CORTICAL EVOKED RESPONSE AUDIOMETRY IN NOISE INDUCED HEARING LOSS CLAIMS

FIELD W. RICKARDS, SANDRA DE VIDI and DON S. McMAHON

Deafness Studies Unit
Department of Learning, Assessment and Special Education
University of Melbourne
Victoria

The relationship between cortical evoked response audiometry (CERA) and pure tone audiometric (PTA) thresholds at 500-, 1000-, 1500-, 2000-, 3000- and 4000 Hz was examined in 500 adult subjects, who had submitted noise induced hearing loss (NIHL) claims between 1984-1994. Subjects were considered to have reliable pure tone audiograms, and had hearing thresholds ranging from normal to profound. Results showed a close relationship between PTA and CERA thresholds ($r = .96$), with a mean difference between the two tests of 0.9 dB (Standard Deviation = 5.0 dB). Overall, for all the frequencies tested, CERA thresholds were within 10 dB of the PTA threshold for 97.9% of cases. The results suggest that CERA can be used as an objective test to estimate hearing thresholds across a range of frequencies in NIHL claims.

The incidence of exaggerated hearing loss in noise induced hearing loss (NIHL) claims is well established. The percentage of workers who exaggerate hearing thresholds in NIHL claims has been estimated to be in the range of 9% (Barrs et al 1994) to 30% (Gleason 1958). In Victoria, the number of exaggerators is at least 17.7% (Rickards and De Vidi 1995). Undetected exaggerated hearing levels will lead to a substantial increase in compensation payouts. Although conventional diagnostic audiology can usually detect exaggeration of hearing levels, subjective hearing tests cannot accurately ascertain the degree of the true hearing loss in the individual who refuses to respond reliably (Hyde et al 1986).

Cortical Evoked Response Audiometry (CERA) has been widely used as an objective test to estimate hearing thresholds across a range of frequencies in alert adults and older children when reliable subjective hearing test results cannot be obtained (Gibson 1978). In estimating hearing thresholds, CERA involves the presentation of tone bursts to each ear at different frequencies, subjectively analysing the averaged brain patterns in order to determine the presence or absence of a response. The presence of a response implies that the ear, associated neural pathways, and the auditory cortex has processed the sound. It is therefore assumed that the subject has hearing at this particular intensity level and frequency (Hall 1990).

Figure 1 shows a set of five cortical evoked responses (CER) at decreasing stimulus levels in an awake adult. The response commences approximately 50 ms after the onset of the stimulus, and is characterised by three main peaks, P1, N1 and P2. The latency of the main peak (N1) is around 150 ms. It can be seen that the amplitude of the response decreases while the latency of the response increases with decreasing stimulus intensity.

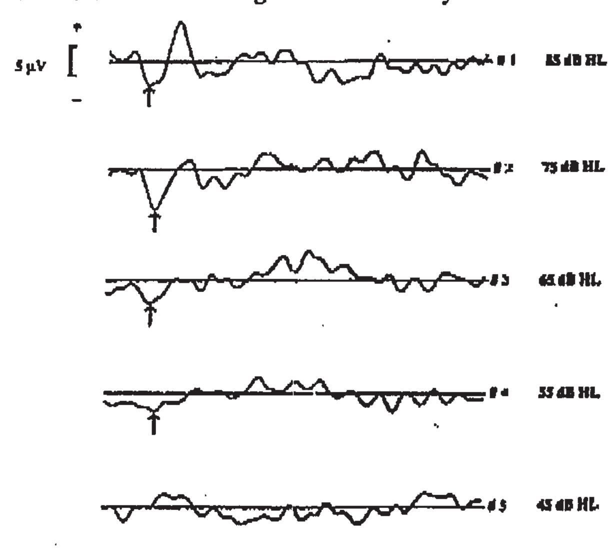

FIG. 1. Cortical evoked responses at 2000 Hz from an adult male with a subjective hearing threshold of 55 dB HL. Responses were elicited at stimulus levels above threshold (#1-#3), and at threshold (#4). No response is evident below the subject's true subjective threshold (#5). The N1 peak in responses #1-#4 is marked by an arrow.

Professor Field W. Rickards
B.Sc. (Hons), M.Ed., Ph.D.
Ms Sandra De Vidi
B.Sc., Dip.Aud.
Mr. Don S. McMahon
M.B., B.S., F.R.A.C.S., DLO

Correspondence:
Professor Field W. Rickards
Deafness Studies Unit
Department of Learning, Assessment and Special Education
University of Melbourne
Parkville, Vic. 3052
Tel: +61 3 9344-7876
Fax: +61 3 9349-1915

CERA has been extensively used to estimate hearing thresholds in individuals undergoing NIHL assessments. It has been used in Victoria in cases of suspected exaggerated hearing loss in NIHL claims for more than 15 years. Currently, up to 18% of all NIHL claimants in Victoria are referred for CERA each year.

The accuracy of CERA has been examined in a number of studies, usually by comparing CERA thresholds to Pure Tone Audiometric (PTA) thresholds. For example, Jones et al (1980) found identical PTA and CERA thresholds in 81%, 70%, and 68% of adult subjects with normal hearing at 250-, 1000- and 4000 Hz respectively. Coles and Mason (1984) examined PTA and CERA thresholds on a group of medico-legal cases and separated the subjects into organic and non-organic hearing losses. In the cases of organic hearing loss, the mean difference between PTA and CERA thresholds was found to be 0 dB, with only 3.2% of cases having a mean difference between PTA and CERA that exceeded 15 dB. Further, 37% of cases with non-organic hearing loss had PTA thresholds which were more than 30 dB greater than the CERA thresholds. In a study by Hyde et al (1986), on a group of medico-legal cases who were considered to have reliable conventional audiometry, PTA and CERA thresholds were found to be within 10 dB for almost all 254 cases. Similar results were found in a recent study by Prasher et al (1993). These researchers compared PTA and CERA thresholds at 1000- and 4000 Hz on a group of compensation cases and a group of Meniere's disease subjects. Prasher et al (1993) found CERA and PTA thresholds to be within 10 dB for 84% and 92% of the workers compensation and Meniere's disease groups respectively. In the workers compensation group, the majority of cases where the difference between PTA and CERA thresholds exceeded 10 dB were usually cases where the subject was considered to be exaggerating his PTA thresholds.

In spite of these findings, and early recommendations for the use of CERA in NIHL assessments (McCandless and Lentz 1968, Alberti 1970), the acceptance of the reliability of CERA has not been universal. This may in part be due to the reliance on subjective interpretation of response tracings during the test, and the high level of skill and training that is required of the tester (Hyde et al 1986, Hoth 1993). As CERA is currently being used in a number of specialist clinics, this paper investigates the accuracy of a CERA procedure in predicting hearing thresholds at the frequencies used in the determination of the percentage loss of hearing (PLH) in NIHL claims in Australia.

Method

Subjects

Five hundred adult male subjects (mean age = 55 years, Standard Deviation = 8.44) who were referred for CERA as part of a NIHL claim in Victoria were chosen for analysis. The subjects were referred for CERA by Insurance Companies or Otologists, and were selected from a pool of over 5000 subjects that were tested by the one tester over a period of more than 10 years between 1984-1994. The subjects were selected randomly, on the basis of having reliable subjective PTA thresholds either at the commencement or conclusion of the CERA test. This reliability was determined primarily using speech threshold testing where the audiogram was accepted as reliable if the 1000 Hz PTA threshold was less than the speech Half Peak Level (HPL) using AB words (Boothroyd 1968). Subjects had hearing thresholds ranging from normal to profound. All losses were sensorineural in nature, with no subject showing any evidence of retrocochlear pathology.

Procedures and apparatus

All subjects were given a thorough audiological examination involving an otological/noise history, impedance audiometry with reflexes, speech audiometry, an initial subjective PTA test, CERA, and a final subjective PTA test after CERA. The order of presentation of these tests remained constant between subjects. For all tests, subjects were seated in a sound attenuated room which was adjacent to the tester. In the speech testing, AB Words were presented live voice via a microphone into headphones using an ascending method. This procedure was followed for all subjects prior to the commencement of PTA. PTA thresholds were measured using a Starkey Acoustic Analyser AA30 audiometer. The procedure for determining thresholds in the initial PTA test involved an ascending method followed by a standard threshold seeking procedure. The procedure for determining thresholds in the final PTA test involved an ascending method only. For both PTA tests, thresholds were normally determined for each ear at each of the frequencies, 500-, 1000-, 1500-, 2000-, 3000-, 4000-, 6000- and 8000 Hz for all of the subjects. In most cases, thresholds obtained in the final PTA were accepted as the true thresholds, since the initial PTA thresholds were often elevated.

CERA was normally carried out for all subjects for each ear at each of the frequencies 500-, 1000-, 1500-, 2000-, 3000- and 4000 Hz. The cortical responses were recorded using silver-silver chloride electrodes. An active electrode was placed at the vertex and a ground and reference electrode on each mastoid. Narrow-band masking was used in the contralateral ear when required. The EEG signal was amplified using a Madsen BPA77 preamplifier with a filter bandwidth of .25-15 Hz, and a rejection rate of 12 dB per octave and 24 dB per octave in the low and high frequency slopes respectively. Stimuli were 100 ms tone bursts with a rise/fall time of 5 ms for all frequencies.

Sampling, averaging, stimulus initiation and response display were controlled using a Hewlett Packard 9816S scientific computer. The system had three non-standard features designed to enhance the response and aid in its recognition. Firstly, stimuli were presented with random inter-stimulus intervals every 1.5 to 2.5 ms (mean = 2.0 ms). Random inter-stimulus intervals have been found to enhance response amplitude (Tyberghein and Forrez 1969). Secondly, 128 samples with 10 ms intervals were recorded following each stimulus presentation, producing a total time window of 1.28s. This long time window enabled easy comparison between the response (<400 ms) and non-response (>400 ms) sections of the tracings. Thirdly, the detection of the response was aided with a template response that remained at the top of the computer screen. This template was obtained at the beginning of the test for each subject at a high sensation level (80 - 90 dB HL) at 2000 Hz.

Once the template response for a particular subject was obtained, stimuli were presented at 5 dB below the subject's best PTA threshold at 2000 Hz. Stimuli were decreased in 10 dB steps following each response, or increased in 10 dB steps if no response was identified. This was continued until no response was present or until 20 dB HL was reached. Presentation of stimuli below 20 dB HL was rarely attempted as thresholds below this level indicated hearing within normal limits, and hence a PLH of 0% at this frequency. The subject's threshold was taken to be equivalent to the lowest level where a CER was obtained or 5 dB less than this level. The subtraction of 5 dB occurred when the response at the lowest level had an N1 amplitude of greater than 50% of the template and a latency within 20 ms of the response 10 dB above. For example, in Figure 1, response #4 was considered to be at threshold. Had no response been recorded at this level, threshold would have been taken as 5 dB below the stimulus level for response #3. Response thresholds were subsequently obtained at each of the other frequencies. Each CER was analysed at the time of testing by the same tester.

For an averaged response tracing to be accepted as a true response, certain amplitude and latency criteria had to be satisfied. Specifically, N1 had to be the largest negative peak, and/or P2 had to be the largest positive peak, and/or N1 to P2 had to be the largest peak to peak amplitude. Further, the latency of any peak could not be less than the latency of the peaks in the template.

During CERA, subjects were instructed to sit quietly and remain as relaxed as possible. These instructions remained constant between subjects. The time taken to complete the CERA test varied between 15-30 minutes.

Results

Figure 2 demonstrates the relationship between the subjective PTA and CERA thresholds at each of the frequencies for the right and left ears. It can be seen that most values cluster closely around the regression line indicating a close relationship between PTA and CERA thresholds regardless of frequency, ear, or hearing threshold. A t-test for dependent samples comparing the PTA and CERA thresholds for the right and left ears showed there was no significant difference in results between ears. Consequently, results from both ears for all subjects were combined for subsequent analysis.

As CERA thresholds were not normally attempted

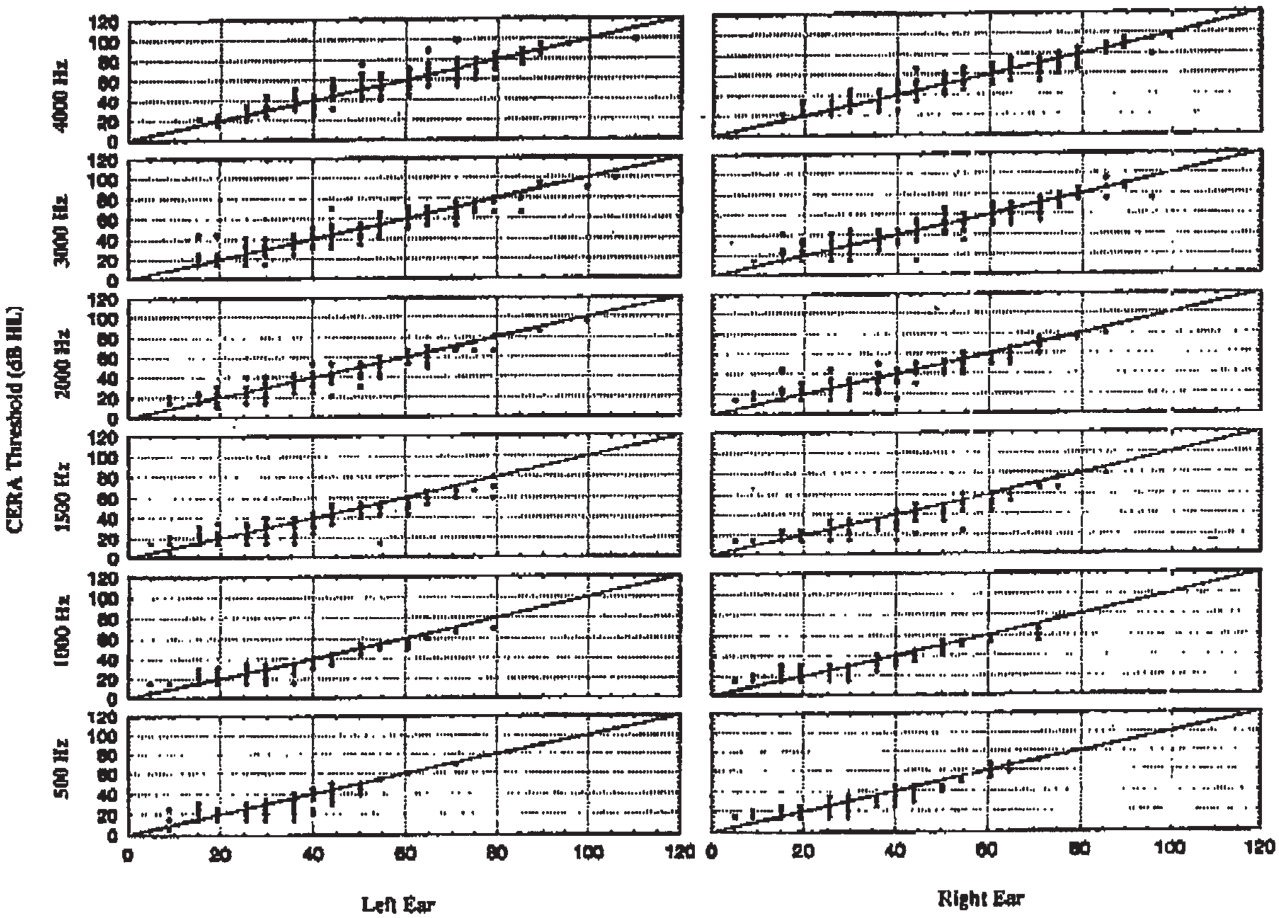

FIG. 2. Regression lines showing the relationship between PTA and CERA thresholds at 500-, 1000-, 1500-, 2000-, 3000- and 4000 Hz for all subjects for the right and left ears.

below 20 dB HL, comparisons with subjective thresholds less than 20 dB HL were not possible. The data were therefore re-analysed by eliminating the comparative data when the CERA thresholds were less than 20 dB HL. After the elimination of these data points, 4304 threshold comparisons remained. The mean differences between PTA and CERA thresholds at each of the frequencies in the remaining data are shown in Table 1. The differences are all less than 2.0 dB. Overall, the mean difference between PTA and CERA thresholds was 0.9 dB (standard deviation = 5.0 dB).

Table 1.
Differences between PTA and CERA thresholds at each frequency.

	Frequency					
	500	1000	1500	2000	3000	4000
Mean difference (dB HL)	1.131	1.310	1.530	1.508	0.498	0.087
Standard Deviation	4.644	4.334	5.172	5.008	5.230	5.184
Number of ears	513	496	624	776	913	982

The correlation between PTA and CERA thresholds at each of the frequencies are listed in Table 2. There is a close relationship between CERA and PTA thresholds at each of the frequencies tested. Overall, a correlation of .96 was obtained.

Table 2.
Pearson product-moment correlation coefficients at each frequency.

	Frequency					
	500	1000	1500	2000	3000	4000
r	.89	.93	.93	.95	.95	.95
Number of ears	513	496	624	776	913	982

The differences between PTA and CERA thresholds for each frequency for all of the subjects is illustrated in Figure 3. Overall, 47.0% of the PTA and CERA thresholds were identical, while 88.5% and 97.9% of cases fell within 5 dB and 10 dB of the subjective PTA threshold respectively. Of the 500 subjects, 62% had initial pure tone audiograms which were confirmed as exaggerated as indicated by an elevated PTA 1000 Hz threshold compared to the speech HPL. In these cases, the tester performing CERA was obtaining thresholds without knowledge of the true PTA values. The percentage of PTA and CERA thresholds that were within 10 dB of each other in this subgroup was 97.1%, similar to the overall value.

Discussion

The close agreement between PTA and CERA thresholds

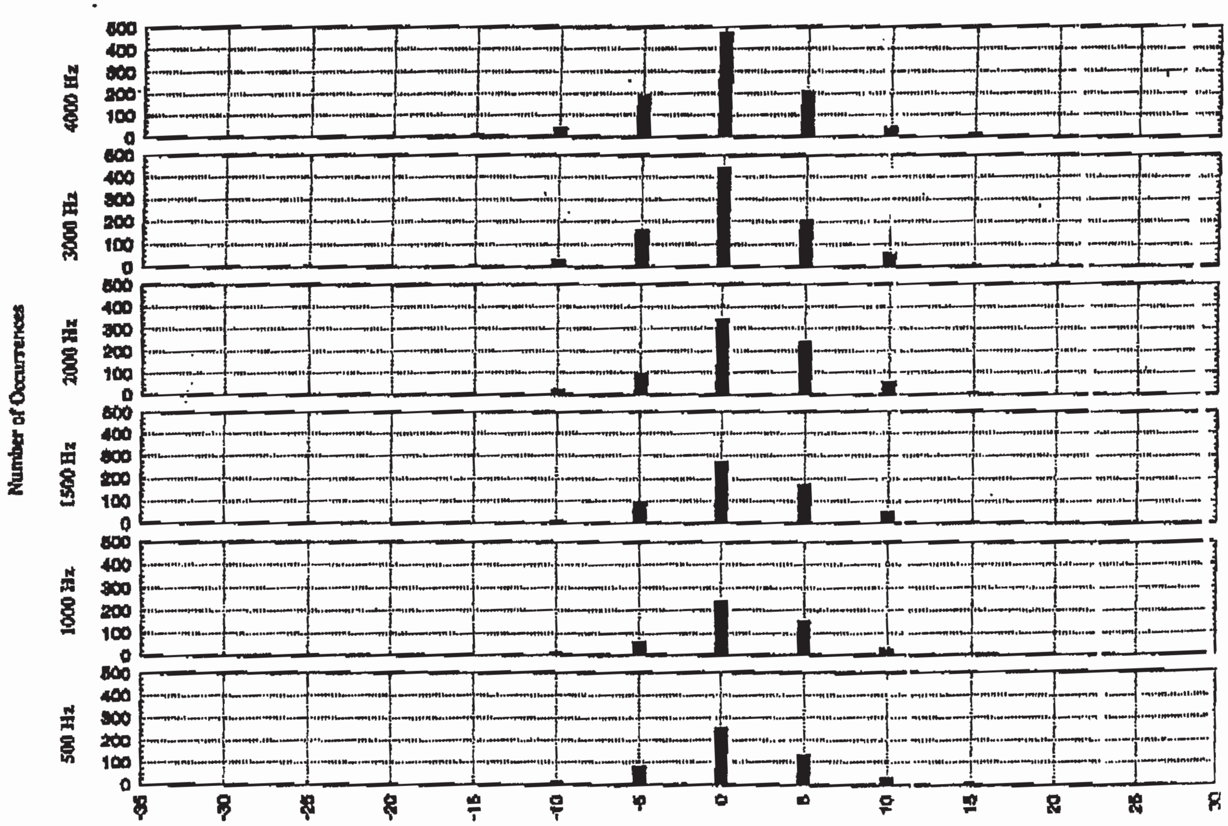

FIG. 3. The difference between PTA and CERA thresholds (PTA - CERA) at 500-, 1000-, 1500-, 2000-, 3000- and 4000 Hz for subjects where CERA thresholds less than 20 dB HL are eliminated.

obtained in this study implies that the CERA procedure can be used to estimate subjects hearing thresholds at a range of frequencies and stimulus levels. The accuracy of the CERA procedure used in this study is similar to that found by other researchers (Coles and Mason 1984, Hyde et al 1986, Prasher et al 1993). This accuracy is contingent upon consistent response identification protocols. Specifically, a random inter-stimulus interval was used to provide larger responses which were easier to detect; a template response was displayed to facilitate recognition of responses at lower levels and especially at threshold; an extended time window enabled the tester to examine the CER with respect to the residual background EEG activity. These protocols appeared to enhance the accuracy of the detection of the response, and helped to remove the subjective aspect of response interpretation. The difficulties in subjective response detection has been highlighted in a number of studies (Hyde et al 1986, Hoth 1993). The results in this study suggest that these difficulties have been minimised using the protocols described. The use of these protocols is further supported by the maintenance of accuracy when CER were obtained without prior knowledge of the true audiogram.

Conclusion

The results of this study show that there is a close relationship between CERA and PTA thresholds at all of the frequencies that are assessed in NIHL claims. This suggests that the CERA procedure used in this study is an accurate and objective test for determining hearing levels in NIHL claims.

References

ALBERTI P.W.R.M. (1970) New tools for old tricks. *Ann. Otol. Rhinol. Laryngol.* 79, 800-807.

BARRS D.M., ALTHOFF L.K., KREUGER W.W., OLSSON J.E (1994) Work related noise induced hearing loss : evaluation including evoked potential audiometry. *Otolaryngol. Head Neck Surg.* **110** (2) 177-184.

BOOTHROYD A. (1968) Developments in speech audiometry. *Sound* 2, 3-10.

COLES R.R.A., MASON S.M. (1984) The results of cortical response audiometry in medico-legal investigations. *Br. J. Audiol.* 18. 71-78.

GIBSON W.P.R. (1978) Cortical electric response audiometry (CERA) – The slow vertex potential. In Essentials of clinical electric response audiometry. Churchill Livingstone. Edinburgh, Great Britain.

GLEASON W.J. (1958) Psychological characteristics of the audiological inconsistent patient. *Arch. Otolaryngol.* 68, 42-46.

HALL J.W. (1992) Handbook of auditory evoked responses. Allyn and Bacon. Boston.

HOTH S. (1993) Computer-aided hearing threshold determination from cortical auditory evoked potentials. *Scand. Audiol.* 22, 165-177.

HYDE M., ALBERTI P., MATSUMOTO N., LI Y. (1986) Auditory evoked potentials in audiometric assessment of compensation and medico-legal patients. *Ann. Otol. Rhinol. Laryngol.* 9, 514-519.

JONES L.M., HARDING G.F.A., SMITH P.A. (1980) Comparison of auditory cortical evoked potentials, brainstem evoked potentials and post-auricular myogenic potentials in normals and patients with known auditory defects. In Evoked Potentials. Ed. Barber, C, University Park Press, Baltimore.

McCANDLESS G.A., LENTZ W.E. (1968) Evoked response (EEG) audiometry in non-organic hearing loss. *Arch. Otolaryngol.* 87, 123 128.

PRASHER D., MULA M., LUXON L. (1993) Cortical evoked potential criteria in the objective assessment of auditory thresholds: A comparison of noise induced hearing loss with Meniere's disease. *J Laryngol. Otol.* 107, 780-786.

RICKARDS F.W., DE VIDI S. (1995) Exaggerated hearing loss in noise induced hearing loss compensation claims in Victoria. *Med. J Aust.* In press.

TYBERGHEIN J., FORREZ G. (1967) Cortical audiometry in normal hearing subjects. *Acta Otolaryngol.* 67, 21-35.