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Introduction to the Longitudinal Outcomes of Children with Hearing Impairment (LOCHI) study: background, design, sample characteristics

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Abstract

Objective: This article describes the background and the design of the Longitudinal Outcomes of Children with Hearing impairment (LOCHI) study, and the characteristics of the study cohort.

Design: Children born between 2002 and 2007 who were identified with hearing loss and received audiological intervention by 3 years of age in Australia enrolled in the study. Their demographic characteristics are described.

Sample: 451 children in New South Wales, Victoria and Southern Queensland.

Results: Data on age at first hearing aid fitting for different degrees of hearing loss are reported together with demographic characteristics of the cohort.

Conclusion: A unique environment in Australia where all children with varied access to universal newborn hearing screening received the same consistent hearing services from a national hearing service provider makes it possible to investigate the effects of access to early auditory intervention on children's outcomes at a population level.

Keywords

children with hearing loss; outcomes; early intervention; universal newborn hearing screening

About 3/1000 children are fitted with hearing aids or received cochlear implants by school entry for a permanent hearing loss (Australian Hearing, 2011). Language and educational outcomes for hearing-impaired children are traditionally much lower than those for their hearing peers. The US Agency for Health Care Research and Quality's review noted that on average, language and educational achievement levels of hearing-impaired graduates from

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high school are below those of the average fourth-grade student with normal hearing, and the average reading scores for hearing-impaired students graduating from high school are at the fifth-grade level (Helfand et al., 2001). The lifetime cost of all care due to deafness and lost productivity has been estimated to be US\$117 million per birth cohort of 80,000 children (Keren et al., 2002). By implementing universal newborn hearing screening (UNHS) to detect hearing loss soon after birth, treatment can begin in infancy with the ultimate goal of improving long-term outcomes, at a population level.

Despite widespread acceptance of UNHS, high-quality evidence on its efficacy is lacking. Systematic reviews (Thompson et al., 2001) have revealed epidemiological and methodological flaws in previous studies, indicating that the evidence was insufficient for supporting recommendations for routine screening of newborns for hearing loss. A recent update of the systematic review (Nelson et al., 2008) indicated that there was “moderate certainty that the net benefit of screening all newborn infants for hearing loss is moderate”, on the basis of findings of a single quasi-randomized trial that found an effect of early intervention for only receptive language, but not for expressive language or speech production of a population at 8–9 years of age (Kennedy et al., 2006).

Conflicting findings were reported in previous studies (see Table 1), most of which included participants self-selected to obtain services from a particular educational or audiological service provider. Several observational studies based on convenience samples have revealed an advantage of early intervention for language development. Yoshinaga-Itano et al. (1998) reported that at 3–5 years of age, 72 children identified before 6 months of age had a significantly higher language quotient than 78 children who were identified between 6 months and 3 years (mean $\pm$ SD: 79 $\pm$ 25.6 vs 63.8 $\pm$ 19.3, $p < 0.001$) for children who were enrolled in the Colorado Home Intervention Program. Similar findings were reported by Calderon and Naidu (2000) for 80 children who completed the Western Washington, State Early Childhood Home Instruction Program at 3 years of age; and by Moeller (2000) on receptive vocabulary of 112 children at 5 years of age who enrolled in the Nebraska Diagnostic Early Intervention Program. Although these studies indicated a positive effect of early intervention, they have also raised uncertainties as to why there were no differences in outcomes between children who first received amplification at 7–12 months compared with those who received amplification between 1 and 3 years of age; whether outcomes were affected by when amplification was provided within the first 6 months of life; or why there were no evidence of any interaction between degree of loss and the effects of intervention timing on outcomes. Sininger et al. (2010) also found a significant effect of age of amplification (ranging from 1 to 72 months) on speech and language outcomes for children measured at ages ranging from 3 to 8 years. On the other hand, Fitzpatrick et al. (2007) did not find a significant relationship between age at intervention and language or speech outcomes for children at 3 to 5 years of age who were attending three early intervention programs.

Population-based studies are scant. Unlike program-based studies, these generally showed very limited positive effects, if any, of UNHS on outcomes. Kennedy et al (2006) reported that confirmation of hearing loss before 9 months of age had a small positive effect on receptive language of children at 9 years of age, but no significant effects on their expressive

language or speech production. More recently, a population-based trial of UNHS at birth versus distraction screening at 9 months of age in the Netherlands found no significant effect of early intervention on any of the language measures of children at 5–7 years of age (Korver et al., 2010). A lack of improved developmental outcomes with screening could be the result of systems that failed to ensure immediate and accurate confirmation of hearing loss after screening, timely and accurate fitting of amplification, and timely access to appropriate intervention services. Indeed, authors of both population-based studies indicated that the trials were conducted when systems were still evolving thereby resulting in delayed confirmation of hearing loss and provision of amplification for children who did not pass screening (Kennedy et al., 2006; Korver et al., 2010).

Despite the need for a prospective study that directly examines whether newborn hearing screening and earlier intervention result in improved speech, language, or educational development (as articulated by the US Preventative Services Task Force), it has been recognized that such a study could probably not be accomplished in the US. Random assignment to screening is ethically not acceptable where universal hearing screening is already implemented, and random assignment to treatment groups ('immediate intervention' versus 'delayed intervention') after screening is not permissible ethically or legally.

To address the evidence gap of whether UNHS is effective in improving long-term outcomes at a population level, we took advantage of a unique research environment in Australia arising from the roll-out of UNHS programs in three Australian states between 2002 and 2007 (Leigh, 2006) to conduct the Longitudinal Outcomes of Children with Hearing Impairment (LOCHI) study.

Unique research environment in Australia

Table 2 shows the commencement year, screening protocol, and relative proportion of Australian births (as at 2002) for each of the state- and territory-wide UNHS programs in Australia. Notably, the three most populous states—New South Wales (NSW), Victoria (VIC), and Queensland (QLD)—each commenced programs within a 3-year period from 2002 to the 2005. In New South Wales the program was implemented across all regions of the state simultaneously whereas in Queensland and Victoria the roll-out of the program was a staged process with different regions of each state commencing screening progressively over periods of 2 years and 6 years respectively. Notably, however, the programs that were implemented in all three states used the same screening protocols and screening techniques (i.e., Automated Auditory Brainstem Response—AABR—testing).

Regardless of the state or territory jurisdiction in which they are born or the age at which their hearing loss is diagnosed, Australian children with childhood hearing loss are referred to a single government-funded organization (i.e., Australian Hearing) for the delivery of hearing services. Those services are provided free of charge according to nationally consistent protocols. This means that all newborns who are identified with hearing loss through UNHS receive a common standard of care in regard to post-diagnostic audiological assessment and the provision of amplification. Taken together, this common standard of care, the employment of common protocols for screening across the three largest states, and

the differential rates and patterns of program implementation across those states provided the opportunity to undertake a population-based study investigating the effects of earlier versus later identification of permanent childhood hearing impairment. By seeking to recruit all children with hearing loss who were born in the three states across a five year period from 2002 to 2007, the differential implementation of UNHS programs provided a sample of children that was naturally divided according to whether their impairment was identified early (through UNHS) or later. Further, because of the similarity of the three state-wide screening programs and the consistency of the other services available to all children in those states, such a study could effectively control for a wide range of other important factors.

Predictors of outcomes

The US Preventative Services Task Force questioned whether there were factors other than age of intervention that might contribute to language development (Thompson et al., 2001). This question was addressed in the LOCHI study by measuring a range of demographic characteristics of the children while they were occurring, rather than being gathered retrospectively. A range of predictor variables that have been implicated in previous studies to affect outcomes were measured. These included child-related factors (gender, birthweight, age of diagnosis, age of hearing aid fitting, age of cochlear implantation, degree of hearing loss, presence of additional disabilities, presence of auditory neuropathy), family-related variables (maternal education, socio-economic status, language used at home, communication mode at home, involvement in intervention), and other education-related variables (communication mode, changes in communication mode over time, hours of service). The relative importance of these variables has not been quantified within a single cohort before, as studies did not have sample sizes that were sufficient for investigations of all variables with adequate statistical power.

In addition to age of hearing aid fitting, we hypothesized that changes in real-ear aided gain as a result of changes in hearing thresholds over time, hearing aid prescription used in fitting, and frequency lowering processing in hearing aids would affect outcomes. Therefore, we incorporated two randomised controlled trials in the LOCHI study. The first examined the effect of choice of prescription. Two prescriptions, the National Acoustic Laboratories (NAL) and the Desired Sensation Level (DSL) prescriptions are widely used internationally for fitting hearing aids to children. The prescriptions differ (sometimes markedly) in real-ear gain at different frequencies (Byrne et al., 2001; Ching et al., 2010), and neither has been validated for children. Although there is some evidence to show that the choice of prescription has little consequence in speech understanding and listening comfort for school-aged children with moderate degrees of hearing loss (Ching et al., 2010; Scollie et al., 2010), the differences may be important for development of speech and language skills in the short and longer term when amplification is provided during the first few months of life, especially when the hearing loss is severe. In this trial, we randomly assigned newly identified children to one of the two prescriptions for fitting, and assessed the impact of prescription on outcomes after allowing for a range of predictor variables.

The second randomized trial within the LOCHI study investigated the effect of nonlinear frequency compression in hearing aids on children's speech and language development. This sub-study was necessitated by the wide availability of frequency-lowering technology in commercial hearing aids for children despite a total lack of evidence on the impact of the processing on language development of young children (McCreery et al, 2012). We randomly assigned children to being fitted with hearing aids that provided either conventional processing or nonlinear frequency compression, and examined whether their outcomes were significantly affected by hearing-aid processing.

There is also a proportion of children for whom management of hearing loss may require cochlear implantation. In previous population studies, only about 2 or 3% of participants had cochlear implants although about 30% of the cohorts had a profound degree of hearing loss. Early diagnosis of hearing loss would be expected to not only enable early hearing aid fitting, but also early cochlear implantation for those with profound loss.

Outcomes measures

The test battery was carefully selected to assess the skills that rely on auditory input to develop. These included auditory functional ability, speech production, receptive and expressive language, and psychosocial development at 3 years of age. The measures included tests directly administered to children, and reports solicited from parents or primary caregivers. At later measurement points, nonverbal cognitive ability, literacy, educational attainment, mental health, and quality of life will also be evaluated. Direct evaluations included the Pre-school Language Scale version 4 (PLS-4; Zimmerman et al., 2002) for assessing receptive and expressive language, the Peabody Picture Vocabulary Test, fourth edition (PPVT-4; Dunn & Dunn, 2007) for assessing receptive vocabulary, and the Diagnostic Evaluation of Articulation and Phonology (DEAP; Dodd et al., 2002) for assessing speech production. In addition, parents were requested to complete the Child Development Inventory (CDI; Ireton, 2005) on their child's language and psychosocial skills, and the Parents' Evaluation of Aural/oral Performance of Children (PEACH; Ching & Hill, 2007) on their child's functional performance in real life. Early education teachers were requested to complete the Teachers' Evaluation of Aural/oral performance of children (TEACH; Ching et al., 2008) to assess the child's functional performance in educational settings. Although other cross-sectional or longitudinal studies have reported on language and speech production and perception skills of children using hearing aids or cochlear implants (e.g., Blamey et al., 2001; Geers et al., 2003), none included the entire range of hearing loss, and hence users of hearing aids and cochlear implants, who received very early intervention in a large cohort to allow investigations of the effect of timing of intervention on development in multiple domains while controlling for a range of predictor variables.

Rationale for the study

As the research arm of Australian Hearing, the National Acoustic Laboratories was well placed to take advantage of the national service provision network to sample from across an entire population, enroll sufficiently large numbers of early or later identified children who accessed hearing services, and include children with hearing loss ranging from mild to

profound degrees, who received hearing aids and/or cochlear implant interventions. The number of predictors measured that potentially could affect outcomes, and the range of outcomes measured at several intervals for the large sample size provided data that have unprecedented potential for examining the relationships between predictors and outcomes.

The LOCHI study is important because (a) the efficacy of UNHS is not established and, without evidence of effectiveness, the costliness of UNHS programs may threaten their sustainability; and (b) The factors influencing language, literacy, psychosocial and quality of life outcomes and their developmental trajectories is unclear, and without evidence on significant factors on which to base post-diagnostic intervention, the potential benefits of early detection may not be fully realised.

This paper describes the design of the study and documents the demographic characteristics of the LOCHI cohort. The information can provide clinicians and researchers with insight regarding the population being studied. To adequately determine the effect of early intervention on outcomes, it is important to control for as many of the predictors as possible. Failure to control for any of these intervening variables may obscure the underlying causes of good or poor performance. Therefore, not only do the demographic and educational characteristics of the LOCHI cohort have inherent descriptive value, they will be even more valuable as predictors of measured outcomes.

DESIGN

This is a prospective cohort study. Outcomes and potential predictors affecting speech, language, psychosocial, and functional performance of children were measured with normed, well validated instruments. Additionally, randomized controlled trials of hearing-aid prescription and of nonlinear frequency compression were conducted.

Sample size was determined according to two principles. First, because the primary analysis tool was multiple non-linear regression, we needed to ensure an adequate ratio of data points to unknown coefficients. With 15 raw predictors, and if necessary a larger number to allow for non-linear transformation of some predictor variables, and potential interactions between the variables, our target sample size was 400. The second principle was the anticipated need to perform analyses of variance. The target sample size was sufficient to detect a difference of 0.4 population standard deviation units on quantitative measures, with 80% power at an error rate of 5%. Because the outcomes data would be corrected for the effects of all the other predictor variables, the within-group standard deviation that applies for this power analysis is likely to be considerably smaller than the raw standard deviation that would otherwise apply. The target total of 400 children therefore provided a design that was very sensitive to the effect of early intervention.

Participants

The families of all children born between 2002 and 2007 who were identified with hearing loss and accessed services at Australian Hearing centers in New South Wales, Victoria, or Southern Queensland below 3 years of age were invited to participate in the LOCHI study. Recruitment commenced in 2005 and was completed in 2007.

All children received the same post-diagnostic audiological intervention from the single government-funded national service-provider of hearing services, Australian Hearing (AH), administered according to national protocols (King, 2010). Timely fitting of hearing aids after diagnosis for all children is provided by the national service network. Accurate information about timing of fitting, hearing assessment, and hearing aid characteristics were retrieved from the AH national client database.

Procedure

Children who enrolled in the study prior to first fitting of hearing aids ($n = 218$) were randomly assigned to fitting with either the NAL or the DSL prescription. The parents and the researchers who evaluated the outcomes of children were blinded to the prescription assignment. In 2009, the randomized trial of nonlinear frequency compression was implemented ($n = 110$), again with double blinding. Evaluations of outcomes were carried out at 6 and 12 months after initial fitting, and at the chronological age of 3 years. The children's outcomes were assessed by using standardized tests and validated measures that combine direct assessment techniques with report-type questionnaires. At each interval, parents were invited to complete questionnaires regarding their demographic characteristics, and to provide ratings on their child's development. These forms were collected by researchers. Speech pathologists visited the child and performed direct assessments using standardized tests. This paper describes the demographic characteristics of children at 3 years of age, as reported by parents.

RESULTS

Of the 451 children (247 boys) enrolled in the study, 239 children were first fitted with hearing aids before 6 months of age. There were 86 (19%) children with mild hearing loss (average between 0.5 and 4 kHz in the better ear; 4FA: 40 dB HL), 149 (33%) with moderate hearing loss (4FA: 41–60 dB HL), 71 (18%) with severe hearing loss (4FA: 61 – 80 dB HL), and 145 (32%) with profound hearing loss (4FA: 81 dB HL). Figure 1 shows the distribution of age at first fitting of hearing aids for different degrees of hearing loss.

At 3 years of age, 134 children were using cochlear implants, with 46 of them having received an implant before 12 months of age. The remainder, except for six children, were using hearing aids. Parents reported that 85% of the children were using their hearing devices for more than 75% of their waking hours.

The cohort included 107 (24%) children who were reported to have disabilities in addition to hearing loss. There were 44 children diagnosed with auditory neuropathy spectrum disorder.

Based on parent reports, 302 children were using an aural/oral mode of communication at home, 3 were using manual communication, and the remainder were using a combination of oral and manual methods at home. Parents' reports on communication mode in educational intervention showed that 301 (67%) used an aural/oral mode of communication; the remainder used a combined oral and manual mode. Between first enrolment in educational intervention and 3 years of age, parents of 50 children reported a change in communication mode in early education.

SUMMARY

This article has described the design of the study and the characteristics of the cohort whose performance were analysed in the subsequent articles in this supplement and in Ching et al., 2013. In addressing challenges for clinicians posed by implementing early intervention, the articles will provide an increased understanding of family perspectives on early intervention, the relative effectiveness of hearing aid prescription and frequency lowering technology for supporting children's speech and language development, and the impact of auditory neuropathy on outcomes. An evidence-based approach to addressing these questions is critical because clinical decisions on management strategies potentially have lifelong impact on children's outcomes.

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Abbreviations

4FA	four-frequency average, across 0.5, 1, 2, and 4 kHz
AH	Australian Hearing
dB HL	decibel, Hearing level
DEAP	Diagnostic Evaluation of Articulation and Phonology
DSL	Desired Sensation Level
DSL v4	Desired Sensation Level prescription, version 4
LOCHI	Longitudinal Outcomes of Children with Hearing Impairment study
NAL	National Acoustic Laboratories
NAL-NL1	National Acoustic Laboratories' prescription for non-linear hearing aids, version 1
PEACH	Parents' Evaluation of Aural/oral performance of CHildren
PLS-4	Preschool Language Scale, 4 th Ed.

PPVT	Peabody Picture Vocabulary Test
TEACH	Teachers' Evaluation of Aural/oral performance of Children
UNHS	universal newborn hearing screening

References

- Australian Hearing 2011 Report on demographics of persons under the age of 21 years with hearing aids. Chatswood, Australia: Australian Hearing.
- Blamey PJ, Sarant JZ, Paatsch LE, Barry JG, Bow CP, et al. 2001 Relationships among speech perception, production, language, hearing loss, and age in children with impaired hearing. *J. Speech Lang. Hear. Res.*, 44, 264–285. [PubMed: 11324650]
- Byrne D, Dillon H, Ching TYC, Katsch R & Keidser G 2001 NAL-NL1 procedure for fitting nonlinear hearing aids: Characteristics and comparisons with other procedures. *Journal of American Academy of Audiology*, 12, 37–51.
- Calderon R & Naidu S 2000 Further support for the benefits of early identification and intervention for children with hearing loss. *Volta Review*, 100, 53.
- Ching TYC, Dillon H, Marnane V, Hou S, Day J, et al. 2013 Outcomes of early- and late-identified children with hearing loss at 3 years of age: Findings from a prospective population-based study. *Ear Hear*, 34, 535–552. [PubMed: 23462376]
- Ching TYC & Hill M 2007 The Parent's Evaluation of Aural/Oral Performance of Children (PEACH) Scale: Normative data. *J. Am. Acad. Audiol*, 18, 220–235. [PubMed: 17479615]
- Ching TYC, Hill M & Dillon H 2008 Effect of variations in hearing-aid frequency response on real-life functional performance of children with severe or profound hearing loss. *Int. J. Audiol*, 47, 461–475. [PubMed: 18698522]
- Ching TYC, Scollie SD, Dillon H & Seewald R 2010 A cross-over, double-blind comparison of the NAL-NL1 and the DSL v4.1 prescriptions for children with mild to moderately severe hearing loss. *Int. J. Audiol*, 49, S4–15. [PubMed: 20109088]
- Ching TYC, Scollie SD, Dillon H, Seewald R, Britton L, et al. 2010 Prescribed real-ear and achieved real-life differences in children's hearing aids adjusted according to the NAL-NL1 and the DSL v4.1 prescriptions. *Int. J. Audiol*, 49, S16–S25. [PubMed: 20109083]
- Dodd BJ, Hua Z, Crosbie S, Holm A & Ozanne A 2002 Diagnostic evaluation of articulation and phonology manual: The Psychological Corporation.
- Dunn LM & Dunn LM 2007 Peabody picture vocabulary test (4th ed.). Minneapolis, MN: Pearson Assessments.
- Fitzpatrick EM, Durieux-Smith A, Eriks-Brophy A, Olds J & Gaines R 2007 The impact of newborn hearing screening on communication development. *J. Med. Screen.*, 14, 123–131. [PubMed: 17925084]
- Geers AE, Nicholas JG & Sedey AL 2003 Language skills of children with early cochlear implantation. *Ear Hear*, 24, 46S–58S. [PubMed: 12612480]
- Helfand M, Thompson DC & Davis R 2001 Newborn Hearing Screening Systematic Evidence Review Number 5. Rockville: Oregon Health & Science University Evidence-based Practice Center.
- Ireton H 2005 Child Development Inventory. Minneapolis, MN: Child Development Review.
- Kennedy CR, McCann DC, Campbell MJ, Law CM, Mullee M, et al. 2006 Language ability after early detection of permanent childhood hearing impairment. *N. Engl. J. Med*, 354, 2131–2141. [PubMed: 16707750]
- Keren R, Helfand M, Homer C, McPhillips H & Lieu TA 2002 Projected cost-effectiveness of statewide universal newborn hearing screening. *Pediatrics*, 110, 855–864. [PubMed: 12415021]
- King AM 2010 The national protocol for paediatric amplification in Australia. *Int. J. Audiol*, 49, S64–S69. [PubMed: 19919326]

- Korver AMH, Konings S, Dekker FW, Beers M, Wever CC, et al. 2010 Newborn hearing screening vs later hearing screening and developmental outcomes in children with permanent childhood hearing impairment. *Journal of the American Medical Association*, 304, 1701–1708. [PubMed: 20959580]
- Leigh G 2006 UNHS in Australia: we've come a long way! *Audiology Now*, 27, 49–51.
- McCreery RW, Venediktov RA, Coleman JJ & Leech HM 2012 An Evidence-Based Systematic Review of Frequency Lowering in Hearing Aids for School-Age Children with Hearing Loss. *American Journal of Audiology*, 21, 313–328. [PubMed: 22858615]
- Moeller MP 2000 Early intervention and language development in children who are deaf and hard of hearing. *Pediatrics*, 106, 1–9. [PubMed: 10878140]
- Nelson HD, Bougatsos C & Nygren P 2008 Universal newborn hearing screening: Systematic review to update the 2001 US Preventive Services Task Force recommendation. *Pediatrics*, 122, e266–276. [PubMed: 18595973]
- Scollie S, Ching TYC, Seewald R, Dillon H, Britton L, et al. 2010 Evaluation of the NAL-NL1 and DSL v4.1 prescriptions for children: Preference in real world use. *Int. J. Audiol*, 49, S49–S63. [PubMed: 20109089]
- Sininger YS, Grimes A & Christensen E 2010 Auditory development in early amplified children: Factors influencing auditory-based communication outcomes in children with hearing loss. *Ear Hear*, 31, 166–185. [PubMed: 20081537]
- Thompson DC, McPhillips H, Davis RL, Lieu TA, Homer CJ, et al. 2001 Universal newborn hearing screening: Summary of evidence. *Journal of the American Medical Association*, 286, 2000–2010. [PubMed: 11667937]
- Yoshinaga-Itano C, Sedey AL, Coulter DK & Mehl AL 1998 Language of early- and later-identified children with hearing loss. *Pediatrics*, 102, 1161–1171. [PubMed: 9794949]
- Zimmerman I, Steiner VG & Pond RE 2002 *Preschool Language Scale, Fourth Edition (PLS-4)*. San Antonio, Texas: The Psychological Corporation.

Figure 1. Histogram of fitting age (months) for children with mild (≤ 40 dB HL), moderate (41 – 60 dB HL), severe (61 – 80 dB HL) and profound hearing loss (>80 dB HL) in the better ear.

Table 1.

Summary of studies on outcomes of children with hearing loss who received early or later intervention.

Study	n	Age at fitting (number 1 year)	Age at evaluation	Outcomes measured	Findings on effect of age of intervention
Yoshinaga-Itano et al. 1998	150	0 – 34 months (72 < 6 months)	13 to 36 months	Parent report: Child Development Inventory.	Yes, enrolment before 6 months significantly better than after 6 months
Moeller, 2000	112	1 – 54 mo (24 < 11 months)	5 years	Receptive vocabulary.	Yes, enrolment before 9 months better than after 9 months
Wake et al, 2004	89	5 to 54 months (11 < 6 months)	7 to 8 years	Language; Speech production.	No significant effect of age of intervention.
Kennedy et al, 2006	120	10 – 40months (57 < 9 months)	5.4 to 11.7 years, Mean: 8 years	Receptive language; Expressive language; Parent report on speech production.	Yes for receptive language, but not for expressive language or speech production.
Fitzpatrick et al, 2007	65	6.6 – 18months (15 < 6 months)	3 to 5 years	Receptive vocabulary; Language; Speech production.	No significant effect of age of intervention on outcomes.
Sininger et al, 2010	44	1 to 72 months (23 < 6 months)	3 to 8 years	Speech perception, Speech production, Language	Yes
Korver et al, 2010	130	15.7 months vs 29.2 months	4 to 5 years	Parent reports: Child Development Inventory; Macarthur-Bates Communicative Inventory.	No significant effect of age of intervention on language outcomes.

Table 2:

Universal Newborn Hearing Screening (UNHS) programs in Australian States and Territories.

State/Territory	Year UNHS Roll-out Commenced	Year UNHS Roll-out Completed*	Screening Approach/Technology	Percentage of National Births (as at 2002)
New South Wales	2002	2003	2-stage AABR**	34.5%
Victoria	2005	2012	2-stage AABR	24.5%
Queensland	2004	2006	2-stage AABR	19.0%
Western Australia	2000	Not yet complete	2-stage mixed (TEOAE*** /AABR) to mid 2013 2 stage AABR from mid 2013	9.4%
South Australia	2005	2006	3-stage mixed (TEOAE x 2/AABR)	7.0%
Tasmania	2006	2009	2-stage AABR	2.4%
Australian Capital Territory	2002	2004	3-stage AABR	1.6%
Northern Territory	2008	2011	N/A	1.5%

* Year in which >95% of all newborns completed a screen for hearing

** Automated Auditory Brainstem Response Testing

*** Transient Evoked Otoacoustic Emissions Testing