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### Key Words

Paediatric hearing loss  
hearing aid fitting  
verification  
evaluation

### Abbreviations

ABR: Auditory brainstem response  
ASSR: Auditory steady state response  
BOA: Behavioural observation  
audiometry  
BTE: Behind the ear  
Baha™: Bone anchored hearing aid  
BC: Bone conduction  
COSI: Client oriented scale of  
improvement  
CROS: Contralateral routing of signal  
FM: Frequency modulated  
LIFE: Listening inventory for  
education  
NAL: National Acoustic Laboratory  
NU-CHIPS: Northwestern University  
children's perception of speech  
PEACH: Parent's evaluation of aural/  
oral performance of children  
RECD: Real ear to coupler difference  
SSPL: Saturation sound pressure level  
SIFTER: Screening identification for  
targeting educational risk  
TEACH: Teacher evaluation of aural/  
oral performance of children

## The national protocol for paediatric amplification in Australia

### Abstract

This document describes the national protocol for the selection, fitting, verification, and evaluation of amplification for hearing-impaired children in Australia. It also outlines the approach to management of children who have auditory neuropathy spectrum disorder, children who have mild and unilateral hearing loss, and children who require cochlear implantation. Audiological management of all Australian citizens and permanent residents under twenty-one years of age who have a hearing loss is carried out by the national hearing service provider, Australian Hearing. It is funded by the Australian Government's Hearing Services Program to provide fully subsidised hearing aids, frequency modulated (FM) systems and ongoing audiological management. All hearing aids for children are multi-channel devices that offer wide dynamic range compression, directional microphone technology and feedback cancellation as well as access to multiple listening programs, telecoil and audio-input facilities. Hearing aid gain, frequency response and maximum power output are derived according to the NAL-NL1 prescription procedure and verified using real ear measurements. Amplification benefit is evaluated using a range of speech perception tests and functional assessment questionnaires.

### Sumario

Este documento describe el protocolo nacional para la selección, la adaptación, la verificación y la evaluación de la amplificación en niños hipoacúsicos en Australia. También esboza el acercamiento para el tratamiento de niños con el espectro de desórdenes de neuropatía auditiva, niños con hipoacusia moderada y unilateral y niños que requieren implante coclear. El tratamiento audiológico de todos los ciudadanos australianos y residentes permanentes menores de veintiún años de edad con hipoacusia se lleva a cabo por el proveedor nacional de servicios auditivos: Australian Hearing. Es financiado por el Programa del Gobierno Australiano de Servicios Auditivos para otorgar auxiliares auditivos, sistemas de frecuencia modulada (FM) y tratamiento audiológico subsidiados. Todos los auxiliares auditivos para niños son de tipo multicanal que ofrecen un amplio rango de compresión, tecnología de micrófono direccional y de cancelación de la retroalimentación, así como acceso a múltiples programas, telecoil y múltiples propiedades de ingreso de la señal. La ganancia del auxiliar auditivo, la frecuencia de respuesta y la máxima salida derivan de acuerdo a los procedimientos de las prescripciones NAL-NL1 y se verifican utilizando las mediciones de oído real. El beneficio de la amplificación se evalúa utilizando un rango de pruebas de habla y cuestionarios prescripción de la prueba de rango de habla y cuestionarios de desempeño funcional.

Australia has a population of approximately 21.57 million (Australian Bureau of Statistics, 2008), and a birth rate of approximately 265 000–266 000 births per year. By the age of four years 1.6 children per thousand are fitted with a hearing aid or cochlear implant; this figure rises to 2.5 per thousand by the age of 21. In the year 2008, 14 467 Australian children under the age of 21 years were fitted with hearing aids or a cochlear implant (Australian Hearing, 2009).

In Australia, approximately 74% of Australian children have their hearing screened at or soon after birth (personal communication, G. Leigh, Australasian Newborn Hearing Screening Committee, May 2009). Publicly funded screening, primary and secondary level diagnostic services are provided by state- and territory-funded services, usually at little or no cost to families. Tertiary level services are provided by Australian Hearing, with the exception of cochlear implantation and speech processor mapping which are provided through cochlear implant clinics.

Australian Hearing is funded through the Australian Government Hearing Services Program to provide hearing services for children who are Australian citizens or permanent residents and who have a permanent or long-term hearing loss, from birth until 21 years of age. Australian Hearing services include hearing assessment, ongoing audiological management, fitting of hearing aids, personal frequency modulated (FM) systems and vibrotactile aids, and ongoing device repairs and maintenance. The service is provided at no cost to the family, other than a small annual maintenance charge. Whilst cochlear implantation and ongoing management of the implant and speech processor are undertaken by specialist clinics, Australian Hearing provides Speech processor maintenance, replacement and technology upgrades for child recipients of cochlear implants. This article will focus on Australian Hearing's practice for management of amplification in infants and children.

## Hearing assessment

Children who have been diagnosed with a permanent hearing loss, or who are known to be at high risk for a permanent hearing loss, are offered an appointment at an Australian Hearing centre within two weeks of referral (Australian Hearing, 2009a). Spoken or sign language interpreters are provided if required.

Determination of the degree, configuration and type of hearing loss is undertaken using a test battery approach that is dependent upon the age of the child. All children receive transient evoked otoacoustic emission testing at Australian Hearing prior to proceeding with hearing aid fitting, regardless of age. Investigations for auditory neuropathy spectrum disorder are undertaken when applicable using click evoked auditory brainstem response audiometry and assessments of cochlear microphonics and otoacoustic emissions. (King et al, 2005).

### Infants

From birth until approximately seven months of age, a behavioural audiogram is estimated from ear-specific, frequency-specific, evoked potential threshold test results that have been undertaken at referral hospitals. Depending upon the clinical protocols adopted at different hospitals, evoked potential tests may include auditory brainstem responses (ABR), and/or auditory steady state responses (ASSR) and/or trans-tympanic round window electrocochleography. Air conduction thresholds measured using the respective methods are converted to behavioural thresholds for amplification purposes, using published factors (Stapells et al, 1995; Rance et al, 2005; Wong et al, 1997).

When it is not possible to obtain ear specific evoked potential thresholds at all octave frequencies from 500 Hz to 4000 Hz, Australian Hearing recommends that at least one low-frequency threshold (500 Hz or 1000 Hz) and one high-frequency threshold (2000 Hz or 4000 Hz) is recorded for each ear. Click-evoked ABR thresholds may be used to predict hearing thresholds in the 2000–4000 Hz region, with conversions based upon the mean of values reported by Van Der Drift et al (1987) and Picton et al (1994). ‘Missing’ thresholds may be estimated based upon the average of the evoked potential thresholds measured for frequencies one octave above and one octave below the frequency of interest and information derived from behavioural observation audiometry (BOA) and acoustic reflexes is used to assist in refining predictions of threshold. Behavioural observation audiometry is also used in parent education for demonstrating the way in which infants respond to sounds.

Middle ear function is evaluated using high-frequency probe tone measures of susceptance and conductance (Purdy & Williams, 2000). Where tympanometry is indicative of middle ear dysfunction, bone conduction ABR assessment for at least one frequency is recommended to provide information about cochlear function for counselling purposes.

### Older children

Behavioural thresholds are used for hearing aid fitting in preference to evoked potentials, unless there is reason to suspect that a child is unable or unwilling to respond at the true threshold levels.

Audiologists aim to measure ear-specific hearing thresholds as soon as an infant has demonstrated that they can be conditioned to visual reinforcement audiometry. Whenever possible, individual ears are tested using insert earphones or headphones; soundfield thresholds

are recorded if the child’s cooperation is limited. Bone conduction thresholds are obtained as soon as possible after sufficient air conduction information is available to determine or confirm the degree and configuration of hearing loss. When there is evidence of chronic conductive hearing loss bone conduction and air conduction thresholds have equal priority. For children aged seven months or older, tympanometry is conducted using admittance measures with a 226 Hz probe tone.

Children aged 2.5 years and upwards are generally assessed using pure tone audiometry. Age-appropriate speech discrimination tests are used both for confirmation of the audiogram with older children and to assist in counselling families. The most commonly used tests include the Kendall Toy Test (Kendall, 1953), the AB Word Lists (Boothroyd 1968) and BKB sentences (Bench et al, 1979). The Northwestern University Children’s Perception of Speech (NU-CHIPS, Elliott & Katz, 1980) is performed using an adaptive technique for audiogram confirmation when the hearing loss is mild (Mackie & Dermody, 1986)

## Candidacy for hearing aid fitting

Hearing aids are provided at no cost to families through Australian Hearing’s program. Device options are discussed with families when sufficient information is available to determine the degree, configuration and chronic nature of the child’s hearing loss. All children are referred for examination by an otologist or paediatrician before hearing aid fitting in order to eliminate medical contraindications to hearing aid use. Hearing aid fitting proceeds when a child has a permanent or long-term sensory, neural, conductive or mixed hearing loss that may be assisted by hearing aids, otological clearance has been obtained and the family have agreed to proceed with a device fitting as part of their overall management plan. Families are offered an appointment within two weeks of the decision to proceed with hearing aid fitting (Australian Hearing, 2009a).

Bilateral air conduction hearing aids are routinely recommended and fitted for children who have a moderate or greater degree of bilateral hearing loss. Children whose hearing loss meets criteria for cochlear implantation are referred for candidacy evaluation when the family agree. Hearing aid fitting and cochlear implant candidacy evaluation often occur in parallel, with results shared between implant clinics and Australian Hearing centres to minimise the burden of additional assessments on families. When children proceed to unilateral cochlear implantation, continued use of a hearing aid in the non-implanted ear is recommended if there is residual hearing in that ear (Ching et al, 2001).

Recommendations about amplification options are more complex when a child has a mild or unilateral hearing loss, or when the loss is due to auditory neuropathy spectrum disorder. The impact of auditory neuropathy spectrum disorder upon children’s outcomes and the benefits and limitations of hearing aids and cochlear implants varies considerably amongst individuals. (e.g. Rance, 2005; Gibson & Sanli, 2007; Rance et al 2007). Children are managed according to Australian Hearing’s protocols for management of Auditory Neuropathy (King et al, 2005). Parents are presented with information about the current state of knowledge regarding outcomes for children with this disorder, along with the benefits and limitations of various technological and non-technological interventions. Hearing aids are discussed as an option when BOA

results are consistently elevated compared with age-appropriate responses, or when a behavioural audiogram shows elevated hearing levels. When parents agree to proceed with amplification, Australian Hearing fit hearing aids that are appropriate to the degree of behavioural hearing loss. Cochlear implant candidacy referrals are arranged with parental consent when the children's behavioural hearing levels meet cochlear implant candidacy criteria or when speech discrimination or functional evaluations suggest that the child is performing at a level where a cochlear implant has the potential to offer improved speech perception.

The impact of mild and unilateral hearing losses on children varies amongst individuals (Davis et al, 1986; Bess & Tharpe, 1988; Brookhouser et al, 1991; Bess et al, 1998; Davis et al, 2001; Wake et al 2006) as does the benefit of amplification, (Yeend, 1992; Davis et al, 2001; McKay, 2002; Kiese-Himmel & Ohlwein, 2003; King, 2008). Therefore when children are diagnosed with a mild or unilateral hearing loss in infancy there is much variability in parents' decisions about device fitting. Decisions about aiding older children are assisted by using functional assessment tools such as the Parent Evaluation of Auditory/oral performance of Children (PEACH), or Teacher Evaluation of Auditory/oral performance of Children (TEACH) (Ching & Hill, 2007; Ching et al, 2008), the Screening Identification for Targeting Educational Risk (SIFTER) (Anderson, 1989), or Listening Inventory for Education (LIFE) (Anderson and Smaldino, 1999), or the Client Oriented Scale of Improvement (COSI) (Dillon et al, 1997).

### Selection of hearing aids

Australian Hearing provides fully subsidised hearing instruments to children.

#### *Style*

Behind the ear (BTE) hearing aids are fitted to children until at least primary school age, while older children have the option of a BTE or a custom hearing aid fitting (in the ear, in the canal, completely in the canal) when appropriate for the degree of hearing loss, the physical size and management abilities of the child. Contralateral routing of signal (CROS) aids, open fittings, and receiver in the canal hearing aids are used when appropriate to the degree of loss and the child's individual circumstances.

Air conduction hearing aids are the device of first choice for most children. However bone conduction (BC) aids are fitted to children who have bilateral ear canal atresia or chronic suppurative otitis media that precludes use of an earmould. The most common fitting configuration is a single bone conduction transducer driven by a high powered BTE aid and worn on a spring-steel headband. Very young children or those who have rejected their BC hearing aid due to cosmetic reasons can have their hearing aid fitted inside a soft, elasticised headband or contained within a baseball hat.

A Bone Anchored Hearing Aid (Baha™) is available fully subsidised to children who have bilateral ear canal atresia and are aged over five years, and for some children with chronic bilateral conductive hearing loss. Children who have chronic bilateral conductive hearing loss are considered for a fully subsidised Baha™ if medical intervention has been unsuccessful in resolving the conductive hearing loss and an otologist has advised that there are medical contraindications to use of air conduction hearing aids. Families of children who meet audiological candidacy criteria must also demonstrate that they

understand what is involved in obtaining a Baha™ and associated surgery and must be able to care appropriately for the skin penetrating abutment. Surgical candidacy criteria are managed by the child's otologist.

Children who have a mild or unilateral hearing loss may be fitted with a personal FM system rather than hearing aids if their main listening goals relate to hearing their teacher at school.

#### *Device features*

Non-linear hearing aid fittings are recommended for children unless the degree of hearing loss is such that the use of input compression would limit audibility. Multi-channel aids are recommended to facilitate accurate matching of prescriptive targets; currently most fully subsidised paediatric aids have 6–8 channels. Feedback cancellation is provided in all current hearing aids.

Directional microphones are recommended for children of all ages, unless this causes problems in meeting low-frequency gain targets for children with severe low-frequency loss (due to low-frequency roll-off in directional mode). Current research suggests that directional microphones do not disadvantage young children in everyday life, and will offer potential for benefits in some listening situations. (Ching et al, in press) When available in hearing aids, automatic switching between directional and omnidirectional programs is recommended.

All BTE hearing aids have multiple listening programs, telecoil and/or direct audio input for FM use, which are activated according to the individual client's needs and goals. When the child and family choose a custom hearing aid, they are counselled on the benefits and limitations of choosing a device that may not accommodate the use of accessories.

Hearing aid safety is of paramount importance. For children aged less than three years, Australian Hearing requires that the devices have a secure, tamper-proof battery door and a friction hook that is either securely glued or screwed in place. Parents are issued with instructions about monitoring the condition of a hearing aid and ear moulds to minimize the risk of ingestion of small parts. All hearing aids are issued with hearing aid retention clips and double-sided adhesive tape. Open fittings that use dome tips rather than ear moulds are not used for young children due to the risk of ingesting the detachable dome.

### Hearing aid fitting and verification procedure

The NAL NL1 prescription (Dillon, 1999) is used to derive gain targets for 50, 65, and 80 dB SPL input levels and SSPL 90 targets using the child's measured or predicted behavioural audiogram in dB HL. The type of target that is derived depends upon the age of the child. Real-ear aided gain targets are recognized as providing the most appropriate hearing-aid prescriptions for young children. Insertion gain targets provide an equivalent fitting when the child's ear canal acoustics approximate those of an adult. (Seewald, 1995; Ching et al, 2002).

Real ear aided gain and 2cc coupler gain targets are derived for children who do not have average adult ear canal sizes, or who have an abnormal ear canal resonance due to the presence of ventilation tubes, an enlarged mastoid cavity due to mastoidectomy, or other physical conditions of the ear and those who will not cooperate for insertion gain tests. Targets are derived using individual real-ear-to-coupler differences (RECDs) that have been measured using the constant depth approach (Tharpe et al, 2001). While the aim is to obtain individual RECD measures for each ear, this is not always clinically

practical or possible. If time constraints or child cooperation is an issue, age appropriate RECDs provided in the NAL-NL1 software are used. Alternatively, the RECD from a single ear can be used to derive targets for both ears if tympanometry and otoscopic examination reveal no obvious physical differences between the ears (Tharpe et al, 2001).

Individual ear RECDs are a high priority in cases where otoscopic examination or ear canal volume measures recorded from tympanometry suggest that the child's ears are obviously physically different from the average for their age, or that there are anatomic disparities between ears. RECD measures are to be repeated every three months until the child reaches six months of age, every six months for children aged between six months to two years, and annually thereafter. Additional RECD measures are required if changes are made to the earmould plumbing. Hearing aids are fine-tuned at these same intervals when required.

For children who are able to cooperate for real-ear measures, and whose ear canal acoustics approximate those of an adult, verification is carried out using real ear insertion gain measurements. During coupler or insertion gain verification procedures, the frequency response slope should be matched to within 5 dB/octave of prescription slope for a 65 dB SPL input level. The 'slope' of the frequency response refers to the difference in gain prescribed between 4000 and 500 Hz. Gain should be within 5 dB of target at octave frequencies from 250–4000 Hz. The same criteria for verification applies for 50 and 80 dB SPL inputs, with priority being given to matching targets at 50 dB SPL input level. The maximum power output of the hearing aids should be set as closely as possible to the NAL-NL1 prescription for SSPL90 and should not exceed the prescription by more than 3 dB.

Hearing-aid settings are routinely reviewed two to three times per year for children aged less than three years and annually for older children. Review of hearing aid settings are carried out if parental reports suggest over- or under-amplification, if a child's audiogram shows a change in one or more thresholds that has been confirmed on consecutive tests or if RECD values have changed. The hearing aids are also adjusted if the first reliable behavioural audiogram differs from the audiogram that has been predicted on the basis of evoked potential results.

### Hearing-aid evaluation

Hearing aids are evaluated using a combination of informal parent and teacher reports, functional assessments, and speech perception tests. For infants aged from birth to three years, functional performance in real life is assessed using the PEACH or TEACH (Ching & Hill, 2007; Ching et al, 2008), with the aim being to administer the questionnaire within three months of regular aid use being established and to monitor progress annually, compared with age norms. The PEACH or TEACH can be administered until the child reaches 6–8 years of age, if indicated. Fittings for older children may be evaluated using the LIFE or the COSI.

Simple speech tests are introduced as appropriate for the child's age and hearing loss and include the Ling five sound test (Ling & Ling, 1978) with the addition of two additional speech sounds (/m/ and the back vowel /ɔ/) to adequately cover the Australian vowels and low frequency speech information (Australian Hearing, 2001) and the Kendall Toy Test. Progress of older children is evaluated by a range of speech tests depending upon degree of hearing loss and language level, including the PLOTT test (Plant and Westcott

1983) and PLOTT screening test (Plant & Moore, 1993) for severely and profoundly hearing impaired children, BKB sentences, and the AB word lists. The Northwestern University Children's Perception of Speech (NU-CHIPS) (Elliott & Katz, 1980) test is used to assess aided advantage in quiet and noise (Australian Hearing, 2001).

When children are fitted bimodally, with a hearing aid in one ear and a cochlear implant in the other ear, hearing aid optimization is conducted using the procedure developed by Ching and colleagues (Ching et al, 2004). Hearing aid optimization is conducted after the child's cochlear implant MAP is stable and the hearing aid has been worn for at least six weeks set to the NAL prescriptions as outlined above.

### Other devices

A personal frequency modulated (FM) system is offered to the family when:

- The child is consistently using the hearing aid/s or cochlear implant.
- The cochlear implant MAP is stable.
- There are specific needs that can be addressed by an FM system (difficulties hearing in noise, over distance, or in reverberant conditions).
- The child and family are motivated to use the FM system.
- Teachers and others are motivated to use the FM system.

Children can be provided with one fully subsidised transmitter and one fully subsidised receiver through Australian Hearing's program. A range of styles is available depending upon the client's needs, including

- ear level or body-worn receivers connected via direct audio input to the child's hearing aid or cochlear implant speech processor;
- induction-coupled receiver;
- body-worn transmitter with lapel or head-worn microphone;
- Hand-held transmitter with fixed or switchable directional microphone.

### Service delivery

While this article has focussed upon the clinical protocols for prescribing and fitting amplification, it is important to remember that parental involvement is a vital part of any hearing management program (Erdman et al, 1994). Australian Hearing adopts a family centred approach to service delivery (Roush & McWilliams, 1994). Parent and teacher education are conducted through a combination of hearing centre-based appointments and school visits. Australian Hearing produces a range of printed information to support families in their decision making processes. These are available in hard copy and via the Australian Hearing website ([www.hearing.com.au](http://www.hearing.com.au)). Parents of newly-diagnosed children are provided with 'Choices', a book which covers topics ranging from audiological information to educational options and contact details for local service providers. This book is also available in five languages other than English.

Client input to service delivery is sought from parents of younger clients and individually from teens and young adults via annual surveys of hearing-aid use and service satisfaction and through a

customer care telephone line. Input from teachers is collected through stakeholder forums. Data from these sources is then used to refine clinical protocols. For instance, as the result of a survey of teenagers and young adults conducted in 2006, Australian Hearing introduced information sessions about the use of assistive listening devices (visible alarms, telephone accessories, personal stereo accessories) to enhance lifestyles into the paediatric clinical pathways.

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