recordings

The ABR recordings used in the study were a sample of the recordings taken during the course of normal clinical practice at CHW (Children's Hospital at Westmead) by the fourth author. All ABR recordings were performed in a double-walled, electrically magnetically isolated audiology test room at the Audiology department at CHW/Sydney. The ABR was recorded using Vivosonic Integrity platform. Prior to the positioning of electrodes on the scalp of the subject, the skin was properly cleansed and abraded. For each baby, four Neuroline 720 electrodes were positioned on the left and right mastoids (inverting lead), the forehead (non-inverting lead) and on the cheek (Amplitrode; ground lead/pre-filter/in-situ amplifier combined). The difference in impedance between electrodes was maintained at less than 3 Ω. To elicit ABR responses at 2-0-2 cycles (rise time- plateau-fall time), 4 kHz was used. Stimuli were presented to subjects using EAR 3a insert phones using an alternating mode of testing. The stimulus rate was set to 37.7 signals per second due to inbuilt click rate constraints regarding Bluetooth compatibility in the Vivosonic platform. The Kalman-weighted averaged ABR was employed. Kalman-weighted averaging, similar to other weighted averaging methods, allocates a higher statistical weight to sweeps with lower levels of noise, and lower weighting to sweeps with a higher level of noise. Studies suggest that the use of Kalman-weighted averaged ABR results in a greater likelihood of measuring Wave V at threshold levels when higher levels of noise are present, and reduction in test time when compared to conventional signal averaging methods [19]-[21]. The output was additionally filtered from 30 Hz to 1500 Hz (2 dB (Decibel)/octave and roll-off of 24 dB/octave, respectively). The Blackman 25 ms window was used to obtain the response [22], [23]. All responses at or near threshold (±10 dB) were repeated. All babies were naturally sleeping with appropriate neck propping to reduce muscle artifact and no sedation or anesthesia were used. The first stimulus level for each baby was either 60 dBnHL or 65 dBnHL, and then it was decreased/ increased according to the elicited waves. "The waveforms were presented as static graphical displays. Neither participants nor researchers had any control over the presentation of the waveforms. For each baby, stimulus levels varied according to the need and the status of the babies. For example, one baby was tested from 60 dBnHL down to 0 dBnHL in a 10 dBnHL-step, while another at only 65 dBnHL, 85 dBnHL and 95 dBnHL.

E. Other Assessments

Before the ABR recordings, the tympanometry and Distortion Product Otoacoustic Emissions (DPOAE) were performed for each subject. The 1 kHz tympanometry was recorded using the GSI Tympstar or the Interacoustics Titan. DPOAEs were recorded using a 60/50 dBSPL (Decibel Sound Pressure Level) (F2/F1) stimulus using an 8 dB SNR (Signal to Noise Ratio). DPOAEs were recording using the Interacoustics OtoRead or GSI Audera system. These data are not included in the present study.

F. Procedure

An online survey was developed on the Survey Monkey platform. The survey consisted of 15 ABR cases presented twice making a total of 30. The order of the cases was originally randomly allocated but consistent between participants. For each case, participants were asked to select ABR threshold from the options of the testing stimuli in addition to the "no response" option. For example if the ABR waves were elicited at four intensity levels, the options included all the four testing stimuli and the "no response" option. As the study investigates accuracy of ABR trace interpretation alone, no additional information other than the age of the baby was provided. For all cases, 'gold standard' thresholds had been determined prior to the study based on a blind judgment by two highly experienced pediatric audiologists (over 10 years of ABR readings). These thresholds were not available to participants but were used to benchmark the accuracy of participants' judgments.

G.Experience-Related Questionnaire

To determine audiologists' experience in ABR interpretation, audiologists were asked to complete a brief questionnaire about their ABR reading experience and practice before they were presented with the ABR cases.

1. ABR Testing Specialty

Audiologists were asked whether they specialized in pediatric or adult assessment or conducted both.

2. Years of Experience in Audiology

Participants were asked about number of years of practice an audiologist. Answers were provided as free text.

3. Years of Experience in Reading ABR

This item asked about number of years in reading ABR results separately from total years of audiology practice. Responses were free text.

4. Weekly Reading Volume

Audiologists were asked to give an estimate of their average number of ABR cases per week. Responses were free text.

5. ABR Training

Audiologists were asked about any training period in ABR testing they undertook before starting their ABR work. For this variable, four options were given to audiologists to choose from; more than one month, 1-4 weeks; one week or less; no training at all.

6. Lifetime Experience in ABR Reading

Whilst audiologists were not asked directly about lifetime experience in ABR reading in the questionnaire, it was compared to the audiologists' performance and was estimated by multiplying weekly reading volume by number of years of ABR testing by 48 (assuming 48 working weeks per annum).

H.Data Analysis

In the view of the research team and professional colleagues, a valid case can be made for both 'conservative' and 'liberal' interpretations of 'accuracy' in interpreting ABR traces. Therefore, two calculations of accuracy were used in all analyses. The 'exact' method treated a response as correct only if the threshold nominated by a participant was the same as the pre-determined threshold by the two experienced audiologists. The '20dB method' regarded a response as correct if it was within 20 dB of the pre-determined threshold. For both measures of accuracy, the means and 95% confidence intervals of the mean were calculated for sensitivity (the fraction of cases with hearing loss that were correctly identified as abnormal), specificity (the fraction of cases with the normal findings that were correctly identified) and accuracy (the fraction of cases that were accurately identified for both normal and abnormal cases) scores. Correlations between these scores and number of years in audiology, number of years in ABR testing, ABR training period, number of ABR cases per week and lifetime experience in ABR testing were performed for the two sets of analysis using the parametric Pearson methods. Software IBM SPSS Statistics, version 22 was used for all statistical computations. The alpha value was set at 0.05 for all analyses.

III. Results

Complete data were available from 61 audiologists. Table I provides summary statistics of audiologists' experience in audiology and reading ABR, number of ABR cases readings per week, lifetime experience and their ABR training period. Years of practice in audiology ranged from one year to 39 years with a mean of 14.02 years.

TABLE I
AUDIOLOGISTS' EXPERIENCE

Parameter	Mean	First Quartile	Third Quartile	Standard Deviation	Interquartile Range
Experience as audiologists (in years)	14.02	5.00	22.00	9.63	1-39
Experience in ABR reading (in years)	9.04	2.00	14.50	7.67	1-25
ABR training (in weeks)	3.18	1.00	5.000	2.08	1-5
ABR cases/ week	3.78	1.00	5.000	3.85	1-25
Life-time experience (in cases)	1812.59	288	2400	2663.62	48- 13200

TABLE II
COMPARISON OF THE PRE-DETERMINED THRESHOLD AND THE ESTIMATED THRESHOLDS BY AUDIOLOGISTS

Case numbers	Pre-determined threshold	Estimated threshold by Audiologists (average of the two readings)	The difference
1	40	45	5
2	100	99	-1
3	40	51	11
4	50	57	7
5	10	9	-1
6	85	99	14
7	60	78	18
8	15	29	14
9	40	59	9
10	50	51	1
11	90	97	7
12	40	50	10
13	45	68	23
14	10	13	3
15	65	67	2

Table II shows a comparison of the pre-determined threshold by the two experienced audiologists (true threshold) and the average of estimated thresholds by participating audiologists. In terms of absolute accuracy over all, for six out of the 15 cases, audiologists consistently nominated hearing thresholds within 5 dB of the pre-determined threshold, which is clinically acceptable. For the nine cases where audiologists were typically inaccurate, the error was consistently to overestimate the hearing threshold by more than 5 dB (Table II).

TABLE III
CORRELATION ANALYSIS OF SENSITIVITY, SPECIFICITY AND ACCURACY VALUES WITH READER PARAMETERS ACCORDING TO THE "EXACT" METHOD OF ANALYSIS*

Parameter	Sensitivity		Specificity		Accuracy	
	R	P	R	P	R	P
Experience as audiologists (in years)	0.16	0.21	0.22	0.07	0.18	0.16
Experience in ABR reading (in years)	0.20	0.12	0.30	0.01	0.23	0.07
ABR training (in weeks)	0.29	0.02	0.22	0.07	0.29	0.02
ABR cases/ week	0.07	0.95	-0.04	0.72	-0.01	0.99
Life-time experience (in cases)	0.01	0.91	0.07	0.56	0.02	0.84

*The "exact" method of analysis treated a response as correct only if the threshold nominated by a participant was the same as the pre-determined threshold.

Tables III and IV show the results from the exact method of determining accuracy, while Tables V and VI show the results

from the '20dB' method of determining accuracy. Under both definitions of accuracy, statistically significant relationships were seen between sensitivity and ABR training period (in weeks); specificity and number of years in ABR testing and accuracy and ABR training period (in weeks). No other significant relationships were found between any experience variable and performance, although the experience variables were highly inter-correlated (years practicing audiology and years conducting ABR, R=0.726, P<0.001; years practicing audiology and lifetime ABR experience, R=0.435, p<0.001).

TABLE IV
MEAN AND STANDARD DEVIATION VALUES FOR EXACT SENSITIVITY, SPECIFICITY, AND ACCURACY ACCORDING TO THE "EXACT" METHOD OF ANALYSIS*

	Mean	Standard deviation
Sensitivity	0.38 (0.34-0.43)	0.18
Specificity	0.70 (0.66-0.74)	0.15
Accuracy	0.45 (0.40-0.49)	0.17

*The "exact" method of analysis treated a response as correct only if the threshold nominated by participant was the same as the pre-determined threshold.
Note: Numbers in parentheses are 95% confidence intervals of the mean.

TABLE V
CORRELATION ANALYSIS OF SENSITIVITY, SPECIFICITY AND ACCURACY VALUES WITH READER PARAMETERS ACCORDING TO THE "20 DB" METHOD OF ANALYSIS*

Parameter	Sensitivity		Specificity		Accuracy	
	r	P	r	P	r	P
Experience as audiologists (in years)	-0.08	0.51	0.22	0.07	0.06	0.96
Experience in ABR reading (in years)	-0.08	0.94	0.30	0.01	0.09	0.48
ABR training (in weeks)	0.29	0.02	0.22	0.07	0.30	0.01
ABR cases/ week	-0.04	0.71	-0.04	0.72	-0.05	0.68
Life-time experience (in cases)	-0.14	0.26	0.07	0.56	-0.08	0.49

*The "20 dB" method of analysis treated a response as correct only if the threshold nominated by a participant was within 20 dB of the pre-determined threshold.

TABLE VI
MEAN AND STANDARD DEVIATION VALUES FOR SENSITIVITY, SPECIFICITY, AND ACCURACY ACCORDING TO THE "20 DB" METHOD OF ANALYSIS*

	Mean	Standard deviation
Sensitivity	0.78 (0.76-0.80)	0.08
Specificity	0.70 (0.66-0.74)	0.15
Accuracy	0.76 (0.74-0.79)	0.09

*The "20 dB" method of analysis treated a response as correct only if the threshold nominated by participant was within 20 dB of the pre-determined threshold.
Note: Numbers in parentheses are 95% confidence intervals of the mean.

IV. DISCUSSION

The relationship between audiologists' characteristics, such as ABR training period and the number of ABR cases read per year, and their diagnostic performance in reading ABR results have not hitherto been investigated. Therefore, the current work examines the performance of 61 audiologists in terms of sensitivity, specificity and accuracy in reading the results of 30 ABR cases.

Data show that over all, there is no relationship between audiologists' performance in ABR threshold estimation and their experience in reading ABR except in terms of training and years of experience in ABR testing. As lifetime number of ABR readings was calculated from weekly reading number and years of experience, those values were highly inter-correlated. The correlations that are significant are small in magnitude and account for relatively little variance in ABR reading performance. Nonetheless, the findings do highlight the role of training and practice in enhancing ABR reading skills.

Audiologists who had more training in ABR testing were more able to identify cases with hearing loss (sensitivity) and they were more accurate in their threshold estimation overall (accuracy) compared to audiologists with no training in ABR testing. Our data also showed that audiologists who had more experience in ABR testing (in years) were more able to identify cases with normal hearing level (specificity).

The data indicate that more training in ABR reading predicts better sensitivity and accuracy. These findings concur with previous research suggestions that linked poor performance in ABR interpretation with training factors. For example, the lack of standardized training in ABR testing across many countries [18], the lack of standardized method of analyzing ABR waveform among audiologists [19] and the absence of practice in ABR waveforms interpretation, especially in countries that do not have a newborn hearing screening program, such as the majority of developing countries [20].

The importance of ABR training is also supported by a recent study that evaluated the impact of simulated training on ABR reading performance for audiology students (Dzulkarnain, Wan Mhd Pandi, Wilson, Bradley, & Sapian, 2014). The research found that students' ability in ABR interpretation increased when manual training was provided compared to the other simulator pattern and higher results are seen when face-to-face training was used [21]. This suggests that any sort of training in ABR analysis can improve audiologists' performance. Such strategies therefore, can potentially help new graduate and less experienced audiologists to gain more practice in analyzing ABR cases (normal and abnormal) before they commence ABR testing on real patients. This type of training strategy has been reported to be effective in other medical domains such as medical education electrocardiogram interpretation, auscultation, and surgery simulations [22]-[24].

It is not possible on the basis of the present data to recommend a specific period of training in ABR testing that would maximize audiologists' performance, however longer training periods were associated with in better performance overall. Therefore, if it is intended to improve audiologists' performance in ABR reading, a certain level of training in ABR testing should be proposed.

Years of experience in ABR testing were found to be associated with higher specificity scores. This result supports previous findings that audiologists who had more experience in ABR testing were more accurate in estimating thresholds, resulting in better judgment and less bias [13]. Naves et al. also found that more experienced audiologists were more

consistent in their latency estimation over time [15]. The results regarding higher performance in terms of specificity (recognizing normal cases) are also consistent with findings from other medical domains, showing decreasing false-positive rates with increasing expertise [25]-[27].

The present data suggest that reading ABR for normal traces was more accurate by more experienced audiologists. This could be explained by the different level of confidence audiologists' gain over their work experience. New graduates and less experienced audiologists might be less confident in identifying normal cases, compared to more experienced audiologists. The difficulty in recognizing normal cases for less experienced audiologists may be balanced through gaining more experience in reading ABR, where ability to identify normal cases is often emphasized over the ability to identify cases with hearing loss.

The ability to identify normal traces through ABR interpretation has important implications for clinicians and policymakers who are encouraging a reduction in false positive rates while not affecting abnormal trace detection. False positive incidences in ABR testing could result in inappropriate management/outcomes to the patient medically, audiologically and educationally. It also can provoke anxiety and confusion for the child's parents, which in turn can reduce client confidence in the audiologist and the subsequent recommendations. Moreover, it results in avoidable additional expenses for both of the families and the health system [28]. Higher ability in identifying normal cases can be achieved only through time and many years of practice [25], [29].

Comparing the pre-determined threshold and the average of estimated thresholds by participating audiologists, data show that audiologists tend to over-estimate the hearing threshold rather than under-estimate it. This conservative behavior of audiologists could be referred to the lack of clinical history information of the cases, which lead audiologists to nominate higher threshold rather than lower threshold, which mean in real world more chances of rehabilitation and management plans.

The overall findings suggest that audiologists show a fair to good level of sensitivity in reading ABR. However, audiologists in this study still fell well short of 100% accuracy, raising the question of whether this failure to achieve maximum diagnostic accuracy is a feature unique to the difficult task of ABR interpretation or is a more generalizable feature within other medical domains and beyond. Previous research has reported accuracy of 90% for specialists in dermatology [30], ECG interpretation [31] and microscopic pathology [32]. On the other hand, specialists in cardiac and pulmonary auscultation showed less accuracy, around 70% [33], [34]. Obviously, the absolute values of the above depend on the task type, difficulty, and the experts' experiences. However, the available data would suggest that high levels of performance even by experts in a number of medical fields is very hard to achieve and, therefore, should not currently be expected by policy makers, judicial systems or the public [30]-[34]. The key question, however that remains unanswered, is to what extent performance amongst experts can be improved through appropriate tailored strategies. At this point, the effect of training duration is the only thing that has been investigated, not what that training comprised.

Some caution must be considered when using nonclinical settings to investigate clinical performance [35], [36], and the participants in the present study did not have access to the same clinical and electrophysiological resources that would be available to them under normal clinical conditions. Nonetheless, the involvement of large numbers of experienced audiologists and the realistic viewing conditions suggest that the results presented in this study are sufficiently valid to allow some conclusions to be drawn. A limitation of the study is that the case history information provided for audiologists was intentionally very limited. Only the age of babies at the time of testing was provided. While information such as risk factors, method of delivery and other hearing tests' results could help audiologists in drawing their conclusion regarding the hearing status, the present study focuses upon audiologists' ability to determine the presence/absence of wave V based upon visual inspection of ABR waves alone. In most clinical situations, babies are referred for diagnostic ABR testing at a young age, often less than three months, and limited information is known about the child's history. Therefore, the limited case history information of the babies should not have significantly affected audiologists' performance. Including only single ABR waveforms is another limitation for this study. ABR tracings were obtained within a clinical setting. The retrospective nature of this study means that ABR tracings were not obtained at set intensity levels or replicated at every intensity tested. The removal of any replicated tracings by the authors prior to perusal may have affected audiologists' interpretation of threshold. While training was discussed in this paper, there is no real information on the types of training the respondents had. Besides, the correlation values that were found are small. Notwithstanding the above limitations, this study is the first to investigate the relationship between audiologists' characteristics and their performance in reading ABR waves.

V. Conclusion

This study found relatively few significant correlations between ABR performance and audiologist' experience metrics. Data suggest that audiologists who had more training in ABR testing were more able to identify cases with hearing loss (sensitivity) and they were more accurate in their threshold estimation overall (accuracy). In addition, audiologists who had more years of experience in ABR testing demonstrated higher abilities in identifying cases with normal hearing level (specificity). Hence, a way to improve audiologists' performance in reading ABR results would be to emphasize on the importance of training in ABR testing before they start performing it independently and to set standardized levels and period for audiologists' training in ABR testing. Another way of enhancing audiologists' performance in reading ABR results is practicing ABR testing more and seeking a second opinion from more experienced audiologist

if that was available.

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