Assessing the applications of cortical auditory evoked potentials as a biomarker in children with hearing aids

Ismail Zohdi Mostafa, Mohamed Ibrahim Shabana, Amira Maged El Shennawy, Hoda Mahmoud Weheiba

ENT Department, Audiology Unit, Cairo University, Cairo, Egypt

Correspondence to Hoda Mahmoud Weheiba, MD, Audiologist in Electricity Hospital, e-mail: hoda_weheiba@hotmail.com

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Background
Cortical auditory evoked potentials (CAEPs) are noninvasive measures used to quantify central auditory system function in humans. More specifically, the P1-N1-P2 CAEP has a unique role in identifying a central auditory system that has benefited from amplification or implantation. P1 reflects the maturation of the auditory system in general as it has developed over time.

Objective
The objective of this study was to assess the CAEP in children with hearing aids versus age-matched controls, and to compare the pattern of P1 CAEP in patients with hearing aids versus those with cochlear implants.

Materials and methods
Twenty hearing-impaired children (using their own binaural digital hearing aids) were compared with 20 age-matched and sex-matched children with normal hearing. In both groups, P1 CAEP latency and waveform morphology were recorded by free-field auditory stimulation using tone bursts at 500 and 2000 Hz at 100 dB sound pressure level. Finally, P1 CAEP was compared between patients using hearing aids and 20 children with cochlear implants.

Results
We have assessed the use of P1 latency and CAEP waveform morphology in a total of 20 children with hearing aids as a biomarker for the development of the central auditory pathway in patients with hearing loss. Children using hearing aids exhibited an exponential decay in P1 latencies, indicating an overall delay in maturation when compared with that in children with normal hearing. There was no statistically significant difference as regards P1 latencies and amplitudes between cochlear implant and hearing aid users, who showed statistically significantly higher mean values compared with the normal group.

Conclusion
Children's auditory systems develop comparatively as long as they are receiving appropriate amplification, whether this is through a cochlear implant or through the use of hearing aids. The P1 CAEP test can be applied as a tool in the diagnosis of central processing disorders in children with hearing impairments fitted with cochlear implants or hearing aids. This information will be useful when monitoring a child's progress with his hearing device and in auditory training.

Keywords:
P1 Cortical auditory evoked potential, free-field auditory responses, hearing aids, hearing impaired children, tone bursts

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Introduction

Cortical auditory evoked potentials (CAEPs) are noninvasive measures used to quantify central auditory system function in humans. More specifically, the P1-N1-P2 CAEP has a unique role in identifying a central auditory system that has benefited from amplification or implantation. P1 reflects the maturation of the auditory system in general as it has developed over time [1].

CAEPs are not widely used as a clinical test, especially in very young children, because of the difficulty in recording. Indeed, the use of tone bursts through hearing aids or cochlear implants, as in CAEP, offers the possibility to evaluate many more frequencies and louder intensities compared with other tests on the basis of a click as a stimulus [2].

On using P1 to assess patients, it may be difficult to make sufficiently audible sounds when testing patients with severe to profound hearing loss, and therefore, no P1 response to stimuli is observed. Moreover, Nash *et al.* [1] performed P1 testing before cochlear implant or hearing aid fitting in children with severe to profound hearing loss and revealed no response to auditory stimulation.

By measuring the central auditory system responses to amplified sound we can learn more about the effects of hearing loss and amplification on the central auditory system and, in turn, improve our understanding of the science underlying auditory rehabilitation [3].

Because P1 latency varies as a function of chronological age, it can be used to infer the maturational status of

auditory pathways in children. Of particular interest are children with significant hearing loss. P1 latency is considered to be a measure of central auditory development in patients who receive intervention in the form of hearing aids or cochlear implants. Sharma *et al*. [4] have described the use of P1 latency and CAEP waveform morphology as biomarkers for the development of the central auditory pathway in patients with hearing loss who receive intervention in the form of conventional hearing aids or cochlear implants.

P1 latency can provide the clinician with an objective tool to evaluate whether acoustic amplification in hearing-impaired patients has provided sufficient stimulation for normal development of the central auditory pathway. This tool when combined with traditional audiological and speech language assessment can give information on whether to provide the patient with a cochlear implant after an appropriate hearing aid trial [5,6].

Many researchers worldwide have suggested that there is a need for further research examining the clinical feasibility of P1 latency as an objective tool to evaluate the normal development of function of central auditory pathways in children with hearing impairment [7–9]; Golding *et al.*, 2008 [10]; and [11–13]. Thus, there is a great need for objective assessment of central auditory development in children after implantation or hearing aid fitting.

Materials and methods

A total of 20 hearing aid users and 20 normal hearing children of both sexes (24 male and 16 female) were included in the present study. The study was conducted at the Audiology Unit, Kasr El Einy Hospitals, Cairo University. At the time of testing, the ages of the patients ranged from 3 to 16 years. The hearing level of the hearing aid group ranged from severe to profound hearing loss. Children with hearing aids were further compared with 35 children with cochlear implants with severe to profound hearing loss, who were implanted between the ages of 3 and 7 years. All children were submitted to full history taking, otological examination, basic audiological evaluation, and aided warble tone response threshold measurements in sound field using a two-channel audiometer (GSI model 1761, Egypt) for hearing aid and cochlear implant children only. Immittance was measured using GSI 33, Egypt (Grason Stadler middle ear analyzer version II) and the P1 CAEP test was performed using Amplaid model MK12, Egypt.

Participants were comfortably seated in a sound-treated room and CAEPs were recorded for each participant by hearing aid amplification or cochlear implantation. One-channel recordings were obtained using an ipsilateral electrode montage. The active (noninverting) electrode was placed on the vertex (Cz), whereas the reference (inverting) electrode, M1/M2, was placed on the right or left mastoid in hearing aid patients and normal participants, and on the contralateral mastoid to the implanted side in the patients with cochlear implants (to minimize the stimulus artifact); the ground electrode was placed on the forehead (Fz). Electrode impedance was kept below 5 Ω.

P1 obligatory cortical auditory responses were recorded in response to tone bursts at 500 and 2000 Hz, applied through a loudspeaker connected to an amplifier to increase its output, placed at an angle of 90° to the side of the patient at a 1-m distance. The stimuli were presented at a rate of 1/s and at a level of 100 dB sound pressure level. It was confirmed with each child that this was at a loud but comfortable listening level.

Responses were recorded using filter settings of 0.1–50 Hz. The time window was taken as 500 ms. At least two runs of 200 response sweeps were collected for each participant. P1 morphology was evaluated and waveforms were judged replicable on the basis of visual inspection of the recordings. P1 was defined as the first robust positivity in the waveform in the latency range from 40 to 300 ms with waveform repeatability. Latency and amplitude values were determined for P1.

Statistical analysis

Normative values were estimated and upper and lower 95% confidence limits were estimated using the linear regression model and were represented by continuous lines. Quantitative (numerical) data were presented as mean and SD values. Student's *t*-test was used in testing significance for the comparison between the means of two groups. The analysis of variance test was used to compare the means of more than two groups. Qualitative (categorical) data were presented as numbers and percentages. The c^2-test was used for comparison between qualitative data. Pearson's correlation coefficient (r) was used to determine significant correlations between the different quantitative variables. The significance level was set at P less than 0.05 and P less than 0.01 was highly significant.

Results and discussion of the P1 cortical auditory evoked potential test

Seventy-five children of both sexes were examined in this study. Their ages ranged between 3 and 16 years,

with a mean age of 5.8 ± 2.8 years. They were 44 male and 31 female children.

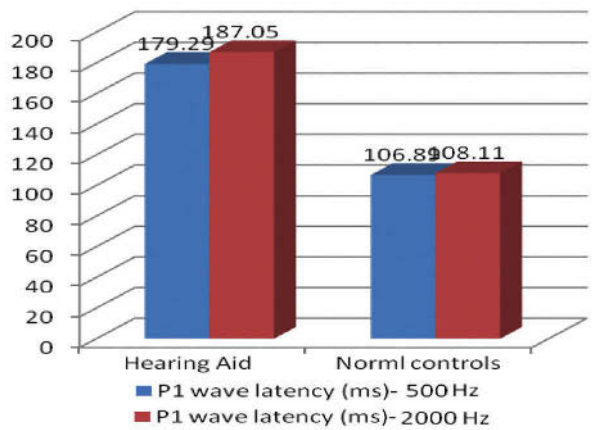
Comparison between hearing aid and normal hearing groups

All of the children using hearing aids showed considerable improvements in the aided versus unaided condition for the behavioral measures, which suggests that the brain processes speech stimuli in a more effective manner when hearing-impaired individuals use their personal hearing aids (Figs. 1 and 2).

This could be explained by central auditory system neural reorganization or plasticity and the acclimatization effect related to hearing aid use [14]. Changes were also expected for cortical responses in the frequency region of 2000 Hz on the basis of previous evidence for high-frequency cortical reorganization in humans with acquired hearing loss [15,16]. These results identified whether the two different stimuli can reliably give rise to different cortical responses, presumably arising from activity in different cortical locations and/or at different time points [3].

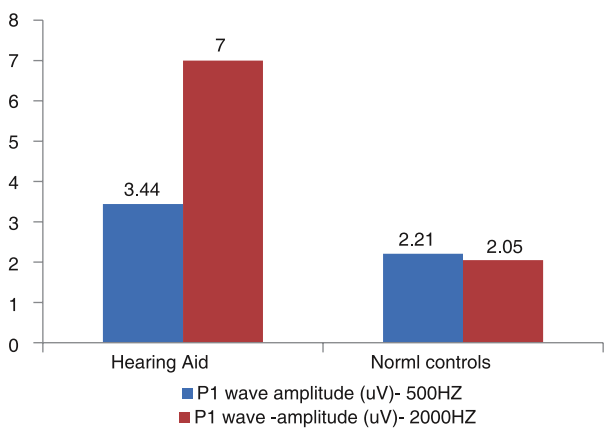
Figures 3–6 show that most latencies of individuals with cochlear implants and hearing aids were outside the 95% confidence limit for age-matched normal-hearing children. This was more evident in P1 latencies than in amplitude measures especially at 500 Hz, at which most children with cochlear implants and hearing aids had amplitudes within the range of normal. There was a highly statistically significant difference between the hearing aid group and the normal hearing group as regards history

Fig. 1



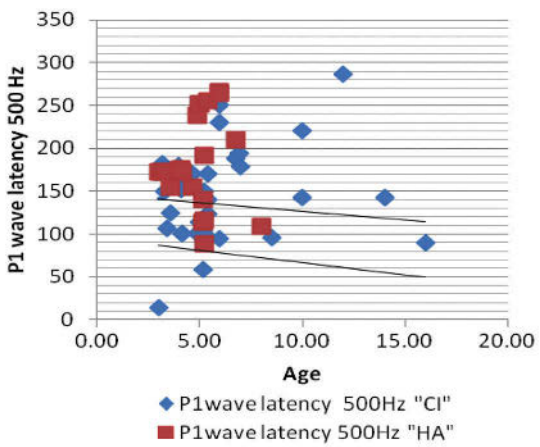
P1 wave latency in the hearing aid group compared with the normal hearing group. There was a statistical significant difference between the hearing aid group and the normal hearing group in the P1 latencies at the tested frequencies (500 and 2000 Hz).

Fig. 2



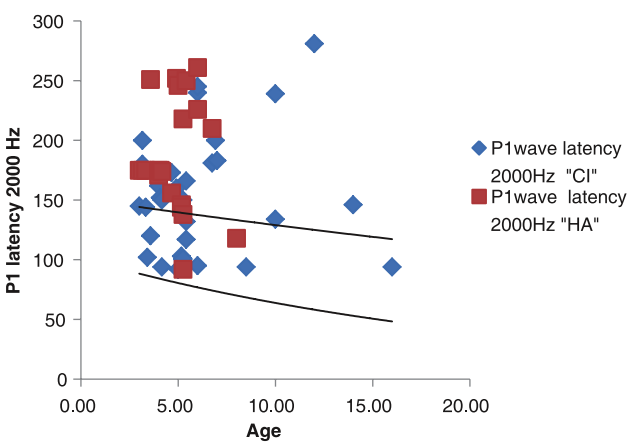
P1 wave amplitude in the hearing aid group compared with the normal hearing group. There was a statistically significant difference between the hearing aid group and the normal hearing group in the P1 amplitude at 2000 Hz only.

Fig. 3



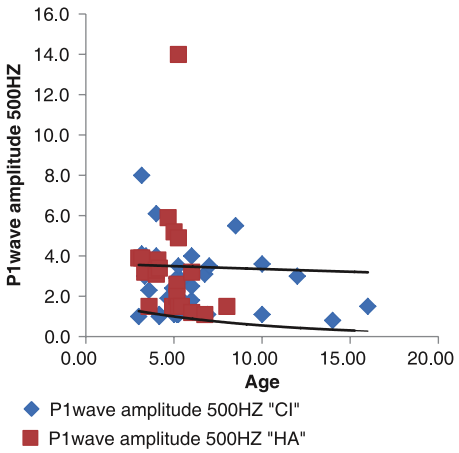
P1 latency of the cochlear implant group (in blue) and P1 latency values of the hearing aid group (in red squares), both at 500 Hz, plotted against the 95% confidence limits for the normal development of the P1 response. CI, cochlear implant; HA, hearing aid.

Fig. 4



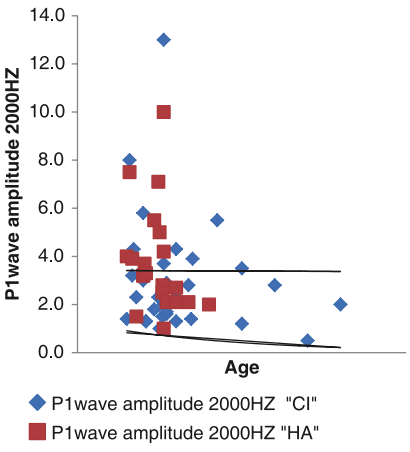
P1 latency of the cochlear implant group (in blue) and P1 latency values of the hearing aid group (in red squares), both at 2000 Hz, plotted against the 95% confidence limits for the normal development of the P1 response. CI, cochlear implant; HA, hearing aid.

Fig. 5



P1 amplitude of the cochlear implant group (in blue) and P1 latency values of the hearing aid group (in red squares), both at 500 Hz, plotted against the 95% confidence limits for the normal development of the P1 response. CI, cochlear implant; HA, hearing aid.

Fig. 6



P1 amplitude of the cochlear implant group (in blue) and P1 latency values of the hearing aid group (in red squares), both at 2000 Hz, plotted against the 95% confidence limits for the normal development of the P1 response. CI, cochlear implant; HA, hearing aid.

of consanguinity, denoting that the two groups are not matched as regards consanguinity (16 of 20 in hearing aid group, only six of 20 in normal hearing group showed positive consanguinity). There was no statistically significant difference in age at onset of deafness, etiology of hearing loss, age at hearing aid fitting, sex, social class, and residency, as well as P1 wave latencies and amplitudes in the hearing aid group. There was no statistically significant difference in P1 wave latency and amplitude at 500 and 2000 Hz in the hearing aid group – that is, there was no effect of frequency on P1 wave test results.

The findings of the present study demonstrated significant differences in all latency measurements recorded for either children with cochlear implants or children with hearing aids versus normal hearing controls when evoked with either 500 or 2000 Hz tone burst stimuli. There was no statistically significant difference as regards P1 latencies and amplitudes between the cochlear implant and heating aid users in the present study, who showed a statistically significantly higher mean value compared with the normal group. This supports our hypothesis that the evoked responses in age-matched children with hearing impairment, who received a hearing instrument during the sensitive period of cortical development, would be identical, whether they are receiving amplification from a cochlear implant or a hearing aid. This strengthens the finding that children's auditory systems develop comparatively as long as they are receiving appropriate amplification, whether through a cochlear implant or through the use of hearing aids.

However, future research is needed to support this emerging theory suggested by this preliminary study comparing directly the CAEP waveforms of age-matched children using different types of hearing instruments (cochlear implant or hearing aid) for the same duration. This study was carried out determine whether children who receive appropriate amplification during the sensitive period of maximal cortical plasticity will have comparable waveforms despite the type of hearing instrument used.

Collectively, these preliminary findings suggest that P1 CAEP might be a useful clinical tool for assessing hearing aid benefit in the younger hearing-impaired population and may be of assistance to audiologists in initially fitting and adjusting these instruments. Additional research is needed, however, before P1 CAEP can be used in the clinic to assess the neural representation of amplified sound.

Clinical implications of the P1 cortical auditory evoked potential test

The P1 CAEP test can be applied as a tool in the diagnosis of central processing disorders in children with hearing impairments fitted with cochlear implants or hearing aids. This information will be useful when monitoring a child's progress with his/her device and in auditory training. Absence of CAEPs while wearing high-powered hearing aids facilitates an early decision about cochlear implant candidacy. Decreases in P1 latency can objectively determine whether a child is receiving adequate amplification from his/her hearing instrument. Therefore, this would assist in the difficult decision making process of whether an implant is required in difficult-to-test populations, such as infants. If latency measurements do not decrease to within the age-appropriate range during the hearing aid trial, this would suggest that they are not receiving

sufficient stimulation and a cochlear implant should be considered [17]; Sharma, Dorman *et al*., 2002a [18]; Sharma, Dorman *et al*., 2002b. Likewise, the presence of robust CAEPs to moderate-level speech sounds (65 dB sound pressure level) can lead to the decision to continue with bilateral hearing aids rather than a referral for cochlear implant candidacy evaluation [19].

Acknowledgements

Conflicts of interest

None declared.

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