**Clinicians' views of using Cortical Auditory Evoked Potentials (CAEP) in the permanent childhood hearing impairment patient pathway.**

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**Abstract**

**Objective:** To obtain clinicians' views on the use of Cortical Auditory Evoked Potentials (CAEP) in the clinical pathway.

**Design:** A questionnaire aimed at clinicians who use the HEARLab system with the Aided Cortical Assessment (ACA) Module. Results compared for Australians (where HEARLab produced) to other countries.

**Sample:** The questionnaire was completed by 49 clinicians; 33 from Australia and 13 clinicians outside of Australia and 3 clinicians, destination unknown.

**Results:** The findings of this research demonstrated that clinicians using CAEPs found them valuable for clinical practice. CAEPs were used to verify or modify hearing aid fittings and were used for counselling parents to reinforce the need for hearing aids. With the use of speech token as the stimulus clinicians had more relevant information to increase confidence in decision-making on paediatric hearing management.

**Conclusion:** The main benefit from the use of CAEPs (using speech token stimuli) was for infant hearing aid fitting programmes, to facilitate earlier decisions relating to hearing aid fitting, for fine-tuning the aids and as an additional measure for cochlear implant referrals.

## Introduction

Neonatal hearing screening programme (NHSP) is one of the most important clinical advances for identifying hearing loss in children, leading to early management with hearing aids. The objective assessment of hearing loss continues to be refined in the development of clinical protocols. Despite early identification, reports persist of deaf children's language levels being below that of their hearing peers (Ching et al., 2013). The reasons for this are complex but may partly be due to under-amplification through hearing devices over the early months. The evaluation of early hearing aid fitting or cochlear implant candidacy for infants is challenging for audiologists due to the lack of tools to support clinical decision making, particularly between 3 and 8 months developmental age.

Assessing hearing using behavioural measures can typically be carried out reliably from around 6 months of age, and these measures are necessary for the audiologist to confidently prescribe appropriate amplification for the individual child. Hearing aid fitting can be verified using real ear measurements (REMs) which takes into account the size and shape of the individual child's ear canal (British Society of Audiology, 2007). REM targets allow audiologists to see the spectrum of sound delivered to the child. However, all the prescribed gains are based on estimated thresholds, which are difficult measurements to obtain reliably thus resulting in uncertainty. The current UK hearing testing protocol during the first 6 months of life relies on estimating hearing thresholds based on objective measures. These are typically a mixture of auditory brainstem response (ABR) and/or auditory steady state responses (ASSR) measurements. Audiologists then make recommendations for and fit hearing aids based on these estimates. Prescribed gains using this approach can often be quite conservative because of uncertainty surrounding the results. In particular, when audiologists

have insufficient information on audibility of speech sounds because the children are too young to respond.

The use of REM verifies the sound levels in the infant's ear, but does not evaluate audibility of the signal for the child or the transmission through the auditory pathway to the brain. In the standard infant audiological patient pathways in the UK, it is not until 6-8 months of age when Visual Reinforcement Audiometry (VRA) is possible, that behavioural responses can be measured to gain a more accurate assessment of the child's access to speech sounds through their hearing aids. The networks in the auditory system for processing speech sounds for normal hearing infants are formed early in life (Sininger et al., 1999). Thus, when sensory input to the auditory nervous system is interrupted during early development, the morphology and functional properties of neurons in the central auditory pathways can result in atypical anatomic and physiologic development (Sininger et al., 1999). Therefore, by the time a hearing-impaired child is able to demonstrate behavioural responses in clinic, important periods for linguistic development may already have passed, if the child did not have audible signals with their hearing aids.

An additional objective measure which has the potential to provide speech-related objective responses indicating detection of sounds in the brain, are the measurements of cortical auditory evoked potentials (CAEPs). These are electrophysiological responses which originate from neurons at the level of the primary auditory cortex, and from the auditory association areas in the temporal lobe. There are three major components in the recorded response referred to as the P1-N1-P2 complex. In the early months of life, P1 component varies as a function of age, occurring around 300 ms in newborns, decreasing rapidly over the first 2-3

years of life, decreasing until reaching a mature adulthood latency around 60 ms (Sharma et al., 2015).

CAEPs can be used to evaluate aided hearing by testing detection thresholds for speech sounds through hearing aids without requiring an active behavioural response. CAEP recording is conducted while the infant is awake, thus avoiding the need for sedation or natural sleep which is required for ABR and ASSR testing. Consequently, they can give supplementary information for evaluating the responses to speech at specific presentation levels in young infants or difficult-to-test children. Sharma et al., (2006) has shown that the latency of the P1 and morphology of the CAEP responses change with the development of the central auditory pathways and that there is a maximal period of cortical plasticity in the first 3.5 years. For children receiving cochlear implants, if they are implanted below this age they often achieve age-appropriate cortical responses within 3–6 months after stimulation. Cardon et al., (2012) has shown two major principles of neuroplasticity direct clinical outcomes: 1) adequate stimulation provided to the cortex and 2) appropriate timing of stimulation through hearing aids or cochlear implants. Early intervention with appropriate auditory input results in high likelihood of normal auditory cortical development in children with congenital deafness.

Munro et al., (2011) tested sound field CAEPs (using HEARLab) on 24 normal-hearing adults, with and without earplugs. The results showed that the CAEP response detection was good except for the lowest presentation level. They stated that this most likely occurs when the stimuli are within 10 dB of the behavioral threshold. Punch et al. (2016) reported a retrospective review of 83 infants with hearing loss in Australia. The infants were fitted with

hearing aids and underwent aided CAEP testing to confirm their hearing loss and to evaluate the initial hearing aid fittings. Their findings showed that CAEP testing facilitated rehabilitation and CAEP testing is now part of routine infant hearing aid fitting programmes in Australia. The introduction of CAEPs where easily implemented in Australia because there is a single organisation that takes care of hearing impaired children, this is Hearing Australia. National Acoustic Laboratories provided the scientific evidence (CAEP presence is correlated with audibility; CAEPs increase with hearing aid gain; the automatic detection works as well as an observer), and built a clinical device. The HEARLab was also used in Australia to test children with auditory neuropathy spectrum disorder (ANSD) where ABR responses or early latency electrophysiological responses were not observed and CAEPs are used to estimate audiograms (Pearce et al., (2007) & Rance et al., (2002)

The current work has expanded on the Punch et al. (2016) study by exploring the viewpoints and attitudes of clinicians towards HEARLab. In addition, attitudes outside of Australia were evaluated, in regions where the use of cortical measurements is not part of the clinical routine and it was determined how the equipment is used in the infant hearing pathways.

Whilst children with severe-to-profound hearing loss are at risk for speech, language, social and emotional difficulties, there is uncertainty for those with a milder degree of hearing loss and are often placed on a programme to monitor and record hearing and speech development (Bagatto et al. 2013). Audiologists face additional challenges when recommending hearing aids for milder degrees of hearing loss because of the uncertainty around the benefits of amplification (Bagatto et al. 2013; Fitzpatrick et al. 2014). Mehta et al. (2017) showed that there can be delays in hearing device provision for mild-to-moderate

hearing loss due to parental and potentially audiologist uncertainty about the benefits of, or requirements for, hearing aids. They demonstrated that with the introduction of CAEPs the median age of hearing aid fitting was reduced from 9.2 to 3.9 months for all extents of hearing loss, but for cases with the mild-to-moderate hearing loss, the median age for hearing aid fitting reduced from 19 to 5 months. It was suggested that the CAEPs offered an educative process for the parents and audiologists to support decision-making for hearing aid fitting, particularly for those infants with a milder degree of hearing loss.

Subsequently, Mehta et al. (2019) explored the idea that the CAEPs may have influenced parental decisions. The findings from that study demonstrated that the use of CAEPs was a major factor in helping families appreciate that hearing aids could be beneficial for their child because of interpreting the presence of a response. Parents found the overall procedure, stimuli and visibility of results valuable.

In order to understand the views of clinicians using CAEP testing as part of hearing management for children referred from the NHSP, a questionnaire was developed. This questionnaire was specifically focussed on understanding the benefits of a commercially available system, HEARLab but it is believed that these findings are generally relevant to all clinically available cortical response measurement systems. The study reported the opinions of audiologists on the use of CAEPs, in particular for those using the HEARLab system with the Aided Cortical Assessment (ACA) Module. One of the features of the HEARLab equipment is that it uses speech tokens /m/,/g/ and /t/ which were extracted from running speech. These stimuli are used to assess aided and unaided responses at different stimuli presentation levels to determine the level at which the speech token(s) are detected by the child. HEARLab uses

an automated statistical analysis of the waveforms, therefore clinicians do not rely on their visual analysis to indicate if a response is absent or present. The findings may therefore be relevant for any cortical response system using speech-like tokens to assess aided responses.

The intention of this current study was to evaluate the effectiveness of the equipment in countries outside of Australia where routine clinical pathways do not include CAEP measurements, as well as updating the Australian viewpoint. The research questions aimed to determine the following:

How does the use of CAEP impact on confidence for patient management decisions (RQ1),
What are the stages in the patient pathway where CAEPs are most helpful in the clinical management of infants with hearing loss (RQ2),
Which patient groups benefit most from the use of CAEPs (RQ3),
In the clinicans' view, what is the impact of having CAEP results for parents of children with hearing loss (RQ4),
What are the overall clinical benefits that may be derived (RQ5).

**Methods**

A questionnaire had been developed for clinicians who use the HEARLab system with the Aided Cortical Assessment (ACA) Module (Punch et al., 2016). This was adapted for the current purpose following feedback from audiologists and expert reviewers. The original questionnaire contained statements that the respondents agreed/disagreed with, choosing their responses from a Likert scale.

Two audiologists initially reviewed the original Punch et al. (2016) questionnaire and revised the questionnaire adding a section on demographics and removing some sections from the original that were not relevant outside Australia. The excluded statements related to training and installation of equipment, additional features such as impedance checking, electrode problems, adverse reaction issues and report writing.

**Expert review of the questionnaire**

A first draft of the questionnaire was sent to three additional experts for review of content and clarity. The panel included one clinical scientist, one speech and language therapist and one research physiologist specialising in auditory evoked potentials. All three had backgrounds in audiology and deafness. The feedback suggested minor amendments to the wording and grammar, which were revised for the new version of the questionnaire. Some additional statements were added to the adapted questionnaire as advised by the experts. These statements were:

- The results of HEARLab do not change my approach to rehabilitation
- The HEARLab is important to my clinical practice
- The information HEARLab provides in achieving optimal habitation outcomes for children has been useful in clinical practice

The questions in the final version of the questionnaire can be seen in Appendix 1.

An online version of the questionnaire was created in UCL OPINIO (Object Planet, Inc., n.d.) survey platform. An e-mail was sent to potential participants informing them of the study and

the link to the questionnaire. Ethical approval to conduct the study was given by UCL research ethics department: project ID: 9781/001.

The British Society of Audiology and the British Academy of Audiology administrative teams circulated the online link to the questionnaire to their members. All audiology departments using a HEARLab system in the UK, Australia and worldwide were sent a link to the questionnaire from the National Acoustic Laboratories in Sydney, Australia (developers of HEARLab). The online questionnaire included a section to indicate consent prior to participating in the on-line questionnaire. All audiology departments using a HEARLab system in the UK, Australia and worldwide received the link which was forwarded by the National Acoustic Laboratories in Sydney, Australia (developers of HEARLab). The online questionnaire contained a section on consent to participate before respondents could complete the online questionnaire.

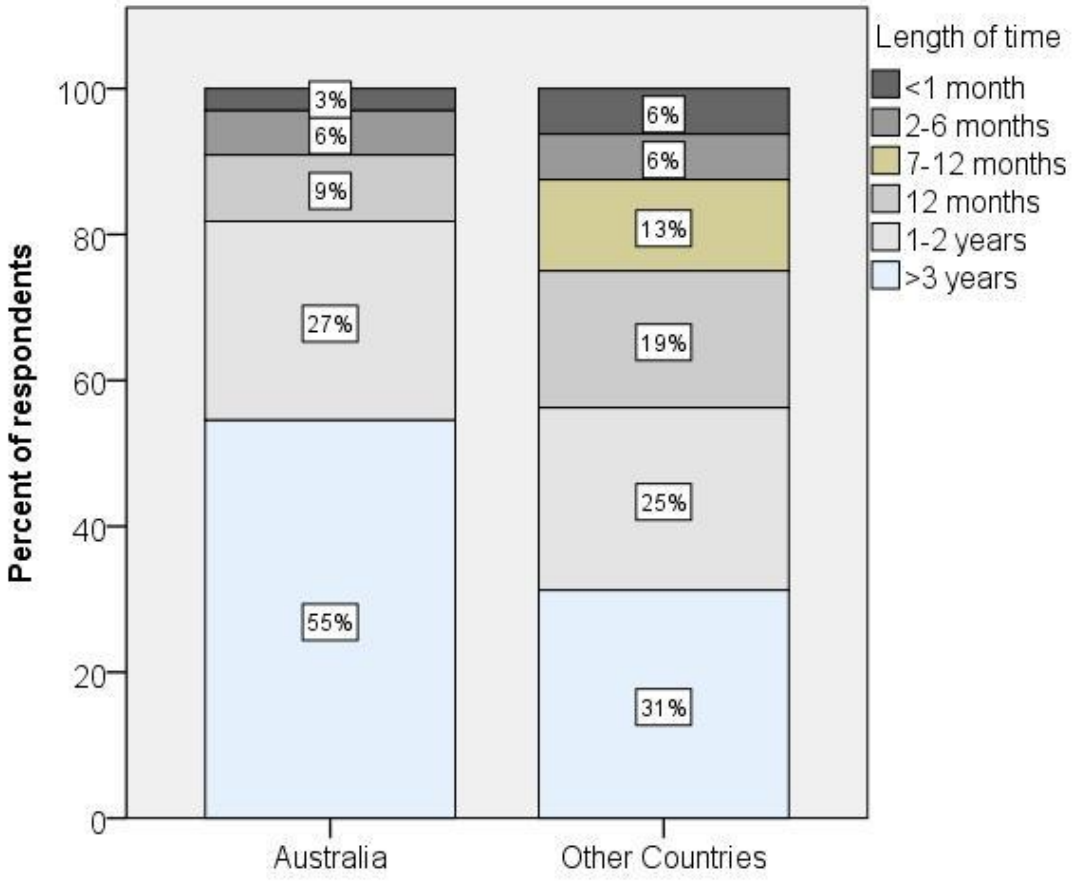
Part 1 of the questionnaire (Q1-Q3), included demographic questions about the clinicians and how much experience they had with HEARLab and with whom they used the equipment. Part 2 of the questionnaire (Q4-Q11), aimed to find out the management pathways that were most appropriate for including the CAEPs; Q12-Q22 addressed clinicians' views on the equipment. The response format used the Likert five point scales. For the analysis the 'strongly agree' and 'agree' options responses were collapsed together as were the 'strongly disagree' and 'disagree'. The responses were compared between Australia vs other-countries because the equipment has been available in Australia for longer with better support and training.

**Results**

**Respondents:**

The online questionnaire was completed by 48 audiologists and 1 clinical university professor. The responses were collected from Australia (33), 16 clinicians outside of Australia (Turkey (2), UK (7), New Zealand (2), Taiwan (1), United States of America (1)) and 3 which were completed from unknown countries outside Australia.

The results showed that 47% of clinicians that completed this survey had >3 years' experience in using the HEARLab equipment and 49% had completed between 11-50 assessments. When the data was categorised into Australians versus other-countries 55% of clinics from Australia have >3 years' experience, compared to 31% of other-countries with >3 years' experience see Figure 1.



**Research Q1. Does the use of CAEPs make audiologists more confident about patient management?**

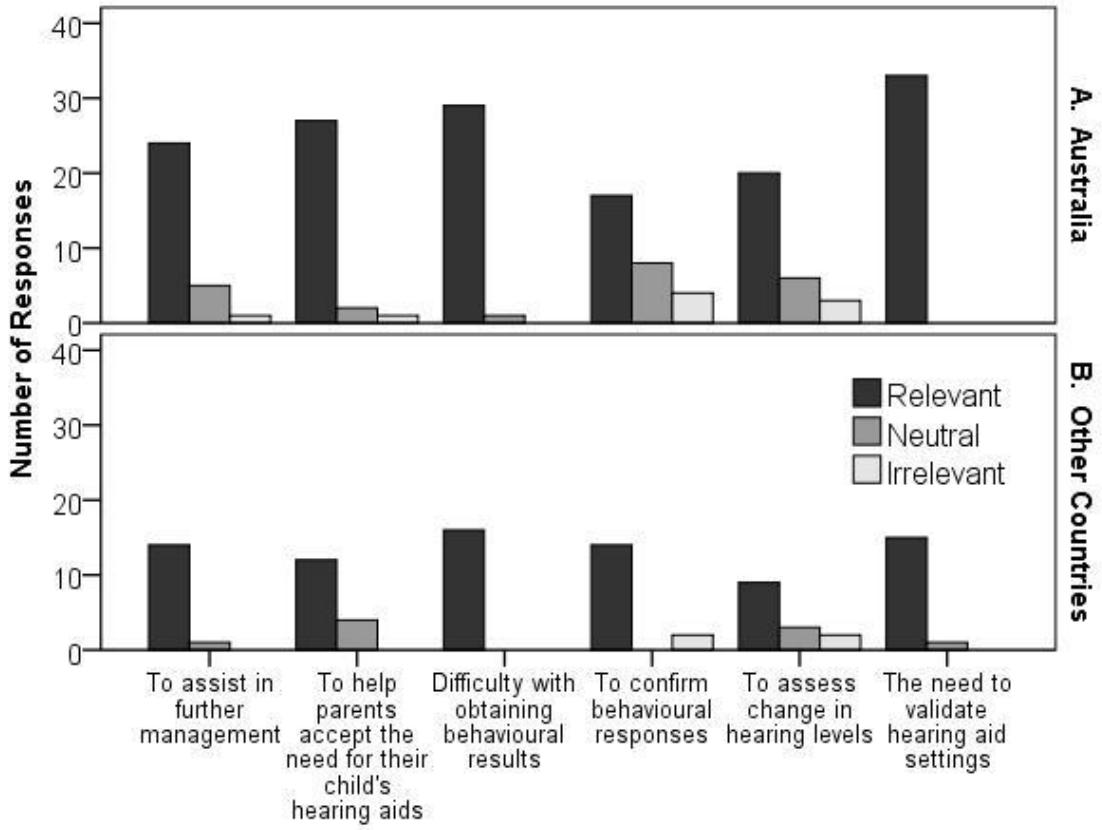
The primary aim of the research was to assess clinicians' views of CAEP use in the management of infant hearing loss. Answers to questions 4-8 were averaged. These questions in the survey were specifically looking at patient management. There was high agreement that CAEP made audiologists more confident in patient management. When responses were separated into Australia and other-countries, the findings were that 73% of responses from Australia agreed that CAEPs made clinicians more confident and 27% clinicians disagreed. This is compared to other-countries where 63% of clinicians agreed and 37% disagreed. Overall, there is a strong agreement that CAEPs made audiologists more confident in their management process. Clinicians commented that they used the equipment *'for children with mild/moderate hearing loss to determine whether to fit hearing aids.'*

Across countries, 91% of clinicians use the HEARLab to validate hearing aid settings. When data was compared by region it showed that 100% of Australians and 93% of other-countries use the CAEPs to validate hearing aid settings. With respect to provision of hearing aids 87% of clinicians' reported basing a decision to provide hearing aids on aided cortical responses (across regions) and 52% used the cortical responses to help adjust the hearing aid setting. A comment on the survey by one of the clinicians stated that: *'we have had excellent success with improvement in performance following hearing aid settings based on cortical assessment'.* However, there were clinicians that also commented '*that they do not feel confident that the HEARLab provides useful and reliable information'.* The questionnaire

responses indicated that 45% of clinicians had something negative to say about the HEARLab and 55% of clinicians had something positive to say about the equipment. Some of the negative comments about the equipment were generally referring to the HEARLab equipment itself. Examples of the negative comments about the equipment were that it was *'very temperamental, have problems with the system very often', 'sometimes it is difficult to identify which peak is the real P1', 'the traffic light button takes a long time before it goes green while testing', 'a smaller unit would be more practical' and 'poor connection between electrodes and pre-amplifier.*

The survey also demonstrated that approximately 67% of clinicians use cortical responses to assess changes in hearing levels. The survey has shown that 85% of clinicians used the visualisation of presence/absence of responses to help parents understand and accept the need for their child to wear hearing aids with 77% of professionals agreeing that parents were positive about the use of the equipment. When broken down by region the data demonstrated that 81% of clinicians from Australia and 75% of other-countries used the CAEP results to help parents. The results of the CAEPs allowed audiologists to discuss the potential management options with parents, and show aided benefits, where they could not in the past. One of the clinicians commented that the '*ability to discuss with families the results from the HEARLab has helped guide management decisions.'* However, some clinicians commented '*we found it difficult to discuss the results when no reliable responses were found due to movement or an unsettled child*.' This experience would most likely be the same for all objective tests but some clinicians found it frustrating that they were not always able to comment on the aided results, and in those cases that this disengaged families from the management discussions. When separating the results into Australian clinicians versus other-

countries the consensus regarding CAEP showed similar proportions agreeing on relevance (Figure 2).




**Clinical benefits of the CAEPs**

**Research Q2. Stages in the patient pathway in which CAEPs are most helpful**

As can be seen in Figure 3 (results of Q10), the results showed that 26% from Australia and 29% of professionals from other-countries use HEARLab at the follow-up after the initial hearing aid fitting and 20% from Australia and 25% from other-countries use the equipment with older children who are difficult to condition behaviourally. One clinician supported this finding by saying that they used the equipment for *'children diagnosed via ABR with slight or*

*mild hearing loss to determine amplification recommendation.' The survey has shown that 18% from both groups showed that* clinicians used the HEARLab for cochlear implant candidacy. Clinicians use the results from CAEP to refer children for cochlear implant assessment. Where aided CAEP responses are absent, the results may help parents and audiologists move towards referral for cochlear implants. A clinician's comment was that CAEPs *'can provide information about whether infants/toddlers/young children/difficult to test clients are getting sufficient benefit from their hearing aids, whether they require adjustments or referral for cochlear implant candidacy assessment.'*

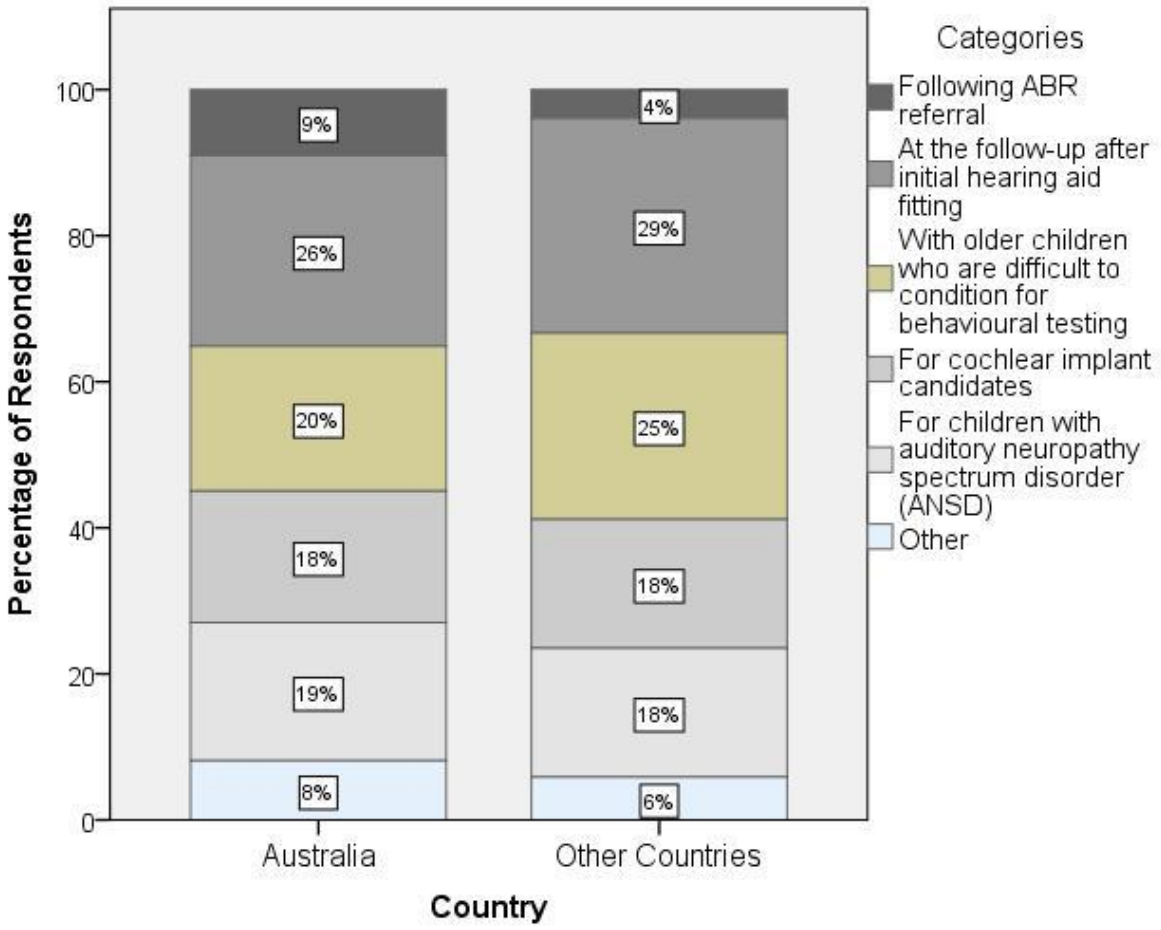
The results have also shown that the percentage of clinicians using the CAEPs following ABRs are low (9% in Australia and 4% from other-countries), showing that clinicians predominantly rely on ABRs as their preferred method for assessing hearing acuity. The CAEPs are typically used either before hearing aid fitting for clinicians to decide whether to aid a child or after the fitting to show aided responses.

The CAEPs were mainly used for determining appropriateness of amplification with 84% of clinicians' claiming that they used CAEPs to determine potential benefit of hearing aids. Clinician comments included the following:

*'Yes - the information (in combination with other sources of information such as parent questionnaires) are used to determine if hearing aids are adequate, if hearing aid settings need to be adjusted, and if cochlear implantation should be considered.'*

*'I use the results to make adjustments to hearing aids before behavioural testing is possible/reliable (7-8 months of age).'*

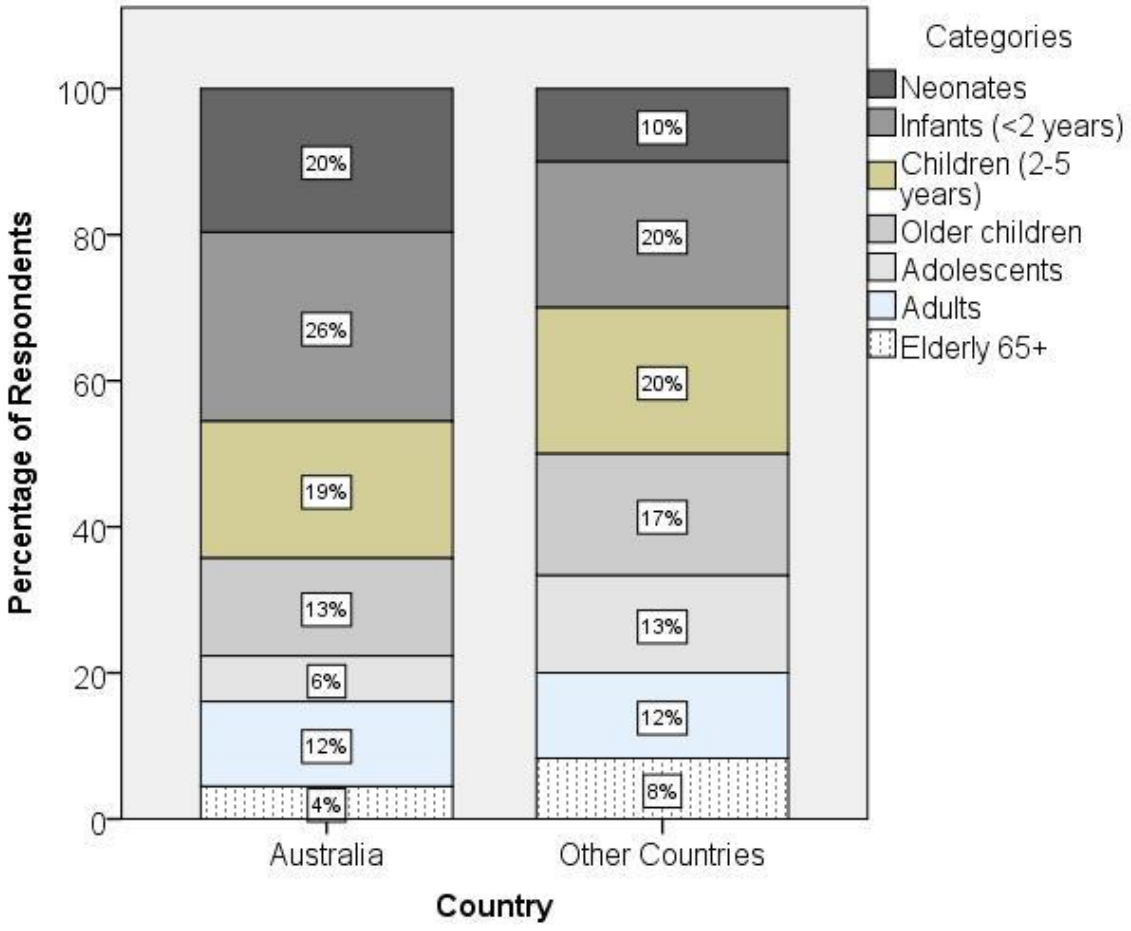
Findings from question 5 from the survey showed that 92% of clinicians used aided CAEPs to fine-tune the aids once fitted. In the Australian group, 94% of clinicians agreed that CAEPs helped them to adjust the aids and 88% of clinicians from other-countries reported the same. One clinician reported that '*they have found excellent success with improvement in performance following hearing aid changes based on the cortical assessments*.'




**Research Q3. Which patient groups benefit most from CAEPs?**

Results from question 11 from the survey showed that CAEPs were most helpful for infants at < 6 months and under 2 years of age. It showed that 20% of the Australian clinicians use the CAEPs as supplementary to the ABR results, on neonates however, a much smaller proportion

(10%) of clinicians from other-countries do this. Twenty percent of clinicians from other-countries used the CAEPs on infants under 2 years of age and with children aged between 2-5 years but it was not so common for very young children. In general, CAEPs are used for children where no reliable responses can be obtained. Figure 4 shows that 46% of clinicians from Australia and 30% from other-countries use the equipment on children under the age of 2 years and 19% from Australia and 17% from other-countries use it on older children to assess their hearing levels. Only 12% from both groups of respondents used CAEPs with adults and the elderly population.




**Research Q4. What are the clinicians' opinions of parental views of the CAEPs?**

Question 12 from the questionnaire was used to answer this question. The results of the questionnaire show that 80% of clinicians from both groups believe that the results from CAEPs are positively received by parents. When the groups were separated into Australians and other-countries there is a similar pattern of results in both groups, with 84% of clinicians from the Australian group and 88% of clinicians from other-countries observing that the HEARLab results are positively received by parents. Clinicians and parents both find the results easy to interpret. One clinician said that *'parents understand the analysis easier as they are able to relate to the sounds'* however, not everyone was positive. A different clinician reported that '*parents mentioned that they found the sounds were cumbersome and seemed artificial, not like /m/, /g/ and /t/.'*

**Research Q5. The overall views on the clinical measurement of CAEPs with the HEARLab equipment:**

**Clinical viability**

In general, the results from question 18 showed that the HEARLab equipment was specifically well received by the respondents with 89% of clinicians stating that they would recommend it to other audiologists. Question 19 revealed that 92% of clinicians found the HEARLab to be important to their clinical practice. One clinician responded and said 'it is *essential to clinical practice for infants fitted at under 6 months and even for those under 12 months and certain patient groups*.' Furthermore, results from question 20 shown that 86% of professionals feel that the information that HEARLab provides optimal habilitation outcomes and 67% of clinicians do change their rehabilitation approach depending on the results. A clinician said '*I always use HEARLab as part of a test battery and management/rehabilitation decisions are made once all information is looked at correctly.'* Question 13 revealed that 26% of clinicians

take 15-20 minutes to complete the measurements using the three speech sounds at one intensity and 28% of clinicians said that it took 21-30 minutes. So the majority suggested that 30 minutes was sufficient to complete the testing at one level. However, this time could vary due to a child's arousal state and restlessness, with 61% reporting that one of the major factors preventing test completion was the restlessness of the children.

Overall, audiologists have found the HEARLab equipment valuable to both themselves and families and discussion of the results provided a way to fill the gap between diagnosis of the hearing loss and the point at which behavioural testing could take place. As mentioned by one of the clinicians, '*the HEARLab is one more tool which helps to verify intervention.'* Another commented that *'every clinic dealing with infants' hearing aid fittings should use CAEPs before behavioural testing is possible.'*

**Clinical views of the speech tokens (Q14)**

This revealed that clinicians found the results easy to interpret and that the detection results for the /g/ stimulus in particular are consistent with the behavioural results. This was found in responses to question 14: 80% of clinicians answered that the /g/ token was similar to the behavioural results and 67% found the /t/ sound to be similar to behavioural results. Clinicians commented that /m/ is most affected by the child's activity level and middle ear status and one of the clinicians commented that *"/m/ is more likely to be absent even if the child is hearing the sound.'* Clinicians reported that 39% of /m/ token correlated to the child's behavioural responses. This shows that clinicians mainly use the /g/ and /t/ stimulus for testing. The survey to question 6 demonstrated that 81% of clinicians feel that the results from CAEPs correlated with behavioural thresholds.

**Difficulties with clinical equipment (Q16)**

Some clinicians reported technical difficulties e.g. with the size of the HEARLab equipment and with poor connections between electrodes and the pre-amplifier. The equipment also requires ongoing repairs and can be 'temperamental'. About 44% percent of clinicians have reported that excessive epoch rejection has meant that clinicians are unable to carry on testing, which can be time consuming. One clinician commented that *'I don't like it, it takes so long for each speech sound, 5-7 minutes on average – it is very hard for many little children to be kept still.'* Around 25% of clinicians who question the reliability of the results, also the size of the equipment and one of the clinicians commented, *'it is too black and white and the equipment is very inflexible.'*

**Discussion**

The aim of this study was to gather clinicians' viewpoints of the CAEPs using the HEARLab in the infant hearing assessment patient pathway. This research specifically focussed on the HEARLab equipment but the findings are generalizable to other CAEP systems which use speech tokens.

Punch et al. (2016) developed a questionnaire to evaluate the use of HEARLab equipment with Australian clinicians. One of our goals was to compare the experiences in other countries with those of Australian clinicians. The findings from this study were similar to those of Punch et al. (2016), the majority of clinicians who routinely used the HEARLab system reported that it was a valuable component in their clinical test battery. The results have shown that clinicians feel confident about using the HEARLab equipment and found it helpful for adjusting and fine-tuning hearing aids. The measures allow clinicians to ensure that adequate amplification is provided and appropriate speech input levels can be achieved, thus increasing

the chances that the child will hear spoken language and this will contribute to/enhance their speech and language development. The clinicians also revealed that the HEARLab was inflexible and time consuming.

Additionally to the above, the current study has shown that clinicians from other countries and Australia who completed the questionnaire felt more confident about patient management, especially for the age groups between 4 and 12 months when other behavioural testing is limited and hearing aids have to be fitted based on estimated audiograms. The results from the HEARLab were easy to interpret especially for parents. Furthermore, this study found the results of CAEPs helpful in decision making and were used for counselling parents to reinforce the need for hearing aids. These findings were different to the Punch et al (2016) which showed that parents were against the use of the test and preferred to wait until behavioural responses and they reported that parents found it hard to relate CAEP results. The findings of this research demonstrate that even though CAEPs have not routinely been used in general clinical practice outside Australia, those clinicians using CAEPs find them valuable for clinical practice. The numbers of non-Australia respondents is small because it is an emerging technique. I have reviewed the literature to determine the proportion of articles outside of Australia using the approach. 31 numbers of articles were identified that discussed using CAEPs and of those 11 did not have any Australian authors. This still reflects a global reflection on the usefulness of CAEPs. The non-Australian viewpoints represented one third of the respondents and the comparison with the Australian respondents is clear in the analysis. Outside of Australia the support network is not as strong and there are different healthcare systems. The smaller number of respondents outside of Australis was expected and has been raised in the study limitations.

Overall, it has shown its value in the clinical environment as audiologists are able to show parents the aided benefit, especially for those with mild hearing losses and also for children with complex need's. It has been reported to be a great counselling tool for parents. In addition, it helped the audiologists themselves understand the need for aiding and provided a tool for fine-tuning the hearing aids. The results indicated that approximately 50% of clinicians use the CAEPs for children <5 years of age. The use of CAEPs have helped clinicans confirm the child's hearing loss and reduce the ambiguity regarding appropriate clinical interventions for children with mild hearing loss. With the use of speech token CAEPs clinicians are able to make a confident decision on the child's further management. The major difference between the two groups is that Australian clinicians are using CAEPs more routinely in clinics than other countries.

The current results showed CAEPs to be useful at different points in the patient's pathway. The questionnaire demonstrated that CAEPs were the most useful after the initial hearing aid fitting. Clinicians reported a positive response from parents because it was easy for them to observe the aided benefit because of the simple visual display of the CAEP measurements when a response was present. It was reported in the questionnaire how CAEPs helped with babies who had mild hearing loss. Audiologists around the world face difficulties when deciding whether to fit hearing aids on children who have mild-to-moderate hearing loss. It has been demonstrated by Fitzpatrick et al. (2010) that there is ambiguity regarding appropriate clinical interventions for children with this level of hearing loss particularly involving the need for audiological management. CAEPs allow a way to show clinicians and families aided benefit. In the cases where the stimulus presentation did not elicit a response

the test helped parents and professionals to know when to consider moving towards cochlear implant referral. The CAEPs have allowed clinicians and parents to see if responses are present to speech tokens, opening up opportunities for clinicians to speak to parents using meaningful results about further management.

Sjoblad et al. (2001) demonstrated that 65% of parents in the early stages of the hearing device fitting questioned aided benefit and 30% of parents requested better education around the benefit that the aids provided to their child. The current study showed that clinicians found that the use of CAEPs were positively received by families. It has highlighted that clinicians from Australia and other countries felt that families valued the demonstration of perception of speech sounds and used this tool as a discussion point for management. Mehta et al. (2017) have demonstrated the importance for families to be educated on hearing loss and hearing aids and CAEPs were a key element for intervention. Their study showed that parents who defer hearing aid fittings fell from 40% to 19% for children who had a mild or moderate hearing loss when CAEPs were used to demonstrate access to sound to parents. They were also able to show 82% of cases with aided benefit through the CAEPs, which motivated the parents to support their child's consistent use of hearing aids.

The data have shown that fewer than 10% of clinicians in both Australia and other countries use it immediately after an auditory brainstem response (ABR) referral. An ABR referral occurs in some countries after failing the neonatal hearing screen as part of the post-screen diagnostic test protocol. Our survey has shown that ABRs are the standard procedure that are used in NHSP to verify hearing acuity. ABRs are the initial stages of diagnosis and are useful in obtaining thresholds in babies. CAEPs are used to supplement initial ABR results when the

child needs to be asleep. Thus, not many clinicians are using CAEPs at this initial stage in the clinical pathway.

Fortnum et al. (1996), showed that 1/1000 in the UK are born deaf, with up to 40% of deaf children showing additional health, social or educational needs ranging from dyslexia to more severe disabilities such as cerebral palsy and Down's syndrome. In Australia 3.3/1000, children are affected by hearing loss (Australian Hearing, 2017) and Ching et al., (2013) has shown that 27% of hearing-impaired children have additional disabilities. Research conducted by McCracken & Pettitt (2011) indicated that patients with complex needs such as autism or cerebral palsy tend to have a later diagnosis of hearing loss than those without. Their research revealed that 14 parents identified significant delays in both achieving detailed assessment and their child being fitted with amplification. Under a third were diagnosed by 6 months and similar numbers were not diagnosed until they were at least a year old. Such delays meant that these children were not appropriately aided and crucial time was lost in the early months of language acquisition. CAEPs are an objective measure and are therefore, not reliant upon a behavioural response which makes it an important tool for assessing children with complex needs to avoid delays in the provision of amplification. The data presented in this study have shown that around 20% of all respondents use CAEPs for assessment of children with additional complex needs and it is considered by those using it to be a valuable measure; it provides a systematic and objective means of indicating some detection of frequency information at low, mid and high levels.

As with any equipment there are drawbacks and the results revealed that the specific HEARLab equipment has some disadvantages and some clinicians expressed how restrictive the equipment is. Clinicians found the equipment bulky and 'temperamental'. In addition,

clinicians indicated that they would like to be able to change the stimulus. Another drawback of the equipment is how restless children sometimes can prevent results from being obtained. Even with this disadvantage, 69% of clinicians reported that the assessment takes around 30 minutes to complete.

One of the limitations of this study is that only 13 clinicians from other countries took part in this study, compared to 49 from Australia. This reflects the widespread use of HEARLab in Australia and that the equipment is used less routinely outside Australia. Clinical experience from Australia shows the benefits achieved from the CAEPs. Between the two groups it shows that 55% of the Australian group have >3 years of experience with the use of the CAEPs compared to 31% of clinicians from other countries. This shows that clinicians from Australia are much more skilled and more confident in using CAEPs than clinicians from other countries. It is important to note that the other countries are not supported by the National Acoustic Laboratories as closely as the Australian clinics and thus, this should be considered when interpreting the results. There seems to be peer-peer working groups set-up in Australia, which is not currently routinely available in other countries. Australian clinicians have more training opportunities on the CAEPs. The lack of support and not routinely using CAEPs means clinicans in other countries may not be so aware of the what the results indicate. HEARLab was the only system at the time of research that used speech tokens and equipment that was easy to use in an clinical setting but other similar CAEP equipment can be used to help assess patients in the pathway. This questionnaire demonstrates that the equipment is useful for supporting clinical decisions and that the use of speech stimuli makes the measurements meaningful for understanding access to speech sounds. It is recommended that more manufacturers should consider using speech tokens in their CAEP equipment.

## Conclusion

CAEPs can be effectively used at many stages in the infant assessment pathway providing valuable information where behavioural testing is unreliable or impossible for babies and infants and is a useful counselling tool for parents to be able to observe impact of hearing loss on speech and benefits of hearing aids. A major area where CAEPs that use speech tokens are beneficial is with infant hearing aid fitting programmes, fine-tuning the aids and providing an additional measure to facilitate earlier patient management decisions relating to hearing aid fitting or cochlear implant referrals. The CAEPs were reported to be important in the complex needs population where routine assessment is not always possible. Specifically in our research, we questioned clinicians using the HEARLab equipment of the ACA module to determine the usage outside of Australia where the equipment was developed and is supported. The general pattern of response was similar when comparing Australia to other countries with general trends suggesting that it was a crucial part of the infant pathway.

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**Appendix 1**

Please see below the list of questions that were asked on the questionnaire.

(The questions which are underlined are the questions which were added to the Punch et al. 2016 questionnaire)

1) Demographic questions

**Clinician's experience with the use of HEARLab:**

2) How long have you been using the HEARLab system for?
3) Approximately how many assessments have you made using the HEARLab system?

**Management Pathway:**

4) "The results of HEARLab influence my approach to rehabilitation."
5) "The results of HEARLab 'help me' adjust the hearing aid setting."
6) The results of HEARLab are clinically consistent with behavioural results.
7) The results of HEARLab are easy to interpret.
8) I feel confident with the results I get from HEARLab.
9) What are the relevant factors when making a decision to book a client for HEARLab assessment?
10) At what point along the clinical pathway have you used HEARLab for?
**11)** What client groups/patients have you assessed using the HEARLab system?

**Clinicians views:**

12) The results of HEARLab are positively received by parents.
13) On average how many minutes does it take you to complete a test run of 3 speech sounds at one intensity?

14) Which stimulus or stimuli from /m/, /g/ and /t/ do you find is consistent with behavioural results?
15) The calibration function for free field testing in efficient.
16) How often do the following issues prevent you from completing HEARLab assessment?
17) The results of HEARLab do not change my approach to rehabilitation.
18) "I would recommend HEARLab to other Audiologists who do not have the HEARLab system."
19) "The HEARLab is important to my clinical practice."
20) The information HEARLab provides in achieving optimal habilitation outcomes for children has been useful in clinical practice.
21) Please list the things you like LEAST about the HEARLab Aided Cortical Assessment (ACA) Module.
22) Please list the things you like MOST about the HEARLab Aided Cortical Assessment (ACA) Module.