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Going digital: Enabling caregivers to optimise the linguistic environment for children with significant hearing loss

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ABSTRACT

Early auditory exposure and linguistic interactions are fundamental in shaping the trajectory of typical language development in hearing children. These early linguistic experiences occur within the context of adult-child exchanges, through daily experiences, care routines and play. For children with prelingual hearing loss, early access to sound through hearing devices enables them to participate in these early linguistic experiences and can mitigate the potential negative effects resulting from hearing loss. In addition to early device fitting, research has demonstrated a strong association between the manner, content and amount of spoken language which infants and toddlers are exposed to at home, to enhance their learning, and their later language outcomes.

While there is growing research awareness with regard to measuring the amount of talk directed to children, establishing how best to provide feedback to caregivers on their language contributions to their children in the context of everyday life, has been a challenge in traditional service delivery models. To this end, automated speech and language processing technology, also known as the Language ENvironment Analysis (LENA) system, offers clinicians the possibility of measuring and imparting quantified information to parents about their child's auditory-language environment. Additionally, the use of mobile applications has been gaining traction as an accessible method of promoting health. The Daily Vroom App (DVA) for example, was created as an outreach initiative to communicate developmental research evidence to parents, presented as practical and implementable content. The DVA content takes the form of daily tips aimed at turning everyday moments for parents and their young children into opportunities for shared interaction. This study evaluated these two technology-driven interventions, using LENA technology and the Daily Vroom App, as ways to increase the amount of conversational turns and words spoken by adults to children.

The present study firstly investigated relationships between family, maternal and child characteristics and language counts (measured using the LENA system) recorded in the children's natural home environments. Secondly, changes in the participants' adult word count and adult-child conversational turn count from baseline were examined after mothers received feedback based on LENA generated language estimates and/or, after mothers had used the Daily Vroom App. Thirdly, survey findings regarding the use of LENA technology and the DVA from the perspective of clinicians and mothers were explored.

There were 10 mother-child dyads (six hearing children and four children with bilateral severe-to-profound hearing loss) who participated in a prospective intervention trial. After

establishing each dyad's baseline LENA-generated language counts (adult words and adult-child conversational turns), mean percentage changes in their language counts were analysed for three study conditions: LENA-Only recordings of adult-child verbal interactions in the child's natural environments (Condition LO); adult-child verbal interactions following specific, individualised feedback from a clinician regarding the quantity of talk (LENA Feedback- Condition LF); and DVA use which provided tips for shared parent-child interactions in addition to Condition LF (LENA Feedback and App- Condition LFA). Maternal and child measures were administered at the beginning of the study. Demographic information and responses to a survey on the use of LENA and mobile technology were collected from participating clinicians and mothers.

Key group findings suggested that the mean percentage increases in adult word and conversational turn counts from baseline were significant after the interventions (i.e. providing participants with LENA feedback and mother's use of the mobile app), compared to Condition LO where only LENA recordings were completed. Significant correlations were found between mothers' occupational skill level, maternal receptive vocabulary and their ratings of eHealth literacy. Participants assigned the DVA an overall mean quality rating of 3.85 out of 5. Significant positive relationships were found between objective app quality indicators (engagement, aesthetics, information) and participants' perceived impact (on help-seeking, intention to change and behaviour change) of using the DVA.

These two contemporary technologies (LENA and DVA) were demonstrated to support adult language input and conversational turns in the home environments for mothers of children with normal hearing, and children with bilateral significant hearing loss. This study addressed the question of whether providing structured information and feedback to mothers would be associated with a change in maternal language behaviours. This study also contributed to current knowledge regarding the practical applications of the LENA system and the Daily Vroom App as a complement to current service models, extending intervention practices beyond the therapy room.

Declaration

This is to certify that

(i) the thesis comprises only my original work towards the PhD except where indicated in the Preface,

(ii) due acknowledgement has been made in the text to all other material used and

(iii) the thesis is fewer than 100,000 words in length exclusive of tables, maps, bibliographies and appendices, and complies with the stipulations set out for the degree of Doctor of Philosophy by The University of Melbourne.

Dawn Choo

PREFACE

This thesis is my original work and, to the best of my knowledge, contains no material written by another person, except where due acknowledgement has been made.

Some of the material and content of this thesis has been published in Studies in Health Technology and Informatics in 2017. Qualitative responses from a subset of participants were analysed and reported on for the publication but were not examined as part of the aims and findings for this thesis. The following people have made significant contributions as co-authors on the publication. Dr Shani Dettman, Prof Richard Dowell and Prof Robert Cowan contributed to the research plan, design and revision of the publication. The publication has been included as Appendix 1 for reference purposes.

The content of thesis does not contain work that was carried out prior to the enrolment of my research higher degree candidature. All of the studies described in this thesis were conducted in a manner consistent with the National Statement on Ethical Conduct of Human Research.

Funding for this thesis was provided by The HEARing Cooperative Research Centre (CRC), established under the Australian Government's Cooperative Research Centres (CRC) Program. The CRC Program supports industry-led collaborations between industry, researchers and the community. This research was also supported by the Australian Government Research Training Program.

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I would like to thank my advisory panel members who have rendered assistance to me throughout the project. I am particularly grateful to Associate Professor Kathleen Gray for carving out time to share her knowledge and expertise in health informatics with me.

Special thanks to the clinicians who had participated in this study and the staff at the HEARing Cooperative Research Centre, Cochlear Implant Clinic (Royal Victorian Eye and Ear Hospital), The University of Melbourne, Hear and Say, Taralye and The Shepherd Centre, who were involved in this project. I am very grateful to all who went above and beyond to ensure that the study was carried out smoothly.

I would like to express my sincere thanks to all the families, mothers and children who volunteered their time to participate in this research. You welcomed me into your busy lives, and it was a privilege to have worked with all of you. Thank you for making this study possible.

I would like to acknowledge The HEARing Cooperative Research Centre for funding this project and for providing full scholarship support for me to undertake this research. I have been very fortunate to receive HEARing CRC support to attend conferences and present on this study's findings.

A thank you to colleagues and friends (and my pod-mate Juju) at 550 Swanston Street for their words of encouragement and for all the valuable corridor chats. A warm thank you to my delightful PhD buddy, Sammi, for walking alongside me on this path. A word of thanks to Agnes for often indulging me with a medley of gourmet treats, all of which saw me through long writing days, and a special mention of thanks to Jess V, for being my sounding board and for seeing the funny side to everything.

To those near (and far) and dear, thank you for listening, for your company and for helping me to keep things in perspective. Life is always better with amazing friends and good food. I am also very grateful for the best friend anyone could ask for, Rachel, I truly appreciate all that you do.

I am incredibly blessed to have a supportive and loving extended family. Thank you for being there and for your many acts of service. To my sister, thank you for frequently checking in on me. To my Mum, thank you for your selfless sacrifices and for being the first person to teach me the power of spreadsheets. To my Dad, thank you for believing in me, you might not have realised that those Saturday library visits helped to fuel my love for the written word. To both of my parents, I am grateful that you have invested abundantly in me and have been so supportive of my educational pursuits. Thank you is not enough.

To my dearest husband and confidant, Benjamin, you deserve exceptional thanks for being there through it all, the best and the worst. Thank you for your attentiveness, your understanding, your strength, and for loving me through times when I was rather hard to love. I will always remember the many occasions when you had to listen patiently to me practise different presentations (i.e. whilst standing in the line outside Duomo di Milano, and on planes, trains and automobiles). I am very fortunate to have found someone who constantly showers me with affection and who makes me laugh. Thank you for all the long talks and walks, for putting up with my odd hours of writing, bringing me cups of water and coffee in bed and for all the little things that you do to take care of me.

And finally, I would like to remember my Grandma, who passed away before the completion of this thesis. Thank you for your unwavering love, for being an extraordinary caregiver in my early years and for playing such an immense role in the first 27 years of my life. This is for you.

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Conference Presentations

Choo, D., Dettman, S., Dowell, R., & Cowan, R. (2018, June). *Partnering with mothers to promote spoken interactions with their children in the home using LENA and mobile technology*. Paper presented at the Family Centred Early Intervention for Children who are Deaf or Hard of Hearing Conference 2018, Bad Ischl, Austria.

Choo, D., Dettman, S., Dowell, R., & Cowan, R. (2018, June). *A parent-focused approach to intervention in the home using mHealth and Language ENvironment Analysis (LENA) technology for infants and toddlers*. Paper presented at the Hearing Across the Lifespan Conference 2018, Cernobbio, Italy.

Choo, D., Dettman, S., Dowell, R., & Cowan, R. (2017, August). *Talking to toddlers: Drawing on mothers' perceptions of using wearable and mobile technology in the home*. Paper presented at Health Informatics Conference 2017, Brisbane, Australia.

Choo, D., Dettman, S., Dowell, R., Cowan, R., Leigh, J. & Courtenay, D. (2017, July). *Preliminary findings of a parent-focused intervention using mobile and wearable technology to enrich the everyday language environments of young children*. Paper presented at the 15th Symposium on Cochlear Implants in Children, San Francisco, USA.

Choo, D., Dettman, S., Dowell, R., Cowan, R. (2017, May). *Engaging parents in their children's early communicative experiences with mobile and wearable (LENA) technology: A pilot study.* Paper presented at the Speech Pathology National Conference 2017, Sydney, Australia.

Choo, D., Dettman, S. J., Dowell, R. C., & Cowan, R. S. C. (2016, June). *Enriching the auditory-linguistic environment for young children with mobile and wearable technology: A pilot study*. Paper presented at the HEaring Across the Lifespan Conference 2016, Cernobbio, Italy.

ABBREVIATIONS

AWC	Adult Word Count
CI	Cochlear Implant
CRC	Cooperative Research Centre(s)
CT	Conversational Turn
CTC	Conversational Turn Count
CV	Child Vocalisation
CVC	Child Vocalisation Count
DAD	Daily Activities Diary
DLP	Digital Language Processor
DeCAF	Designing eHealth for Clinicians And Families
DVA	Daily Vroom App
eHEALS	eHealth Literacy Scale
EL	Expressive Language
FamED-Q2	Family and Educational Characteristics Questionnaire
HA	Hearing Aid
Hd	Hearing mother and child with hearing loss
Hh	Hearing mother and hearing child
IQR	Interquartile Range
KBIT	Kaufman Brief Intelligence Test
KIDI	Knowledge of Infant Development Inventory
LDS	LENA Developmental Snapshot
LENA	Language ENvironment Analysis
LF	LENA Feedback
LFA	LENA Feedback and App
LO	LENA recording Only
MLU	Mean Length of Utterance
PEACH	Parents' Evaluation of Aural/oral performance of CHildren
PPVT	Peabody Picture Vocabulary Test
PLS	Preschool Language Scale
PSOC	Parenting Sense of Competence

PTA	Pure Tone Average
RL	Receptive Language
SD	Standard Deviation
SES	Socioeconomic Status
SEIFA	Socio-Economic Indexes for Areas
SNHL	Sensorineural Hearing Loss
TL	Total Language
UTAUT2	extended Unified Theory of Acceptance and Use of Technology
uMARS	user version of the Mobile App Rating Scale

1 INTRODUCTION

When a flower doesn't bloom, you fix the environment in which it grows, not the flower.
— Alexander Den Heijer (2015)

Children's early exposure to spoken language occurs in the context of their daily experiences, through family interactions which takes place largely in the home environment (Cole, 2011). From the first year of life, typically developing and normal-hearing young children and their primary caregivers establish a communication foundation which facilitates rapid language development during sensitive learning periods (Levine, Strother-Garcia, Golinkoff, & Hirsh-Pasek, 2016). Within the first two years of life, the existing body of research has suggested that disparities in children's early language competence begin to emerge due to the socioeconomic status (SES) influences on the language environments for infants and toddlers (Betancourt, Brodsky, & Hurt, 2015), and on caregivers' communication with their children (Pace, Luo, Hirsh-Pasek, & Golinkoff, 2017). The language or word gap is a well-known phenomenon which was famously characterised by American researchers, Hart and Risley, denoting how children's preschool language abilities, resulting from their cumulative early language exposure, affected their developmental trajectories and later educational achievements (Hart & Risley, 1995).

For children with significant bilateral sensorineural hearing loss (SNHL), the experience of early auditory-linguistic deprivation adds a further layer of complexity to this equation, leading to substantial variability in later language performance for this population (Levine et al., 2016). Early age at hearing loss detection and first fitting of hearing devices have been found to mitigate the effects of auditory deprivation on language development (Ching, Dillon, Leigh, & Cupples, 2018). Nonetheless, providing linguistically and conversationally rich environments may be particularly important for children with bilateral SNHL to ensure optimal communicative outcomes (Levine et al., 2016). Niparko and colleagues (2010) suggested that directing intervention efforts at increasing maternal engagement in the child's early communication could be an effective strategy for enriching children's language exposure in the home.

Early language intervention studies have similarly emphasised the potential for optimising children's early language development via the adult primary caregiver (Roberts & Kaiser, 2011). The terms 'parent', 'family' and 'mother' were found to be used interchangeably in different sources of literature when describing caregiver-implemented interventions (Rodriguez & Tamis-LeMonda, 2011; Soderstrom & Wittebolle, 2013; Suskind et al., 2016b; Vanormelingen, De Maeyer, & Gillis, 2016). For the purposes of the present study, the previously mentioned terms were all used to denote the role of 'caregiver' relating to the child's adult conversational partner, typically the child's mother, who also takes primary responsibility for caring for the child in everyday circumstances.

Two prevalent approaches found in language intervention studies to date are aimed at influencing caregiver's quantity and quality of language input to children aged between 18 and 60 months (Roberts & Kaiser, 2011). For younger children, exposure to a greater quantity of language input appeared to be of most benefit to their early language development (Rowe, 2012). The increased number of opportunities for children to connect the phonological form of words with their meaning, provides the rationale for exposing children to a large quantity of linguistic input in everyday life (Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991). Additionally, it was proposed that higher rates of adult-child conversational exchanges may stimulate early language development as conversations provide children with occasions to practice and amalgamate recently learnt language (Zimmerman et al., 2009). Clinically, professionals working with young children recognise that parents have the capacity to extend benefits of these therapeutic interventions to the child's natural environment (Sacks et al., 2014). Yet, it remains a challenge for clinicians to ensure that caregivers transfer skills learnt in speech and language therapy to naturalistic contexts which occur outside of clinical settings (Paul & Roth, 2011).

Attempts to analyse the home environment have often been hampered by the presence of the clinician/researcher in the families' homes, and the extensive resources and time required to undertake manual transcription and coding of audio data collected using static recording devices (Smyth & Brinkman, 2014). Early intervention programs therefore relied on information collected via questionnaires, short recorded video samples and parent self-report measures to better understand the child's home communication environment. Recent technological advancements have addressed the challenge of measuring the frequency of parent-child verbal interactions and amount of auditory-linguistic exposure in a child's naturalistic environment using Language ENvironment Analysis (LENA) technology (Smyth & Brinkman, 2014). Furthermore, the LENA System makes it possible to provide parents with objective and personalised feedback on the quantity of language input recorded in their child's home environment (Suskind et al., 2013). The goal of LENA feedback is to help increase parental awareness of their language behaviours to effect positive changes which can benefit the child's early language development (Suskind et al., 2013).

In addition to LENA technology, the unexplored potential to use parent-targeted mobile apps to deliver parent-child interaction strategies to stimulate early language learning requires our attention. The Bezos Family Foundation, an American philanthropic organisation with an interest in education, recognised the pivotal role which caregivers play in young children's early development. They launched the Daily Vroom App (DVA), also known as Vroom, in 2014, as part of a public outreach and communication initiative (Galinsky et al., 2017). The DVA was aimed at disseminating scientific knowledge about child development in the form of activity tips which parents can implement with their children within their everyday routines to promote early learning (Galinsky et al., 2017). Mobile apps, such as the DVA, offered the possibility of communicating with target populations directly and delivering information to supplement intervention programs at appropriate times, regardless of geographical distance (Whittaker, Merry, Dorey, & Maddison, 2012). The efficacy of supporting parents with mobile-based tools/ education to enrich their child's home language environment, and specifically its impact for children with hearing loss remains unknown due to its recent inception and lack of objective measurement in everyday life.

This thesis explored the use of modern digital tools, namely LENA technology and the DVA, to support caregivers in making positive impacts on the early language environments for both hearing children and children with significant hearing loss aged between six months to three years. This central question was examined using two separate approaches. Study 1 (Intervention Trial) is presented in Chapters 4, 5 and 6, and Study 2 (Survey) is presented in Chapters 7, 8 and 9, following a review of the relevant literature (see Chapter 2). An outline of the research aims guiding both approaches is provided in Chapter 3.

The ability to quantify the degree of change following an intervention is important for advancing evidence-based approaches. To achieve this, LENA-generated language counts were used as the primary outcome measure following a novel caregiver-implemented intervention trial in Study 1 (Intervention Trial). The intervention consisted of two strategies, namely providing personalised LENA feedback to mothers, and asking mothers to complete suggested DVA activities. Study 1 attempted to uncover whether the quantity of adult talk and adult-child conversational turns increased in children's natural, everyday language environments following the use of the intervention strategies. Contextual factors, including family, maternal and child variables, that were likely to be associated with the quantity of talk in children's home environments prior to the trial, were also explored. The intervention protocol and methodology for Study 1 are described in detail in Chapter 4. Group results for Study 1 are presented, followed by case descriptions of the four mothers and their children with bilateral SNHL in Chapter 5. The findings for the intervention trial are discussed in Chapter 6.

It has been argued that the end-user experience of using digital technologies for intervention may also affect uptake and retention rates in the intended user populations (Diefenbach, 2018). There is currently limited published research regarding end-user experiences and perceptions of using LENA and DVA as part of language interventions. Study 2 (Survey) adopted a user-centric approach by investigating the perceived eHealth literacy skills, DVA quality, and perceived impact of using LENA and DVA on early child language from the perspectives of mothers and clinicians working in paediatric settings. Methodology for the development and use of the Designing eHealth For Clinicians and Family (DeCAF) survey for Study 2 is outlined in Chapter 7, followed by the survey results which are reported in Chapter 8 and discussed in Chapter 9.

With the increasing adoption of technology use in healthcare, the present research builds on current knowledge by demonstrating the value of digital tools in promoting rich early home language environments for children with normal hearing, and children with significant hearing loss, through their caregivers. This research will help to address some of the opportunities and challenges associated with the implementation of LENA and the DVA mobile technology as part of a home-based, language intervention approach for mother-child dyads. To conclude, recommendations for future research and implications for clinical practice are detailed in Chapter 10.

2 Literature Review

The scope of this literature review addresses five key themes to set the stage for the present research. The first section outlines the mechanisms of early language learning and describes the long-term cumulative impact of early language competence on later literacy and educational outcomes. For populations for example, children with prelingual, sensorineural hearing loss, who are at-risk of language delays, converging evidence promoting an increase in access to auditory information through audiological interventions, such as hearing aids (HA) and cochlear implants (CI), is presented as a means to alleviate the experience of auditory-language deprivation. Disparities in language outcomes, however, continue to persist for children with hearing loss despite best efforts to provide early access to audition. In the second theme (2.2) a social-ecological perspective is used to illustrate some of the complexities, such as the nuanced effect of socio-economic status and the role of family, and maternal factors, which impact on the early language experiences and outcomes for both typically hearing children and children with hearing loss. The third section (2.3) focuses on aspects of caregiver language input which are reported in the literature as being particularly germane to child language development. The fourth theme (2.4) discusses the merits of using language tracking technology (Language ENvironment Analysis) to measure and provide feedback to parents on their language behaviours in naturalistic environments. Mobile technology, such as the Daily Vroom App initiative, is considered as a possible strategy for fostering learning opportunities through shared parent-child interactions in everyday life. Finally, the fifth section (2.5) describes the value of incorporating the intended users' attributes and views when designing digitally-driven interventions using the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2; Venkatesh, 2012).

2.1 Language and The Developing Brain

Early childhood marks a precarious time of both vulnerability and opportunity as the foundations of developing brain structure are laid to support later learning (Fox, Levitt & Nelson, 2010; Shonkoff & Phillips, 2000). In the formative years of life, the architecture of the brain is shaped through a process of dynamic interactions between genetic contributions, individual experiences and environmental conditions (Fox et al., 2010; Friederici, 2006; Leisman, Mualem, & Mughrabi, 2015). An individual's genetic blueprint provides a basis for neural networks to be established (Fox et al., 2010) and neural circuits continue to alter and mature with the influences of an individual's interactions with, and exposure to the environment (Fox et al., 2010). Developmental plasticity or the brain's capacity to adapt to experiences in the immediate environment has been recognised to be at its greatest in infancy and early childhood (Barker, 2012; Gluckman, Hanson, & Mitchell, 2010; Moore, Arefadib, Deery, & West, 2017). This early childhood phenomenon is characterised by intervals when different neural circuits are maximally receptive to environmental input, allowing for an accelerated proliferation of synaptic connections between neurons to occur (Katz & Shatz, 1996; Pascalis, de Haan, & Nelson, 2002). During this privileged time of rapid learning, neural pathways are strengthened through recurrent use and reinforced by the child's experiences in their environment, while neural connections which are not used (due to under-stimulation), diminish through a mechanism called synaptic pruning (Moore et al., 2017; Shonkoff & Phillips, 2000). The effects of the environment on biological embedding demonstrate that a child's experience and exposure to their early language environment has a critical influence on the building blocks of language, which can in turn, impact on later development (Fox et al., 2010; Szagun & Stumper, 2012).

This period of heightened sensitivity for language learning can be demonstrated by the rapid expansion of children's oral communication abilities in the first three years of life (Szagun & Stumper, 2012; Zauche, Thul, Mahoney, & Stapel-Wax, 2016). Before beginning to speak, infants influence interactions with their caregivers through vocalisations and non-verbal communication using gestures, gaze and facial expressions (Adamson, Bakeman, Deckner, & Nelson, 2014; Rowe, 2012). The current state of behavioural, neurocognitive and developmental research suggests a sensitive period for language acquisition exists where children progress from a prelinguistic stage to using language as a functional means of communication (Fox et al., 2010; Holt & Svirsky, 2008; Leisman et al., 2015; Newport, Bavelier, & Neville, 2001). In the stage model, protophones which are unique precursors to human speech, are differentiated from reflexive or vegetative sounds such as coughing, respiratory noises, burping and sneezing (Oller, Eilers, Neal, & Schwartz, 1999). Examples of the earliest protophones observed during the first few months of an infant's life, include glottal sounds or quasivowels (vocalisations without any posturing of articulators) which are produced during the phonation stage, followed by cooing and gooing in the articulation stage (Oller et al., 1999).

Typically developing infants would also begin to explore meaningful and stable patterns they hear within spoken speech in the first twelve months of life (Newman, Ratner, Jusczyk, Jusczyk, & Dow, 2006); learning to discriminate between phonemes and to parse words (Kuhl, 2011; Levine et al., 2016). Word comprehension and phonetic learning has been observed to occur from eight months of age and towards the end of the first year for typically developing monolingual children (Kuhl, 2011). Research findings have also noted that as children start to make connections between language and the environment, their vocabulary development begins to flourish at 18 months of age

(Hollich et al., 2000; Kuhl, 2011). This is followed by syntactic learning or grammar (rules of a language and word order in sentences) between 18 to 36 months of age (Kuhl, 2011). There is evidence that adults can adjust their speech towards infants, making it easier for infants to process and increase their attention to speech which in turn, facilitates language learning (Ma, Golinkoff, Houston, & Hirsh-Pasek, 2011).

Research interest in the early years has also been driven by the growing awareness that early disparities in language learning have significant implications on future literacy and academic outcomes (Zauche et al., 2016), which in turn have lifelong consequences for children (Fox et al., 2010; Moore et al., 2017; Shonkoff & Phillips, 2000). Early language ability is associated with the skill of detecting distinct speech sounds which supports phonological awareness (Munson, Kurtz, & Windsor, 2005), vocabulary acquisition and grammatical development (Hoff, 2006). Each of these language systems contribute to later reading comprehension and literacy success (Hirsh-Pasek & Golinkoff, 2012). To illustrate, exposure to spoken language input helps children to develop a functional knowledge of phonological structure, which later reinforces their abilities for decoding and comprehending written text (Wang, Bergeson, & Houston, 2017a). Research evidence also indicates that a child's vocabulary skills underpin the trajectory of subsequent language performance and educational attainment (Hart & Risley, 1995; Rodriguez & Tamis-LeMonda, 2011; Rowe, 2008). Rowe (2008) found that children's receptive vocabulary skills measured using the Peabody Picture Vocabulary Test at 2.5 years of age predicted their vocabulary performance at 3.5 years of age, and in Hart and Risley's (1995) study, a child's rate of vocabulary growth at the age of three was identified as the strongest predictor of reading in third grade at 9 to 10 years of age. As children transition from the expectation that they are 'learning to read' to 'reading to learn' during the primary school years, the understanding of increasingly complex concepts hinges on an individual's language proficiency, making Hart and Risley's (1995) findings exceptionally noteworthy. Having good language skills and having a large vocabulary provides a learning advantage, whereas possessing a smaller vocabulary and having poorer language skills inhibits educational growth, having a cumulative toll on academic achievements in the longer-term (Snow, 2016; Stanovich, 1986). Children who do not have the same expected grade-level literacy skills as their peers tend to fall behind in their academic achievements, hence creating an achievement gap which widens over time (Zauche et al., 2017). The observation known as the Matthew Effect, where individuals who are at an advantage early, are able to accumulate greater advantage in future, compared to their peers with less advantage. This observation may also apply to language development as early access to language provides the child with more opportunities to gain greater language skills. The compounding consequences of language competence on pathways of opportunities and human capital in later-life highlights the importance of early language skills (Pace et al., 2017; Snow, 2016; Stanovich, 1986). To reduce language and educational disparities in the long-term, there is need to understand proximal risk factors which directly impact the child's language acquisition journey during the early developmental years.

2.1.1 The Role of Audition

For hearing children, auditory-linguistic gains in the first year of life are robust predictors of preschool language outcomes (Levine et al., 2016). For example, the ability to discriminate between phonemes at 7.5 months was associated with word and sentence production at 18 to 24 months (Kuhl, Conboy, Padden, Nelson, & Pruitt, 2005), and the verbal recognition of familiar words at 7.5 to 12 months was strongly linked to expressive vocabulary performance at 2 years of age (Newman et al., 2006). The lasting effects of phonetic learning and vowel perception in the first 12 months of life was also shown to predict language abilities between 18 to 30 months of age, and future language and pre-literacy performance at five years of age (Kuhl, 2011). Similar findings by Newman and colleagues (2006) also demonstrated that children's ability to segment words from fluent speech in infancy (under 12 months of age) was related to their language skills between four to six years of age, suggesting that speech processing abilities were essential for developing oral language (Newman et al., 2006).

A child's environmental exposure to auditory stimuli has been identified as a salient contributor to the brain's synaptic growth and oral language development (Kral & Sharma, 2012; Levine et al., 2016; Shonkoff & Phillips, 2000). An infant's environment is replete with continual sensory input which the neonate has to adapt to through pattern discovery, as part of the process of developing attentional selectivity (Kral & Sharma, 2012; Levine et al., 2016). Children capitalise on statistical learning using acoustic-phonetic cues and perceptual information derived from the speech stream to recognise their native language (Kuhl, 2011; Levine et al., 2016), as a precursor to developing oral language. For children with SNHL, limited access to sounds of speech could impact significantly on their communication development. Thus, oral language development is reported to be compromised when auditory deprivation occurs (Kral & Sharma, 2012).

An Australian epidemiological study reported that 1.12 children in every 1000 have a congenital, moderate or greater (>40 dB HL) hearing loss (Russ et al., 2003). Approximately 40% of these children have a bilateral hearing loss greater than 70 decibels (Ching, Dillon, Day, & Crowe, 2009). Children with moderate to profound prelingual hearing loss who have experienced significant auditory deprivation have an increased susceptibility to demonstrating delays in language skills (Cruz, Quittner, Marker, DesJardin et al., 2013). In an Australian study investigating children's attainment of early spoken language milestones, typically hearing children were found to have acquired their first hundred words and to have produced first word combinations earlier than children with profound hearing loss who were fitted with cochlear implants and/or hearing aids (Nott, Cowan, Brown, & Wigglesworth, 2009).

Over 90% of children with a hearing loss are born to hearing parents (Albertini, 2010), who tend to prefer an oral mode of communication (Fulcher, Purcell, Baker, & Munro, 2015). Opportunities for children with congenital SNHL to develop oral language skills have grown in recent years given the advancement in hearing technology (Cruz et al., 2013), and the implementation of newborn hearing screening programs which promote early identification and intervention for hearing loss (VanDam, Ambrose, & Moeller, 2012). In the past, hearing aids were the only means of increasing amplification for children with SNHL, but those with severe to profound hearing loss tended to receive insufficient access to the acoustics of speech to facilitate spoken language acquisition (Campbell, MacSweeney, & Woll, 2014; Cruz et al., 2013; Pisoni, Kronenberger, Harris, & Moberly, 2018). Since the 1980's cochlear implants have become a standard intervention for children who did not derive significant benefit from hearing aids. A cochlear implant (CI) device is used to treat sensorineural hearing loss by transducing environmental acoustic cues into electrical impulses which stimulate the auditory nerve (Campbell et al., 2014). For children with prelingual hearing loss, CIs provide a gateway into acquiring oral language (Campbell et al., 2014). While CIs do not mimic natural hearing, it has been found that young children who receive CIs are capable of attaining levels of speech and language skills which surpass abilities seen in their peers who have received hearing aids alone (Yoshinaga-Itano, Baca, & Sedey, 2010). By examining the growth in auditory and speech recognition skills in children using cochlear implants, findings from longitudinal outcome studies have revealed patterns of language acquisition that are not distinguishable from typical development observed for children with normal hearing (Dunn et al., 2013; Houston & Miyamoto, 2010). Additionally, it has been observed that children with cochlear implants develop language growth trajectories at rates more closely aligned to that of their hearing age-matched peers (Dettman et al., 2016; Svirsky, Robbins, Kirk, Pisoni, & Miyamoto, 2000; Wie, 2010). While it has been demonstrated that some children who have been diagnosed with severe to profound hearing loss in infancy are capable of achieving age-appropriate speech and language test scores post-implant, communication gains are not universal (Markman et al., 2011; Niparko et al., 2010).

Research efforts have been directed towards identifying factors contributing to the substantial variability in speech and language performance observed for children using cochlear implants (Pimperton & Walker, 2018). Age at implantation has been consistently highlighted in the literature as a prevailing factor influencing optimal communication outcomes (Dettman et al., 2016;

Dettman, Pinder, Briggs, Dowell, & Leigh, 2007; Geers, Moog, Biedenstein, Brenner, & Hayes, 2009; Holt & Svirsky, 2008; Moog, Geers, & Moog, & Geers, 2003; Nicholas & Geers, 2013; Pimperton & Walker, 2018; Szagun & Stumper, 2012). In their sample of 153 children who received CIs under 5 years of age who had at least one year of device experience, who used spoken language exclusively and who had received auditory-oral intervention in their preschool years, Geers and colleagues (2009) found that just under half (47%) achieved age-appropriate receptive language skills and 39% of the sample achieved expressive language skills by school-entry (between five to six years of age). When age at implant as a sole variable was examined more closely for a sample of 27 children who received their implants between 6 to 11 months of age (under 12 months of age) and who had enrolled in intervention programs focused on listening and spoken communication, a higher percentage of the children received language standard scores (93% for receptive vocabulary, 85% for receptive language and 77% for expressive language) within the average range at 4.5 years of age (Nicholas & Geers, 2013). Niparko and colleagues (2010) found that children, who had shorter durations of auditory deprivation and lesser severity of hearing loss prior to the use of cochlear implants, had steeper slopes of receptive and expressive language growth compared to their pre-implant baseline performance. These studies suggested that there was a sensitive period for the provision of CIs to maximise the chances for children with SNHL to achieve language abilities comparable to their age-matched peers (Geers et al., 2009). Further studies have indicated that children who receive CIs at younger ages have better language outcomes compared to children who receive their implants later (Ching et al., 2018; Colletti, Mandalà, Shannon, & Colletti, 2011; Dettman et al., 2016; Houston, Stewart, Moberly, Hollich, & Miyamoto, 2012; Levine et al., 2016). In a mixed prospective and retrospective comparative study by Fulcher and colleagues (2012), 45 children who had been diagnosed with a hearing loss early, who received amplification by three months, who were enrolled into an auditory-verbal intervention by six months of age and who received a CI by 18 months of age, significantly outperformed 49 later-diagnosed and later-implanted children between the ages of three to five years. The early-identified group were able to progress to a similar level of speech and language development as their normal-hearing, typically developing peers (Fulcher et al., 2012). A longitudinal, American multi-centre study of 188 children reported that children who received implants under 18 months of age showed greater improvement in language skills over a three-year period compared to children implanted after 18 months and before five years of age (Niparko et al., 2010). Their findings were supported by results from a recent Australian multi-centre study of 403 children who received CIs under six years of age (Dettman et al., 2016). At school entry, a larger proportion of children who were implanted under 12 months of age had achieved age-appropriate language standard scores. Children in this group also demonstrated greater speech production accuracy and word intelligibility compared with children who were implanted later than 12 months of age (Dettman et al., 2016). These research findings supported the concept of age-dependent sensitive periods: opportunities for auditory-linguistic exposure for children with limited residual hearing need to be provided early (Fitzpatrick, Ham, & Whittingham, 2015; Kral & Sharma, 2012). Children who receive implants at younger age have the advantage of accumulating more oral communicative experiences through earlier engagement with others in their language environments (Szagun & Stumper, 2012; Tomblin, Barker, & Hubbs, 2007).

Despite a body of evidence advocating for the benefits for children receiving implants at a young age, the attainment of age-appropriate language skills is not assured for all (Moog et al., 2003; Tobey, Geers, Brenner, Altuna, & Gabbert, 2003). Age at implantation does not fully explain the individual variability of language outcomes which exists between children (James, Rajput, Brinton, & Goswami, 2008). Interim findings of the Longitudinal Outcomes of Children with Hearing Impairment (LOCHI) study indicated that 45%-49% of the variation in language development at three years of age in a cohort of 356 child participants could be explained by a group of known predictors (Ching et al., 2009). These predictors consisted of an early age at implant, severity of hearing loss, the presence of additional disabilities as well as early scores on the Preschool Language Scale (4th Edition) or early functional auditory performance (Parents' Evaluation of Aural/Oral Performance of Children; PEACH) ratings obtained at either 6- or 12-month post-hearing aid fitting (Ching et al., 2009). Findings of five-years of age LOCHI data affirmed that early CI/HA age at fitting was associated with higher global language scores (Ching et al., 2018). The effect of age at implantation on outcomes at school entry was further explored in Dettman et al's (2016) multi-centre study where 18% of the variance in standard scores on the Preschool Language Scale, 27% in receptive vocabulary (Peabody Picture Vocabulary Test) performance and 16% of the variance in the Clinical Evaluation of Language Fundamentals (CELF) standard scores was accounted for by age at first cochlear implant (Dettman et al., 2016). Findings from multiple regression analyses highlighted that the provision of early cochlear implants is only part of the optimal intervention formula for children with SNHL. Apart from audiological efforts to intervene early, it has been suggested that underpinning the efficacy of CI are individual differences related to child experiential factors, habilitation choices, demographic characteristics and contextual influences (Pisoni, Cleary, Geers, & Tobey, 1999; Wie, 2010). Some factors inherent in the child and/or uncontrollable factors which affect outcomes from early access to CIs include: surgical complications (Waltzman & Roland, 2005); presence of additional disabilities (Ching et al., 2018; Fitzpatrick et al., 2015; Wakil, Fitzpatrick, Olds, Schramm, & Whittingham, 2014); and cognitive factors and nonverbal intelligence (Colletti, Mandalà, Zoccante, Shannon, & Colletti, 2011). There are other considerations associated with CI outcomes including concepts of personal autonomy, such as: device usage and compliance with hours of device use (Özdemir et al., 2013); and the choice of communication modality (Geers & Brenner, 2003; Moog et al., 2003; Tobey et al., 2003). Recurring research themes in paediatric CI outcomes have included the interaction between psychosocial issues (Punch & Hyde, 2011); family and maternal factors (Geers & Brenner, 2003; Holt, Beer, Kronenberger, Pisoni, & Lalonde, 2012; Szagun & Stumper, 2012); amount of parental involvement (Moeller, 2000); and the child's home language environment (Szagun & Stumper, 2012). In summary, the performance variability seen in CI paediatric recipients may reflect sources of variation as seen in normally-hearing children (Kral, Kronenberger, Pisoni, & O'Donoghue, 2018; Pisoni et al., 2018). Given that similar determinants of language outcomes (i.e. family, maternal, socio-environmental characteristics) have been identified in both normally hearing and hearing-impaired child populations, adopting a theory which attempts to explain how contextual influences affect children's language development irrespective of hearing status, is warranted.

2.2 A Socio-Ecological Perspective

To understand how a child's development is shaped by interactions within the wider context of their environment, Bronfenbrenner's (1977) ecological system theory places the individual at the centre of the interaction with multiple, interconnected nested settings (systems). An individual's macrosystem forms the overarching yet distal climate (i.e. socio-cultural, educational and political values) which exerts a significant influence over an individual's life (Bronfenbrenner, 1977). Within the macrosystem, lies the exosystem which contains indirect structures which impinge on a child's circumstances, such as the neighbourhood, informal social networks, government organisations and access to services (Bronfenbrenner, 1977). The mesosystem which is contained within the exosystem, represents the connections between a child's microsystems for example, the interrelations which exist between home and school environments (Bronfenbrenner, 1977). At the core of the system, an individual's microsystem encompasses direct interactions between the individual and other people in immediate settings for example, family members in the home (Bronfenbrenner, 1977). Whilst indirect structures may have a bearing on a child's upbringing, more immediate and direct influences are also recognised as being pertinent to a child's development.

Socioeconomic status (SES) or an individual's attainment of financial security, resources and positioning on the social gradient is a commonly cited example (in health and education studies) of a pathway of influence on language development (Pace et al., 2017). SES can have a cascading effect through the topography of the socio-ecological systems. SES is often investigated as an aggregate-level measure derived from multiple indicators (for example: family demographic characteristics;

residential address; family income range and eligibility for governance assistance) due to the lack of available individual-level data such as, personal expenditure and financial standing (Krishnan, 2010). Research evidence has suggested that there is a higher prevalence of children at-risk of developmental concerns who come from socioeconomically disadvantaged backgrounds (Evans, 2006). The association of SES disparities on child language development have been observed as early as 7 and 18 months of age, where typically developing infants in more socioeconomically-advantaged families had been found to have higher expressive and receptive language scores on the Preschool Language Scale, 5th Edition (Betancourt et al., 2015) and have acquired larger expressive vocabularies compared with their age-matched peers from less socioeconomically-advantaged families (Fernald, Marchman, & Weisleder, 2013). Similarly, it has also been reported in Hart and Risely's landmark study (1995) that typically developing children's exposure to spoken language varies extensively in relation to their SES group. Children from lower-SES backgrounds were on average, exposed to less complex utterances and 30 million fewer words by the age of three years compared with peers from higher-SES backgrounds (Hart & Risley, 1995). The effects of SES on a child's domestic/family context appears to be closely linked. The effect of SES on language development may be partially explained by the family investment model which suggests that children from families of higher SES backgrounds have greater access to economic resources and are well-positioned to invest in supports which optimise child development while families with fewer resources would invest in addressing more immediate family needs (Conger & Donnellan, 2007). Socioeconomic disparities, which are closely associated with inequitable differences in health and developmental outcomes that are potentially avoidable, have also been described for children with hearing loss (Boss, Niparko, Gaskin, & Levinson, 2011). The presence of significant inequities for children from lower SES homes (measured using median family income thresholds and eligibility for benefits) compared to their more affluent peers has also been well documented in studies investigating rates of post-operative language and reading performance for paediatric cochlear implant recipients (Connor & Zwolan, 2004; Geers & Brenner, 2003; Niparko et al., 2010; Tobey et al., 2003). These SES-related language disparities which manifest early in life can influence later academic trajectories, school success (Burchinal, Peisner-Feinberg, Pianta, & Howes, 2002) and future employment prospects (Moore et al., 2017).

For children with CIs who may need to access frequent habilitation services, the presence of socioeconomic inequities is a barrier which could further magnify disparities (Boss et al., 2011). Families in Australia who live in regional or rural areas are often unable to readily access specialist support services (McCarthy, Duncan, & Leigh, 2012). Recent research has highlighted the demand for innovation solutions to provide these families and patients with distance or remote services (Cullington et al., 2016).

On closer examination of other specific markers related to SES: levels of parental education (Geers et al., 2009; Hoff, 2003; Vernon-Feagans & Bratsch-Hines, 2013); parental occupation skill level (Hart & Risley, 1995; Stacey, Fortnum, Barton, & Summerfield, 2006); and parental intelligence (Rowe, 2008) have also been identified as predictors of receptive and expressive language abilities for both children with hearing loss and children with normal hearing (Pace et al., 2017). For example, in Geers and colleagues' (2009) American study of 153 children with CIs, it was demonstrated that parental educational level explained a larger proportion of variance in both expressive (8.8%) and receptive (10.6%) vocabulary scores at five to six years of age than the children's age at implant (2.6% and 2.7% of variance in expressive and receptive vocabulary respectively). More specifically, maternal education emerged as a stronger predictor of children's language skills when compared to family income (Rowe, 2008). Limited levels of education may also be related to parents' knowledge of child development and being aware of the importance of hearing to learning (Boss et al., 2011). Similarly, varying levels of maternal education have been linked to differences in maternal language input directed towards children. In Hoff's (2006) study, mothers who had higher levels of education tended to talk more, use language to elicit conversation from their children and use more responsive communication approaches contingent to their child's actions; whereas families with lower levels of maternal education used shorter utterances with less diversity in language input and tended to be more directive of their children's behaviour (Hoff, 2006). Likewise, a similar observation between maternal intelligence and responsive parenting practices have been reported (Bornstein, Hendricks, Haynes, & Painter, 2007). These parental characteristics (education, intelligence and occupational skill level) may be broadly categorised as predictors which exert indirect effects on child language and would necessitate interventions to be implemented at a population level through social policy initiatives (McKean et al., 2015). SES-related family and parent variables are not very amenable to direct intervention, however identifying these characteristics provides information about parenting behaviour and the broader social context, which inevitably impacts on the experiences of children, for example the availability of resources in the home (Pace et al., 2017; Rowe, 2008). In contrast, there are proximal factors to a child's language growth which can be modified through direct interventions with the child or family (McKean et al., 2015). Proximal systems contain sources of the child's direct engagement with the world which fuel the primary medium of development (Bronfenbrenner, 1977). A child's linguistic environment has been suggested as a proximal predictor of language growth (Bornstein, Haynes, & Painter, 1998; Rowe, 2008; Weizman & Snow, 2001). Given that early language acquisition is contingent on a child's exposure to language-rich interactions, examining key social and communication aspects of a child's early relationships within the home environment can assist with informing language-facilitative strategies in early intervention.

2.3 Home Language Environment and the Role of Parents

Language-rich home environments can be described as contexts which nourish a child's social, linguistic, and neurological needs by providing the child with ample experiences of language use through adult-child engagement, and sufficient quality and quantity of language models (Zauche et al., 2017). Early language environments which are lacking in abundant and rich language experiences, communicative reciprocity or lexical complexity, are contrary to the development of children's vocabulary and preliteracy performance (Fernald et al., 2013; Hart & Risley, 1995). Rodriguez and Tamis-LeMonda (2011) demonstrated through their study of 1852 children from low-income backgrounds that the quality of learning environments which children are exposed to before two years of age, may foretell their later language skills. Children who experienced language environments which were characterised by low-quality experiences at 15 months of age did not perform as well on letter-word identification or receptive vocabulary measures at five years of age, compared with age-matched peers who were engaged in environments enriched with literacy activities (i.e. shared book-reading or storytelling with their mothers), high-quality mother-child play interactions (i.e. use of clear and appropriate child-directed speech) and learning materials (i.e. children's books or role-playing toys) (Rodriguez & Tamis-LeMonda, 2011). The timing and provision of quality early language environments has consistently been shown to have an SES-mediating effect in altering the life-course of children from low-income backgrounds (Ramey & Ramey, 2004). Children from lower-income backgrounds learnt language at rates comparable to their more advantaged peers when they experienced more enriched learning environments (Ramey & Ramey, 2004). At six months of age, children from low-SES families were enrolled in the treatment group of the Abecedarian Program and received intervention in the form of a high-quality early childhood education program until they entered public kindergarten (Ramey & Ramey, 2004). These children achieved higher reading scores on the Woodcock-Johnson test at every age tested during the school-years and at 21 years of age, with almost 70% of them found to be engaged in skilled employment or enrolled in higher education compared to 40% of participants who were in the control group (Ramey & Ramey, 2004). There were nine replication studies conducted with other at-risk populations; including infants who were premature or of low birth weight, mothers who had less than a high school education or a lower IQ average; which demonstrated that providing less-resourced children with enriched learning opportunities yielded similar significant child development benefits (Ramey & Ramey, 1998; Ramey & Ramey, 2004).

In Szagun and Stumper's (2012) study of 25 children who received cochlear implants between 6 and 42 months of age, it was the children's home language environment, specifically experience with language in the context of parent-child interactions, which affected their language progress at 12, 18, 24 and 30 months post-operatively more decisively than their age at implantation. Szagun and Stumper's findings have significant implications when contrasted with previous literature regarding the influence of early age at implantation on language development. Access to audition alone does not guarantee communication and oral language attainment, however providing enriched language environments to young children has demonstrable merits for language development given the compelling evidence seen from studies with hearing children from at-risk populations.

Drawing on a socio-interactionalist model of learning, an individual constructs meaningful knowledge about the world based on the interactions and communication with others in their environment (Vygotsky, 1978). Vygotsky's theory also emphasises the crucial role that parents play in child language development (Vygotsky, 1978; Zauche et al., 2017), as parents largely determine the type of language environment children are immersed in during the first few critical learning years (Sacks et al., 2014). Typically developing children at a mean age of three years (range seven months to seven years) were found to have acquired lexical and phonological forms of words which they were exposed to more frequently in their auditory environment as compared to words which were used less frequently by adult caregivers around them (Goodman, Dale, & Li, 2008). In the same vein, social learning theory proposes that children's language skills are reinforced through family experiences and parent-child interactions (Bandura, 1994).

Parents are primary contributors to the amount of spoken communication to which children are exposed (Hart & Risley, 1995). Given the inextricable link between parents and children's language exposure in the home, supporting parents in providing a rich language environment for their children may have a protective function against SES disparities (Pace et al., 2017). Research studies have also commonly investigated levels of caregiver involvement in conjunction with caregiver uptake of linguistic strategies for enhancing the communicative experiences of children with SNHL (Cruz et al., 2013; DesJardin & Eisenberg, 2007). Caregivers who are warm and responsive, actively participate in their child's daily activities and provide rich language experiences such as interactive book reading, promote a language stimulating environment for their children (Dodici, Draper, & Peterson, 2003).

The role which mothers have as primary caregivers holds relevance for a child's proximal learning. According to recent statistics (Australian Bureau of Statistics, 2006) derived from Australia's National Time Use Survey, mothers were found to spend more than twice as much time caring for their children (aged 14 years and under) than fathers. Gilkerson and Richards (2009) reported that in their study of 250 families with children aged between 2 to 30 months, mothers spoke substantially more words to their children than fathers did, contributing to approximately 75% of the total number of words versus 25% of words contributed by fathers. Supporting studies have established maternal speech input as an influential factor which impacts on child language acquisition (Bornstein et al., 2007; DesJardin & Eisenberg, 2007; Grieser & Kuhl, 1988; Hoff, 2006; Huttenlocher, Waterfall, Vasilyeva, Vevea, & Hedges, 2010).

A source of variability in rates of language learning among children lies in the differential access to language from mothers/caregivers (Huttenlocher et al., 2010). Evidence indicates that the quality and amount (quantity) of words spoken to a child in the first three years of life predicts child language and emergent literacy skills more strongly than parental education and SES (Hart & Risley, 1995; Hoff, 2003; Huttenlocher et al., 2010; Zauche et al., 2017). By understanding how aspects of maternal language behaviours (e.g. quantity and quality of input) can be shaped, this knowledge could be implemented as opportunities for children to optimise their language experiences (Pace et al., 2017). One focus of early intervention research is on identifying both proximal and malleable factors which can be taught, or characteristics which can be changed through intervention, to foster optimal speech and language outcomes (Fulcher et al., 2012). Niparko and colleagues (2010) have also suggested that directing intervention efforts at increasing parental involvement and engagement in their child's language development would be an effective strategy in maximising outcomes for children with hearing loss.

2.3.1 Quality of Language Input

The quality of language input which a child receives encompasses a wide range of linguistic features, including the sophistication of vocabulary, the complexity of utterances, use of scaffolding techniques designed to engage the child in verbal interactions, and maternal communication style (Ambrose, Walker, Unflat-Berry, Oleson, & Moeller, 2015). Vocabulary and mean length of utterance (MLU) have been explored most comprehensively in the literature with a majority view that positive associations exist between child language outcomes and the length of utterance and number of different word types used in parental talk (Hoff, 2003; Hurtado, Marchman, & Fernald, 2008; Pan, Rowe, Singer, & Snow, 2005; Rowe, 2008). In Hoff (2003)'s study of maternal speech, MLU emerged as a significant predictor of the children's sizes of productive vocabularies at two years of age, accounting for 22% of the variance (Hoff, 2003). It has been proposed that a higher ratio of diverse words could be reflected in the parental use of longer utterances, hence providing children with more opportunities to learn an expansive lexicon of words, promoting faster rates of child vocabulary growth (Hoff, 2003). Similarly, findings from Rowe's (2012) longitudinal study of caregiver input in a sample of fifty dyads showed that after SES, quantity of input and the children's baseline vocabulary skills were controlled for, the use of high-level vocabulary during parent-child interactions still predicted children's vocabulary scores a year later.

In other studies, researchers have investigated the complexity of maternal language input during verbal interactions with both hearing children and children with a hearing loss (Cruz et al., 2013; DesJardin & Eisenberg, 2007; Hart & Risley, 1995). Hart and Risley (1995) coded hour-long recordings with a specific focus on discourse attributes (e.g. imperatives and declaratives); sentiment-weighted utterances (e.g. affirmations and prohibitions), as well as the frequency of speaker initiations and responses, which were associated with the rates of children's vocabulary growth. Additionally, qualitative differences in linguistic input were found between groups of families from varying SES backgrounds, with children from higher SES households receiving more encouraging parental input, as well as more recasts (language modelling by rephrasing) and expansions of the children's' own utterances (Hart & Risley, 1995).

Hart and Risley's (1995) findings were echoed in more recent research studies regarding the use of scaffolding techniques to engage children with cochlear implants in verbal interactions (Cruz et al., 2013; DesJardin & Eisenberg, 2007). High facilitative language techniques including parents' use of expansions, recasts in the form of questions, use of open-ended questions (designed to invoke a response which is not limited to a one-word answer) and parallel talk (describing an activity which the child is involved in), were found to support growth in expressive language for children under the age of five using cochlear implants (Cruz et al., 2013; DesJardin & Eisenberg, 2007). A significant finding from Cruz and colleagues' (2013) study showed that parental use of higher-level facilitative language techniques promoted gains in the children's oral language up to three years post-implant regardless of family SES.

Maternal verbal communication styles, characterised by the use of infant-directed speech and demonstration of attuned responsiveness to the child's communication, have also been found to modulate the process of early language learning both for children with normal hearing and children with hearing loss (Ambrose et al., 2015; Wang et al., 2017a). The ability to capture and sustain a young child's attention to speech through infant-directed speech is associated with greater expressive vocabulary and efficiency in word processing for two-year-old children with normal hearing (Weisleder & Fernald, 2013). This may be explained by Ma, Golinkoff, Houston and Hirsh-

Pasek (2011) findings which showed that 21-month-old children learnt novel words when infant-directed speech was used, as opposed to adult-directed speech. Infant-directed speech, or motherese, was the focus of many earlier studies concerned with modifications made by primary caregivers to their speech register when addressing infants (Gerken & Aslin, 2005; Houston & Bergeson, 2014). Motherese is characterised by attention-getting acoustic characteristics of speech, coupled with simplified language which contains syntactically and lexically less complex utterances, to promote infant's attention to language (Golinkoff, Can, Soderstrom, & Hirsh-Pasek, 2015; Poulain & Brauer, 2017). This speech style marked by greater variations in pitch contours to signal word-boundaries, long pauses, exaggerated intonation patterns and hyperarticulation of vowels, is differentiated from adult-directed speech (Grieser & Kuhl, 1988; Houston & Bergeson, 2014; Wang et al., 2017a). A recent finding showed that prelingually deaf infants using CIs were found to have a listening preference for infant-directed speech compared to adult-directed speech (Wang et al., 2017a). Attending and listening to spoken language is important for early language acquisition; supporting the use of infant-directed speech as an intervention strategy for children with CIs may mitigate the effects of early hearing loss (Wang et al., 2017a). In addition to infant-directed speech, there are compelling grounds for mothers to employ responsive behaviours when communicating with their children using CIs (Cruz et al., 2013). The duration of hearing experience (adjusted hearing age) and the stage(s) of language development warrant greater consideration for children with SNHL using CIs, compared to their normal-hearing, typically developing peers (Cruz et al., 2013). Desjardin and colleagues (2007) suggested that hearing mothers have the ability to exercise 'intuitive parenting' which is a communication technique used to compensate for their child's hearing loss and linguistic abilities during interactions. For instance, a mother may adapt her communication if her child does not respond to an open-ended question by reverting to a lower-level facilitative language strategy and posing a closed-ended question instead (DesJardin & Eisenberg, 2007). The demonstration of a responsive communication style which is contingent upon the child's behaviours, has been linked to higher levels of social engagement and expressive language skills in children with hearing loss (Guttentag et al., 2014). On the contrary, a directive maternal communication style, where the mothers' input is not related to the child's focus of attention is associated with poorer child language outcomes (Rowe, 2008).

Recent longitudinal research on children at various age ranges has indicated that different aspects of quality might have more consequential effects on child language during particular developmental periods (Rowe, 2012). Although quality of input as a whole has been established as an integral component across the formative years of language, it has been shown to be of most significance at three and four years of age (Rowe, 2012). For example, the diversity and sophistication of vocabulary exposure during toddlerhood facilitates lexical growth whereas, parental use of decontextualised language (e.g. narratives or explanations) was found to be a more beneficial linguistic technique for preschool vocabulary growth (Rowe, 2012). Research has found, however that the amount of language input received at 18 months was specifically predictive of the children's later vocabulary skills (Rowe, 2012). Therefore, quantity of language input was deemed to be of most benefit to younger children's language development before and at approximately two years of age (Rowe, 2012).

2.3.2 Quantity of Language Input

The quantity of parent talk directed at neonates even as young as 32 weeks of (gestational) age was associated with language skills and accounted for 20% of the variance for cognitive scores at 7 and 18 months of age (Caskey, Stephens, Tucker, & Vohr, 2014). More notably, a strong association was found between the amount of linguistic input a child receives before the age of three (during the sensitive period) and the growth of cognitive and language skills to follow (Arterberry, Bornstein, Midgett, Putnick, & Bornstein, 2007; Bornstein, Haynes, & Painter, 1998). The increased number of opportunities for children to connect the phonological form of words with their meanings and increased number of occasions to hear a variety of grammatical combinations, are well-grounded rationales for exposing children to a large quantity of linguistic input (Huttenlocher et al., 1991; Zauche et al., 2017). Hart and Risley (1995) also found that it was beneficial for children to be exposed to different linguistic features including: tense markers, grammatical markers, adjectives and adverbs (modifiers). They proposed that parents who were more vocally expressive, have a greater likelihood of modelling the use of various linguistic features in their utterances to their children (Hart & Risley, 1995).

2.3.2.1 Amount of Parental Talk

There is a recurring theme in the research literature linking SES, to the amount of parental talk in the home, and children's language growth (Fernald et al., 2013; Gilkerson & Richards, 2009; Hart & Risley, 1995; Huttenlocher et al., 1991; Levine et al., 2018; Pace et al., 2017). The talkativeness (based on the number of words spoken) of mothers from middle-class families was explored and found to be a contributor to children's rate of vocabulary growth between 14 months to 26 months of age (Huttenlocher et al., 1991). In Hart and Risley's (1995) analysis of the variability in amount of talk observed in 42 American families, children from professional working-class families were exposed to a mean of 2153 words in an hour, 2151 words for working class families and 616 words for welfare families. Children from lower SES families were estimated to have heard 30 million words fewer than their counterparts from higher SES families by the age of three years and these differences in language exposure correlated with the children's vocabulary sizes (Hart & Risley, 1995). Children who were exposed to more words, had richer vocabularies and performed better during primary school years compared to their peers who were exposed to less language at home (Hart & Risley, 1995). These results were confirmed by Gilkerson and Richards in a 2009 study using an automated, Language ENvironment Analysis (LENA) system to measure the amount of talk for a representative sample of 329 American families.

The predictive value of early exposure to the quantity of language and preschool language performance was demonstrated in children aged between 2 to 36 months (Zimmerman et al., 2009). A 0.4 point (95% CI: 0.09–0.79) increase in language scores was associated with every additional thousand words spoken to a child, as measured on the Preschool Language Scale, 4th edition (Zimmerman et al., 2009). Shneidman and colleagues (2013) also reported that the number of words spoken by a child's primary caregiver when the child was 30 months old, was positively correlated with an increase in the variance in the child's vocabulary on the Peabody Picture Vocabulary Test (PPVT) at 42 months of age. In both studies, however, reciprocal verbal caregiver-child exchanges were observed to be mediating factors, which suggested that while the quantity of language input promoted vocabulary acquisition in typically developing children with normal hearing, the conversational turn-taking aspect of social interactions should also be explored (Zauche et al., 2016).

Considering that the amount of language to which normal-hearing children are exposed has a significant effect on their early language development, it is proposed that the quantity of caregiver input would have comparable or have even greater impact on the language outcomes for children with hearing loss who use CIs or HAs. Studies examining the amount of caregiver language directed to children with hearing loss were exposed to have yielded mixed findings. Earlier studies, (for example Meadow, Greenberg, Erting, & Carmichael, 1981) reported that hearing mothers had shorter communicative interactions with their children with a hearing loss, whereas other studies did not find group differences in the quantity of language input which hearing mothers provided to their children who are hearing versus their children with a hearing loss (Lederberg & Everhart, 2000; Spencer, 1993). During the time when these studies were completed, it is important to point out that populations of children with hearing loss were not typically enrolled in newborn hearing screening programs (VanDam et al., 2012). In the last two decades, universal newborn hearing screening lead to earlier diagnosis of hearing loss and streamlined referral pathways for hearing aid and/or cochlear implant interventions (Yoshinaga-Itano et al., 2010).

In more recent studies, the amount of maternal language input (defined as the amount of speaking time, number of conversational turns and utterances) provided to children with CIs was demonstrated to be equivalent to the amount of input provided by mothers of children with typical hearing (Vanormelingen et al., 2016). Whilst the authors discussed that hearing mothers of children with CIs tended to treat them as normally hearing, it could be argued that children with CIs would still require a larger amount of language input (Vanormelingen et al., 2016). For children with SNHL who have experienced early auditory deprivation, the consistent and early use of hearing devices partially ameliorates SNHL, nonetheless the speech signal which they have access to, may still be degraded compared to natural hearing (VanDam et al., 2012). Furthermore, the external, auditory environment i.e. competing or background noise, poses acoustical challenges that may jeopardise learning for children using CIs (Busch, Vanpoucke, & van Wieringen, 2017). Given the younger age of hearing experience and current advancements in hearing technology, the present-day cohort of children with SNHL who are aided and use an auditory-oral modality to communicate, may rely even more heavily on auditory input for language learning, making the amount of language input exceptionally important for them (VanDam et al., 2012). For children with hearing loss, it is presently not known what the optimum quantity of language exposure is to facilitate linguistic performance comparable to their hearing peers (VanDam et al., 2012).

2.3.2.2 Conversational Turn taking

Apart from the sheer amount of exposure to adult talk which has been shown to support children's early language development, there is emerging evidence linking the amount of adult-child conversational turns recorded in their early language environments with a child's neural functioning between the ages of four to six years (Romeo et al., 2018b). Conversational turn counts (CTC) are defined as the back and forth verbal communicative exchange between an adult-and child (Romeo et al., 2018a) which provide children with opportunities to practice and amalgamate recently learnt language and promoted early language growth (Zimmerman et al., 2009). A greater number of CTC were significantly associated with greater activation of the left inferior frontal region (Broca's area) on a functional MRI task, but the same relationship was not observed for the amount of adult words (Romeo et al., 2018b).

Drawing on research with hearing children, Zimmerman and colleagues (2009) reported a robust, positive association between the amount of adult-child CTC and child language development. Specifically, a hundred conversational turns taken per day was linked with a 1.92 increase in the child's language score as measured on the PLS-4 (Zimmerman et al., 2009). Parents who were able to elicit more communication from their children in conversation may have had greater opportunities to scaffold their child's language use (VanDam et al., 2012). Empirical evidence has demonstrated that the amount of adult-child conversations which children aged between 18 and 23 months of age participated in predicted their cognitive abilities, verbal comprehension and language skills at 9 to 13 years of age (Richards et al., 2018). More importantly, the relationships between the number of adult-child CTC and later child performance remained significant, independent of SES variables (Richards et al., 2018). Richards and colleagues' (2018) ground-breaking findings suggested that increasing the amount of CTC, provided the potential to intervene early and make a long-term impact on the child's developmental outcomes, regardless of the child's family SES characteristics.

The bidirectional nature of adult-child conversations indicates that both an active child and a responsive caregiver are required to participate in the verbal exchange (Krishnan, 2010). This leads to the idea that a mother and child can influence and regulate each other's behaviours (DesJardin & Eisenberg, 2007). Children's behaviours and language abilities may affect their mothers' language input (DesJardin & Eisenberg, 2007), and the child's hearing status and volubility may affect the frequency of CTC (VanDam et al., 2012). For children with hearing loss, efficient conversational turns may be more challenging for hearing parents who have little prior knowledge or communication experience with individuals who have a hearing loss (Luckner & Pierce, 2013). VanDam and colleagues' (2012) found in their study with 22 hearing impaired children that that the number of adult-child CTC recorded was associated with the children's auditory characteristics at two years of age. It was suggested that children with better hearing or aided thresholds and stronger receptive language skills permitted easier engagement in adult-child conversation turn-taking and vice versa (VanDam et al., 2012).

Conflicting findings regarding volubility or talkativeness for children with hearing loss relative to their hearing peers have also been reported in the research literature (Vanormelingen et al., 2016). Some studies have found that young children with hearing loss and children with normal hearing are equally talkative during the prelinguistic stages of development (Iyer & Oller, 2008; Moeller, Tomblin, Yoshinaga-Itano, Connor, & Jerger, 2007; Spencer, 1993). Contemporary research has shown that children who received CIs later than 12 months of age exhibited lower volubility compared to children who received CIs before 12 months of age (Binos, Polemikou, & Loizou, 2018). Child vocalisation count (CVC) reflects the amount of speech-related vocalisations produced by a child (Gilkerson et al., 2017). In the examination of the early home language experiences for children with normal hearing, CVC was found to be strongly correlated with the amount of adult-child CTC in Gilkerson's (2017) study. Furthermore, an effect of maternal education was also found to be related to the amount of CTC and CVC in their sample of 325 families with typically developing children aged between 2 to 48 months (Gilkerson et al., 2017). The amount of CTC and CVC both significantly increased with levels of maternal education; families with children of most educated mothers producing 42% more vocalisations than mothers of children with less education (Gilkerson et al., 2017). Future research is needed to understand the overlapping mother and child variables which impact on adult-child CTC.

2.4 Language ENvironment Analysis (LENA) and Mobile App Technology

A number of studies in the past two decades have made attempts to quantify the amount of language exposure and language interaction behaviours in a child's home environment and have begun uncovering meaningful links to children's developmental trajectories (Gilkerson et al., 2017; Hart & Risley, 1995; Hoff, 2003; Huttenlocher et al., 1991; Rowe, 2008). Child language and interaction data collection is often resource intensive, resulting in compromised study methodologies, such as the use of retrospective information to test hypotheses, or employing clinical/laboratory settings to observe mother-child conversational exchanges in place of naturalistic language sampling (Smyth & Brinkman, 2014). The time consuming and subjective nature of 'in-person' live observation/coding versus analysis of recorded samples also impacted past research (Ganek & Eriks-Brophy, 2017). Research aside, the costs and time investment required to carry out home observation visits for child on the caseloads of speech language pathologists is clinically impracticable (Ganek & Eriks-Brophy, 2017).

Recent technological advancements have addressed these methodological challenges of measuring the frequency of language behaviours and amount of auditory-linguistic exposure in a child's naturalistic environment on a large scale (Smyth & Brinkman, 2014). The Language ENvironment Analysis (LENA) system is comprised of a small, wearable audio recording device and associated computer software which performs automated speech and language analyses (Gilkerson & Richards, 2009). The small, wearable recorder or Digital Language Processor (DLP) designed for use in children's natural environments can store up to 16 hours of recorded audio data. The audio data is analysed by the LENA software which generates information about the child's audio environment (for example, the duration of the recording which was in meaningful speech, distant speech, background/silence, noise and electronic media) and quantitative language frequency counts at 5 minute, hourly, daily and monthly intervals (Gilkerson & Richards, 2009). The LENA system's objective language metrics include, Adult Word Count (AWC) measured by the amount of words spoken by adults to the child in close range, the number of paired conversational turns taken between an adult and child (CTC) and the number of times a child produces speech-like sounds (CVC) (Gilkerson & Richards, 2009).

LENA technology offers clinicians and researchers the ability to solve challenges associated with traditional manual coding of language samples. It has also enabled researchers on the LENA Natural Language Study to extend Hart and Risley's seminal work by establishing a normative database and percentile estimates for daily (12-hour day) AWC, CTC and CVC based on recordings from 378 American families comprised of 2 to 48 month old children (Gilkerson & Richards, 2009). Ideal targets for the amount of spoken words in a day have not yet been defined in clinical practice, however in the Natural Language Study, the average (50^{th} percentile) AWC for a typical day was approximately 12,000 words. There was no relationship between the child's chronological age and the AWC after five months of age (Gilkerson & Richards, 2009). Although the AWC did not increase with the child's age, the CTC increased by around 15 conversational turns per month before plateauing by the child's second birthday (Gilkerson et al., 2017). This finding was not unexpected, considering that children are recognised as increasingly active participants in verbal exchanges. It is anticipated that children's spoken language would become more sophisticated during sensitive periods of learning, resulting in more vocalisations as they developed, resulting in greater ability to elicit more verbal interactions from their caregivers (Gilkerson et al., 2017; Krishnan, 2010). This premise was supported by LENA Natural Language Study data which found that CVC also increased steadily with developmental age, with an average of 60 more child vocalisations per month, until the age of 26 months (Gilkerson et al., 2017). The day to day AWC or CTC was found to vary considerably both within-families, and between families in Gilkerson and Richard's sample (2017). Regarding the high variability in talk observed across families, the LENA Natural Language Study was able to confirm conclusions drawn by Hart and Risley (1995) that the amount of AWC and CTC recorded per hour in the children's home environments, were stronger predictors of child language and cognitive performance on standardised assessments, relative to parental education and SES (Gilkerson & Richards, 2009).

Beyond the LENA Natural Language Study, the LENA system has been utilised as an assessment measure in various studies investigating of the effects of parent-child talk (Greenwood, Thiemann-Bourque, Walker, Buzhardt, & Gilkerson, 2011; VanDam et al., 2012), electronic media and television (Ambrose, VanDam, & Moeller, 2014; Christakis et al., 2009), and socio-economic disadvantage (Gilkerson et al., 2017; Sacks et al., 2014) on child language acquisition. The normative LENA database also provides a standard method of quantifying and distinguishing between the language environments for different populations of children, giving rise to reliability and comparative studies involving typically developing children from bilingual-speaking (Ribot, Hoff, & Burridge, 2018) or linguistically diverse backgrounds such as European French (Canault, Le Normand, Foudil, Loundon, & Thai-Van, 2016), Spanish (Aragon & Yoshinaga-Itano, 2012), Chinese (Gilkerson et al., 2015) and Dutch (Busch, Sangen, Vanpoucke, & van Wieringen, 2018). Regarding clinical populations of interest, studies have used LENA technology to document the relationship between adult talk and child volubility in preterm infants (Caskey et al., 2014), the vocal activity of children with autism and language delays (Warren et al., 2010) and of more relevance, caregiver interactions with children who have a hearing loss (Aragon & Yoshinaga-Itano, 2012; VanDam et al., 2012; Vohr, Topol, Watson, St Pierre, & Tucker, 2014).

Further evidence which used the LENA system to highlight the relationships between child hearing loss and home language environments was demonstrated by Vohr and colleagues (2014) for 23 children with permanent hearing loss. Results indicated that the greater amounts of spoken language in the home and child vocalisations were associated with higher child expressive scores on the Reynell Developmental Language Scales (Vohr et al., 2014). Moreover, a greater percentage of silence (ranging from 2% to 33%) in homes for children with hearing loss was associated with lower receptive and expressive abilities (Vohr et al., 2014). This inverse relationship between silence and language abilities, was observed for children with hearing loss but not their hearing peers (Vohr et al., 2014). It was theorised that children with SNHL may experience greater disruptions in adult-child communication interactions which could have resulted in increased, accumulated periods of silence detected by the LENA system. The data demonstrated the utility of LENA to differentiate between the language environmental characteristics of children with normal hearing, and their peers with permanent hearing loss (Vohr et al., 2014).

Although the LENA System is limited in its capacity to analyse the quality of language input or semantic content of recordings, some studies have demonstrated its utility to monitor changes in the quantity of language directed to the child over time, and/or in response to intervention efforts (Gilkerson, Richards, & Topping, 2017; Wang et al., 2017b). The validation of Hart and Risley's work, using LENA technology, underscored the importance of children's early language environments and the impact on later developmental, literacy and educational outcomes. This knowledge inspired a growing number of intervention initiatives in recent years which aimed to increase AWC and CTC and alleviate the cumulative disparities in children's early linguistic experiences (Leffel & Suskind, 2013; Roberts & Kaiser, 2011). Additionally, growing confidence in existing research evidence has shaped the content of current interventions by focusing efforts on changing parental behaviours in the home (Leffel & Suskind, 2013; Ribot et al., 2018; Suskind, Kuhl, et al., 2013). Underpinning these parent-focused interventions is the assumption that training caregivers in adjusting their behaviours within daily routines can be effective in the long-term (Delaney & Kaiser, 2001; Roberts & Kaiser, 2011). Parents have frequent contact with their children and share extensive amounts of time in everyday life, permitting more frequent practice of intervention targets compared to traditional once-weekly therapeutic service delivery models (Roberts & Kaiser, 2011). With the ability to implement intervention measures at home, the difficulty of generalising strategies learnt from clinical to naturalistic settings is potentially removed (Leffel & Suskind, 2013).

Roberts and Kaiser (2011) conducted a meta-analysis of 18 intervention studies examining the impact of parent-implemented language interventions on the child language for participants aged 1.5 to 5 years. Results indicated that parent-implemented intervention approaches had significant and positive effects on the receptive and expressive language skills of children with and without intellectual disabilities (Roberts & Kaiser, 2011). They also observed that few studies provided measures of treatment fidelity of parental uptake of strategies (Roberts & Kaiser, 2011). In parent-implemented interventions emphasising communicative interactions and quantity of input, tracking parental intervention efforts is important (Richards, Gilkerson, Xu, & Topping, 2017). In Richards and colleagues' 2017 study, parents' overestimation of the amount of input to their child could be partially due to a lack of objective data and data-based feedback.

The delivery of personalised information from external sources about an individual's performance is reported to enhance accurate self-monitoring and facilitate behavioural change (Hermsen, Frost, Renes, & Kerkhof, 2016). The LENA System makes it possible to provide parents with quantified data; clinicians can summarise these counts to form the basis of objective feedback and can compare data with percentile estimates from normative data taken from day-long recordings in the child's home environment (Suskind et al., 2013). Providing parents with LENA-generated feedback may help to start a dialogue between the clinician and parents about their child's language experiences in the home. It is uncommon for adults to be consciously aware of the amount of talk spoken in a day even if they recognise the effect that it has on their children's development environment (Suskind et al., 2013). Social learning theory (Glanz, Rimer, Babara, & Viswanath, 2008) however, postulates that once individuals recognise that performing certain actions affects their environment and others around them, they may alter their actions to influence outcomes. Presenting parents with quantified feedback regarding their child's home language environment may increase their awareness of language behaviours, and may lead to improvements in self-regulation of parental language input and increased interaction attempts (Suskind et al., 2013). In parent-implemented interventions, individualised feedback may be provided verbally by clinicians, and may include written progress notes and summary graphs (Kaiser, Hancock, & Kaiser, 2003).

Project Aspire and the Thirty Million Words Projects are two recent caregiver-focused programs in the United States that draw on principles from the theory of planned behaviour (Armitage & Conner, 2001) which have developed intervention curricula incorporating the use of LENA-generated estimates of AWC and CTC (Leffel & Suskind, 2013; Suskind, 2013). AWC and CTC feedback which were provided by clinicians, furnished parents with objective and measurable targets (Leffel & Suskind, 2013). In Suskind and colleagues' (2013) exploratory study, this behavioural change strategy was used with 17 non-parental caregivers of typically developing children aged 10 to 40 months. Participants were involved in one educational session on strategies to enrich a child's home language environment followed by one feedback session using LENA-generated metrics from their baseline recordings (Suskind et al., 2013). There was a 31% and a 24% increase in AWC and CTC respectively following the intervention, which highlighted the potential of this feedback to motivate adults to modify communicative interactions (Suskind et al., 2013). A follow-on pilot randomised controlled study with 23 normally hearing children aged 1.5 to 3 years and their families from low socioeconomic backgrounds demonstrated significant increases in AWC, CTC and CVC for 12 families in the experimental group (Suskind et al., 2016b). Similar intervention programs utilising LENA-generated metrics to provide feedback with parents of children with hearing loss (aided with CI and/or HA) from low SES backgrounds did not show the same increases (Sacks et al., 2014; Suskind et al., 2016a). There were significant increases in post-feedback CTC in 11 dyads where the parents had normal hearing and their children had hearing loss, but not significant changes in AWC compared to pre-feedback counts (Sacks et al., 2014). In 32 caregiver-child dyads where the parents had normal hearing and their children had hearing loss, Suskind and colleagues (2016a) found no significant changes in AWC and CTC but there were significant increases in caregiver's different word types, mean length of utterances and caregiver knowledge of child development. These outcome measures (i.e. word tokens, types and mean length of utterances) used in Suskind and colleagues' (2016a) study may have been sensitive in detecting changes in the participants' quality of language input, whereas LENA technology utilises a speech recognition algorithm to generate gross quantitative language counts of adult words and conversational turns (Suskind et al., 2016a). It is possible that Suskind and colleagues' intervention had positively impacted on the richness of the dyads' language interactions without changing the frequency of talk. Mixed results following the use of LENA-generated metrics to provide feedback have been demonstrated in diverse populations including Mandarin-Chinese (Zhang et al., 2015) and Korean (Pae et al., 2016) parent-child dyads. In these two Asian language studies, the subset of parents who commenced the intervention with below-average LENA-generated metrics demonstrated significant increases in LENA-generated metrics post-feedback compared to parents who commence the study with metrics that were already above the 50th percentile (Pae et al., 2016; Zhang et al., 2015).

A recent pilot study of an online parent intervention involving 72 parents of typically developing children (Gilkerson et al., 2017) was able to demonstrate changes in LENA-generated metrics post-feedback. Gilkerson and colleagues (2017) recognised that traditional forms of service delivery, characterised by in-person, individualised early intervention provision, is resource-intensive and has both travel and equity of access implications for families requiring frequent appointments.

Parents, who participated in the online intervention trial, were provided with feedback reports comprised of LENA-generated estimates from day-long recordings, in conjunction with phone-based coaching and access to online resources about child language development (Gilkerson et al., 2017). A subset of parents who had below-average AWC or CTC at baseline demonstrated significant increases in their language counts three months post-feedback, hence demonstrating the viability of providing parents at a distance with feedback based on LENA-generated estimates (Gilkerson et al., 2017). Cost savings in travel and ease of access to objective information and services are among the proposed benefits of alternative service delivery models such as video, written information or text messaging (Gilkerson et al., 2017). In an age of rapid data exchange, there are opportunities to combine automated language analysis methods (such as LENA-generated data) with feedback to parents, thus capitalising on the internet and technological capabilities to improve early intervention impact (Gilkerson et al., 2017).

In addition to advances in technology, the expectations of young parents who are recipients of early childhood and intervention services are also shifting (Theodoros, 2012). Porter and Edirippulige (2007) reported that more families of children with hearing loss are seeking online sources of information regarding hearing loss to complement available traditional service delivery models. Over the past decade, mobile technology has been widely adopted in individuals' daily lives (Whittaker et al., 2012). The most valuable contribution of mobile technology lies in its ability to directly reach individuals regardless of their location (Whittaker et al., 2012). Consequently, mobile apps offer the possibility of communicating with people directly and delivering information to supplement intervention programs at appropriate times, regardless of geographical distance (Whittaker et al., 2012). Mobile health (mHealth) a subset of digital health, has been characterised as health practice which is supported by the use of smartphones, wireless devices and other activity monitoring technology (Kay, Santos, & Takane, 2011). Moreover, with the advantage of scalability, automated systems can easily facilitate knowledge transfer and mHealth interventions to large populations through mobile devices (Whittaker et al., 2012). There is presently a limited evidence-base investigating the use of parent-targeted mobile apps to foster rich parent-child communication experiences. Given that the home context offers a promising avenue for implementing early intervention with young children (Wilson, Norvell, & Kissinger, 2016), engaging parents in completing language-promoting activities with their children through information provided via mobile technology warrants further exploration.

There is a range of recent early childhood outreach programs which leverage the use of mobile technology and the internet to disseminate practical knowledge and skills to parents of young children to promote early learning for optimal development (Galinsky et al., 2017). For instance, Mind in the Making and Vroom are partner initiatives aimed at translating scientific discoveries regarding child development principles into accessible content for general public use (Galinsky et al., 2017). The Daily Vroom App (DVA) in particular, was developed as an app-based communication channel with daily activity tips to help parents identify learning and interaction opportunities with their children through everyday routines (Galinsky et al., 2017). The tips are organised by chronological age (in years) and activity type to suit a range of indoor (e.g. meal time, bath time) and outdoor scenarios (e.g. shopping time, walking to the park) which are typical for families with young children (Galinsky et al., 2017). These tips foster back and forth communicative interactions between parent and child, and promote strong executive functioning in young children (Galinsky et al., 2017). The premise for the DVA overlaps to some extent with guiding principles characteristic of parent-implemented early language intervention practices for both children with normal hearing and children with hearing loss (Decker & Vallotton, 2016; Roberts & Kaiser, 2011). There is an emphasis on parental involvement and building parent-child communicative exchanges through daily interactions within the home context to promote early language skills for children with hearing loss, and enhance CI use (Decker & Vallotton, 2016; Zaidman-Zait & Young, 2008). Provision of resources to parents which influence children's early communicative experiences and strategies which enrich everyday interactions are paramount (Cruz et al., 2013; Decker & Vallotton, 2016; Desjardin, 2006). Preliminary evidence from Mind in the Making and Vroom initiatives appear to increase families' belief in their efficacy and increase families' engagement in their child's development (Galinsky et al., 2017).

In the first year after its launch, the DVA had been downloaded more than 100,000 times by families in more than 100 countries (Galinsky et al., 2017), exemplifying the reach of mobile technology. Research investigating patient engagement and the design of digital health has found that individuals will only use new technologies if they feel that the digital tools are relevant to alleviating their concerns and are engaging and effective in achieving changes in their own behaviour (Birnbaum, Lewis, Rosen, & Ranney, 2015). Therefore, the uptake and adoption of mHealth initiatives by intended population(s) is a simple indicator of usefulness (Birnbaum et al., 2015). Despite anticipated advantages of mHealth tools such as the DVA, objective outcomes measuring parental behaviour change post-DVA use and families' perceptions of the app, have yet to be evaluated.

2.5 Designing User-Centred Technologies

In a narrative review on the use of mHealth in promoting early language development, McClure and colleagues (2018) acknowledged that mobile applications are widely accessible among the general population, but in order to be effective, apps had to be easy to use and used frequently. In the case of the DVA which encourages shared parent-child interactions, providing parents with activities that can be easily integrated into the families' typical routine promotes ease of use (McClure et al., 2018). There are other elements, however, known to influence a parent's use of technology and their willingness to adopt digitally-driven interventions. A more recently discussed attribute known as eHealth literacy, has been recognised is an important variable in determining an individual's effective use of eHealth resources (Norman & Skinner, 2006a). eHealth literacy is defined as the ability to seek, search, comprehend and appraise health information from electronic sources and apply knowledge learnt to addressing a health concern (Norman & Skinner, 2006a). There is a need to understand the fit between eHealth technologies and the skill levels of intended users for successful uptake of digital interventions (Norman & Skinner, 2006b). On the other hand, predicting uptake and technology usage cannot simply be reduced to the mere examination of an individual's abilities, without taking user experience into account (Barello et al., 2016).

Supporting positive user experiences of technology in digital interventions has prompted a growing field of research which draws upon multi-disciplinary, theoretical concepts from psychology, information communication technology and human-computer interaction (Diefenbach, 2018). The UTAUT2 is a theoretical model which identified seven key constructs which influence an individuals' use of new technology from behavioural perspectives, namely: facilitating conditions, habit, effect expectancy, hedonic motivation, social influence, price value and performance expectancy (Venkatesh, Thong, & Xu, 2012). Facilitating conditions relate to conduciveness and accessibility of using the technology, which may be precursory to habit formation (Hew, Lee, Ooi, & Wei, 2015). The operationalisation of a habit has been reported to have a direct effect on technology use (Hew et al., 2015). Thus, it is proposed that effective mHealth app design needs to include app-related messages which pop up on the home screen of a mobile device without the user having to first access the specific app (i.e. push notifications) to entrain app checking habits (Karapanos, 2015). Effect expectancy is related to individual's perceived ease of use of the technology, whereas hedonic motivation represents the enjoyment derived from the user while using the technology (Venkatesh et al., 2012). The extent to which individuals perceive the use of particular technology as important by mass media and others around them is characterised as social influence, while price value refers to the monetary cost of using the technology (Venkatesh et al., 2012). In the UTAUT2 model, price value was a proposed predictor for the intention to use a type of technology (Venkatesh et al., 2012). Lastly, performance expectancy represents the perceived usefulness or degree of benefit which the digital tool has to the user, based on its content and features (Hew et al., 2015; Venkatesh et al., 2012).

The integration of mHealth has the potential to be therapeutically useful in promoting health (Furlong, Morris, Serry, & Erickson, 2018). Examining user feedback regarding the experience of using technology is a way of understanding the performance expectancy of mobile technology from the intended users' perspective (Diefenbach, 2018; Venkatesh et al., 2012). Stoyanov and colleagues (2016) recently developed the user version of the Mobile App Rating Scale (uMARS) for end-users to reliability appraise the quality of mHealth apps. The uMARS obtains user feedback about the quality of mobile apps based on six indicators: app engagement; functionality; aesthetics; information quality; subjective quality; and perceived impact to improve user's awareness, knowledge, attitudes, help-seeking, motivation and behavioural change towards the targeted health behaviour (Stoyanov, Hides, Kavanagh, & Wilson, 2016). In Furlong and colleagues' (2018) systematic search of speech therapy apps on the market, the uMARS provided standardised comparisons to critique mHealth apps for children with speech disorders. Despite this, there is still more work required to identify and evaluate high quality and clinically useful mHealth apps which can increase families' access to speech language therapy and facilitate implementation of therapeutic strategies outside of clinical settings (Furlong et al., 2018).

In summary, there is strong supporting evidence that the early language experiences of children have a cumulative effect on their later developmental outcomes. These early language experiences occur within the context of adult-child interactions and through daily family routines. The early language experiences for children have been found to vary due in part to family socioeconomic advantage, maternal characteristics, such as level of educational attainment, communication style and language behaviours and child hearing status. For children with prelingual SNHL, the experience of early auditory-language deprivation, although mitigated in recent years with earlier access to amplification devices, still leaves many susceptible to spoken language delay. Early intervention has focused on providing children with enriched early language environments to address disparities in language development trajectories and the home is an influential, natural context for parents to implement language strategies with their children. The content and quantity of adult language input towards children has been shown to have a significant impact on child language outcomes (Hart & Risley, 1995; Richards et al., 2018). Persuasive technology may have a place in modifying the dynamics of adult-child interactions. Modern, automated language processing technology such as the LENA system, can generate metrics which clinicians may use to offer parents personalised feedback about their amount of talk and adult-child conversational turns. Mobile applications such as the Daily Vroom App, offer an accessible means of providing caregivers with activity tips which promote parent-child interactions in daily routines. The efficacy of digital interventions incorporating such technologies is still emerging, and limited insight regarding user experiences and perceived usefulness of these digital tools in speech and language practice, presents an opportunity for further research investigation.

3 Aims of the Current Research

The present research builds on current intervention efforts reported in the research literature by focusing on increasing the amount of talk and adult-child conversational turns in the home environment for young children within their sensitive period of oral language development. There is emerging evidence that modern technologies have the capability to enhance traditional intervention practices by influencing parental behaviour through: objective, quantitative measures of automated speech language analysis based on day-long recordings in a child's natural language environment (LENA technology); and accessible, app-based resources for parents (Daily Vroom App). The LENA system and the Daily Vroom App were integrated into a parent-implemented home language intervention protocol developed for Study 1, with the overall objective of impacting on the language behaviours of primary caregivers (mothers) of young children with normal hearing and children with significant, prelingual hearing loss (aided with cochlear implants and/or hearing aids). Beyond the examination of measurable language behavioural outcomes which were the focus of Study 1, the overall objective of Study 2 was to provide insights into the end-user experience of these technologies, which can in turn serve to inform the design of future digital interventions. Survey findings in Study 2 reflected the eHealth literacy abilities of participants in the sample, appraisal of the DVA quality and the perceived impact of using LENA and the DVA on child language from the perspectives of clinicians and mothers.

Aims and Hypotheses for Study 1 (Intervention Trial)

The first aim of Study 1 was to explore whether there were relationships between child hearing status, family SES-related indicators, maternal characteristics, and the mean amount of adult talk (AWC) adults, adult-child conversational turns (CTC) and child vocalisations (CVC) recorded in the participants' home language environments. Specifically, there were 2 hypotheses for Aim 1:

1.1. Using LENA-generated metrics, six mothers and their hearing children (Hh group) will demonstrate a higher mean AWC, adult-child CTC and CVC at baseline as compared to four hearing mothers and their children with bilateral severe-profound hearing loss (Hd group).

1.2. Using LENA-generated metrics (AWC, CTC and CVC), there will be significant associations between socio-demographic factors, maternal characteristics and the quantity of talk by adults and children recorded in the home environments for the 10 mother-child dyads.

The second aim of Study 1 was to examine changes in AWC and CTC from the participants' baseline language counts, across the three study conditions: when LENA-Only recordings were collected (LO condition), after mothers received personalised feedback based on LENA-generated information of their child's home language environment (LENA Feedback; LF condition), after mothers received personalised feedback based on LENA-generated information of their child's home language environment and used the Daily Vroom App (LENA Feedback and App; LFA condition). Specifically, there were 2 hypotheses for Aim 2:

2.1. There will be significant percentage differences observed in participants' mean AWC from baseline, following personalised feedback based on LENA-generated information of their child's home language environment (LF condition) and additionally, after mothers used the Daily Vroom App (LFA condition), compared to LENA-Only recordings (LO condition).

2.2. There will be significant percentage differences observed in participants' mean CTC from baseline, following personalised feedback based on LENA-generated information of their child's home language environment (LF condition) and additionally, after mothers used the Daily Vroom App (LFA condition), compared to LENA-Only recordings (LO condition).

Aims and Hypotheses for Study 2 (Survey)

The first aim of Study 2 was to determine whether there were relationships between background attributes of the survey participants (mothers and clinicians) and their ratings of perceived eHealth literacy. Specifically, there were 2 hypotheses for Aim 1:

1.1. Participants from younger age groups will rate themselves higher on perceived eHealth literacy skills than participants in older age groups.

1.2. Mothers' ratings on the eHealth Literacy Scale (eHEALS) will be associated with maternal characteristics including maternal education, occupational skill level, cognitive and language abilities reported on in Study 1.

The second aim of Study 2 was to report on the participants' evaluation of app quality for the Daily Vroom App (DVA), and the mean ratings of perceived impact of using LENA and the DVA on early child language. Finally, the third aim of Study 2 was to explore relationships between the participants' DVA quality ratings and perceived impact ratings of using the DVA.

4 Study 1: Intervention Trial Method

This chapter outlines the methodology for the prospective intervention trial (Study 1) which involved mothers and their young children (aged between six months and three years). The technology-based approach included the use of the Language ENvironment Analysis (LENA) system and the Daily Vroom App as parts of the protocol, with a focus on measuring LENA-estimated quantities of spoken language and verbal interactions recorded in each child's natural environment. The recruitment process and participant characteristics are described in sections 4.2 to 4.5. The study design, assessment measures and intervention procedures are outlined in sections 4.6 to 4.9, followed by a discussion on the feasibility of the protocol, resolution of methodological issues and the approach to data analysis.

4.1 Ethical Approval

The National Ethics Application Form (NEAF) proposal and supporting documents were submitted to a National Health and Medical Research Council (NH & MRC) accredited body, The Royal Victorian Eye and Ear Hospital (RVEEH) Human Research and Ethics Committee (HREC) in Melbourne, Australia. Approval from the RVEEH HREC was granted prior to the commencement of data collection (HREC Reference Number: 15/1250H; Appendix 4). The relevant study documentation, including the study protocol and Participant Information and Consent Forms (PICF) for both Study 1 and Study 2, were reviewed and approved by the HEARing CRC, partner sites and early intervention centres, including Hear and Say's Research and Ethical Advisory Committee, The Shepherd Centre's Research Advisory Committee and Taralye's Internal Research Committee. The study's conduct was consistent with the National Statement on Ethical Conduct in Human Research (NH&MRC, 2018).

4.2 Recruitment and Study Consent

Flyers which described the study (Appendix 2) were distributed through the HEARing CRC's professional and research networks to mothers who had hearing children under the age of three. For children with hearing loss, speech pathologists and case managers at collaborating early intervention recruitment sites at The Shepherd Centre (New South Wales), Hear and Say Centres (Queensland), Taralye and Cochlear Implant Clinic (Victoria), identified potential participants (mother-child dyads) who met the study's inclusion criteria and provided them with a written invitation to participate.

Each potential participant expressed their interest in the study by completing a Permission to Contact form and returning it by post or email, hence permitting the study researcher to contact them to discuss details of the study in greater depth. Written and signed informed consent on the study's Participant Information and Consent Form (Appendix 3) was obtained from each participating mother, and parental consent was sought on behalf of each child, before participants were enrolled in the intervention study.

During the consenting process, participants were informed that their decision to participate in the study was not part of, nor dependent on their usual care and clinical management (if any). Participating mothers were also given two options regarding the use and management of their LENA audio recordings on the consent form. Each participant provided consent to: (1) the use of LENA recordings only to obtain the automatically-generated LENA software metrics (e.g. word count) based on the recorded audio files, and/or, (2) the retention of the LENA audio files for transcription and further analysis. Additionally, each participant communicated the inclusion/exclusion of selected audio recorded segments via a log of the day's activities (i.e. Daily Activities Diary; Appendix 5).

4.3 Participants

A total of 10 mother-child dyads were recruited for Study 1. All mothers who participated in the intervention study had hearing thresholds within normal limits and communicated orally, hence the dyads were characterised according to the children's audiological attributes. The dyads in this study's sample were categorised into two main groups: the Hh group was used to describe mothers and children who are both hearing, and the Hd group represented hearing mothers and their children with bilateral hearing loss. In six of the hearing dyads (Hh), five children were reported to have typical bilateral hearing within normal audiological threshold limits (i.e. passed hearing screenings), and one child had hearing within the normal range (i.e. passed hearing test and was able to imitate Ling sounds from a distance of one metre in her right ear) but was diagnosed with a unilateral, profound loss in her left ear (Hhu). In four of the dyads, the children had a significant congenital bilateral, sensorineural hearing loss (Hd). Significant hearing loss was defined in this study as having a best, unaided 3-frequency average (for 500Hz, 1 kHz and 2kHz) of equal to or greater than 65 dB HL.

Sample Characteristics

4.3.1 Mothers

Inclusion Criteria:

- Smartphone users;
- Working level of spoken and written English language proficiency (did not require an interpreter); and
- Availability to carry out weekly or fortnightly day-long LENA recordings with child.

All participating mothers (N=10) were the primary caregivers of their child. Mothers were also smartphone users with either an Apple or Android supported device as this was a pre-requisite for downloading the Daily Vroom App. The nature of the intervention required mothers to be home with their children (i.e. children not attending regular formal or informal care) for at least one day per week, allowing for the completion of weekly, day-long LENA recordings. All mothers possessed a working level of English language proficiency and could read English sufficiently to: read the plain language summary and consent to the study; to use the mobile application; and to understand the app content. None of the mothers required an interpreter during any of the study appointments. The mean age of the 10 mothers at the time of study commencement was 36.8 years (*SD* 4.02; *range* 28- 41). Maternal education ranged from the attainment of a vocational certificate to postgraduate degrees. There were three mothers (30%) who had completed a university undergraduate degree, four mothers (40%) who had completed a diploma/post-high school vocational certification and three mothers (30%) who had completed postgraduate education. Using the Australian and New Zealand Standard Classification of Occupations (ANZSCO; Australian Bureau of Statistics, 2013), 50% of the mothers in this study had worked/were working in occupations at ANZSCO skill levels two to four, which were equivalent to having had secondary education to diploma training, while the remaining 50% reported occupations involving managerial or professional duties which required a skill level commensurate with a bachelor degree or higher qualification (ANZSCO skill level one). There were three mothers (30%) who were working full-time, three (30%) were working part-time, one (10%) was self-employed and worked from home, two (20%) were on maternity leave when the study took place and one (10%) mother who was not working. Mothers in this sample reported spending a mean of 146.3 hours per week with their child (*SD* 23.57; *range* 104- 168).

Mothers (N=10) obtained a group mean of 70.36% (*SD* 12.57; *range* 43.33- 80) on measures pertaining to parenting knowledge and a mean rating of 72% (*SD* 9.33; *range* 60.78- 88.54) for their self-reported sense of parenting competence. A subset of mothers completed optional standardised measures as part of Study 1 that evaluated their knowledge of receptive vocabulary (n=9) and their intellectual (n=7) abilities. Mothers (n=9) demonstrated receptive vocabulary skills within the average range (*mean standard score* 102.56; *SD* 13.37; *range* 75-123) when assessed using the Peabody Picture Vocabulary Test, 4th Edition. For the mothers (n=7) who completed the Kaufman's Brief Intelligence Test, 2nd Edition, their scores of verbal, non-verbal and general intelligence were also within the normal range. The mean verbal intelligence standard score was 109.14 (*SD* 14.5; *range* 86- 129); the mean general intelligence (IQ Composite) standard scores was 110.57 (*SD* 12.82; *range* 86- 122), and the mean non-verbal intelligence standard score was 110 (*SD* 10.81; *range* 88-125). Table 1 details the maternal characteristics of individual participants in Study 1.

Table 1: Maternal characteristics of individual participants (N=10)

Mothers	Group	Age	Highest Level of Education	Occupational Skill Level [a]	Work/Study Load at Time of Study	Reported Time Spent with Child (hours per week)	Government Concession Entitlement	Receptive vocabulary [b]	Verbal ability [c]	Non-verbal Ability [d]	IQ Composite [e]	Parenting Knowledge percentage score [f]	Parenting Sense of Competence percentage score [g]
M1	Hh	38	Postgraduate degree	1	Maternity leave	168	No	105	120	109	117	77.59	64.71
M2	Hh	41	Bachelor's degree	1	Full-time	104	Yes	100	98	109	103	75.86	88.54
M3	Hh	37	Diploma/ vocational certification	2	Self-employed	168	No	108	104	125	115	51.72	82.29
M4	Hh	40	Bachelor's degree	4	Full-time	120	No	75	*	109	*	74.14	82.35
M5	Hh	39	Postgraduate degree	1	Full-time	120	No	115	129	112	122	77.59	64.71
M6	Hd	28	Postgraduate degree	1	Part-time	152	No	123	117	120	122	73.33	75.49
M7	Hd	36	Diploma/ vocational certification	3	Part-time	152	Yes	96	86	88	86	43.33	66.67
M8	Hd	32	Diploma/ vocational certification	5	Maternity leave	165	Yes	99	110	105	109	80.00	60.78
M9	Hd	40	Diploma/ vocational certification	4	Part-time	146	No	102	*	*	*	80.00	67.65
M10	Hhu	37	Bachelor's degree	1	Not working	168	No	*	*	120	*	70.00	75.49

[a] *Occupational skill levels grouped according to the Australian and New Zealand Standard Classification of Occupations (ANZSCO Version 1.2; Australian Bureau of Statistics, 2013).*

[b] *Receptive vocabulary standard scores were measured on the Peabody Picture Vocabulary Test, 4th Edition (PPVT-4; Dunn & Dunn, 2007)*

[c] *Verbal ability standard scores were measured on the Kaufman Brief Intelligence Test, Second Edition (KBIT-2; Kaufman, 2004)*

[d] *Non-verbal ability standard scores were measured on the Kaufman Brief Intelligence Test, Second Edition (KBIT-2; Kaufman, 2004)*

[e] *Overall intelligence standard scores were measured on the Kaufman Brief Intelligence Test, Second Edition (KBIT-2; Kaufman, 2004)*

[f] *Parenting knowledge was measured using either the Knowledge of Infant Development Inventory (KIDI; MacPhee, 1981, revised in 2002) or parent knowledge of child language development questionnaire (Suskind et al., 2015)*

[g] *Self-reported parenting competence was measured using the Parenting Sense of Competence scale (PSOC; Wallston & Wandersman, 1978)*

4.3.2 Child Participants

Inclusion Criteria:

- Between six months and three years of age at the time of study commencement;
- Exposure to and use of spoken/oral communication in English at home;
- No reported additional disabilities or medical conditions (apart from hearing loss) which may affect communication development;
- Reported to have typical hearing within normal audiological threshold limits and/or passed hearing screenings *(only applicable to the Hh group)*;
- Diagnosis of a congenital bilateral sensorineural hearing loss consistent with current candidacy criteria for cochlear implantation *(only applicable to the Hd group)*; and
- Fitted with, and regularly wearing, hearing aids and/or cochlear implants *(only applicable to the Hd group)*

All participating children (6 males, 3 females) were aged between 6 months and 2 years 10 months (*mean* 1.6 years; *SD* 0.75*)* at the time of study commencement. This age range was chosen based on previous studies which suggest that the sensitive window for early language learning occurs before the age of three (Kuhl, 2011). The children were exposed to spoken interactions in English (either exclusively or non-exclusively) in their family environments. All children in Study 1 were born in Australia and had no additional diagnoses of developmental disability. Each of the 10 children received scores in the *competent* category of skill (cognitive domain) for their respective ages on the Bayley III Screening Test which placed them at minimal risk of having a cognitive developmental delay at the time of testing.

The 10 children were divided into two groups based on their hearing levels: Child Participants 1 to 5 with hearing within normal audiological limits (Hh) and Child Participant 10 was included as part of the Hh group and denoted as Hhu, due to her unilateral, left profound hearing loss (normal-hearing in contralateral ear). Child 10's inclusion in the Hh group was based on her age-appropriate communication skills. Her language development profile was representative of a hearing child, despite not having been fitted with any hearing devices since birth, as observed from formal receptive and expressive language assessment testing. The Hd group consisted of Child Participants 6 to 9 who were diagnosed with congenital, bilateral prelingual hearing loss. The parents' evaluation of their own child's aural/oral performance on the PEACH scale (refer to Section 4.8.4 for Parents' Evaluation of Aural/oral performance of CHildren) was completed for nine of the children with a mean and median of 68.08% (*SD* 28.53; *range* 0- 100) and 72.5% respectively. There was an incomplete PEACH form for one of the 10 dyads. The median PEACH rating for the Hh group (n=5) was higher (*Mdn* 77.3%; *IQR* 29.6) than the overall group median (72.5%; *IQR* 22.4), and the Hd group (n=4; *Mdn* 66.3%; IQR 61.1).

The mean receptive language (RL) and total language (TL) standard scores on the Preschool Language Scale, 5^{th} Edition (PLS-5; refer to Section 4.8.1) for the children (n=8) were 101.75 (*SD* 9.21; *range* 86- 112) and 102.38 (*SD* 10.21; *range* 86- 117) respectively. Child Participant 8 in the Hd group was unable complete the PLS-5 due to bilateral severe hearing loss, and Child Participant 10's PLS-5 test scores were used only for descriptive purposes as she completed the assessment in both Mandarin and English. Median standard scores on the PLS-5 were not significantly different for the remaining eight children in the Hh group (RL *Mdn* 108; TL *Mdn* 105) versus the Hd group (RL *Mdn* 100; TL *Mdn* 99), p=0.14 and p=0.37. The mean expressive language (EL) standard score on the PLS-5 (n=9) was 101.89 and the median was 98 for the sample (n=9). A Mann-Whitney test showed that the difference between the median EL standard score for the Hh group (117) was not significant as compared to the Hd group (*Mdn* 96.5), p=0.47.

All 10 mothers completed the LENA Developmental Snapshot (LDS; refer to Section 4.8.3 fo the test description) for their children, achieving a group mean standard score of 91.68 (*SD* 13.92; *range* 71.18- 114.78) and a median of 93.11. A Mann-Whitney test indicated that children (n=6) in the Hh group had higher language scores (*Mdn* 95.68) on the LDS, compared to children (n=4) in the Hd group (*Mdn* 76.72), W=12, p=0.043. Table 2 details the characteristics and communication scores of each individual child in Study 1.

Table 2: Child characteristics of individual participants (N=10)

Child	Group	Age	Gender	Cognitive Developmental Category [a]	Receptive Language Score [b]	Expressive Language Score [c]	Total Language Score [d]	LENA Developmental Snapshot (LDS) Score	LDS Age	PEACH % [e]
C1	Hh	1.04	Male	Competent	92	117	105	114.78	1.17	92.5
C2	Hh	0.91	Male	Competent	106	125	117	90.67	0.58	*
C3	Hh	1.13	Female	Competent	108	89	98	109.1	1.17	77.27
C4	Hh	1.3	Male	Competent	112	117	116	95.85	1.08	68.18
C5	Hh	2.09	Male	Competent	109	88	98	95.51	1.92	100
C6	Hd	1.6	Male	Competent	100	98	99	76.83	1.00	72.50
C7	Hd	2.01	Male	Competent	86	88	86	71.18	1.17	60
C8	Hd	0.54	Male	Competent	*	95	*	76.6	0.25	0
C9	Hd	2.53	Female	Competent	101	100	100	93.49	2.42	77.27
C10	Hhu	2.86	Female	Competent	109 ^	97 ^	103 ^	92.74	2.58	65

[a] *Cognitive Developmental Categories were assigned based on raw scores from the Bayley III Screening Test, Cognitive Subtest (Bayley, 2006)*

[b] *Receptive language standard scores were measured on the Preschool Language Scale, 5th Edition (Zimmerman, Steiner, & Pond, 2011)*

[c] *Expressive language standard scores were measured on the Preschool Language Scale, 5th Edition (Zimmerman, Steiner, & Pond, 2011)*

[d] *Total language standard scores were measured on the Preschool Language Scale, 5th Edition (Zimmerman, Steiner, & Pond, 2011)*

[e] *Overall scores were expressed as a percentage on the Parents' Evaluation of Aural/oral performance of Children (PEACH; Ching & Hill, 2007)*

[^] *Child participant 10's standard scores on the Preschool Language Scale, 5th Edition were for descriptive purposes only as the testing was completed in Mandarin and English*

4.4 FAMILY DEMOGRAPHIC CHARACTERISTICS

All mother-child dyads (N=10) reported that two adults (both mother and father of the child) were living at home. All parents reported on Family and Educational Characteristics Questionnaire (FamEd-Q2; Leigh, 2016) that they did not have a hearing loss. All parents spoke English at home as either a primary (n=8) or secondary (n=2) language. There were two families who spoke English and used Auslan (signed communication) at home and four bilingual/multilingual families who spoke English and/or Mandarin, Cantonese, Vietnamese or Italian. Based on the Australian Bureau of Statistics Census data 2016, the ratio of families in this sample (40%) who used an additional spoken language other than English at home, is noted to be higher than the ratio observed nationally (21%). There were six of the 10 participating children who had one or more older siblings, between 2.9 to 9 years of age. Using SEIFA: Socio-Economic Indexes for Areas 2011 reference data to infer socio-economic status based on their home postcode. The 10 families lived in areas of mean and median relative socio-economic advantage deciles of 7.3 and 7.5 respectively (*SD* 1.89; *range* 4-10). According to the distribution of the SEIFA scale for Australia, the lowest scoring 10% of areas are assigned a decile of one and the highest 10% of areas are assigned a decile of 10. The mean and median SEIFA rank for this sample was 1639 and 1745 respectively (*SD* 471; *range* 782- 2321). Table 3 details the family demographic for individual participants in Study 1.

Table 3: Family demographic characteristics of the 10 mother-child dyads

Mother-Child Dyad	**Group**	**Primary Language**	**Secondary Language(s)**	**Number Adults at Home**	**Number of Siblings**	**Sibling age(s)**	**Child's position in family**	**SEIFA Decile ^**	**SEIFA Rank ^**
1	Hh	English	Mandarin, Cantonese	2	0	*	*	8	1774
2	Hh	Italian	English	2	1	3.5	Youngest	5	1072
3	Hh	English	*	2	0	*	*	8	1774
4	Hh	English	Vietnamese	2	0	*	*	7	1575
5	Hh	English	*	2	1	5	Youngest	10	2321
6	Hd	English	Auslan	2	1	2.9	Youngest	9	2050
7	Hd	English	*	2	0	*	*	7	1716
8	Hd	English	*	2	1	3	Youngest	6	1305
9	Hd	English	Auslan	2	2	7, 9	Youngest	4	782
10	Hhu	Mandarin	English	2	1	4	Youngest	9	2019

^ SEIFA deciles and ranks were derived from the Socio-Economic Indexes for Areas (SEIFA) 2011 measure based on Australian Bureau of Statistics' (ABS) census data

4.5 AUDIOLOGICAL AND EARLY INTERVENTION CHARACTERISTICS FOR DYADS IN THE HD GROUP

All children (n=4) in the Hd group were diagnosed with a congenital, bilateral hearing loss by 4 months of age and were fitted with hearing aids (HA) within a month of diagnosis. The unaided, 3 frequency (500Hz, 1kHz and 2kHz) Pure Tone Average (PTA) in the better ear was 65, 78, 118 and 100 dB HL for Child Participants 6, 7, 8 and 9 respectively. At the time of the study, 3 children had received cochlear implants (Child Participant 9 had bilateral CIs; Child Participants 6 and 7 had unilateral CIs), and Child Participant 8 was wearing bilateral hearing aids while undergoing pre-implant medical and audiological CI investigations.

Two mothers reported the use of oral communication as their primary mode at home and two mothers reported the additional use of sign (Auslan). Involvement in existing early intervention (EI) programs did not preclude the dyads from participating in Study 1 as the primary outcome measures of the study were based on changes in maternal language behaviour external to the EI settings (i.e. in the home environment). All children in the Hd group received EI services in either Victoria (n=3) or Queensland (n=1). Child Participants 7, 8 and 9 were enrolled in EI programs which used an oral communication mode only (n=3). Child Participant 6 was enrolled in an EI program that used spoken language and sign (Auslan). The average frequency and duration of individual EI sessions was one hour per week for Child Participant 7 and one to two hours per fortnight for Child Participants 6, 8 and 9. Additionally, there were two dyads (Child Participants 6 and 7) who attended group EI sessions for 1.5 hours a week and 2 hours per fortnight.

With regard to family participation, this small group of families were rated between three (average participation) to five (ideal participation) based on Moeller's (2000) Family Participation Rating Scale. Speech pathologists (case managers) of the four dyads assigned ratings of family participation in the child's intervention program(s) before rating their degree of confidence on a two-point scale. All the speech pathologists provided self-ratings of two (very confident). Further details regarding the audiological and Early Intervention (EI) factors for the four Child Participants in the Hd group (including hearing levels, age at diagnosis, aetiologies, age at HA fitting, hearing device experience, age at cochlear implantation (Age 1st CI), choice of communication approach at home and at EI, have been provided in Table 4 and Table 5.

Table 4: Audiological characteristics for Child Participants in the Hd Group (n=4)

Child	Right Hearing Levels (dB HL) [a]	Left Hearing Levels (dB HL) [a]	Age at Diagnosis (in years)	Aetiology	Hearing device(s)	Parent reported Device Usage	Age at Hearing Aid (HA) Fitting	HA Device Experience	Age 1st CI	Age at Switch-on	CI Device Experience
C6	65	97	0.33	Prematurity and hypoxia	Right hearing aid; Left cochlear implant	Full-time	0.33	1.27	1.20	1.23	0.37
C7	83	78	0.04-0.08	Unknown	Right cochlear implant; Left hearing aid	Full-time	0.16	1.85	1.51	1.54	0.47
C8	118	120	0.04-0.08	Unknown	Bilateral hearing aids ^	Full-time (Most waking hours)	0.08	0.66	*	*	*
C9	100	100	0.08	Unknown	Bilateral cochlear implants	Full-time	0.16	*	0.90	0.94	1.94

[a] *best unaided 3 frequency pure tone average at 500Hz, 1kHz and 2kHz*

^ Child was undergoing investigations for CI candidacy during course of the study

Table 5: Early Intervention characteristics for Participants in the Hd Group (n=4)

Dyad	Mode of Communication (Home)	Mode of Communication (EI)	Frequency and Duration of Individual EI	Frequency and Duration of Group EI	Family Participation Rating [b]	Clinician's Confidence Rating [c]
6	Spoken language and Sign (Auslan)	Spoken language and Sign (Auslan)	1-2 hours per fortnight	2 hours per fortnight	5	2
7	Spoken/Oral Language only	Spoken/Oral Language only	1 hour per week	1.5 hours per week	3	2
8	Spoken/Oral Language only	Spoken/Oral Language only	1 hour per fortnight	0	5	2
9	Spoken language and Sign (Auslan)	Spoken/Oral Language only	1 hour per fortnight	0	5	2

[b] *Ratings based on Moeller's (2000) Family Participation Rating Scale*

[c] *Clinician's self-ratings of confidence on the scores assigned for Family Participation*

4.6 GENERAL PROCEDURES

Following the signing of consent to participate, each participant was provided with a set of parent-report questionnaires: Family and Educational Characteristics Questionnaire 2 (FamEd-Q2); Parenting Sense of Competence Scale (PSOC); Parents' Evaluation of Aural/oral performance of Children (PEACH); LENA Developmental Snapshot (LDS); and a questionnaire on Parenting Knowledge. Participants were asked to complete and return the questionnaires to the researcher at their baseline research session or by post. The protocol for Study 1 was comprised of a baseline phase, followed by an experimental phase which was conducted using mediating technology. In the baseline phase, all participants attended an initial face-to-face research session which involved the completion of study assessments and a briefing on the study's LENA recording procedure. All participants also completed baseline LENA recordings prior to the intervention phase, in which they completed LENA recordings in 3 study conditions.

The baseline session took place within a quiet clinical environment either at the Department of Audiology and Speech Pathology at the University of Melbourne or at a HEARing CRC partner site (i.e. Hear and Say's Gold Coast Centre). During this session, both mothers and children completed standardised assessments administered by a speech pathologist. Each mother was given detailed verbal and written operating instructions for the LENA Digital Language Processor (DLP) and the Daily Activities Diary (DAD) and were briefed on the completion of study activities for the duration of the trial. Each mother was provided with a LENA kit, which included: a personalised study recording schedule for each dyad; LENA DLP(s); DADs for the baseline recordings; two clothing items for the child to wear with pockets suitable for the LENA DLP; and a laminated study explanation card.

The assessment battery for the children included the Bayley-III Screening Test (Cognitive subtest) and the PLS-5. The optional assessment battery for mothers included the PPVT-4 and KBIT-2. All assessments were conducted by a speech pathologist. The speech pathologist or case manager who was familiar with each Hd dyad rated each family's participation levels (from limited to ideal) on a 5-point Likert scale (Family Participation Rating Scale; Moeller, 2000). Each Child Participant's audiological history (including PTA scores, aetiologies of hearing loss, age at first hearing aid fitting and dates of CI operations/switch-on) was also collected.

4.6.1 Materials

4.6.1.1 Use of the Language ENvironment Analysis (LENA) System

The primary outcome measures for Study 1 were based on estimated language counts (frequencies of Adult Words and Conversational Turns) generated using the LENA system. The hardware component of the LENA system, also known as the Digital Language Processor (DLP), is a small, wearable recording device (approximately 8.5cm x 5.8cm x 1.2cm, 57 grams) which records audio data using an in-built omnidirectional microphone with a frequency response range of 20 Hz to 20 kHz (Ford, Baer, Xu, Yapanel, & Gray, 2008). Extreme frequencies are suppressed, with the resultant spectrum corresponding with the frequency range of human hearing, and recorded data is initially processed in the DLP to conserve both device memory space and battery life. Bespoke LENA clothing for children, including t-shirts, dresses, overalls and vests, were designed with a front pocket to hold the DLP securely (Figure 1) in place. Each audio recording of up to 16 hours from the child's natural language environment is stored on the DLP before the data is uploaded to a computer via a USB port transfer for further processing. The audio quality of the uploaded LENA recordings is decompressed to an audio format with a 16-bit amplitude resolution at a 16 kHz sample rate (Ford et al., 2008). Data from the uploaded recording is assigned to a participant under the LENA software's client manager, allowing for multiple recordings to be saved to the same participant's profile and compared over time. Once a recording has been uploaded to the LENA software, it is erased from the DLP's memory storage. The DLP is recharged and prepared for the next recording.

Figure 1: A child wearing a LENA t-shirt with the Digital Language Processor (DLP) placed in the front pocket.

The software automatically analyses three key quantitative measures: Adult Word Count (AWC); Conversational Turn Count (CTC); and Child Vocalisation Count (CVC). LENA data reports on each of these key measures are generated in five-minute, hourly, daily and monthly intervals. The LENA software also has the ability to provide 12-hour projected AWC, CTC and CVC estimates if an uploaded audio sample exceeds a minimum recording duration of 10 hours.

In the software development of LENA's automated algorithms, training sets derived from the LENA Natural Language Corpus, were comprised of 309, 30-minute long audio recordings controlled for child's age (between 1 to 42 months) and gender, were used to train statistical models in the analysis of auditory-language environments (Gilkerson, Coulter, & Richards, 2008).

In addition to these three quantitative measures (AWC, CTC and CVC), LENA software generates audio environmental reports regarding the proportions of close-range speech, distant speech, electronic media sounds, background noise and silence. The LENA Pro Software Version 3.4 uses pattern recognition and speech signal processing algorithmic models to filter and extract different acoustic features from the audio stream before segmenting and classifying these sound categories (e.g. speech and environmental noises) (Ford et al., 2008). Non-speech sounds including vegetative sounds and coughing are filtered in the segmentation process. Overlapping speech segments are excluded from the estimates of adult or child speech (Xu, Yapanel, & Gray, 2009). Macro-statistical models are applied to both adult sound segments and conversational data in order to estimate the number of adult words which a child hears in close-range (AWC), and the number of back-and-forth verbal exchanges (CTC) alternating between the key child (wearing the DLP) and an adult. A LENA conversational turn is counted when a verbal interaction, consisting of a pair of adult and child speech segments, occurs within five seconds of each other (Ford et al., 2008). A conversation boundary is defined as a continuous stream of live human speech separated by pauses of five seconds or greater (Ford et al., 2008). Key child vocalisation estimates include words, babbles, protophones or pre-speech communicative sounds (e.g. growls, squeals or raspberries) and exclude reflexive noises (e.g. laughing, crying and sneezing). A child vocalisation (CV) is counted each time a speech sound produced by the key child was surrounded by a pause (silence or non-speech) of at least 300 milliseconds (Gilkerson & Richards, 2009).

Gilkerson and colleagues (2017) have recognised that the LENA software's automated approach to counting vocalisations is distinguished from traditional approaches of identifying utterance boundaries based on semantic content (Brown, 1973). Direct comparison between methods would not be appropriate given the inherent operational differences in semantically derived utterances versus LENA's vocalisation counts. The LENA system's automated analysis of the children's natural language environment provides a unique advantage of allowing unrestricted audio recordings to be taken independently by participants outside of clinical settings, and without the need for an extensive transcription and coding process (Gilkerson et al., 2017). Previous studies (Ford et al., 2008; Zimmerman et al., 2009; Xu et al., 2009; Gilkerson et al., 2017) have nevertheless, reported on the reliability and validity of AWC, CTC and CVC metrics and a high level of fidelity in coding categories of audio environmental data was shown when compared to human transcribers. Using 70 hours of audio test files, the percentage-agreement between human transcribed and LENA identified speech activity was found to be 82% for adult and 76% for child speech segments (Xu et al., 2009).

The LENA software also provides information on AWC, CTC and CVC percentile ranks based on the distribution of the LENA normative sample (3384, 12-hour recordings from 378 American families with typically developing children) collected as part of the Natural Language Study (Gilkerson & Richards, 2009). Percentile estimates are available for children aged between 2 and 48 months and are based on the 12-hour projected AWC, CTC and CVC for LENA recordings of at least 10 hours. The distribution of talk by adults (AWC) was found to remain relatively consistent across child recording ages, whereas CTC and CVC measures were correlated with child recording ages on LENA's normative charts. LENA software generated percentile rank information (where available) was one component of the feedback provided to mothers in the present study.

4.6.1.2 Weekly Recording Schedule

Each participant mother was asked to nominate one or two days per week when she and her child planned to spend the most amount of time together at home (i.e. when she was the primary caregiver for the day and the child was not attending day care). The LENA recordings in this study were designed to measure each child's exposure to language in their naturalistic environments throughout the day until bedtime, which could include time spent at home, at the shops, in the car or at a park. None of the LENA recordings were taken when the children were attending day care as parent-implemented intervention in the child's natural environment was the central focus of this study. Participants were not required to deviate from their usual schedules on their nominated LENA recording days; the children were involved in typical family routines and activities inside and outside of the home. Apart from nominating a LENA recording day which was representative of an average day for their child, each mother was asked to consider convenience in their preference. Specific dates were discussed with each participant to ensure that LENA recording days did not clash with existing plans (e.g. trips or holidays), attendance at group programs, events of long duration with high levels of noise, and/or events with multiple speakers at close range. Controlling the LENA recording conditions in this manner assisted with maintaining the stability and accuracy of the LENA output (Xu et al., 2009). The agreed LENA recording days formed the basis of each dyad's individual recording schedule (see Appendix 6: Example of a Recording Schedule) which timetabled each LENA recording over the duration of the trial. The designated dates when each mother would be available to receive her LENA feedback was planned as close as possible (typically 24-48 hours prior) to their next LENA recording date. For example, if the dyad's recording day was on Wednesday, their LENA feedback would be provided by Tuesday in the same week. Each participant was requested to contact the study researcher if she missed a scheduled LENA recording, so that suitable alternative dates could be arranged. The interval between recordings was adjusted from weekly to fortnightly recordings for one mother-child dyad in this study in order to accommodate extended postal turnaround times; this participant resided outside the express post network in Australia.

4.6.1.3 Recording Procedure

Each mother was asked to record between 10 to 16 hours on their LENA recording days. This minimum length of recording time is a requirement for the LENA software to generate percentile rankings for AWC, CTC and CVC and reported as part of feedback to mothers. Data from 61.9% of the LENA recordings were derived from a single day as mothers reported that this was more convenient. Data from the remaining 38.1% were derived from two consecutive recording days.

Prior to the nominated LENA recording day, each mother was provided with their recording kit containing the LENA DLP(s), a Daily Activities Diary and a return prepaid express post satchel (where required). Mothers were instructed to begin each recording from the time their children woke up in the morning, and to secure the DLP in the LENA clothing pocket before dressing the children and continuing with their daily routine. To simplify procedures, mothers were instructed to leave the DLP on until the end of the recording day; the DLP switches off automatically once it has reached full recording capacity (16 hours). Mothers could refer to the written instructions (Appendix 7) included in the LENA kit or contact the researcher if they had any difficulties operating the DLP. The DLP remained on the child except during nap/sleep times, car rides, bath-time or time spent in a swimming pool. In these environments, mothers were asked to place the DLP close to the child and to keep recording. Each mother was also instructed how to use the 'pause' function to suspend recording when: participants became uncomfortable with recording; they chose to finish recording for the day, and/or they chose to resume recording at a later time/ next day. Each mother completed an activity-time log (i.e. the Daily Activities Diary), packed the DLP into the prepaid express postal satchel and returned the satchel to the researcher. In some cases, it was convenient to return the satchel in person. A new LENA kit for the next recording was provided to each participant during this weekly (or fortnightly) exchange over the course of the trial.

4.6.1.4 Daily Activities Diary

The Daily Activities Diary (DAD; see Appendix 5) is comprised of a double-sided sheet with time allocations designed to facilitate the review and interpretation of LENA data and subsequent feedback provided to mothers. Mothers were asked to note the environmental setting/ activity in 2-hour intervals (e.g. 7- 9am, 6- 8pm) over the course of the LENA recording day. The DAD also seeks information regarding: other persons who were present during the activities; the child's hearing aids or speech processors (for the Hd group); use of the Daily Vroom mobile app (when applicable); how typical the activities were; and the child's health. These latter two questions on the DAD (i.e. ''Is this a typical example of your parent-child talk time?'' and ''Is your child feeling well today?'') were important to determine whether the resultant data was considered as representative of the dyad's typical day. If mothers circled the ''no'' option to either of these questions, further discussion between the researcher and mother ensued and a decision was applied as to whether to include/exclude the data from further analysis. The DAD was also used: to note times/hours participants did not want the recordings used for further analyses (i.e. when mothers were having conversations with her friends); to provide reminders for the next scheduled recording day, LENA feedback session or LENA kit exchange day; and to note any additional comments, observations or notes for the researcher.

4.6.1.5 Family and Educational Characteristics Questionnaire 2 (FamEd-Q2)

In the baseline phase, participants completed the FamEd-Q2 (see Appendix 8 for a copy of the questionnaire can be found) which is an adaptation of a family characteristics and early educational placement questionnaire administered routinely to families at the Cochlear Implant Clinic, RVEEH (Leigh, 2016). The FamEd-Q2 seeks participant details relating to the socio-demographics of the child, mother (primary caregiver), family and early education/intervention enrolment.

4.6.1.6 Socio-Economic Indexes for Areas

Participants' residential postcodes (N=10) were collected as part of the FamED-Q2 and used to approximate each family's relative socio-economic advantage by geographical area derived from 2011 Census data (Australian Bureau of Statistics, 2011). The Socio-Economic Indexes for Areas (SEIFA; (Australian Bureau of Statistics, 2011) summarises different variables, including an individual's access to resources and their ability to participate in the community, and assigns a decile and rank to postcodes. SEIFA decile scores range from 1 being a relatively disadvantaged area to 10 being a relatively advantaged area. SEIFA rank scores are on a continuum with lower scores indicating a relative degree of socio-economic disadvantage and higher scores representing greater socio-economic advantage. Due to the multidimensional nature of quantifying socioeconomic status, the SEIFA only provides an estimate which may not reflect actual household income, nor capture the housing quality of the dwelling and living standards. This indirect measure was used in place of asking participants for potentially sensitive financial information.

4.6.1.7 Family Participation Rating Scale

For participants in the Hd group (n=4), a family participation rating scale developed by Moeller (2000) was used to characterise the quality of parental (family) participation in the child's usual intervention program. The importance of parental involvement in therapy and rehabilitation adherence has been identified as a critical component in improving outcomes for children with hearing loss (Niparko et al., 2010; Sacks et al., 2014). Parent participation was rated on a 5-category scale by their treating CI speech pathologist (case manager), who was most familiar with the dyad. Each rating category contained specific descriptors (refer to Appendix 9) pertaining to the parents' level of adjustment to their child's hearing loss, involvement in intervention sessions, effectiveness of communication with the child and the capacity to advocate for their child. The clinicians assigned a rating to reflect a parental involvement category: *1=limited participation, 2=below average participation, 3=average participation, 4=good participation* and *5=ideal participation* (Moeller, 2000). Given the reliance on a single clinician's rating per participant, each clinician also completed a self-report measure of confidence of their own rating. Clinicians' confidence ratings provided on a scale of *0=not confident at all* to *2=very confident,* were reported on in this study as part of the Family Participation Rating measure. Each family participation rating was only included if the clinician was very confident (confidence rating of 2) of their assigned rating(s).

4.6.1.8 End of Trial Survey Questions

At the end of the study, each participant in the Hd group (n=4) were asked to respond to two questions about their experience of participating in the intervention's technology-based approach, which included the use of the LENA system and the Daily Vroom App. The first multiple choice question asked if they would like to use the LENA, DVA or both digital tools (LENA and DVA) again in the future. The second open-ended question sought a short, general comment(s) from each dyad regarding the interventions using LENA and DVA from their point of view. The four dyads provided written responses to the questions to inform observations made about their responses to the intervention for the single-subject cases (Results section 5.5)

4.7 Maternal Measures

4.7.1 Maternal Occupational Skill Levels

The Australian and New Zealand Standard Classification of Occupations (ANZSCO; Australian Bureau of Statistics, 2013) was used to categorise each mother's occupation based on skill level and specialization required to perform tasks in that role: 1 (commensurate with having a university or higher degree); 2 (commensurate with attaining a diploma or at least 3 years of relevant experience in substitution for formal qualifications); 3 (commensurate with a certificate 3 or 4 with 2 years on the job training); 4 (commensurate with a vocational certificate 2, 3, or at least 1 year of previous experience in the absence of formal training); and 5 (commensurate with certificate 1 or secondary education). The classification of maternal occupations was used in the present study to complement the SEIFA measure of participants' socio-economic status. Hart and Risley's (1995) showed variations in the amount of talk which young children from professional, working-class and welfare families heard at home.

4.7.2 Peabody Picture Vocabulary Test, Fourth Edition

The Peabody Picture Vocabulary Test, 4th Edition, is a norm-referenced measure of receptive vocabulary which is suitable for persons aged 2 years and 6 months to 90 years and older (Dunn & Dunn, 2007). A measure of maternal vocabulary was sought as this has been suggested as a predictor of child vocabulary and a source of variance which could contribute to a child's language exposure (Bornstein et al., 1998). As an optional measure in the present study, the PPVT was administered with eight out of 10 participants; two mothers chose not to complete the PPVT-4.

As per the PPVT-4 manual guidelines, each one-word test item was presented verbally. Mothers were asked to choose one of four pictures which matched the spoken word. Once a basal level was established (a set of 12 items with one or less errors), the test proceeded until the individual attained a ceiling level (eight incorrect responses within a set) or completed the test. The PPVT-4 evaluated an individual's understanding of vocabulary by providing a raw score (i.e. ceiling item number subtracted by the total number of errors) which was then converted to a standard score for interpretation.

4.7.3 Kaufman Brief Intelligence Test, Second Edition

The Kaufman Brief Intelligence Test, Second Edition (KBIT-2; Kaufman, 2004) is a validated screening measure of intelligence comprised of a Verbal (Verbal Knowledge and Riddles) and a Non-verbal (Matrices) domain. The test is suited for individuals aged between 4 to 90 years, and has been used in a variety of clinical, educational, vocational and research settings to obtain an estimate of an individual's verbal and non-verbal intelligence (Kaufman, 2004). The completion of the KBIT-2 was optional for mothers in this study; nine mothers completed the Non-verbal scale and seven mothers completed both Non-verbal and Verbal components.

The Verbal scale measured the ability to apply acquired knowledge to problems (crystallised intelligence). Participants were shown six pictures and asked to select one of these pictures in response to each test item on the Verbal Knowledge subtest as a measure of receptive vocabulary and general knowledge abilities. The Riddles subtest required oral responses to items assessing the individual's verbal comprehension, reasoning and vocabulary skills. The total number of correct responses on Verbal Knowledge and Riddles subtests were tallied to derive a Verbal ability standard score. The Non-verbal scale consisted of only the Matrices subtest. Participants were required to apply non-verbal reasoning and flexibility in problem-solving as part of the non-verbal (Matrices) scale items. They were asked to identify relationships through pictures and abstract stimuli in a 2x2 or 3x3 matrix format. The total number of correct responses were scored to derive a Non-verbal ability standard score. The IQ Composite standard score of general intelligence on the KBIT-2 was based on a combination of both Verbal and Non-verbal standard scores.

4.7.4 Parenting Knowledge

Each mother completed either the Knowledge of Infant Development Inventory (KIDI; MacPhee, 1981, revised in 2002) or the Parent Knowledge of Child Language Development questionnaire (Suskind et al., 2016b) which are both well-supported, reliability-tested instruments of parenting knowledge. The first five mothers provided feedback that the KIDI questionnaire was extensive and required a long completion time, therefore the remaining five mothers completed the latter, shorter measure of parental knowledge. The KIDI (MacPhee, 2002) is a widely used, standardised measure of parental knowledge regarding parenting practices, early developmental milestones from birth to two years of age, health and safety guidelines, as well as infants' and toddlers' early experiences. The KIDI was found to have a reliability coefficient of 0.85 for mothers and a two-week, retest coefficient of 0.92 (Bornstein, Cote, Haynes, et al, 2010). The KIDI was used as an indicator of the knowledge base which participants possessed, which could in turn influence and regulate behaviour towards their child. Mothers (n=5) in the Hh group, completed the 58-item revised version of the KIDI (MacPhee, 2002). Their responses were scored as correct or incorrect in accordance with predetermined answers provided on a reference sheet. Results were expressed as the percentage of correct answers.

The Parent Knowledge of Child Language Development questionnaire was developed by Suskind and colleagues, revised and evaluated for test-retest stability for use in a randomised controlled, parent-directed language intervention pilot study (2016). The test-retest reliability coefficient for this instrument was 0.75 with an average lapsed time of 77 days (range 50 to 105 days) (Suskind et al., 2016b). This 35-item instrument represented 5 domains of knowledge; including language acquisition, dialogic reading practices, predictors of school achievement, learning support for mathematics and television habits. Questions on Suskind et al (2016b)'s questionnaire reflected more contemporary practices with an emphasis on measuring parental knowledge relevant to early child language development. Mothers (n=5) completed the self-administered questionnaire by providing their responses to all items on a 5-point Likert scale ranging from *1=Strongly disagree* to *5=Strongly agree*. Response choices were collapsed into two categories: Agree (4, 5) or Disagree (1, 2) before each question was scored based on an answer sheet. Results were expressed as the percentage of correct answers. An overall score was calculated by expressing a percentage of correct responses out of the total number of items on this questionnaire, to best normalise scores obtained on both parenting knowledge measures.

4.7.5 Parenting Sense of Competence

The Parenting Sense of Competence scale (PSOC; Gibuad-Wallston & Wandersman, 1978) was completed by all mothers (N=10) at the start of the trial. The PSOC is a validated self-report tool comprised of 17 statements used to measure participant's perception of self-efficacy (Gibaud-Wallston & Wandersman, 1978; Ohan, Leung, & Johnston, 2000). Participants rated their responses to each statement on a 6-point scale ranging from *1=Strongly disagree* to *6=Strongly agree.* Responses to eight items were scored based on the ratings participants had assigned to the statements. There were nine individual items on the PSOC which were negatively worded which required reverse scoring. A higher summed score on the PSOC indicated a greater sense of parenting competency. Summed values on the PSOC were converted to percentage-scores.

4.8 Child Measures

4.8.1 Preschool Language Scale 5

The Preschool Language Scale-5 (PLS-5; Zimmerman, Steiner, & Pond, 2011) is a standardised assessment tool used to evaluate a child's language abilities. The developmental tasks on the PLS-5 are designed for children from birth to 7 years and 11 months of age. It is comprised of two subscales: *Auditory Comprehension* which evaluates a child's receptive language and *Expressive*

Communication which assesses a child's expressive language ability. A raw score, standard score and age equivalent score are generated for each subscale (Auditory Comprehension and Expressive Communication) from which a Total Language age equivalence and standard score are derived. Standard scores are used to measure a child's abilities in relation to the average performance for a normative sample of age-matched, typically developing children. A standard score of 100 reflects the mean performance of children in a given age range, and standard scores between 85- 115 are within the typical performance range for the child age group.

At each of the dyad's baseline study sessions, the PLS-5 was administered to the participating child in a quiet clinic room, in the presence of the child's mother and/or additional caregiver(s). One infant in the Hd group was not able to complete the *Auditory Comprehension* subscale of the PLS-5 due to the child's severity of hearing loss and young age (six months old at time of test). There were six children in this sample who were also exposed to varying degrees of bilingualism (English and another spoken/signed language) in the home. It was noted that one child (Hhu)'s PLS-5 standard scores was used in the present study for descriptive purposes only, as the testing was conducted in both English and Mandarin (the child's dominant language). The study researcher could understand Mandarin and was able to validate the mother's interpretation of the test items. Any comparison with normative data for this child, however, must be used with caution due to the language change.

4.8.2 Bayley III Screening Test- Cognitive Subtest

The cognitive component of the Bayley-III Screening Test (Bayley, 2006) was used to screen the children in the present study during the baseline session. The subtest is designed to assess cognitive functioning of infants and young children between the ages of 1 to 42 months and can determine whether a child is progressing in relation to expected cognitive developmental milestones. Tasks on the cognitive subtest are designed to examine different aspects of cognition, such as, how a child explores and plays with different types of objects. Activities on the subtest also focus on the child's capacity for problem-solving, concept formation, forming relationships between objects and ability to demonstrate novelty preference and habituation. On the Bayley-III Screening Test, a child's progress in the skill area is measured by a raw score which is related to one of three screening categories: *at risk, emerging* and *competent*. A child with a score in the *at risk* category would benefit from having further comprehensive evaluation. A score in the *emerging* category indicates that a child's progress should be monitored for any possible concerns and rescreened after a time interval, and if necessary, reviewed for further evaluations. A child is considered to be at minimal risk for a developmental delay if he/she obtains a score in the *competen*t category. All children who participated in the present study were found to be progressing in relation to expected cognitive developmental milestones for their age; achieving competency either at the first administration of the Bayley-III Screening test during the baseline session, or at the second administration at the end of the study.

4.8.3 LENA Developmental Snapshot (LDS)

The LENA Developmental Snapshot (LDS; Gilkerson & Richards, 2008) is a 52-item statistically validated parent-report survey tool designed to evaluate expressive and receptive language skills in children aged between 2 to 36 months. The LDS can be used as a monthly language developmental progress monitor (Gilkerson et al., 2017) and has been demonstrated to be highly correlated with standardised early language assessments (e.g. Preschool Language Scale- 4th Edition, Child Development Inventory and the Receptive-Expressive Emergent Language Test-3rd Edition). The LDS consisted of age-ordered dichotomous questions with the response option of 'yes' to indicate that the child consistently demonstrates the skill or behaviour or 'not yet' if the child has not yet acquired the skill or demonstrated the behaviour. Parents responded to each item beginning with the first question, 'When you talk to your child, does he/she look in the direction of your voice?' until a ceiling level of five consecutive 'not yet' responses was obtained.

All 10 dyads completed the LDS on their own during the baseline phase using a printout of the questionnaire. Participant responses were entered by the researcher onto the Developmental Snapshot tool using LENA Software and automatically scored. An estimate of each child's language skills compared to age-matched peers on the LDS was expressed in the form of a standard score (up to 36 months of age) and a developmental age as a function of chronological age.

4.8.4 Parents' Evaluation of Aural/oral performance of CHildren (PEACH)

All participating mothers (N=10) completed the Parents' Evaluation of Aural/oral performance of CHildren (PEACH; Ching & Hill, 2007) rating scale. This measure is used to assess a child's real-world functional listening performance (normative data was collected on both normally hearing and hearing-impaired children) in a range of everyday situations based on parental observations.

Responses to each item on the PEACH were rated on a 5-point scale guided by the following descriptors: 0=Never, 0%; 1=Seldom, 25%; 2= Sometimes, 26-50%; 3=Often, 51-75%; 4=Always, 76-100%. Ratings on the 11 items for each subscale (Quiet and Noise) were added together to form an overall score of functional listening performance. The overall score was expressed as a percentage out of a total of 44. There were five mothers who noted that the item, 'how often does your child successfully use a phone?' did not apply to them, either due to their children's ages or the children's lack of understanding about the use of a telephone. This item was removed when individual PEACH scores for the five participants were calculated and the corrected total of 44 was adjusted to 40 in these five cases.

4.9 Study Design

Study 1 was designed with a two-fold purpose. The first objective was to trial the use of the LENA system with mother-child dyads in their home environments and to compare participant characteristics and abilities, as well as contextual family and demographic factors, with automatically generated language data obtained from baseline LENA recordings. The second objective involved the use of a multiple treatment design to determine the relative effects on adult word count (AWC) and adult-child conversational turn count (CTC) by providing mothers with feedback based on LENA generated auditory-language information and additionally, by asking mothers to use the Daily Vroom app as part of their everyday routine. For the second aim of Study 1, this experimental intervention was replicated with both Hh and Hd groups. It has been proposed by Byiers, Reichle, and Symons (2012) that the implementation of systematic replications allows researchers to determine the extent to which findings will generalise across different trial durations and participant groups with more heterogeneous characteristics (i.e. young children with varying hearing thresholds levels).

4.9.1 Study Conditions

At the start of the trial, baseline LENA recordings were obtained from all participants (N=10) as per the weekly recording procedure described in section 4.6.1.3. Participants were introduced to three study conditions in the intervention phase: LENA recordings Only (LO), LENA Feedback (LF), and LENA Feedback and use of the Daily Vroom App (LFA). A fourth study condition using only the Daily Vroom App as an isolated intervention strategy (without LENA Feedback) was considered and rejected. Including a fourth condition may have implications on participant recruitment, adherence and participant commitment to the study as a consequence of extending the duration of the protocol. The potential benefits (app quality and perceived impact) of using the Daily Vroom App were evaluated from the perspective of participating mothers (and clinicians) in Study 2, in lieu of implementing this fourth condition, use of the Daily Vroom App, in isolation.

A counterbalanced design was introduced to ensure that all participants were involved in the three conditions, while controlling for order effects. At the time of enrolment, each mother-child dyad was sequentially assigned to a predetermined, alternating study order of conditions (refer to

Appendix 10 for examples of desired study sequences A, B and C; study sequence A is shown in Figure 2). In some cases, there were order variations for individual dyads due to their compliance with the prescribed interventions. The three study conditions are described below.

Baseline Phase		Experimental Phase																	
Baseline		LENA recording Only Condition			Intervention Condition (LENA FEEDBACK)							Intervention Condition (LENA Feedback + App)							
LENA Recording	LENA Recording	LENA Recording	LENA Recording	LENA Recording	LENA Feedback	LENA Recording	LENA Feedback	LENA Recording	LENA Feedback	LENA Recording	LENA Feedback	Use of App	LENA Recording	LENA Feedback	Use of App	LENA Recording	LENA Feedback	Use of App	LENA Recording

Figure 2: Study Sequence A

4.9.1.1 LENA recording Only Condition

LENA recordings in the LENA recording Only condition (LO) were completed in the child's everyday environment and DAD information was collected from participants according to the procedure outlined in sections 4.6.1.2 to 4.6.1.4. Recorded data taken in the LO condition was used for comparison against two experimental conditions where interventions were implemented. No intervention measures were introduced in this condition, i.e. mothers were not provided with any feedback based on LENA estimated language counts and they were instructed not to use the Daily Vroom mobile app.

4.9.1.2 LENA Feedback Condition

The effect of providing objective feedback to mothers about their language behaviours and information about their child's auditory-language exposure was investigated in the LENA Feedback (LF) condition. Providing 'biofeedback' or quantified linguistic feedback to caregivers and parents has been proposed as an effective strategy associated with positive behaviour change (Leffel & Suskind, 2013; Suskind et al., 2013). In this study, feedback was based on the LENA-generated estimated language counts from the dyad's previous (most recent) recording in their everyday home environment. After the participant's LENA kit containing the DLP was returned, the recording data was processed using the LENA Pro software. Graphs for four core LENA measures were generated for each recording and incorporated into the Summary Report which was personalised for each dyad.

The template for a one-page Summary Report (refer to Figure 3) was created specifically for this study and designed as a way of presenting quantitative auditory-language information visually to mothers. The first three graphs on the Summary Report displayed the amount (y-axis) of adult talk, adult-child conversational turns and child vocalisations which occurred hourly during a recording day (x-axis). A brief written description was added below each graph stating a cumulative count across the recording day, percentile estimates when compared to LENA's normative data (where applicable) and the time(s) of the day when the highest amount of each count (number of words adults spoke to the child, conversational turns or child vocalisations) occurred. A Snapshot Summary was included on the report highlighting 12-hour projected LENA counts of adult words, adult-child conversational turns and child vocalisations analysed from the participating dyad's recording. Additionally, the average number of counts over 12 hours for a child in the same age group (based on counts derived from LENA's normative sample) was reported for comparison. An overall daily ratio of audio components recorded in the child's environment was also presented as a pie chart as part of the Summary Report. Percentages of each audio component (i.e. meaningful speech, distance and overlapping speech, TV and electronic media sounds, background noise and silence) were stated under the pie chart. A tailored Summary Report and the corresponding scanned DAD for the recording day was emailed to each mother as an encrypted, password-protected Adobe Portable Document (PDF) file prior to the participant's scheduled LENA Feedback. A printed copy of the Summary Report and scanned DAD was also included in the next LENA satchel for the participants.

LENA feedback, delivered by the study researcher, was scheduled to be held 24 to 48 hours prior to the participants' next recording. Individualised Summary Reports explained in detail during LENA Feedback discussions over the phone or in-person (depending on each participant's preference). Each LENA feedback discussion generally lasted between 15 and 30 minutes. All mothers received Summary Reports and feedback prior to their next recording day, although there were occasions when shorter discussions were held over the phone or feedback was provided on email due to changes in the mother's schedule or availability.

Feedback was centred primarily on the information compiled on the Summary Report and in relation to the activities listed on the DAD. The study researcher systematically explained graphs to the mothers, outlining patterns and the hourly breakdown of the amount of adult words, conversational turns, child vocalisations and audio environment, in the context of activities/events which occurred during the recording day. A comparison of the dyad's day-long (projected 12-hour) performance on those key measures compared to the US LENA norms in terms of percentiles and average counts was discussed with each mother. The feedback approach was informed by Pendleton's rules where positive instances were highlighted early in the session (Pendleton, 1984), for example, when the highest amount of talk and verbal exchanges occurred during the dyad's recording. The dyad's feedback from the previous week (if applicable) was also reviewed as a benchmark of their progress. LENA Feedback discussions with mothers were also guided by the following questions/prompts:

- 'How do you feel that the most recent recording went?';

- ‘Do you think that the graphs (generated by LENA) are an accurate representation of the amount of talk on the day of the recording?’;
- ‘Is there a notable difference in the amount of talk by adults (AWC)/ frequency of adult-child interactions (CTC) analysed by LENA on this recording compared with previously discussed counts?’ (if applicable);
- ‘What can you recall about this time of the day?’ i.e. hour when the amount of talk by adults (AWC)/ conversation between an adult and their child (CTC) / vocalisations by their child (CVC) was highest or lowest (with the exception of nap times);
- ‘Do you feel that the amount of talk or verbal interactions with your child varies depending on the type of activity you were involved in (list specific activities which the dyad was involved in on the recording day i.e. reading versus watching television)?’;
- ‘What do you think inspired more talk or interaction with your child during this time of the day?’ i.e. times during the day when the amount of talk by adults (AWC)/ conversation between an adult and their child (CTC) / vocalisations by their child (CVC) was high; and
- ‘What would you like to work on for the next recording?’ i.e. increasing back and forth interactions with child during bath time

In accordance with provision of any feedback (Chowdhury & Kalu, 2004), the researcher also provided numerous opportunities for each mother to clarify her understanding and to ask questions during the LENA feedback discussions.

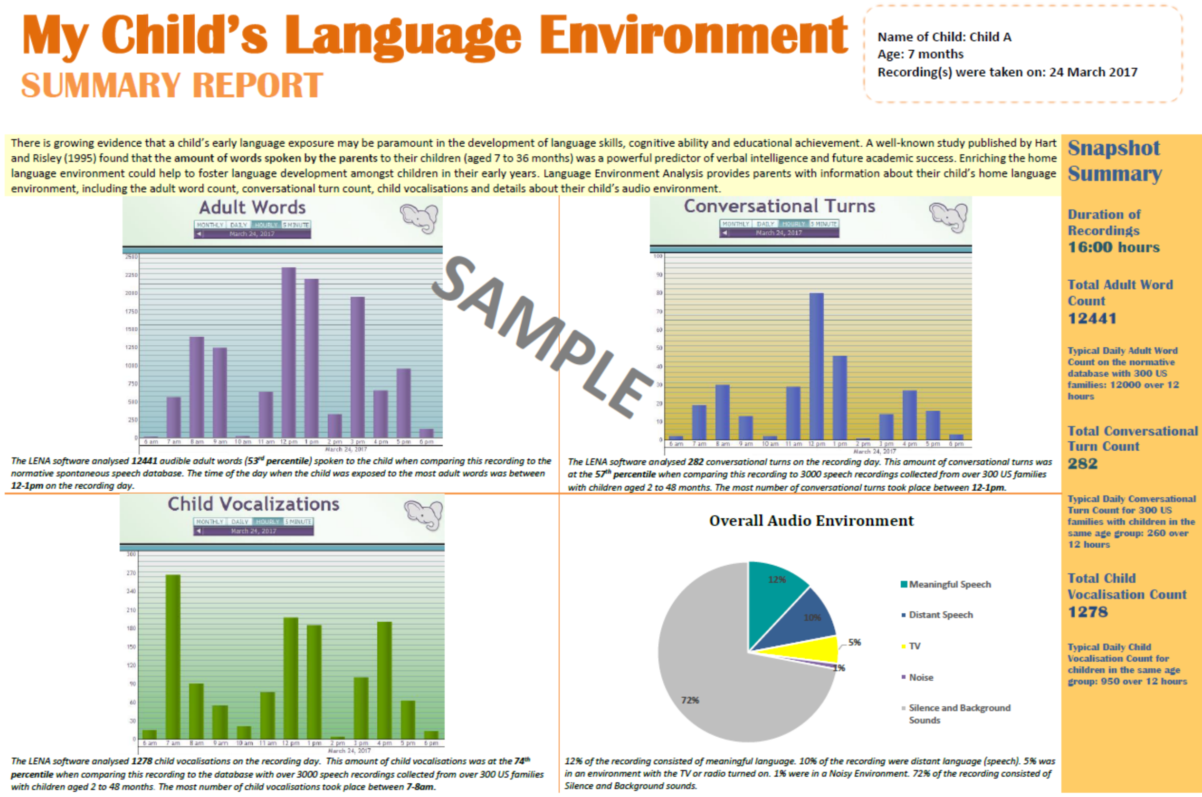


Figure 3: Example Summary Report used in providing LENA Feedback to mothers

4.9.1.3 LENA Feedback and use of the Daily Vroom App Condition

In the second intervention condition, mothers were asked to incorporate suggested Daily Vroom App activities into their everyday routines with their children, in addition to receiving LENA Feedback. The Daily Vroom App was introduced to mothers prior to their first scheduled recording day in the LENA Feedback and Daily Vroom App (LFA) condition only. An instructional handout (Appendix 11) on downloading and using the app was included in each dyad's LENA kit for the designated week's recording. The study researcher also provided mothers with guidance on downloading and using the app in person, over the phone and/or through text messaging. Mothers were firstly asked to install the Daily Vroom app on their iPhone, iPad or Android mobile device and to create a customised profile on the application. The app required the mother to enter the age of her participating child, as this facilitated the app's selection of age appropriate activities for the child. After mothers had registered their app profiles, they would receive a daily notification on their mobile devices containing a DVA tip, suggesting an activity which promoted interaction and engagement with their children through common family routines, for example, during meal time, shopping, travelling on the bus/in a car or preparing for bed time. A rationale or 'Brainy Background' was included with each tip which explained why the shared parent-child activity fostered learning for children. An example of a Daily Vroom App tip for a child aged between one to two years would be ‘Multiplying Words: When your child starts to say words or make sounds that could be words, connect them to more words. If he/she says ‘nose’, you can say, ‘There’s your nose and there’s mine.’ If your child says, ‘’beep’’, you can say, ‘The horns on the car go beep, beep.’ Later you can ask, ‘What sounds do cars make?’. The Brainy Background explains that, ‘children learn to speak by hearing you connect the sounds they make with words. And they learn more words by you adding words to their words’. Mothers were also provided with a printed copy of the Daily Vroom app activities (known as Tip Cards) organised by age range upon request.

The tips written in English were within 250-300 characters and were estimated to be at a grade three to grade five reading level (Galinksy et al., 2017). Reminders could also be customised so that mothers could decide on the timing of the notification tip over the course of the day. In addition to each new daily notification tip, the app also contained a range of different activities categorised by different contexts and times which spanned across the day. Mothers were advised to complete at least one activity on the recording days during the LFA condition. They could also select another activity which was more suited to their schedule instead of the daily notification tip. After an activity was marked as completed by the mother on the app, a virtual badge of completion was automatically generated. Mothers could track a list of completed activities and badges which they had earned on the Daily Vroom App. When mothers received their LENA Feedback as per the procedures outlined in the LF condition, they were also asked about the time(s) of day they had used the app, and which activities they had completed in relation to the amount of talk and adult-child interactions for each recording days.

4.9.2 Duration of Study Trials

All participants (N=10) were presented with the same three study conditions allowing for within-subjects effects to be explored and participant data collected in each condition to be pooled for group comparisons. The protocol was designed for participants to complete an average of one LENA recording of up to 16 hours, per week. A maximum of 11 LENA recordings were taken per participant as each participant attended a baseline study session and completed one to two LENA recording(s) taken in the baseline phase, followed by 2-3 LENA recordings taken in each of the three alternating conditions (LENA recording Only, LENA Feedback, LENA Feedback and use of the App). The rate of participation and LENA recording intervals varied depending on participants’ abilities to comply with the protocol. The trial recording schedule for one participant (16.1 weeks) was adjusted to accommodate fortnightly instead of weekly recordings which the participant preferred. The fortnightly recording interval also allowed for adequate LENA kit exchange time as the dyad resided in a regional area located beyond the express postal service network. The total duration which the 10 mother-child dyads were involved in completing LENA recordings over the trial (baseline and three study conditions) ranged from 7 weeks to 16.1 weeks, with a trial participation mean of 9.6 weeks and a median of 8.1 weeks. All 10 participants were retained despite the considerable length of study involvement.

4.10 Procedures for Normalising Data and Resolving Methodological Issues

There were two strategies which were implemented to facilitate data analysis across all measures. The Knowledge of Infant Development Inventory (KIDI) was completed by five participants whereas Suskind and colleagues' (2016b) parent knowledge of child language development questionnaire was completed by the remaining half of the participants. Converting points score to percentage-correct scores enabled pooling of participant responses from both parenting knowledge questionnaires.

The second strategy involved the normalisation of the degree of change across conditions by assigning the baseline LENA recordings and language count estimates (AWC, CTC and CVC) as zero, and then comparing change/no change in other conditions to this baseline. To establish a benchmark for each participant's language behaviours, and for comparison against changes in language behaviours in subsequent study conditions, LENA estimates of adult words, conversational turns and child vocalisations were calculated using individual participant data obtained from the baseline recordings. A minimum of 57 data points of 5-minutes each was collected from the LENA recordings which each participant had completed during the baseline week to establish an average word count per 5-minutes. The mean baseline counts for adult words and conversational turns for each of the 10 dyads were subtracted from actual 5-minute interval counts in the three remaining study conditions (LO condition, LF condition and LFA condition) to derive a measurement of actual change. A percentage change from baseline for adult words and conversational turns was also calculated for each individual dyad across conditions. This also facilitated the visual interpretation of differences between the conditions. Furthermore, even though the actual order of the three study conditions varied (as described in section 4.9.1) to counterbalance any carryover effects, the data was represented as if the study conditions LO, LF and LFA followed consecutively.

Where participants were unable to complete the condition according to the prescribed procedures, it was usually possible to adjust the order, rather than exclude these data from analysis. Where changes in order could not be made (e.g. the experimental condition had already been completed) these data were excluded from analysis. By the end of the trial, all participants were still exposed to the same number of study conditions (i.e. LO, LF, LFA).

4.11 Data Management

Using the LENA system as the primary measurement tool, data exported from the LENA system was first screened and organised prior to analysis. The LENA software was limited by daily, hourly or 5-minute data exports of language counts. LENA data was exported in 5-minute time intervals to ensure that there was a standardised time sampling interval across the participants. Given that recordings were taken in the dyads' naturalistic home environments, a sensitive measure of data collection (narrow time interval) was required to readily capture changes in the dyad's activities. For example, taking a longer sample duration (e.g. one hour) would fail to capture the variation in the amount of talk by adults or children, if the child was napping for part of the hour, then waking and interacting with a caregiver for the remainder of the hour.

Activity-time log information and notes about each participant's recording on the DAD were reviewed. Mothers reported if their child was not feeling well or if the recording was not a typical example of the mother-child talk time on the DAD. LENA data on recording days were excluded if they were not representative of the participant's typical day. For example, LENA data was not analysed when a mother had reported that the dyad did not have much time together on a recording day as they were moving to a new house. Additionally, LENA estimates during DAD nap and sleep times were eliminated from the dataset. Data points where AWC and CTC were zero within a 5-minute interval were removed as a means to manage various times when for example, the child was asleep, mothers were out of recording range (i.e. mother and child were in different rooms), or when mothers were involved in a separate activity (e.g. working from home) while being in the vicinity of their child. The reasons for all 5-minute intervals with silence were not always known as the start and end times for activities on the DAD log were not reliably reported by parents and only brief descriptions of activities which had taken place over the course of the day were provided in 2-hourly time frames. Excluding 5-minute time intervals with zero counts was an approach to ensure that the average frequency of talk was consistently measured across the dyads in this sample.

4.11.1 Data Analysis

Data analysis was conducted using Minitab Statistical Software Version 17 (2010). The first aim of Study 1 was to explore whether there were relationships between family, maternal, audiological (hearing status) and child factors, and the mean amount of talk by adults and verbal interactions recorded in the naturalistic home language environments. Using baseline adult word and conversational turn counts in 5-minute intervals (N=1314), a 2-sample *t*-test was completed to investigate whether the mean amount of talk by adults, children and adult-child verbal interactions in 5-minutes differed for the Hh group (n=861) as compared to the Hd group (n=453). Analyses using a correlation matrix was completed to investigate the strength and direction of relationships between mean baseline LENA counts and the participants' socio-demographic variables, maternal characteristics and child factors.

The second aim was to describe changes in adult word count and adult-child conversational turn count after mothers had received feedback based on LENA generated auditory-language estimates and, after they had used the Daily Vroom App. A repeated-measures, within-subjects approach was used for group comparisons. Analysis of variance testing was used to examine the effect on adult word count and conversational turns after providing LENA Feedback to mothers, and with the use of the Daily Vroom App, in the group of 10 dyads, and then for Hh and Hd subgroups. A series of one-way ANOVAs was conducted with the study conditions as the factor and changes in adult word and conversational turn counts as response variables.

4.11.1.1 Single-subject analysis

A single-subject case approach was also used for the four dyads in the Hd group, where individual-level changes were described. Weekly mean LENA language count estimates collected continuously during baseline and in the intervention phase for each of the four dyads were represented graphically for visual inspection. Visualisation of graphs is often regarded as a method characteristic of single-subject research, which allows for better observation of variability and distribution of outcome data, which could in turn, facilitate interpretation (Cohen, Feinstein, Masuda, & Vowles, 2014). Individual value plots displaying AWC and CTC in 5-minute intervals and interval plots showing the mean percentage changes in AWC and CTC from baseline were graphed in the actual week order of study conditions for each of the four dyads. Each case served as its own control, allowing for descriptive comparison of data before and during an intervention. The data were also interpreted with regard to the dyads' end of trial responses as well as family, maternal and child factors.

5 Study 1: Intervention Trial Results

This chapter reports on findings from the prospective intervention trial (Study 1). To address the first aim of Study 1, associations between family, maternal, and child factors were explored in relation to the mean amount of talk by adults, and adult-child verbal interactions recorded by the LENA system in the participants' naturalistic home language environments (sections 5.1 and 5.2). Additionally, baseline measurements of the mean amount of adult words, adult-child conversational turns and child vocalisations between the Hh and Hd group were compared.

Using LENA as the outcome measure tool, 5.3 and 5.4 addressed the second aim of Study 1 by exploring the participants' mean adult word and adult-child conversational turn counts recorded in 5-minute intervals at baseline, and over the duration of the intervention trial. Group comparisons of percentage changes from baseline across the three study conditions (LO, LF, LFA) were analysed and reported. Descriptive findings were presented where appropriate, as the range of inferential statistics performed to address the primary research questions was limited by Study 1's relatively small sample size.

The last section of this chapter focused on single-subject case descriptions of the four participants in the Hd group. A summary of key family, maternal and child factors defined in Chapter 4 (Study 1 Methodology) were described, each dyad's perspective on using the LENA and/or DVA at the end of the study and the variability of adult word and conversational turn counts over the trial were documented for each of the four cases.

5.1 Baseline comparisons of mean amount of talk by adults, adult-child conversational turns and child vocalisations

The first set of analyses considered whether the quantity of talk by adults, adult-child conversational turns and child vocalisations were comparable across both hearing mother-child dyads in the Hh group (n=6), and hearing mothers with their children with bilateral, prelingual hearing loss (Hd group; n=4). Using LENA data collected from the 10 participants' baseline recordings, 1314 LENA-generated data points of AWC, CTC and CVC were exported in 5-minute intervals. Descriptive statistics outlining baseline language counts for both Hh and Hd groups are provided in Table 6.

Table 6: Descriptive statistics for adult word, conversational turn and child vocalisation counts recorded in 5-minute intervals at baseline

Group	Number of observations (5 min data points)	Adult Word Count			Conversational Turn Count			Child Vocalisations		
		Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Hh	861	147.6	155.5	1- 868	5.8	6.4	1- 48	20.7	17.3	1- 35.2
Hd	453	142.9	139.7	1- 771	5.7	5.7	1- 38	21.1	17.5	1- 31.5

Given that a greater number of baseline observations were recorded for the Hh group (861 data points) compared to 453 data points for the Hd group, the assumption of homogeneity of variance was tested. A Levene's Test of Equality of Variances found that the assumption of homogeneity was met, F=0.08, p= 0.78; therefore, a 2-sample t-test based on equal group variances was carried out to compare baseline language counts. No significant differences in AWC; (t(1008)=0.56, p=0.58), CTC (t(996)=0.43, p=0.66) and CVC (t(908)=0.46, p=0.65) were found between the Hh and Hd groups at baseline. In this study, the mean amount of words spoken by adults at baseline was 147.6 words/5-minutes for the Hh group and 142.9 words/5-minutes for the Hd group. The mean amount of adult-child conversational turns was 5.8 turns/5-minutes for the Hh group and 5.7 words/5-minutes. A mean of 20.7 child vocalisations/5-minutes was recorded for the Hh group and 21.1 child vocalisations/5-minutes was found for the Hd group. Findings indicated that baseline AWC, CTC, CVC for both groups in this study were comparable irrespective of the child's hearing status.

5.2 Relationships between participant characteristics and LENA counts

Correlation analyses were conducted on all participant demographics characteristics, potential moderating variables (as outlined in the methodology) and participant language counts to determine significant associations between factors. With alpha value set at .05, a Spearman's rank correlation coefficient matrix was constructed to measure monotonic relationships between: (i) family factors; (ii) maternal characteristics; (iii) child attributes; (iv) AWC and CTC, CVC at baseline and; (v) percentage changes in AWC and CTC after LENA Feedback was provided for the 10 mother-child participants in this study. Significant correlation findings are reported in Table 7 and Table 8 below.

Table 7: Matrix of significant Spearman correlations between family, maternal, child characteristics and language counts.
N.B. Significant correlations are in bold. Spearman correlation (r_s) value (above) and p-value (below) are provided for each correlation.

	SEIFA Decile	**SEIFA Rank**	**Government Concession Entitlement**	**Maternal Occupational Skill Level**	**Maternal Education**	**Maternal IQ Composite (KBIT-2)**	**Maternal Non-Verbal ability (KBIT-2)**	**Maternal Verbal ability (KBIT-2)**	**Maternal Receptive Vocabulary (PPVT-4)**	**Child (LDS) Standard Score**	**Child PEACH %**	**Mean Baseline CVC/5mins**
	0.994											
SEIFA Rank	**0.000**											
	-0.537	-0.495										
Government Concession Entitlement	0.110	0.145										
	-0.638	**-0.644**	0.285									
Maternal Occupational Skill Level	**0.047**	**0.044**	0.425									
	0.648	**0.641**	-0.443	**-0.766**								
Maternal Education	**0.043**	**0.046**	0.200	**0.010**								
	0.873	**0.873**	**-0.874**	-0.596	**0.778**							
Maternal IQ Composite (KBIT-2)	**0.010**	**0.010**	**0.010**	0.157	**0.039**							
	0.664	0.633	**-0.746**	-0.504	0.296	0.691						
Maternal Non-Verbal ability (KBIT-2)	0.051	0.068	**0.021**	0.167	0.439	0.086						
	0.739	0.739	-0.722	-0.512	**0.772**	**0.901**	0.396					
Maternal Verbal ability (KBIT-2)	0.058	0.058	0.067	0.240	**0.042**	**0.006**	0.379					
	0.655	0.661	-0.548	**-0.673**	0.517	**0.919**	**0.781**	0.679				
Maternal Receptive Vocabulary (PPVT-4)	0.055	0.053	0.127	**0.047**	0.154	**0.003**	**0.022**	0.094				
	0.239	0.182	**-0.722**	-0.201	0.315	0.505	0.477	0.536	0.267			
Child (LDS) Standard Score	0.507	0.614	**0.018**	0.535	0.376	0.248	0.194	0.215	0.488			
	0.502	0.498	**-0.803**	-0.310	0.443	0.727	0.53	0.721	0.647	**0.732**		
Child PEACH %	0.140	0.143	**0.005**	0.383	0.2	0.064	0.142	0.068	0.06	**0.016**		
	0.453	0.438	**-0.646**	-0.272	0.103	0.667	**0.681**	0.429	0.533	0.115	0.47	
Mean Baseline CVC/5mins	0.189	0.206	**0.044**	0.446	0.778	0.102	**0.043**	0.337	0.139	0.751	0.171	
	0.068	-0.602	0.190	0.616	**-0.854**	-0.721	-0.179	-0.75	-0.417	0.042	-0.177	0.006
AWC % Change Post LF	0.071	0.066	0.599	0.058	**0.002**	0.068	0.645	0.052	0.265	0.907	0.625	0.987

5.2.1 Family Factors

There were significant correlations between family relative socio-economic advantage (SEIFA decile and rank), maternal occupational skill level, highest level of maternal education attainment and maternal intelligence (IQ Composite) measured using standard scores on the KBIT-2. In this study, higher family SEIFA decile and rank (r_s= -0.64, p<0.05) were significantly correlated with mothers who had more specialised and higher occupational skill levels. The category of 5 denotes more generalist skills; the ANZSCO represents a descending order of skill levels to a category of 1 to reflect roles which require more specialised, occupational skills. There were statistically significant positive associations between SEIFA decile and rank, and maternal education (r_s= 0.64, p<0.05) and maternal intelligence (r_s= 0.87, p<0.05).

Family entitlement to government concessions was also found to be significantly, negatively correlated with maternal intelligence (r_s=-0.87, p<0.05), maternal non-verbal ability on the KBIT-2 (r_s=-0.75, p<0.05) child's language performance on the parent-reported LDS measure (r_s=-0.72, p<0.05), parents' evaluation of the child's auditory performance on the PEACH (r_s=-0.8, p<0.05) and the mean number of child vocalisations at baseline (r_s=-0.65, p<0.05).

5.2.2 Maternal Characteristics

Significant correlations between multiple maternal characteristics measured in this study suggested inter-relationships between maternal cognitive and language abilities, and educational and occupational outcomes. There were statistically significant positive correlations between maternal education and maternal intelligence (IQ Composite standard score on the KBIT-2; r_s=0.78, p<0.05), and maternal education and verbal ability on the KBIT-2 (r_s=0.77, p<0.05).

In this study, there were also statistically significant relationships between maternal receptive vocabulary skills and both maternal intelligence (r_s=-0.92, p<0.01) and maternal non-verbal ability (r_s=-0.78, p<0.05) as measured on the KBIT-2. Maternal receptive vocabulary skills on the PPVT-4 was also found to be significantly associated with more specialised maternal occupational skill levels (r_s=-0.67, p<0.05). More specialised maternal occupational skill levels were significantly correlated with higher maternal receptive vocabulary standard scores on the PPVT-4 (r_s=-0.67, p<0.05) and higher levels of maternal education (r_s=-0.77, p<0.05).

A strong inverse correlation was found between maternal education and percentage change in adult word count from baseline (a key outcome measure for this study) after mothers had received LENA feedback (r_s=-0.85, p<0.01), which was statistically significant. This finding suggested that following LENA feedback, more mothers who had either a diploma/vocational certificate or undergraduate degree were observed to demonstrate a mean percentage increase in AWC/5-minutes from baseline AWC, whereas more mothers who had attained a postgraduate degree did not demonstrate in mean increase in AWC after feedback. Further regression analyses were limited by Study 1's sample size of 10 mothers.

The actual mean AWC/ 5-minutes at baseline and mean AWC/5-minutes after receiving LENA feedback are illustrated for each of the 10 dyads in the bar graph below (Figure 4). Dyads were grouped into three categories based on the highest level of maternal education attained. The first group of mothers (n=4) represented in blue had attained either a diploma/vocational certificate, followed by the second group of mothers (n=3) shown in lilac who had an undergraduate degree and the third group of mothers (n=3) represented in dark purple who had a postgraduate degree. Dyads in the first two groups (n=7) demonstrated a mean increase in AWC/5-minutes post-feedback compared to baseline, whereas only one dyad in the third group was observed to have shown an increase in mean AWC/5-minutes after receiving feedback. Of the two dyads in the third group who did not demonstrate an increase in AWC/5-minutes post-feedback, one child had normal hearing and the other child had a hearing loss.

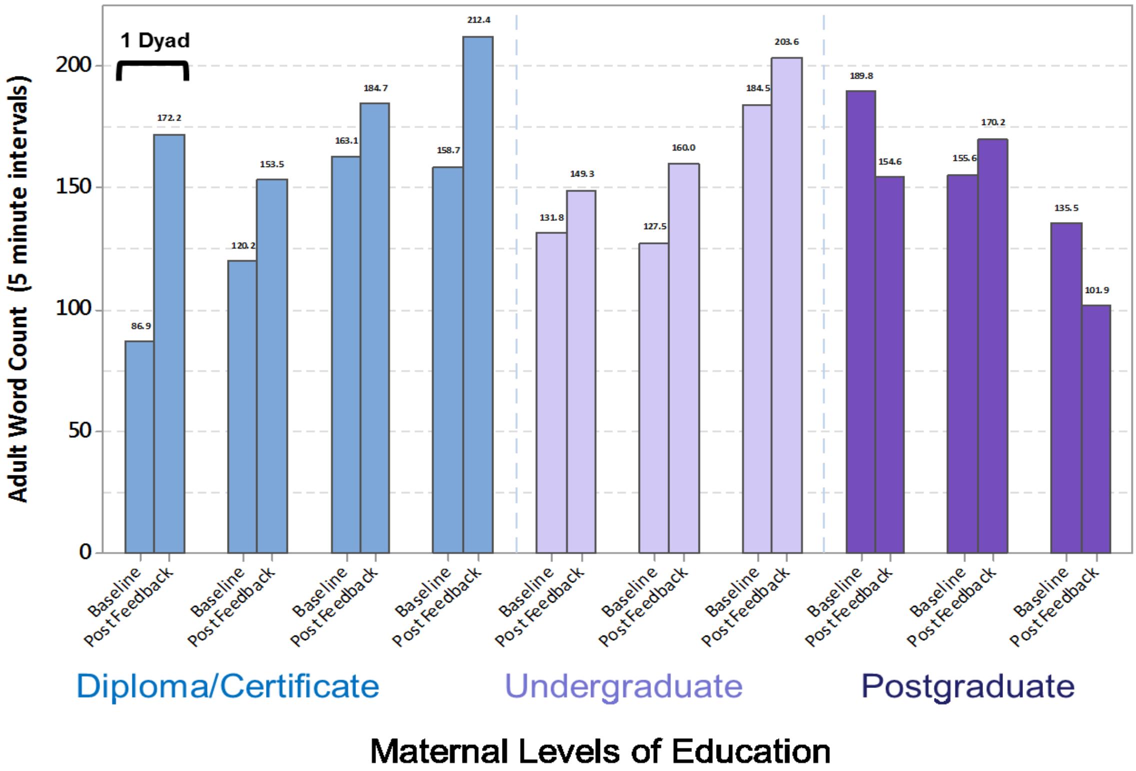


Figure 4: Mean AWC/ 5-minute intervals at baseline and post-LENA feedback for each of the 10 mother-child dyads

5.2.3 Child Attributes

Child's language performance on the parent-reported LDS measure completed at the beginning of the study was significantly, positively correlated with parents' evaluation of the child's auditory performance on the PEACH (r_s=0.73, p<0.05). A positive association between mean baseline child vocalisation count (CVC) and maternal non-verbal ability measured on the KBIT-2 (r_s= 0.78, p<0.05), was found to be statistically significant.

5.2.4 Relationships between Test Measures for Child Participants

A statistically significant, positive association was found between the children's hearing levels (i.e. typical-hearing or bilateral SNHL) and language scores on the LDS (r_s =0.71, p<0.05). Significant spearman correlations were also found between the test measures completed by the child. The correlation matrix (Table 8) illustrates associations between the following measures of child abilities: receptive, expressive and total age equivalent scores on the Preschool Language Scale (PLS-5); LENA Developmental Snapshot (LDS) language score; LDS Developmental age; Bayley III Cognitive score; and percentage score on the PEACH.

Table 8: Matrix of significant Spearman correlations between child measures.
Significant correlations are in bold. Spearman correlation (r_s) value (above) and p-value (below) are provided for each correlation.

	Child's Hearing	**PLS Receptive Language Age Equivalence**	**PLS Expressive Language Age Equivalence**	**PLS Expressive Language Age Equivalence**	**LDS Score**	**LDS Developmental Age**	**Bayley III Cognitive Raw Score**
PLS Receptive Language Age Equivalence	-0.365						
	0.334						
PLS Expressive Language Age Equivalence	-0.464	**0.881**					
	0.208	**0.002**					
PLS Total Language Age Equivalence	-0.365	**0.983**	**0.932**				
	0.334	**0.001**	**0.001**				
LDS Score	**0.711**	-0.3	-0.322	-0.283			
	0.021	0.433	0.398	0.46			
LDS Developmental Age	0.216	**0.797**	**0.741**	0.797	0.35		
	0.549	**0.01**	**0.022**	0.01	0.322		
Bayley III Cognitive Raw Score	0	**0.964**	**0.929**	0.964	0.167	**0.92**	
	1	**0.001**	**0.003**	**0.001**	0.693	**0.001**	
PEACH %	0.286	0.109	0.034	0.134	**0.732**	0.549	0.422
	0.423	0.781	0.931	0.731	**0.016**	0.1	0.298

5.3 Changes in Adult Word and Conversational Turns Counts from Baseline

In regards to the second aim of Study 1, statistically significant changes in AWC and CTC from baseline were observed across the three study conditions (LO, LF, LFA). Using LENA-generated counts from 5-minute long samples (6871 observations), descriptive statistics of actual mean adult word count and conversational turns in 5- minute intervals for each of the 10 mother-child dyads at baseline, and across the three study conditions (LO, LF, LFA) are displayed in Table 9 below.

Table 9: Descriptive statistics for mean AWC and CTC in 5-minute intervals for 10 dyads across baseline and study conditions.

Mother-Child Dyad	**Counts (5-minute intervals)**	**Baseline**			**LENA Only (LO)**			**LENA Feedback (LF)**			**LENA Feedback and Use of App (LFA)**		
		Mean	**SD**	**Range**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**
1	AWC	189.8	195.1	3- 868	135.2	144.8	3- 713	154.6	115.6	4 -596	128.8	117.4	2- 694
	CTC	4.1	2.8	1- 13	3.5	2.963	1- 17	5.3	4.468	1- 21	5.2	4.210	1-19
2	AWC	131.8	90.1	5- 508	138.9	112.9	4- 638	149.3	117.7	2- 654	177.2	126.6	3- 736
	CTC	3.5	2.9	1- 17	3.9	3.033	1- 20	3.4	3.1	1- 21	4.0	3.1	1- 20
3	AWC	86.9	85.4	1- 476	103.5	110.3	3- 584	172.2	142.3	4- 785	142.1	134.5	5- 740
	CTC	3.7	3.0	1- 18	3.5	3.14	1- 17	5.9	5.4	1- 34	3.8	3.2	1- 19
4	AWC	127.5	118.3	2- 684	114.7	127.44	1- 767	160.0	133.0	4- 734	165.3	121.2	1- 660
	CTC	4.2	3.7	1- 20	3.5	3.358	1- 19	5.4	4.1	1- 19	5.8	4.6	1- 22
5	AWC	155.6	99.2	11- 599	149.5	133.61	4- 646	170.2	128.5	3- 658	141.1	91.1	5- 434
	CTC	6.9	4.8	1- 23	7.2	5.755	1- 38	8.1	6.4	1- 37	6.6	4.9	1- 24
6	AWC	135.5	124.7	8-470	104.9	117.39	1-676	101.9	103.0	4- 666	125.7	129.0	1- 771
	CTC	5.1	4.2	1- 19	4.1	3.613	1- 25	5.4	4.1	1- 28	5.7	5.2	1- 33
7	AWC	120.2	139.5	4- 771	90.3	147.2	2- 1015	153.5	182.6	7- 767	45.9	48.2	3- 221
	CTC	4.4	3.4	1- 24	3.4	2.6	1- 12	4.3	3.8	1- 15	2.2	1.8	1- 8
8	AWC	163.1	132.7	3- 606	156.1	125.5	7- 629	184.7	146.3	1- 658	219.1	180.7	12- 826
	CTC	3.0	3.6	1- 22	3.3	2.56	1- 14	3.9	3.9	1- 20	3.3	3.4	1- 18
9	AWC	158.7	144.5	1- 664	183.9	160	1- 764	212.4	170.6	2- 740	189.1	133.3	3- 597
	CTC	7.8	7.6	1- 38	8.7	6.035	1- 31	9.3	7.7	1- 38	9.1	7.4	1- 28
10	AWC	184.5	214.9	3- 855	217.1	246.7	2-981	203.6	206.6	1- 954	219.9	205.2	1- 941
	CTC	9.6	10.0	1- 48	9.5	8.216	1- 38	10.8	10.3	1- 44	10.5	9.0	1- 40

5.3.1 Adult Word Count

Changes from baseline for the mean amount of adult words were calculated across the three conditions for the 10 mother-child dyads. To enable group comparisons to be made, the difference from baseline to each condition for each dyad's mean adult words count was expressed as a percentage and plotted on the interval plot across the study conditions below (Figure 5).

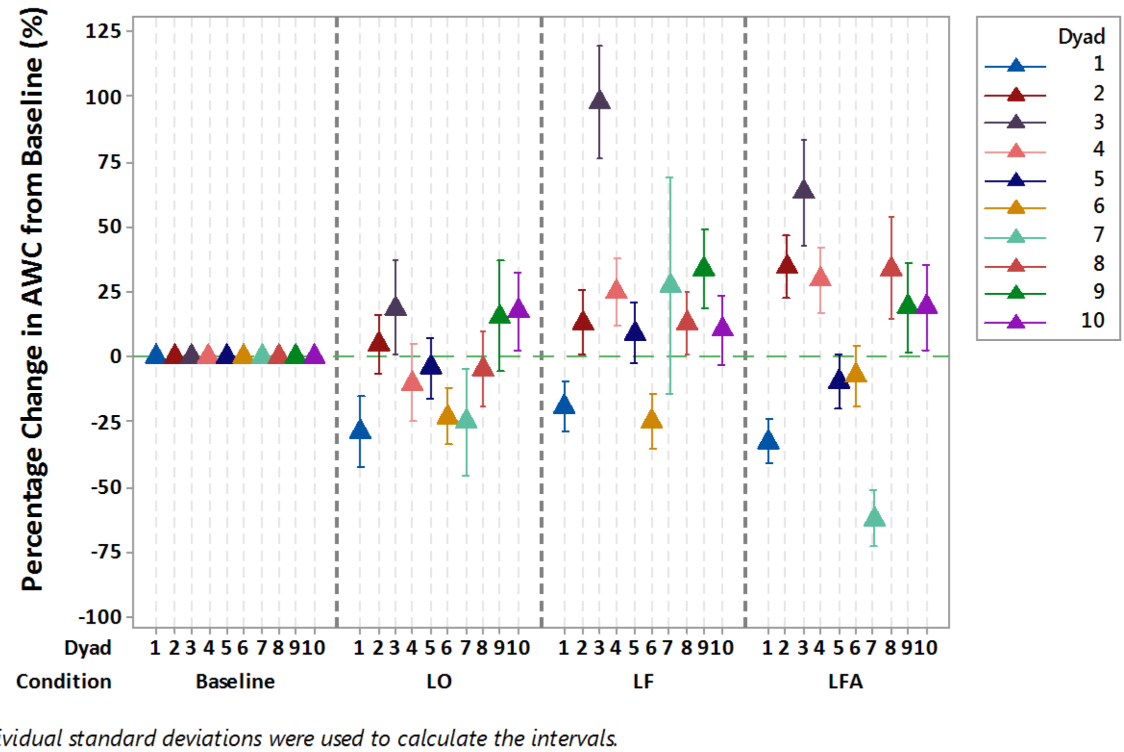


Figure 5: Percentage change in mean AWC from baseline (5-minute intervals) for each dyad across conditions

5.3.2 Group findings (N=10) for mean percentage changes observed in Adult Word Count from baseline

Mean percentage changes from baseline for the group data (10 dyads) were compared across conditions to examine intervention effects on adult words spoken in 5-minute intervals. Based on 5557 5-minute observations from the group data, Figure 6 showed a higher group mean percentage change in AWC for the LF and LFA intervention conditions as compared to baseline and the LO condition. Adjustments were made for the multiple comparisons across the four conditions. With an alpha value set at 0.05, the Bonferroni-corrected significance level was $p<0.0125$. ANOVA testing indicated a significant effect at the $p<0.001$ level for changes in the mean amount of adult words across intervention conditions [$F(3, 5554) = 21.22$, $p<0.001$]. Post-hoc comparisons using the Tukey HSD test indicated that the mean AWC percentage changes occurred between baseline and the LENA Feedback condition (*Mean* +19.86%; *SD* 111.1) and also between baseline and the LENA Feedback and App condition (*Mean* +14.85%; *SD* 105.43). Mean AWC percentage changes in both experimental conditions were significantly different to the LENA recording only (LO) condition (*Mean* -2%; *SD* 105.7). The group result for the 10 dyads suggested that providing LENA Feedback and mothers' use of the app had positive effects on the amount of adult words spoken in 5-minute intervals.

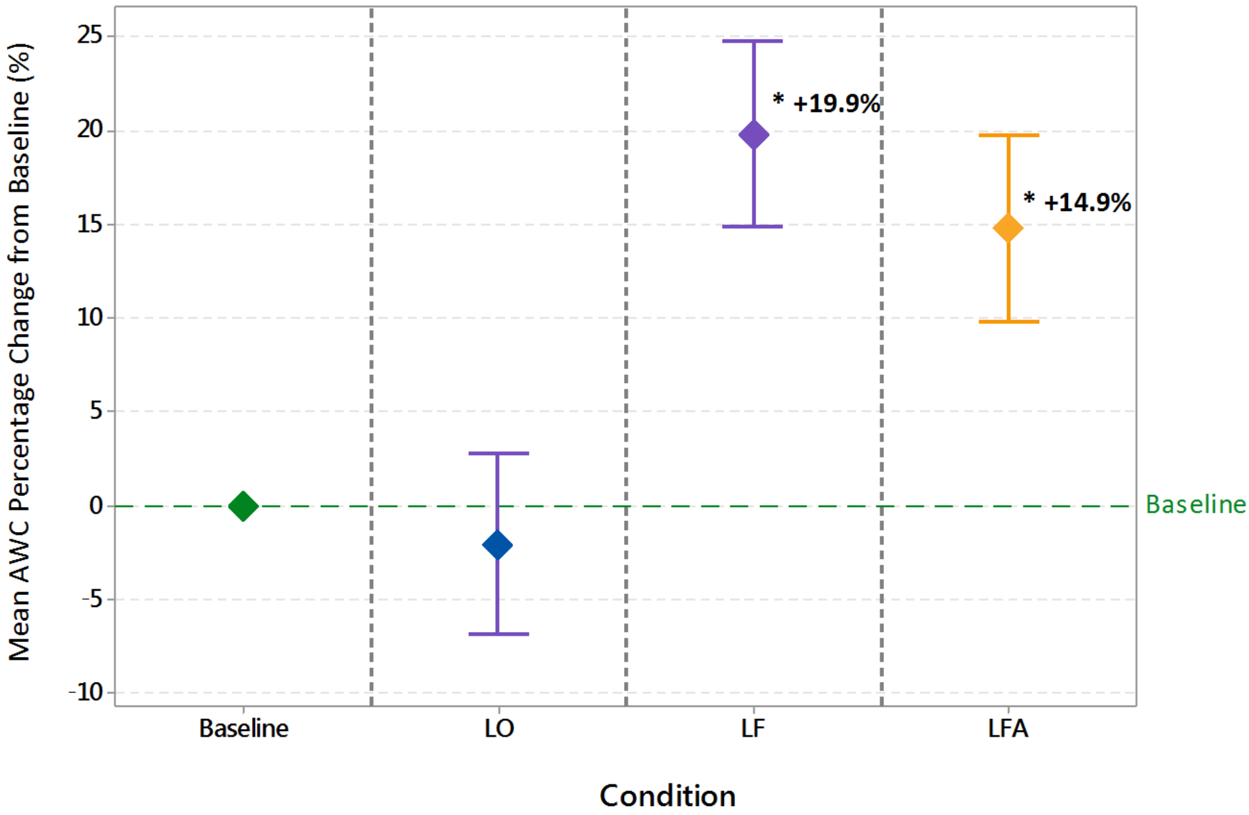


Figure 6: Group mean percentage change of Mean Adult Word Count from baseline (5-minute intervals) across conditions for 10 mother-child dyads

5.3.3 Hh Group findings (n=6) for mean percentage changes observed in Adult Word Count from baseline

Using a subset of 3779 5-minute observations for the Hh group, Figure 7 showed a higher group mean percentage change in AWC for the LF and LFA intervention conditions as compared to baseline and the LO condition. A one-way analysis of variance testing revealed a statistically significant difference between the group means of percentage change in AWC from baseline across the three study conditions for the 6 Hh dyads [$F(2,3777)=13.45$, $p<0.001$]. Post-hoc testing using Tukey HSD indicated that the mean percentage AWC change from baseline was significantly higher in the LF (*Mean* +25.32%; *SD* 115.5) condition and LFA (*Mean* +20.62%; *SD* 108.43) condition compared to the LO (*Mean* +3.57%; *SD* 108.76) condition. Similar to the overall sample of 10, the group result for the six hearing mothers and their hearing children reflected an increase in mean AWC from baseline in both intervention conditions compared to the LO condition, which were statistically significant.

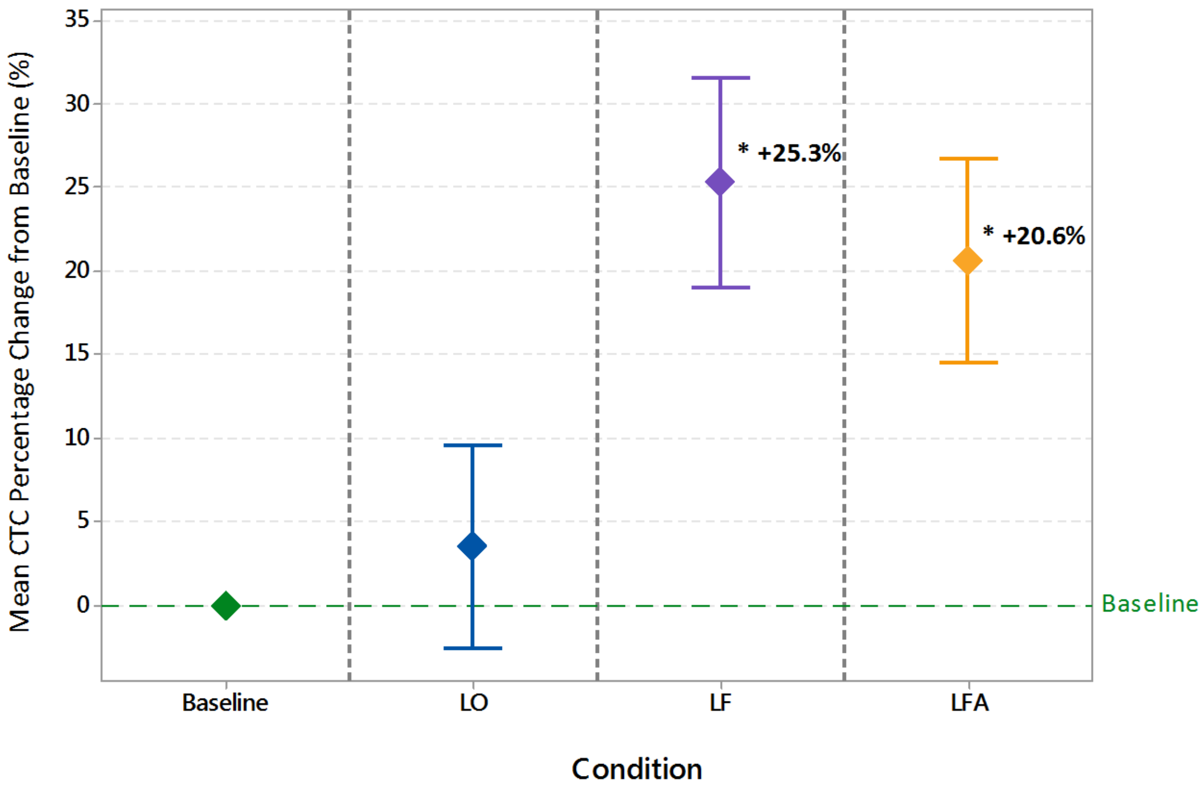


Figure 7: Group mean percentage change of Mean Adult Word Count from baseline (5-minute intervals) across conditions for the 6 hearing mother-child dyads

5.3.4 Hd Group findings (n=4) for mean percentage changes observed in Adult Word Count from baseline

Using a subset of 1776 5-minute observations for the Hd group, Figure 8 showed a higher group mean percentage change in AWC for the LF and LFA intervention conditions as compared to baseline and the LO condition. A one-way ANOVA determined a statistically significant difference between the mean percentage change from baseline recorded across the three study conditions [$F(2,1774)= 8.54$, $p<0.001$]. Post-hoc testing using Tukey HSD indicated that the mean percentage

AWC change from baseline were significantly different in the LF (*Mean* +8.91%; *SD* 100.62) and LFA (*Mean +1.78%; SD 97.15*) conditions compared to the LO condition (*Mean* -13.93%; *SD* 97.87*).* For the four hearing mothers and their children with bilateral SNHL, there were statistically significant increases in AWC in both intervention conditions.

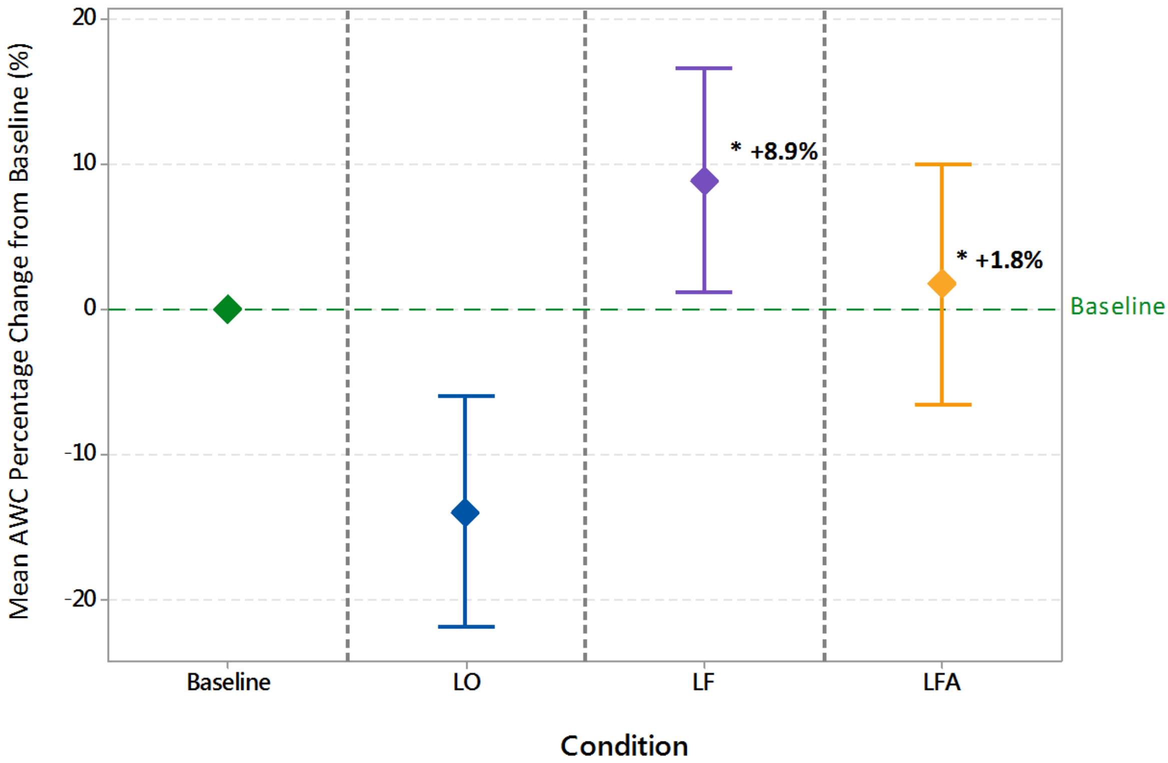
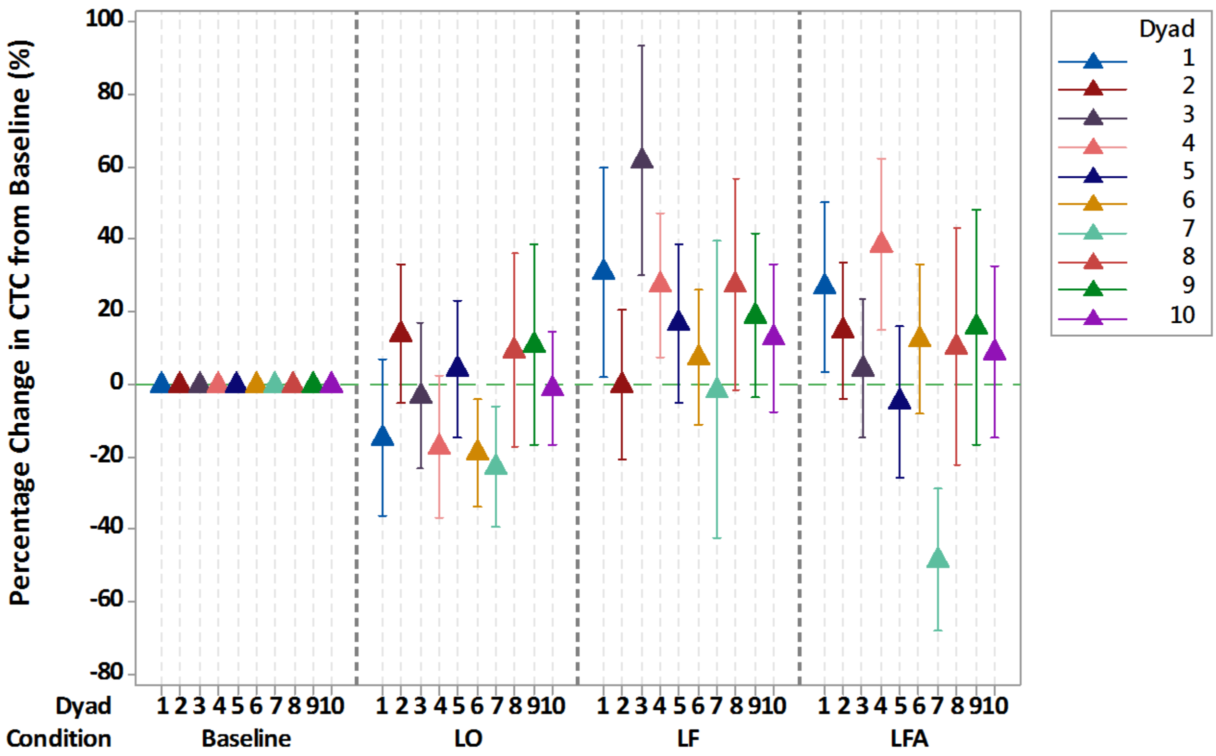


Figure 8: Group mean percentage change of Mean Adult Word Count from baseline (5-minute intervals) across conditions for 4 hearing mother and their children with bilateral SNHL

5.4 Conversational Turn Count

Changes in mean conversational turn from the baseline for the 10 respective dyads were calculated in 5-minute intervals across the study conditions. To enable group comparisons to be made, the difference in counts across conditions compared to each dyad's mean baseline CTC, was expressed as a percentage change and plotted on the interval plot below (Figure 9).



Individual standard deviations were used to calculate the intervals.

Figure 9: Percentage change of Conversational Turn Count from baseline (5-minute intervals) for each individual dyad across conditions

5.4.1 Group findings (N=10) for mean percentage changes observed in Conversational Turn Count from baseline

A one-way ANOVA was conducted to investigate whether the changes in the amount of adult-child conversational turns recorded at baseline were different after dyads were exposed to the intervention conditions (LENA Feedback and LENA feedback plus use of the App).

Using 5556 5-minute observations, Figure 10 showed positive increases from baseline in CTC in the two intervention conditions (LF and LFA) compared to the LO condition. A significant effect of the intervention(s) on the mean amount of adult-child conversational turns at the p<0.001 level was found across the conditions [$F(4, 5554) = 36.39$, p<0.001] for the 10 dyads. Post-hoc comparisons using the Tukey HSD test indicated that the mean changes in amount of adult-child conversational turns recorded for the LENA Feedback condition (*Mean* +22.14%; *SD* 108.34), the LENA Feedback and App condition (*Mean* +13.57%; *SD* 97.44) were significantly different from the LO condition (*Mean* -4.18%; *SD* 81.03). This group result suggested that providing LENA Feedback and mothers' use of the app affected the amount of adult-child conversational turns.

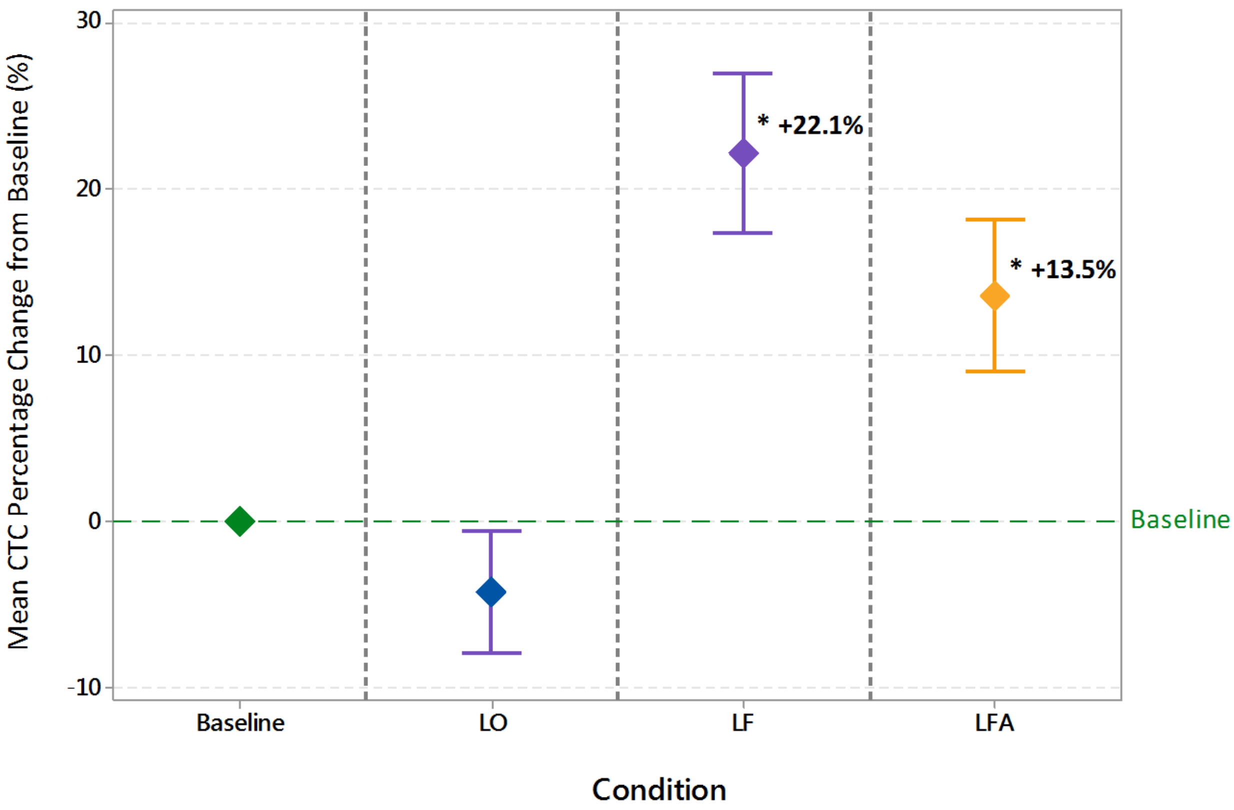


Figure 10: Group mean percentage change of Mean Conversational Turn Count from baseline (5-minute intervals) across conditions for 10 mother-child dyads

5.4.2 Hh Group findings (n=6) for mean percentage changes observed in Conversational Turn Count from baseline

Using a subset of 3779 5-minute observations, Figure 11 showed increases from baseline in CTC in the intervention conditions (LF and LFA) compared to the LO condition. A one-way analysis of variance indicated statistically significant differences between the group means of percentage change in CTC from baseline across the three study conditions for the 6 Hh dyads [$F(2,3777)= 24.36$, $p<0.001$]. Post-hoc testing using Tukey HSD indicated that the mean percentage CTC change from baseline was significantly greater when comparing both the LF (*Mean* +24.91%; *SD* 110.51) and LFA (*Mean* +16.7%; *SD* 95.84) conditions against the LO *(Mean -1.5%; SD* 84.15) condition. The group result for the six hearing mothers and their hearing children indicated statistically significant changes from mean baseline CTC and LO conditions to increased CTC in both intervention conditions.

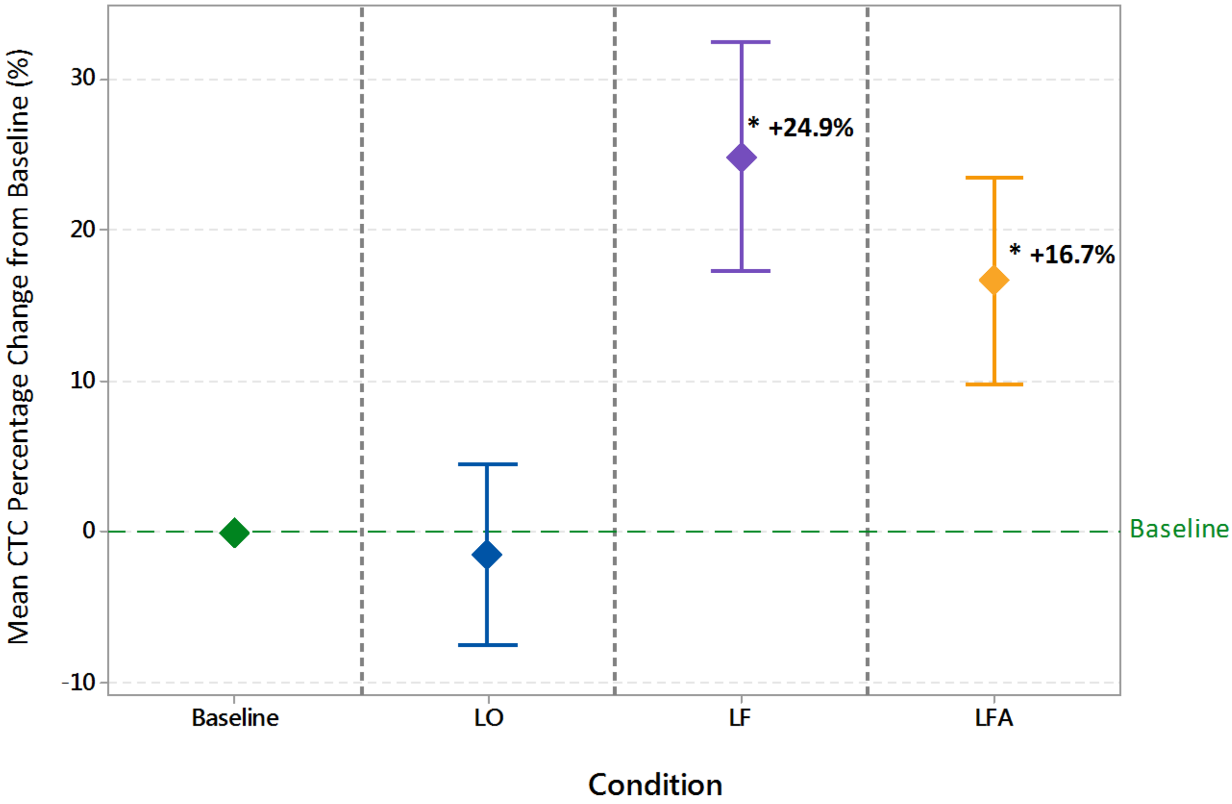


Figure 11: Group mean percentage change of Mean Conversational Turn Count from baseline (5-minute intervals) across conditions for the 6 hearing mother-child dyads

5.4.3 Hd Group findings (n=4) for mean percentage changes observed in Conversational Turn Count from baseline

Using a subset of 1776 5-minute observations of conversational turns for dyads in the Hd group, Figure 12 showed increases from baseline in CTC in the intervention conditions (LF and LFA) compared to the LO condition. A one-way ANOVA determined a statistically significant difference between the mean percentage change from baseline recorded across the three study conditions [$F(2, 1774) = 12.43$, $p<0.001$]. Post-hoc testing using Tukey HSD indicated that the mean percentage CTC change from baseline was significantly greater when comparing both the LF (*Mean* +16.57%; *SD* 103.71) and LFA *(Mean* +6.48%; *SD* 100.69) conditions against the LO condition *(Mean* -9.93%; *SD* 73.64).

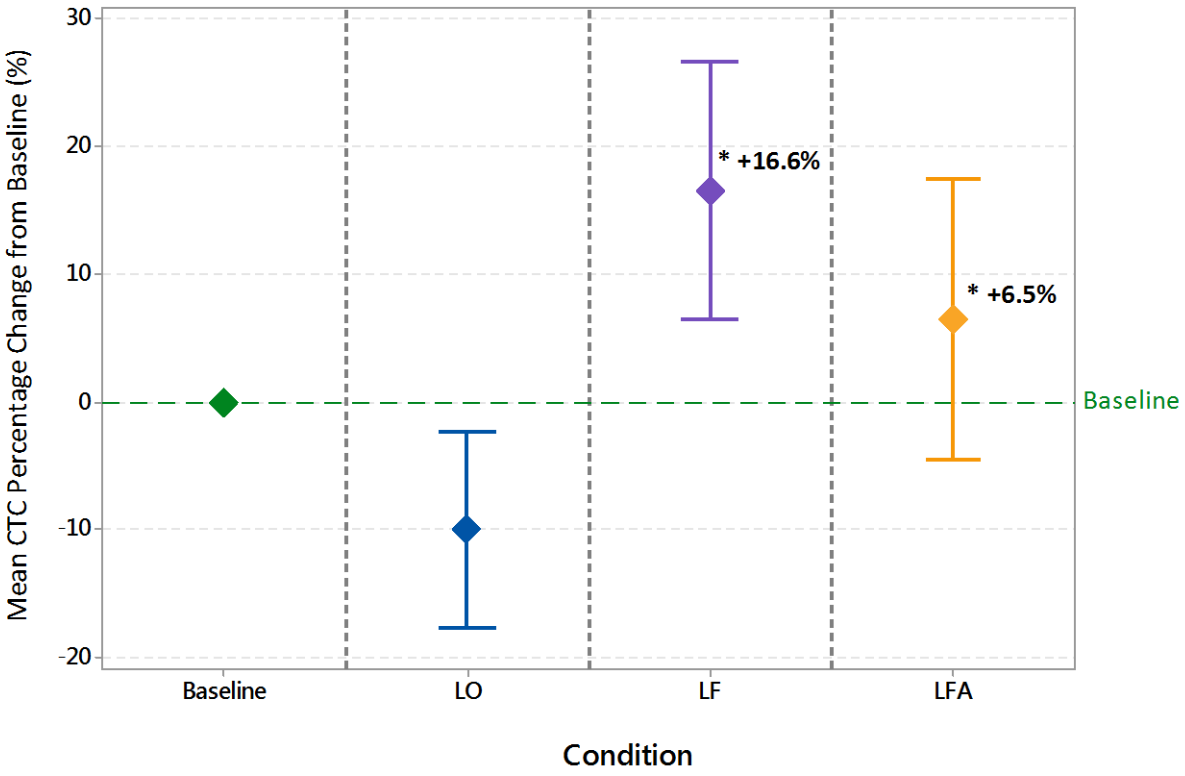


Figure 12: Group mean percentage change of Mean Conversational Turn Count from baseline (5-minute intervals) across conditions for the 4 hearing mothers and their children with bilateral SNHL

5.5 Single-subject analysis

Findings from each of the four-individual mother-child dyads in the Hd group are reported in this section with a focus on the dyad's recorded AWC and CTC across the study conditions. Statistical analyses conducted on group data (reported in the previous section) has the potential to obscure individual variability among participants, which may surface with a case study approach. Single-subject research provides the ability to document trend changes in the dependent variable(s) using visual analysis and comparisons of variations in observations across experimental conditions (Horner et al., 2005). Each of the four participants' observations of actual AWC and CTC in 5-minute intervals were graphed on individual value plots according to the actual study sequence. Weekly measures of mean AWC and CTC were displayed as a black mean symbol with a mean connect line between the study conditions on the value plots. Comparisons of mean percentage change in AWC and CTC (in 5-minute intervals) from baseline were presented using interval plots for each participant. A green reference line denoted a percentage change of zero at baseline which facilitated the display of responses to intervention as either a mean increase or decrease in AWC and CTC compared to baseline across the study conditions (LO, LF, LFA).

Inferential statistics have not been applied to the single-subject cases and caution is advised with regard to extrapolating these findings to the wider population of mothers and their children with sensorineural hearing loss. This approach examined individual differences and similarities in participant responses to the interventions, with reference to family, maternal and child factors. Observations for each Hd dyad were supplemented with each mother's end of study comments and preference for using the LENA and/or DVA again in the future in response to two end of trial survey questions as specified in Section 4.6.1.8. The names* of each mother and child in the cases have been changed; each dyad was assigned a pseudonym to preserve their anonymity.

5.5.1 Mother-Child Dyad A: Sally and Harry*

Harry was the youngest infant in this study at six months of age when data collection commenced. His congenital, bilateral profound sensorineural hearing loss (best unaided three frequency pure tone average of 118 dB HL) of unknown aetiology was identified at birth and he was fitted with bilateral hearing aids at one month of age. Harry was reported to wear both hearing aids for almost all waking hours and was also undergoing pre-operative evaluations to assess his cochlear implant candidacy at the time of the study. The mother-child dyad had attended an EI program using an oral communication mode once a fortnight for hourly sessions since Harry was four months of age.

His mother, Sally, was 32 years of age when the study commenced. She had completed high school education, attained a vocational/ diploma certificate and was working in an administrative role prior to being on maternity leave. She reported spending an estimated 165 hours per week with Harry as his primary caregiver, with Harry's father (who also lived in the family home with Harry) as his secondary caregiver. Harry was the second-born child in the family and had an older brother who was 2.5 years older. English was the primary language spoken at home and their speech pathologist assigned the family a participation rating of 5 (Ideal).

Throughout the study, the dyad's typical LENA recording day began at 7 to 8 am with Harry's morning feed and breakfast. The dyad's routine as reported on the DAD generally consisted of a walk after breakfast, another late morning feed and playtime, followed by lunch, Harry's nap time (counts excluded from analysis), an afternoon feed, play time, dinner, bath time and another feed before bed.

After the baseline phase, this dyad's study protocol sequence was: three representative weekly recordings in the LENA Feedback (LF) condition; followed by two recordings in the LENA

Feedback and use of App (LFA) condition; and two recordings in the LO condition. Data from week 5 (LF condition) and week 9 (LFA condition) were not represented in the figures. Sally and Harry's actual AWC in 5-minute intervals were depicted on a weekly basis an individual value plot as seen in Figure 13. At baseline (week 1), Sally and Harry had a mean AWC of 163.1/ 5-minutes and a range of 3 to 606 adult words/ 5-minutes. Figure 14 showed the mean percentage change in AWC/ 5-minute interval from baseline across the study conditions in the respective study sequence completed by Sally and Harry (Dyad A). There was an increase in mean from baseline after the dyad were exposed to the LF condition (+13.25%), followed by the LFA condition (+34.32%). The percentage increase in mean AWC/ 5-minutes was highest after the dyad received LENA Feedback and used the DVA compared to the other study conditions. A percentage decrease in mean AWC/ 5-minutes was recorded for this dyad in the LO condition (-4.28%).

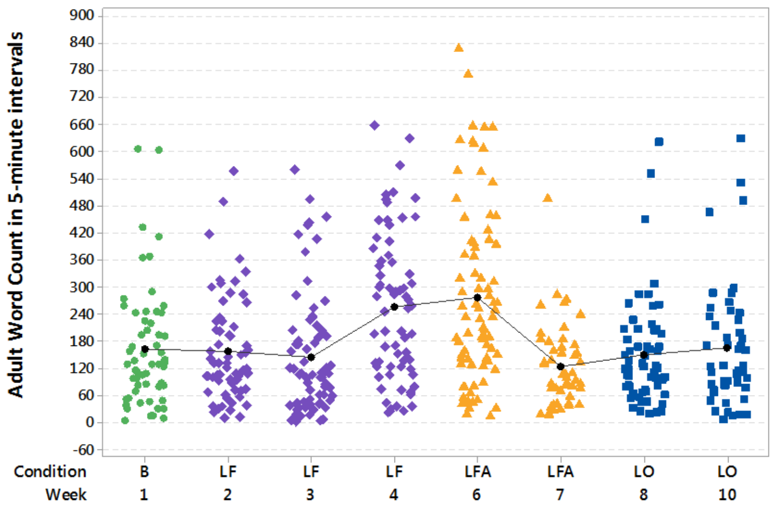


Figure 13: Individual value plot of weekly measures of AWC in 5-minute intervals across conditions for Dyad A

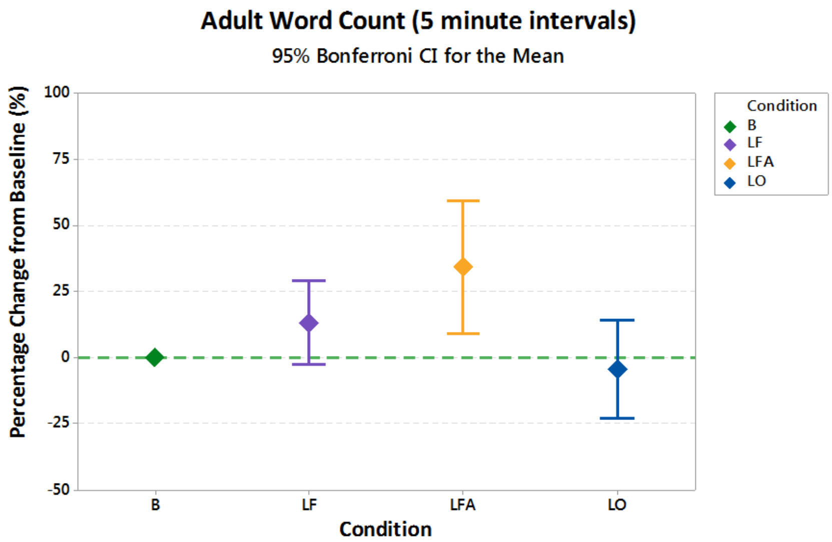


Figure 14: Mean percentage change in AWC in 5-minute intervals from baseline across study conditions for Dyad A

Sally and Harry's actual CTC in 5-minute intervals were depicted on a weekly basis an individual value plot as seen in Figure 15. At baseline (week 1), Sally and Harry had a mean CTC of 3/ 5-minutes and a recorded range of 1 to 22 conversational turns/ 5-minutes. Figure 16 showed the mean percentage change in CTC/ 5-minute interval from baseline across the study conditions for Sally and Harry (Dyad A). The highest increase in mean CTC from baseline was after the dyad had received LENA Feedback (+27.8%), compared to when the dyad received LENA Feedback and was using the mobile app (LFA condition; +10.35%). The mean percentage increase in CTC/ 5-minute in the LFA condition was similar to the mean percentage increase in the LO condition (+9.63%) from baseline.

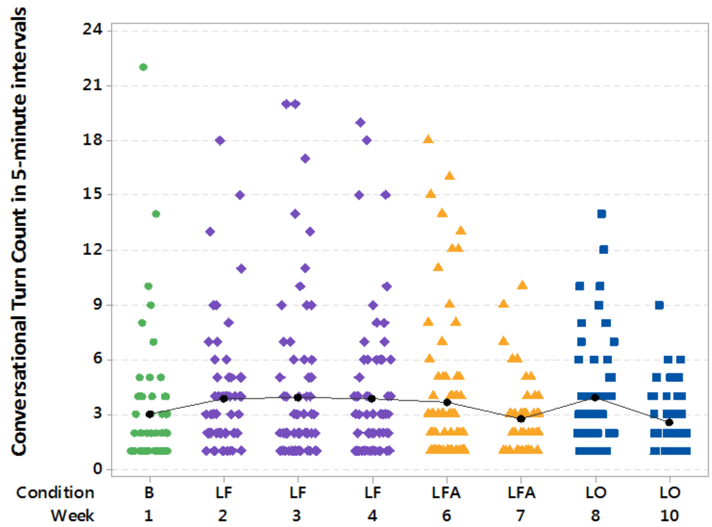


Figure 15: Individual value plot of weekly measures of CTC in 5-minute intervals across conditions for Dyad A.

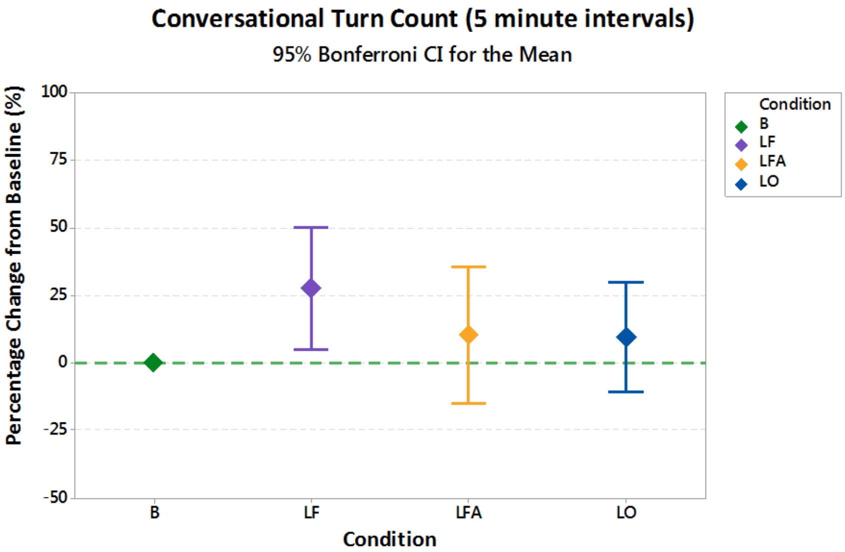


Figure 16: Mean percentage change in CTC in 5-minute intervals from baseline across study conditions for Dyad A.

In summary, Harry and Sally demonstrated higher mean percentage increases from baseline in both AWC/ 5-minutes and CTC/ 5-minutes in both intervention conditions (LF and LFA), compared to counts recorded in the LO condition. At the end of the study, Sally reported that she would be open to using both the LENA system and the Daily Vroom App again in the future and commented that, '*It has been really interesting to track Harry's vocalisations and our interactions.'*

Results suggested that this intervention study was well-suited to this dyad's profile which included the following characteristics: Sally's availability to be a full-time caregiver (165 hours/ week) to Harry while on maternity leave; the family's preference for using an oral communication approach only both at home and in their EI program; as well as the family's active participation (ideal family participating rating) in Harry's intervention. The observation was further supported by Sally's willingness to use both the LENA system and DVA again in the future. Dyad A's findings also highlighted the practical application of using LENA (with feedback) and mobile technology to facilitate a greater amount of talk by adults and adult-child conversational turns, in the context of a family with a 6-month old infant preparing to receive CI(s).

5.5.2 Mother-Child Dyad B: Lucy and Charlie*

Charlie was a 2-year-old toddler when data collection commenced. His congenital, bilateral severe-profound sensorineural hearing loss (best unaided 3 frequency pure tone average of 78 dB HL) of unknown aetiology was identified at birth and he was fitted with bilateral hearing aids at two months of age. Charlie received a unilateral cochlear implant at 1.5 years of age. At the time of the study, his mother reported full-time use of his right cochlear implant and left hearing aid. It was observed that his left hearing aid was misplaced at the beginning of study appointment and noted that Charlie had a habit of removing his hearing aid frequently. He was not observed to remove his CI speech processor. The mother-child dyad had been attending an EI program using an oral communication mode once a week for hourly individual sessions and 1.5 hours a week for group sessions since Charlie was 1 year old.

His mother, Lucy, was 36 years of age when the study commenced. She had completed high school education, attained a vocational/ diploma certificate and was working part-time (2 days per week) in the service industry. She was Charlie's primary caregiver and spent an estimated 152 hours per week with him, with Charlie's father (who also lived in the family home with Charlie) as his secondary caregiver. Charlie was their first and only child. English was the primary language spoken at home and their speech pathologist had assigned the family a participation rating of 3 (Average).

This dyad's (B) typical LENA recording day began between five to seven in the morning. Their routine as reported on the DAD generally consisted of having breakfast, sometimes while watching television, followed by playtime in the first part of the morning. The dyad either had appointments to attend or played outside in the mid or late morning, followed by Charlie's sleep time (usually 3 hours long). In the mid-afternoon, they either had play time or went out (i.e. for appointments or shopping) before dinner and bed time at 8pm. After the baseline phase (week 1), Charlie and Lucy completed a weekly recording in the LO condition, followed by the LF condition, the LO condition and lastly, the LFA condition. The remaining (5 of 11) recordings were excluded due to limited adherence to the intervention protocol and/or Lucy's report on the DAD that the recording(s) were not representative of a typical day for the dyad (i.e. Charlie was feeling unwell).

Lucy and Charlie's actual AWC in 5-minute intervals were depicted on a weekly basis an individual value plot as seen in Figure 17. At baseline (week 1), Dyad B had a recorded mean AWC of 120/ 5-minutes and a range of 4 to 771 adult words/ 5-minutes. Figure 18 showed the mean percentage change in AWC/ 5-minute interval from baseline across the study conditions for Lucy and Charlie (Dyad B). A mean percentage decrease from baseline was observed (-24.9%) for LENA recordings in the LO condition. There was a percentage decrease in mean AWC from baseline was recorded for this dyad in the LFA condition (-61.79%). The percentage increase in mean AWC/ 5-minutes was highest after the dyad received only LENA Feedback (+27.9%) compared to the other study conditions.

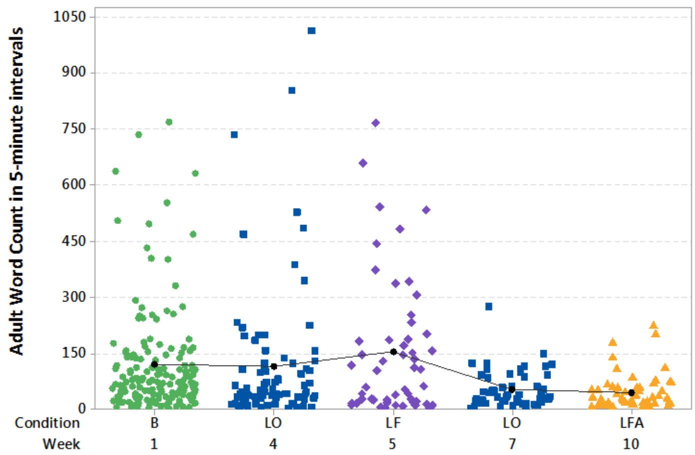


Figure 17: Individual value plot of weekly measures of AWC in 5-minute intervals across conditions for Dyad B

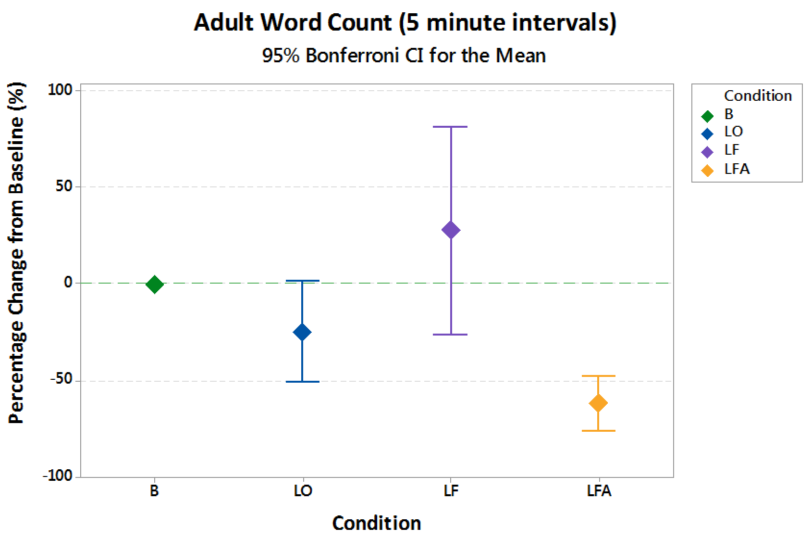


Figure 18: Mean percentage change in AWC in 5-minute intervals from baseline across study conditions for Dyad B

Lucy and Charlie's actual CTC in 5-minute intervals were depicted on a weekly basis an individual value plot as seen in Figure 19. At baseline (week 1), Lucy and Charlie had a mean CTC of 4.4 / 5-minutes and a recorded range of 1 to 24 conversational turns/ 5-minutes. Figure 20 showed the mean percentage change in CTC/ 5-minute interval from baseline across the study conditions for Lucy and Charlie (Dyad B). A mean percentage decrease from baseline was observed in both the LO condition (-22.73%) and in the LF condition (-1.5%). Similar to the observed pattern in AWC across conditions for Dyad B, the largest decrease in mean CTC from baseline was in the LFA condition (-48.39).

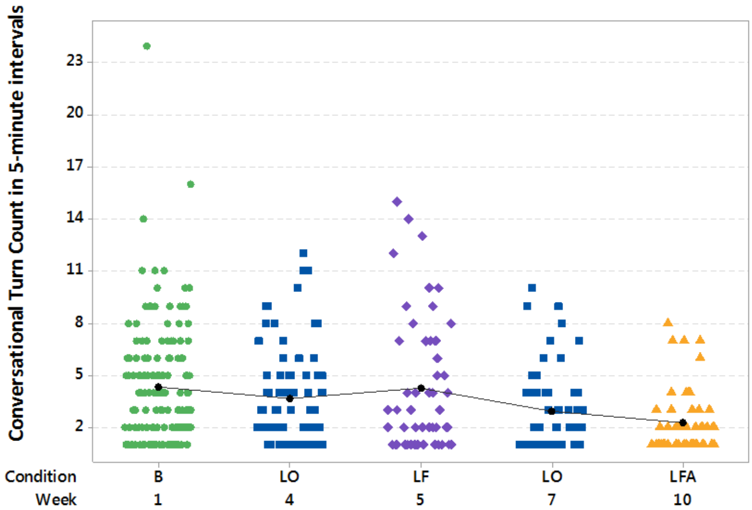


Figure 19: Individual value plot of weekly measures of CTC in 5-minute intervals across conditions for Dyad B

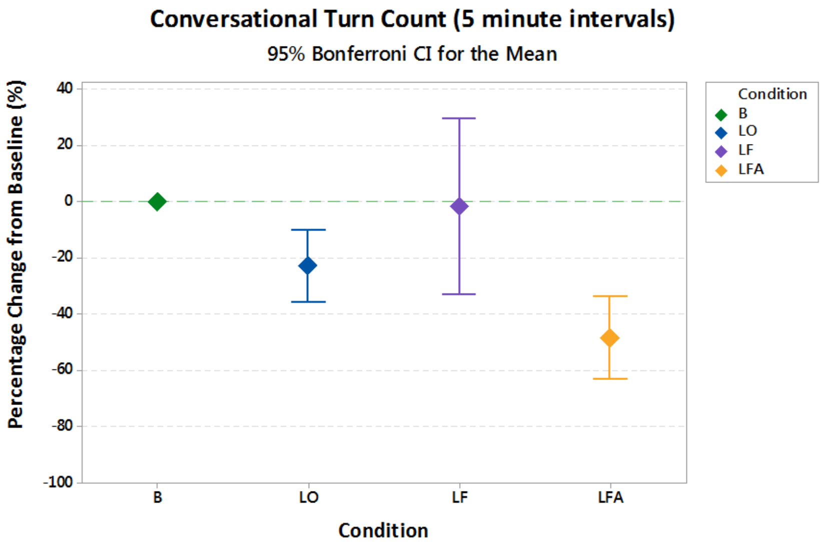


Figure 20: Mean percentage change in CTC in 5-minute intervals from baseline across study conditions for Dyad B

In summary, Lucy and Charlie demonstrated a mean percentage increase in AWC/ 5-minutes from baseline after receiving LENA Feedback (LF condition) compared to the other study conditions, however there was not clear evidence to suggest that this intervention approach was well-suited to this dyad's characteristics as compared to Dyad A. The activities which Lucy and Charlie's were involved in on recording days varied more from week-to-week compared to the other dyads, which could have impacted on their ability to commit to the intervention protocol, thus affecting comparisons of their estimated language counts. Lucy was also working part-time (2 days/week) and this family were assigned an average participation rating in Charlie's intervention by their treating speech pathologist. At the end of the study, Lucy reported that she would be open to using only the LENA system again in the future, stating that *'I like the LENA System because it helps me promote more language and shows me our interactions. I didn't find the app useful'.* Lucy's comment that she did not find the app useful was accurately reflected in the dyad's marked mean percentage decrease from baseline in the LFA condition for both AWC and CTC.

5.5.3 Mother-Child Dyad C: Marge and Lisa*

Lisa was a 2.5-year-old toddler at the time of data collection. Her congenital, bilateral severe-profound sensorineural hearing loss (best unaided three frequency pure tone average of 100 dB HL) of unknown aetiology was identified at one month of age. She was fitted with bilateral hearing aids at 2 months of age and received simultaneous, bilateral implants at 11 months of age. At the time of the study, Lisa was reported to be using both implants for all waking hours. The mother-child dyad had attended an EI program using an oral communication mode once a fortnight for hourly individual sessions since she was 10 months old.

Her mother, Marge, was 40 years of age when the study commenced. She had completed high school education, attained a vocational/ diploma certificate and was working part-time (two to three days per week) in a bookkeeping role. She was Lisa's primary caregiver and reported spending an estimated 146 hours per week with her. Lisa's father (who also lived in the family home with Lisa) was her secondary caregiver. Lisa has two older siblings (aged seven and nine years). An oral communication mode (English as the primary language) and sign was used at home. Dyad C's treating speech pathologist assigned the family a participation rating of 5 (Ideal).

Marge and Lisa's typical LENA recording day began between seven to nine in the morning. Their routine as reported on the DAD generally consisted of having breakfast and getting ready for the day, before going out for a walk down the valley. The dyad had play time at home in the late morning till early afternoon, followed by Lisa's nap time. In the mid-afternoon, they had more play time before getting ready for bed at approximately 7 pm. After the dyad's baseline recording(s) was completed, a recording in the LO condition, followed by two recordings in the LF condition, and lastly, a recording in the LFA condition were included for analyses. There were six recordings which were excluded due to unavoidable changes in the dyad's schedules and when Marge had reported on the DAD that the recording(s) were not representative of a typical day for the dyad (i.e. both mother and child were unwell).

Marge and Lisa's actual AWC in 5-minute intervals were depicted on a weekly basis an individual value plot as seen in Figure 21. At baseline (week 1), the dyad had a mean AWC of 158.7/5-minutes and a range of 1 to 664 adult words/5-minutes. Figure 22 showed the mean percentage change in AWC/5-minute interval from baseline across the study conditions for Marge and Lisa (Dyad C). A mean percentage increase from baseline was observed (+15.9%) when only LENA recordings were taken in the LO condition. The percentage increases in mean AWC from baseline recorded in both intervention (LF and LFA) conditions were observed to be higher than in the LO condition, although counts recorded after the dyad received LENA Feedback (+33.9%) were higher compared to the LFA condition (+19.7%).

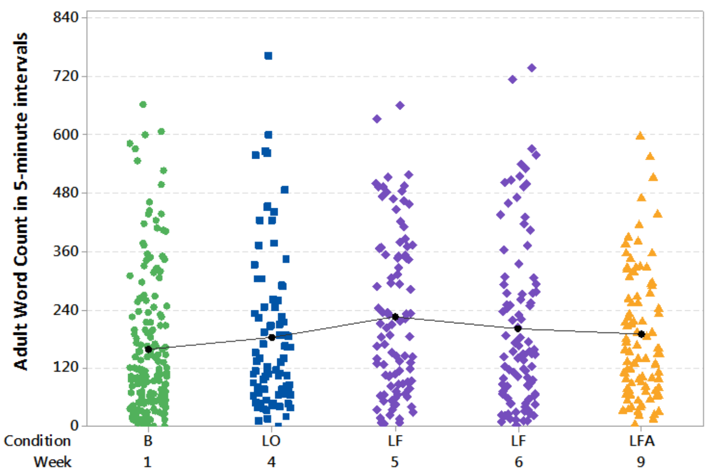


Figure 21: Individual value plot of weekly measures of AWC in 5-minute intervals across conditions for Dyad C

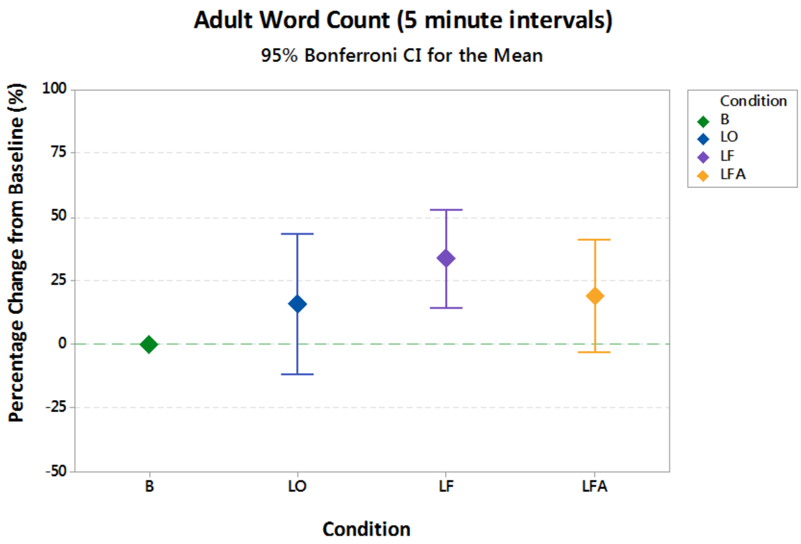


Figure 22: Mean percentage change in AWC in 5-minute intervals from baseline across study conditions for Dyad C

Marge and Lisa's actual CTC in 5-minute intervals were depicted on a weekly basis an individual value plot as seen in Figure 23. At baseline (week 1), Marge and Lisa had a mean CTC of 7.8 /5-minutes and a recorded range of 1 to 38 conversational turns/5-minutes. Figure 24 showed the mean percentage change in CTC/ 5-minute interval from baseline across the study conditions for Marge and Lisa (Dyad C). A mean percentage increase from baseline was observed (+11.07%) when only LENA recordings were taken in the LO condition. Counts recorded in the LF condition (+19.7%) were higher compared to the LFA condition (+16%). Similar to the dyad's pattern of change observed for AWC, the percentage increase in mean CTC from baseline recorded in both intervention (LF and LFA) conditions were observed to be higher than in the LO condition.

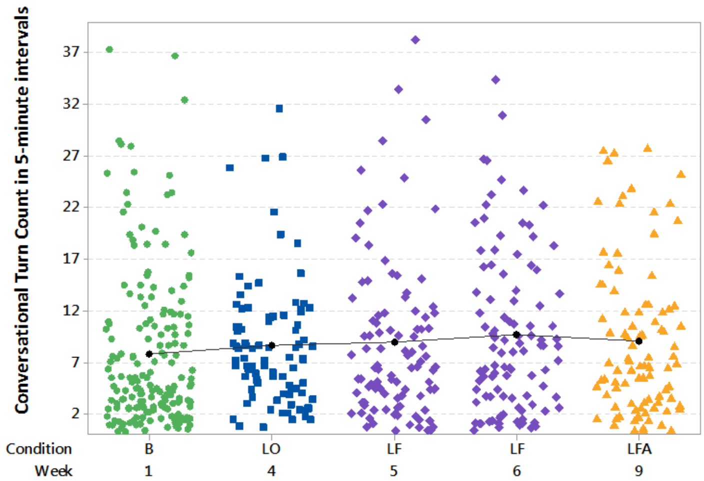


Figure 23: Individual value plot of weekly measures of CTC in 5-minute intervals across conditions for Dyad C

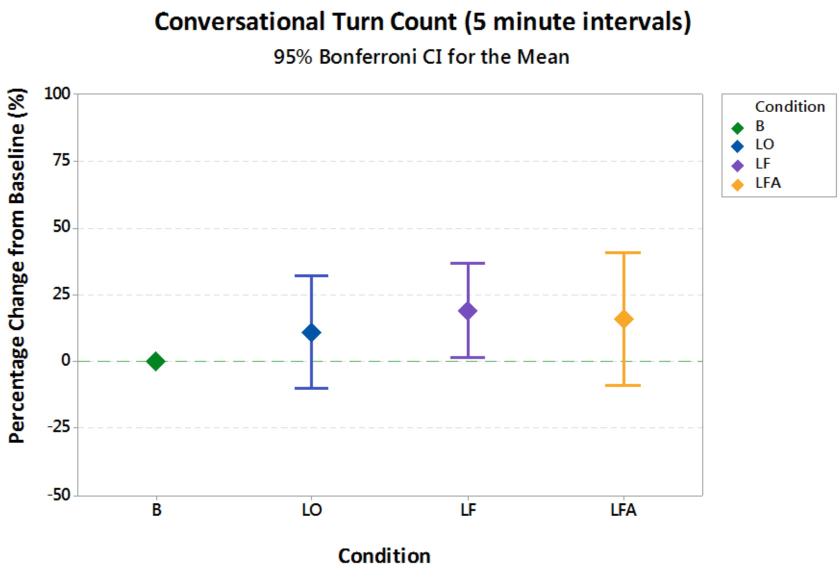


Figure 24: Mean percentage change in CTC in 5-minute intervals from baseline across study conditions for Dyad C

In summary, Marge and Lisa demonstrated small, albeit higher, mean AWC and CTC in both LF and LFA conditions, compared to the LO and baseline conditions. At the end of the study, Marge reported that she would be open to using both the LENA system and the DVA again in the future, and commented, *'I like feedback from the LENA system and the good ideas from the Vroom App'.*

Lisa had the longest device experience among the children in this study (having received simultaneous bilateral implants under 12 months of age) and the dyad had established higher baseline AWC compared to two of the three Hd dyads, and higher baseline CTC relative to the other three dyads in the Hd group. The small increase in AWC and CTC after both interventions (LF, LFA) may represent a ceiling effect. The small changes may have been adequate responses to the intervention for this dyad considering the existing audiological and baseline characteristics of Dyad C. The highest mean percentage increase in AWC and CTC in 5-minute intervals from baseline was observed in the LF condition above and beyond their counts in the LFA and LO conditions, suggesting that this dyad responded best to receiving LENA feedback as an intervention approach. The observation was further supported by Marge's comment at the end of the study that she liked the feedback from the LENA system.

5.5.4 Mother-Child Dyad D: Wilma and Fred*

Fred was 1.6 years of age when data collection commenced. The cause of his bilateral hearing loss (best unaided three frequency pure tone average of 65 dB HL) was reported to be associated with prematurity and poor oxygenation at birth. He was fitted with bilateral hearing aids at 4 months of age, and received a unilateral cochlear implant at 1.2 years of age. At the time of the study, he was reported to be using a left cochlear implant and right hearing aid for all waking hours of the day. The mother-child dyad had attended an EI program using oral communication and sign once a fortnight for one to two hourly sessions since Fred was eight months old.

His mother, Wilma, was 28 years of age when the study was conducted. She had completed a postgraduate degree and was working part-time (two days a week) in healthcare. She reported spending an estimated 152 hours per week with Fred as his primary caregiver, and Fred's father (who lived in the family home) was listed as his secondary caregiver. Fred was the second-born child in the family and had one older brother who was 2.92 years old at the beginning of the study. English was the primary spoken language, and the family used both oral communication and sign at home. Their speech pathologist assigned the family a participation rating of five (Ideal).

Throughout the study, the dyad's typical LENA recording day began at 7 to 8 am and their morning routine consisted of breakfast time, dressing for the day and followed by play time. In the later part of the morning, Wilma and Fred either went out (i.e. for a walk, to the shops/park) or attended appointments before Fred's nap time at mid-day until 2 pm. The dyad would have play time in the afternoon, either at home or outdoors before dinner, followed by bath time, story time and Fred's bed time by 8 pm. After the baseline recording phase, Wilma and Fred had: three consecutive recordings in the LO condition; followed by two recordings in the LF condition; and three recordings in the LFA condition. Data from week 7 (LF condition) was not represented in the figures.

Wilma and Fred's actual AWC in 5-minute intervals were depicted on a weekly basis an individual value plot as seen in Figure 25. At baseline (week 1), the dyad had a mean AWC of 135.5/ 5-minutes and a range of 8 to 470 adult words/5-minutes. Figure 26 showed the mean percentage change in AWC/5-minute interval from baseline across the study conditions for Wilma and Fred (Dyad D). Dyad D showed a decrease in mean AWC percentage change (-22.5% and -24.8%) in the LO and LF conditions from baseline. The mean percentage change recorded in the LFA condition was -7.19%.

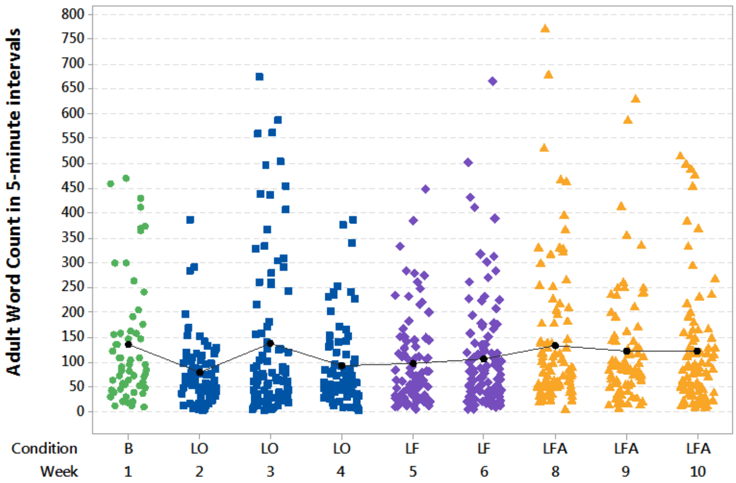


Figure 25: Individual value plot of weekly measures of AWC in 5-minute intervals across conditions for Dyad D

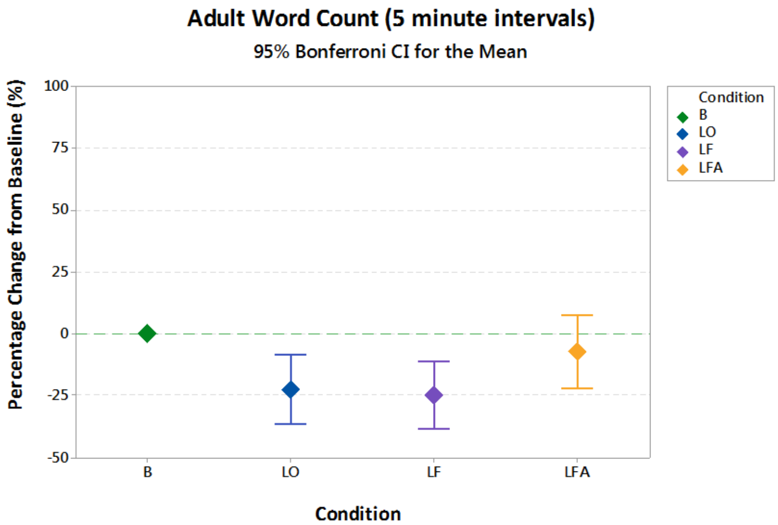


Figure 26: Mean percentage change in AWC in 5-minute intervals from baseline across study conditions for Dyad D

Wilma and Fred's actual CTC in 5-minute intervals were depicted on a weekly basis an individual value plot as seen in Figure 27. At baseline (week 1), Wilma and Fred had a mean CTC of 5.1 /5-minutes and a recorded range of 1 to 19 conversational turns/5-minutes. Figure 28 showed the mean percentage change in CTC/5-minute interval from baseline across the study conditions for Wilma and Fred (Dyad D). Mean increases in CTC from baseline were observed in both intervention (LF and LFA) conditions for Dyad D. A mean percentage decrease from baseline was observed (-18.8%) when only LENA recordings were taken in the LO condition, followed by a mean percentage increase from baseline for counts recorded in the LF condition (+7.5%). The highest increase (+12.4%) in CTC/5-minute intervals was observed in the LFA condition for this dyad.

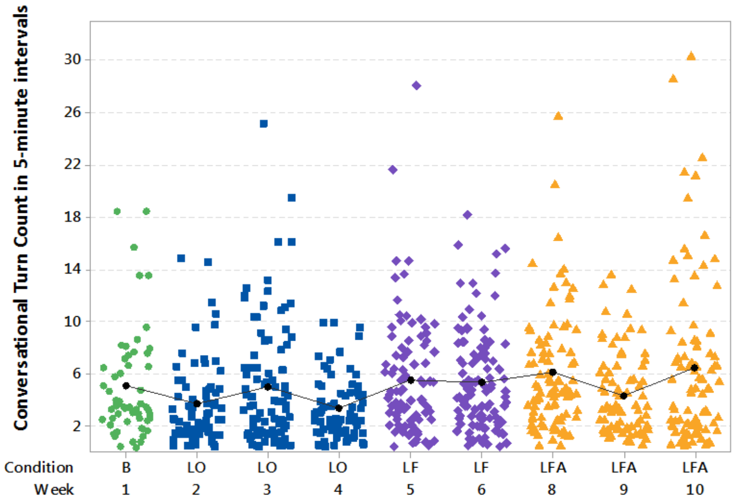


Figure 27: Individual value plot of weekly measures of CTC in 5-minute intervals across conditions for Dyad D

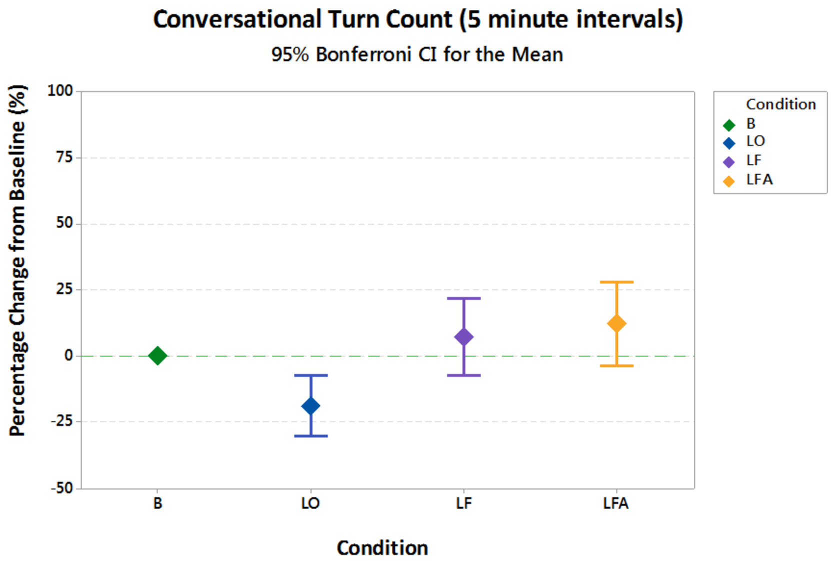


Figure 28: Mean percentage change in CTC in 5-minute intervals from baseline across study conditions for Dyad D

In summary, Wilma and Fred did not demonstrate an increase from baseline for adult words spoken across the three study conditions in the intervention phase. However, the dyad demonstrated increases after both interventions (LF, LFA) on measures of adult-child conversational turns. Dyad D's results suggest that the intervention study promoted an increase in CTC, despite no clear reciprocal intervention effects on AWC. This suggest that AWC and CTC are not exclusively dependent on each other; given that AWC referred to an estimate of words spoken by an adult near a child (speech directed to child) and conversational turns were recorded for each instance of adult-child verbal interaction (bi-directional talk). In the case of Wilma and Fred, it is possible that Wilma did not increase her amount of talk directed towards Fred as result of receiving LENA feedback and using the DVA, but instead, involved Fred in more shared communicative exchanges.

At the end of the study, Wilma reported that she would be open to using the Daily Vroom App again in the future and commented that, *'The LENA was a great tool to visualise the amount of speech Fred is exposed to. After the study, it leaves you with an understanding of the degree of talking required. If you were competitive, I could see people enjoying using it (on an) ongoing (basis), and continuing to try and beat their own counts'.* This premise that the intervention was of benefit to the dyad was supported by Wilma's willingness to use the DVA (which suggested activities aimed at increasing shared parent-child interactions) again in the future.

6 Study 1: Intervention Trial Discussion

Study 1 presented data from a caregiver-implemented intervention trial using LENA and mobile technology with 10 mother-child dyads, which focused on language exposure and verbal interactions, in the everyday environments of young children aged six months to three years. In the first section (6.1) of this chapter, a summary of results regarding associations between contextual (child, family, maternal) variables and the participants' home language environment, and the changes in adult-child language behaviours following the study interventions, are reported in relation to the research aims. The following sections of this chapter provide a discussion of this study's key findings in light of the literature, followed by a discussion of the strengths and limitations of the study and its implications for future research.

6.1 Study 1: Summary of Results

The first aim of Study 1 was to explore whether the early language experiences of young children were affected by child (hearing status), family and maternal factors. By measuring the quantity of language recorded in the participants' natural environments using the LENA system at the beginning of the study, the first set of comparisons examined the effect of child hearing status (hypothesis 1.1) on mean AWC, CTC and CVC recorded in 5-minute intervals for two groups of participants: mothers with hearing children (Hh group), and mothers with children who had a bilateral, significant hearing loss and were aided with hearing devices (Hd group). T-test analyses indicated no significant differences between the two groups, suggesting that child hearing status was not a strong influence affecting the average quantity of talk by adults, the amount of child vocalisations or adult-child conversational turns in this small cohort. The first hypothesis (1.1) was not supported as children with bilateral, prelingual hearing loss and children with typical hearing were exposed to comparable levels of adult words and conversational turns, and on average, both groups of children in the present study produced a similar number of vocalisations at baseline.

Correlation analyses however, revealed multiple significant interrelationships between maternal factors, socio-demographic characteristics and the change in quantity of talk recorded in the home, hence supporting the second hypothesis (1.2). Family measures of SES (residential postcode and means tested government entitlement) were shown to be significantly correlated with maternal characteristics (abilities, education and occupation skill levels). There were also significant relationships between government concession entitlements, maternal intelligence (verbal and IQ composite standard scores) and the child's performance on communication (auditory performance and language) measures. Additionally, higher maternal non-verbal intelligence was associated with greater amounts of child vocalisations in the home environment. Mothers who had attained less than postgraduate qualifications in this sample were more likely to have increased their AWC after receiving LENA feedback. Secondary findings included associations between child language abilities and functional auditory performance on parent-report, norm-reference measures and on formally administered language and cognitive tests.

The second aim of Study 1 was to investigate measurable changes in AWC and CTC from baseline CTC in the three study conditions (LO, LF, LFA). Group findings (N=10) supported hypotheses 2.1. and 2.2 for Study 1. Significant mean percentage changes in AWC and CTC from baseline were demonstrated after the mothers received feedback based on LENA generated information (LF condition) and additionally, after participants had also used the Daily Vroom App (LFA condition), compared to their counts when only LENA recordings were taken (LO condition). Overall, there was a 19.9% increase in AWC recorded in 5-minute intervals from baseline after providing mothers with LENA feedback and a 14.9% increase in AWC after providing mothers with LENA feedback and mothers' use of the DVA from baseline. Regarding mean CTC recorded in 5-minute intervals for the 10 dyads, there was a 22.1% increase from baseline following LENA feedback and a 13.6% increase following LENA feedback and the use of the DVA. Post-hoc analysis using the Tukey HSD test showed that the difference in percentage means of CTC from baseline was significantly higher in the LF condition compared to the LFA condition for the overall group. For dyads in the Hh and Hd groups, significant analysis of variance results were found for AWC and CTC across the three study conditions; reflecting a consistent pattern of mean percentage increases from baseline in both intervention conditions (LF and LFA) compared to the LO condition. For the six mother-child dyads in the Hh group, a mean AWC increase of 25.3% in the LF condition and a 20.6% increase in the LFA condition were found in comparison to the LO condition, where only a mean AWC increase of 3.6% was observed from baseline AWC. There was a mean CTC increase of 24.91% in the LF condition and a 16.7% increase in the LFA condition compared to a CTC decrease of 1.5% in the LO condition from baseline CTC for dyads in the Hh group. Varied individual changes in AWC and CTC were described for the four dyads in the Hd group, but collectively there were statistically significant percentage changes in AWC from baseline, following LENA feedback (+8.9%) and following LENA feedback and the use of the DVA (+1.8%) compared to their AWC when only LENA recordings were taken (-13.9%). Similarly, mean percentage CTC change from baseline was found to be significantly greater when comparing both the LF (+16.6%) and LFA (+6.6%) conditions against the LO condition (-9.9%) for dyads in the Hd group.

6.2 Baseline quantity of talk recorded in their respective language environments for hearing children and children with bilateral hearing loss

6.2.1 Adult Word Count

Primary caregivers and parents are often regarded as the main source of spoken language input to their children (Entwisle, Brouwer, Hanson, & Messersmith, 2016). Some of the variability in their language input may be related to the language level which parents perceive is appropriate for their child (Ambrose et al., 2014). Early findings from paediatric studies (Lederberg & Everhart, 1998; Meadow et al., 1981) suggested a decreased amount of spoken input by mothers of children with hearing loss, in comparison to mothers of hearing children. The present study's results, however, were consistent with recent findings suggesting no difference between cohorts who differed on hearing status (Ambrose et al., 2015; VanDam et al., 2012; Vanormelingen et al., 2016). Vanormelingen and colleagues (2016) analysed one-hour mother-child video recordings for 25 children with normal hearing and typical development from six months of age, and nine children with severe to profound hearing loss using CIs, and found that the duration of spoken input and number of utterances by mothers did not differ significantly between groups. Similar findings were observed in VanDam and colleagues' 2012 study of 30 families with broader audiological criteria (mild to severe hearing loss). The present study and VanDam and colleagues' (2012) used similar methodology with automated LENA analyses of full day recordings as the primary outcome measure. No significant differences were found in the amount of adult talk or mean conversational turns between parents of children (aged 2.5 years with mild to severe hearing loss using hearing aids), and their age-matched peers with typical hearing (VanDam et al., 2012).

This emerging consensus across recent studies is that parents of children with hearing loss (using HAs or CIs) expose their children to a similar amount of adult input as parents of hearing children. This appears to signify a favourable paradigm shift in that children with hearing loss may be treated as 'normally hearing' by their mothers, given recent advances in hearing technology (i.e. CIs), implementation of newborn hearing screening programmes, early access to audiological interventions, and, in turn, greater uptake of oral communication approaches.

Despite the apparent similarity in adult quantity of input directed to children with typical development and those with hearing loss, some caution in interpretation is required; suggestions that both groups receive comparable amounts of adult input, are not straightforward. For the child with hearing loss, the child's access and uptake of the parental input may not equate to the actual amount delivered (Houston & Bergeson, 2014; VanDam et al., 2012).

Whilst LENA technology affords researchers with greater ease of automatic speech and language analysis (Greenwood et al., 2011), researchers and clinicians need to understand that there are some assumptions that the adult words are actually being attended to by the child. The actual amount of adult talk heard and attended to by a child with hearing loss, however, may vary depending on their cognitive function, attentiveness, interest levels (Houston & Bergeson, 2014; van Wieringen & Wouters, 2014), aided thresholds, degree of hearing loss and competing noise levels in various auditory environments (VanDam et al., 2012). It has been proposed that exposure to greater amounts of adult input would still be necessary for children who have received CIs at a young age: to counteract the experience of early auditory deprivation, and to compensate for an inconsistent access to language models due to limitations in the speech signal relative to natural hearing (VanDam et al., 2012; Vanormelingen et al., 2016). Children with hearing loss may require exposure to more linguistic examples compared to typically-hearing children (Houston & Bergeson, 2014) in order to acquire the same level of speech and language comprehension (Ambrose et al., 2014). Further exploration of more sensitive measures of the amount of adult talk attended to by children with significant hearing loss versus the amount of talk provided, may be required. Gaining a more informed understanding about this (access-dependent) differentiation is the initial step in addressing sufficient versus optimal language exposure for children with hearing loss so that communication can develop at rates comparable to hearing peers.

6.2.2 Conversational Turn Count

The findings of the present study support those of VanDam and colleagues' (2012) and Vanormeligen and colleagues' (2016) in that, there were comparable amounts of conversational turns between parents of children with typical hearing and development, and parents of children with hearing loss. The finding that a similar quantity of conversational turns occur for both hearing children and children with a hearing loss is reassuring. As with adult quantity of input, it appears that more recent cohorts have benefitted from early detection and diagnosis; the child's hearing status was not a significant influence on the quantity of conversational turns (VanDam et al., 2012). Contextual factors, found to facilitate early spoken language use, in both the present study and VanDam and colleagues' study were as follows, the children in the Hd group had access to newborn hearing screening; were fitted with hearing aids by four months of age; and were enrolled in early intervention services using oral communication approaches. Dyads in the Hd group in the present study were concurrently enrolled in early intervention programs where families received ongoing coaching to support communication interaction which may have resulted in higher baselines when measuring the quantity of talk in the home.

Recent research regarding children with typical development and normal hearing, have demonstrated that adult-child conversational turns have a greater impact on the child's language development than the sheer amount of words which adults provided (Hirsh-Pasek et al., 2015; Zimmerman et al., 2009). A longitudinal study of 71 children with typical development and normal hearing, aged 2 to 48 months, showed that the amount of adult-child conversational turns predicted the children's language growth over 18 months (Zimmerman et al., 2009). Furthermore, the amount of conversational turns which four to six-year-old children had with their parents was linked to brain function measured on a functional MRI task, specifically the activation of the Broca's area which is a prominent neural domain underlying language processing (Romeo et al., 2018a).

Vanormeligen and colleagues' (2016) study highlighted the reciprocal relationship between the amount of talk contributed by both conversational partners; the number of conversational turns taken by mothers directly predicted the number of turns taken by children and vice versa. Children with poorer speech and auditory perception may be less responsive to the language input provided by their parents, leading to fewer turns being taken within verbal interactions (VanDam et al., 2012). Additionally, conversational breakdowns may occur more frequently between parents and children with delayed oral language, hence reducing the amount of conversational turn-taking (VanDam et al., 2012). In addition to the child's speech perception development which may moderate their responsiveness to verbal interaction, each child's expressive language ability is also likely to play a role in his/her capacity to initiate or maintain conversations, which in turn may affect the amount of adult-child conversational turns (VanDam et al., 2012).

6.2.3 Child Vocalisation Count

In the present study, each child's vocalisations were explored using LENA's automated count at baseline and mean differences between Hh and Hd groups were analysed. A child vocalisation count (CVC) was tallied each time the participating child produced a speech sound surrounded by a pause (silence or non-speech) of at least 300 milliseconds (Gilkerson & Richards, 2009). There was no significant relationship between child hearing status and child volubility in this sample of 10 mother-child dyads, which was consistent with previously reported results (Iyer & Oller, 2008; Spencer, 1993). Previous research has suggested that infants with moderate to severe bilateral hearing loss who were aided did not show a decrease in the vocalisations compared to hearing peers. Authors proposed that vocal communication attempts were positively influenced through the use of appropriate amplification and were further reinforced through communication experiences and access to early intervention programs (Iyer & Oller, 2008; Spencer, 1993). Vanormelingen and colleagues' (2016) study provided recent support for this premise as children using cochlear implants were found to be more talkative (i.e. produced more utterances per turn) than their hearing peers. This result was explained in conjunction with the finding that mothers of children using CIs responded more frequently to their children's utterances relative to mothers of hearing children. It is proposed that mothers of children using CIs provided more contingent responses to their children, which in turn prompted more child vocalisations (Vanormelingen et al., 2016). The present study focused primarily on maternal language contributions which were characterised by AWC and CTC as primary, quantitative measures of child language exposure in everyday environments. The LENA generated data for child vocalisations in the present study indicated volubility but could not provide a measure of a child's level of sophistication in speech sound development. Other dimensions of early child vocal production, which were beyond the scope of the present study, have been thoroughly investigated in the research literature. For children with typical development and normal hearing, well-established guidelines in the hierarchical development of prelinguistic communication exist to inform recognition of early infant vocalisations including protophones, canonical and variegated babble to early word forms (Cantle Moore, 2014; Oller et al., 1999). Thus, CVC as a broad estimate of child volubility generated from LENA, is limited in classifying the full range of emerging vocalisation types.

In summarising LENA AWC, CTC and CVC comparisons, the present study found no significant differences in the mean amount of talk by adults, conversational turns between the Hh and Hd groups, and no significant differences in child vocalisations. More refined analysis of child early vocalisation types may be able to provide further insight into a child's contribution to everyday interactions. Parental language input is not however, driven independently by contributions by the child (Ambrose et al., 2014). Recent evidence has indicated that after controlling for earlier child language abilities, the frequency which parents engage their children in conversational exchanges (Zimmerman et al., 2009) and amount of parental talk, still predicted later child language outcomes (Hurtado et al., 2008; Rowe, 2008). Given the reciprocal nature of adult language input and child language abilities, it remains challenging and time consuming to use traditional transcription methods, to tease apart the separate effect of each conversational partner (VanDam et al., 2012)

6.3 Relationships between participant characteristics and quantity of talk in the home language environment

Environmental factors, such as a family's socio-economic status (SES), also underpin early child language experiences. Previous research studies have highlighted the intricate nature of SES and its relation to the family context, maternal characteristics, children's language experiences and communication development. Children from families with greater relative socioeconomic advantage were reported to be exposed to substantially more language input compared to children with relatively less advantage (Dwyer, Jones, Davis, Kitamura, & Ching, 2018; Gilkerson & Richards, 2009; Hart & Risley, 1995). The present study, with a small sample size, however, did not demonstrate any significant associations between parental talk as measured by AWC and CTC at baseline and SES-related variables. The present study did, however, find a significant relationship between SES and the amount of talk by the children. Families who reported that they were receiving means-tested government concession entitlements, another SES-related marker, had children using fewer vocalisations at baseline. The variability in amount of child vocalisations as a function of socio-economic advantage was also observed in Hart and Risley's (1995) study; children from families on welfare were found to produce fewer utterances and different word types per hour compared to children from working class families or children from parents who were professionals. The present study also identified significant correlations between families receiving government concession entitlements and the children's language standard scores on the LDS checklist and functional listening performance scores on the PEACH.

Research studies have yet to reach consensus on the most effective indices or proxy measures of SES (Ensminger, & Fothergill, 2003; Pace, Alper, Burchinal, Golinkoff, & Hirsh-Pasek, 2018), nonetheless, family SES-related child language disparities, as seen in the present study, have also been identified in earlier studies with concomitant impacts on child language outcomes (Hart & Risley, 1995; McKean et al., 2015). Syntactic complexity and lexical diversity in the language interactions of mother-child dyads from different socio-economic backgrounds could partially explain this association between SES and child language growth (Huttenlocher et al., 2010). Quantity of parental talk did not appear to be a sufficiently sensitive measure linking SES to child language outcomes in the present study, however recent studies (Huttenlocher et al., 2010; Rowe, 2012) have proposed that SES-related differences in the analysis of qualitative language characteristics at home are other dimensions worth investigating.

6.3.1 Maternal Characteristics

It is challenging to quantify the effect of SES on child language outcomes when a range of more proximal factors are implicated as mediators in this relationship, including the role of maternal characteristics. Examining associations between family SES and maternal personal attributes (i.e. education level, parenting knowledge, parenting sense of self-competence, verbal and non-verbal cognitive abilities, and occupational skill levels) might offer explanations for communication differences which occur in home environments. Relationships between SES and child language outcomes could also be attributed to traits which parents bring to the communicative interactions with their children in everyday life (Hart & Risley, 1995; Hoff, 2003; Huttenlocher et al., 2010; Rowe, 2008). Greater family relative socio-economic advantage estimated in the present study with the participants' residential postcode, was significantly correlated with higher levels of maternal education and more specialised occupational skill levels. Significant negative correlations suggested that families receiving government concession entitlements were more likely to have lower maternal non-verbal ability and IQ composite standard scores measured on the KBIT-2.

Maternal intelligence has been found to predict children's verbal skills (Ronfani et al., 2015). The link between maternal intelligence was not observed with child language standard scores on the LDS or PLS-5 in the present study, rather a significant relationship was found between scores of maternal non-verbal cognitive abilities on the KBIT-2 and child vocalisations recorded at baseline. Higher maternal intelligence has been associated with more responsive parenting practices, resulting in more communicatively responsive children (Bornstein et al., 2007), although the present study did not directly examine the effect of maternal traits on child behaviour. Knowledge of parenting and self-efficacy have also been implicated as protective factors in fostering more optimal mother-child interactions (Bornstein et al., 1998; Bornstein et al., 2007), but the present study did not reveal any significant relationships between maternal performance on standardised language and cognitive tests and mothers' self-reported scores on parenting knowledge and parenting sense of self-competence measures. Regardless, the present study found significant relationships between higher levels of maternal education, more specialised skill levels of maternal occupation, maternal verbal cognitive abilities and greater maternal receptive vocabulary skills. There were strong positive relationships between mothers' receptive vocabulary scores on the PPVT-4, overall IQ composite and non-verbal cognitive standard scores on the KBIT-2. These findings are consistent with prior studies linking maternal verbal IQ with maternal education (Betancourt et al., 2015; Bornstein et al., 1998; Rowe, 2008).

There is much interest in the research literature regarding maternal education, as it plays a pertinent role in: early child language experiences (Dwyer et al., 2018); maternal behaviours directed towards their infants (Ensminger et al., 2003); parenting practices (Hoff, 2006); predicting child language outcomes for children with hearing loss (Cupples et al., 2018; van Wieringen & Wouters, 2014) and children with typical development and normal hearing (Reilly et al., 2010). The socio-educational profile of parents has also been linked to expectations regarding their children's development and subsequent child language outcomes (Diaz, Labrell, Le Normand, Guinchat, & Dellatolas, 2018). The present study adds to prior findings by highlighting how maternal education may affect uptake of a caregiver-implemented intervention. Findings based on Study 1's sample, suggested that LENA feedback may be better suited to mothers who had either a diploma/vocational certificate or undergraduate degree than mothers with postgraduate education. All participating mothers who had attained a diploma/vocational qualifications or a bachelor's degree, and one mother with a postgraduate degree, demonstrated increases in mean AWC from their baseline counts after receiving LENA Feedback only. Two of the 10 dyads in the postgraduate education group did not demonstrate a mean increase in AWC after receiving feedback in the present study. Two educational research meta-analyses also found that provision of feedback on performance is not universally beneficial; neutral or negative effects do occur in approximately a third of cases (Bangert-Drowns, Kulik, Kulik, & Morgan, 1991; Kluger & DeNisi, 1996). The theory of planned behaviour may explain some individual differences in responses to feedback. The behavioural intent, based on the participant's attitudes and set of beliefs, is theorised to be a key proximal predictor of the respective behaviour (Sniehotta, 2009). Applying this theory to the two dyads who did not demonstrate an increase in AWC post-feedback, mothers with a higher level of education may not share the same readiness to change the amount of talk directed at their children if they had perceived their language input to be sufficient and/or, perceived that positive parenting practices which included provision of linguistically stimulating input, were already modelled. This hypothesis was not tested on the present study's sample, nonetheless, one of the two dyads was observed to have a high mean baseline AWC (189.8 words/ 5-minutes) compared to the other study participants. This observation is consistent with past literature which suggested that mothers with higher levels of education used more sophisticated verbal abilities and immersed their children in richer language environments without the need for intervention (Harding, Morris, & Hughes, 2015; Rodriguez et al., 2009). Having a high baseline AWC (i.e. ceiling effect) may have left little room for further improvement in this case. That is, greater increases in AWC post-intervention could be related to lower baselines (Gilkerson et al., 2017). The study's sample size of 10 mother-child dyads may be insufficient to draw any strong conclusions regarding ceiling and baseline effects and limits the generalisability of this finding to a larger population.

6.3.2 Relationships between Child Test Measures

One of the present study's aims was to explore relationships between family factors, maternal characteristics and child language abilities. The present study found no significant relationships between measures of maternal language abilities (PPVT-4 and the verbal domain of the KBIT-2), LENA measures of parental quantity of input (AWC and CTC) or the children's standardised language scores on the PLS-5. Spearman correlation findings did indicate significant relationships between child measures (the developmental age estimates on the LDS, the PLS 5th Edition's receptive and expressive age equivalences, and the raw scores on the cognitive subtest of the Bayley III screening test). These results support the convergent validity of the 52-item parent survey LENA Developmental Snapshot (LDS) measure and the standardised language and cognitive assessments in this group of children. Correlation results in the present study adds support to previous validation evidence based on larger sample sizes of up to 143 typically developing children (Gilkerson & Richards, 2008b). In the LENA Natural Language Study, norm-referenced LDS scores and developmental age estimates were statistically correlated (overall average of *r= 0.93*) with formal developmental age equivalences derived from measures including: the Preschool Language Scale (PLS; 4th Edition), Receptive-Expressive Emergent Language Test (REEL-3), Child Development Inventory (CDI), the Cognitive Adaptive Test (CAT) and the Clinical Linguistic and Auditory Milestone Scale (CLAMS) (Gilkerson & Richards, 2008a). Apart from standardised assessments, the LDS score which evaluated both child expressive and receptive language skills, was significantly associated in the present study with the child's hearing status, and the percentage scores on the parent-report PEACH tool which gauges a child's auditory functional performance in real-world environments. Children in the present study with a hearing loss who had lower percentage scores on the PEACH, were also observed to have lower LDS scores. These results support the use of the LDS as a reliable quick language screener and monitoring tool for children under three years of age. The LDS was able to identify differences in receptive and expressive language abilities as a function of chronological age, and possibly to differentiate between children with normal hearing and children with hearing loss in the present study. The LDS, albeit not a standardised assessment, relies on parent-report and requires far less administration time than formal assessments. The LDS offers flexibility of administration as it can be completed in monthly intervals, bypassing the test/retest administration restrictions for most standardised language tests. The LDS could be utilised with young children with hearing loss: to estimate their rate of language growth after receiving auditory intervention; to potentially evaluate intervention outcomes; to raise parents' awareness of child language behaviours; and to accurately track early language skill acquisition over short intervals of time.

In summary, results of the study's first aim supported SES-related influences on child communication skills. Furthermore, examination of interrelated maternal characteristics indicated that maternal non-verbal intelligence and families receipt of government concession entitlements in this sample also influenced child vocalisations, language and auditory performance. Quantity of adult language input and adult-child conversational turns recorded at baseline were not related to family or maternal factors as reported in previous research. Quality of adult language input, while not addressed or measured as part of the present study, should not be discounted as an important dimension which may also impact child language development. A key finding of the present study was that, providing personalised LENA feedback was associated with increases in the amount of talk (AWC) at home, for all mothers in the study who had attained vocational education or an undergraduate degree. These findings highlight the importance of adopting a caregiver-centred approach; considering each mothers' level of education when planning and delivering intervention(s) goals and feedback. Regarding the evaluation of child language development, the LDS was found to be a quick, easily administered norm-referenced measure for both hearing children and children with a hearing loss and it also demonstrated high validity based on correlations with more widely used standardised language and cognitive tests. Future exploration into the identification of discrete or tiered intervention pathways for mother-child dyads of diverse background characteristics is required so as to influence positive changes in the child's home language environment. Given that child language trajectories are malleable (McKean et al., 2015; Yoshinaga-Itano et al., 2010), the indirect goal of parent-focused interventions is to influence children's language outcomes. It is recommended that for future studies, the LDS could be considered as a quick, repeatable language progress monitoring tool to evaluate the efficacy of intervention(s).

6.4 VARIABILITY IN THE QUANTITY OF TALK RECORDED IN HOME LANGUAGE ENVIRONMENTS

The present caregiver-implemented intervention approach focused on capturing measurable changes in the language behaviours (AWC and CTC) from the participants' baseline counts over the duration of the trial, in response to different study conditions involving: the use of the LENA system as both an outcome measure and a mechanism for providing feedback to mothers; and the Daily Vroom app as a vehicle to promote parent-child interactions in daily routines. LENA generated language counts revealed substantial variability in the amount of talk (AWC) and conversational turns (CTC) in the children's home language environments at baseline, both between and within participants. LENA estimates over the course of the study (at baseline and across the 3 study conditions) indicated large standard deviations in measurements, as the participants' AWC and CTC ranged widely from 1 to 1015 words, and from 1 to 48 turns within a 5-minute interval. Fluctuations in the pattern of talk throughout the day within families has been recognised as a common phenomenon in children's early language environment. Typically, higher amounts of talk are observed in the mornings, late afternoons and early evening time intervals (Gilkerson & Richards, 2009; Greenwood et al., 2011). A high degree of variability in adult words and conversational turns occurred from day to day variability and from family to family in LENA studies with typically developing, normal-hearing children and children with hearing loss (Gilkerson & Richards, 2009; Vohr et al., 2014). In the LENA Natural Language Study (2009), it was found that the total amount of adult talk on any given day for typical families in their normative sample varied by 52.5% of the average word count recorded. For adult-child conversational turns in a family with a two-year-old child, the number of turns could vary by a coefficient of 53% (250 to 800 turns) with an average of 520 conversational turns per day (Gilkerson & Richards, 2009). The present study attempted to preserve real-life approximations of language counts by collecting long participant recordings for between 10 to 16 hours in any one day, rather than opting for shorter recording samples. Fluctuations in the amount of talk and variability in length of recordings across participants, were controlled by taking an average of language counts generated in 5-minute intervals for each family across the entire day(s) of recording.

Some of the pre-existing variability in LENA-generated estimates at baseline between families in the present study could also be attributed to characteristics of individual families and the differences in their environments (Ganek & Eriks-Brophy, 2017; Greenwood et al., 2011). For example, language counts vary due to the types of surroundings, the kinds of activities, and their usual routines (Soderstrom & Wittebolle, 2013). Given that the present study focused on children's language environments in naturalistic settings, controlling for multiple speakers in busy households and/or large families was not always possible. This limitation was considered by advising participants at the outset of the study against recording on days when there may be many different people speaking in close range and/or recording activities with long episodes of competing background noise. The Daily Activities Diary (DAD) provided an avenue for noting whether family members or other people were present during the mother-child dyad's usual recording days.

Previous research studies have also found that the amount of adult-child talk differs systematically across activity contexts. A higher amount of talk has been observed to occur during reading time (Zauche et al., 2016) and a decrease in parent-child verbal interaction has been associated with watching television (Christakis et al., 2009). The different activities which the respective dyads were involved in throughout their recording days could thus, in part, account for the wide range in AWC and CTC. To account for the fact that each family would differ in their interests, activities and the proportion of child involvement in their family life, each participant acted as their own baseline in the present intervention trial. This study design allowed for dyads to maintain their usual routines on their recording days, and also attempted to ensure that the amount of talk recorded was representative of an average day for the children in the present study. Notwithstanding, there are still week to week variations within the social schedules of families due to the real-life setting of this study. Detailed analysis of the relationships between quantity of adult talk and number of adult-child conversation turns during different activities reported on the DAD activity-time logs are available for future analyses.

The present study included both children with and without a hearing loss from families who spoke English. However, six families also reported using an additional language (including Auslan) at home which could also have confounded measurement of intervention effects. It is a possibility that the use of Auslan or sign language communication could have contributed to the language experiences for the children with hearing loss, however LENA technology cannot encode visual information (Ambrose, VanDam, & Moeller, 2014). Families who used Auslan as part of their home language were likely to have had their overall communication undercounted. The proportion of time participants spent communicating in Auslan or sign language was not investigated as increasing oral language interactions was a primary focus for the study.

It was both a strength and limitation of the present study's intervention design that the use of additional languages reflected real-life circumstances of these diverse families. Firstly, given the changing demographics of Australia and the projected rise in children from linguistically diverse populations, it is increasingly important to consider the early intervention management of children with hearing loss from bilingual/ multilingual environments (Alfano & Douglas, 2018; Forli et al., 2018; Guiberson & Crowe, 2018). It has been recognised that bilingual/ multilingual home environments may be associated with greater variation in early child language experiences and skills compared to monolingual language environments (Guiberson & Crowe, 2018). Measuring the amount of spoken language for bilingual/ multilingual families for children with hearing loss could be an initial step in further describing home language environments. LENA algorithms derive automated estimates of word count and conversation turns by analysing acoustic energy patterns, otherwise known as segments, hence LENA has the potential to extend its applicability to cross-linguistic contexts (Gilkerson et al., 2015). The majority of LENA research and early studies were based on typically developing children from English-speaking families, but the reliability and validity of using LENA technology has since been demonstrated in various other languages including: Mandarin; Spanish; French; Dutch and Korean (Busch et al., 2018; Canault et al., 2016; Gilkerson et al., 2015; Gilkerson & Richards, 2009; Pae et al., 2016). In addition to quantifying a child's language exposure, there has been emerging evidence justifying greater benefit of using dual languages in intervention for children using cochlear implants compared to providing English-only language intervention (Bunta et al., 2016). Nonetheless, the paucity of intervention practices which cater to the support of bilingual/multilingual children with hearing loss in their natural language environments still remains (Alfano & Douglas, 2018). The present study's parent-focused intervention was built on data from children from monolingual English-speaking households and children from bilingual/ multilingual families. The use of each dyad's baseline counts was warranted to control for the use of additional language(s) in the home and other family-specific factors.

The purpose of recruiting mother-child dyads in the Hd group was to examine whether the potential effects of the caregiver-implemented intervention strategies employed would be beneficial, not just for mothers of children with typical hearing, but also for mothers of children using hearing aids and/or cochlear implants. The inclusion of subgroups based on the child's hearing status, nonetheless, allows for between-group performance comparisons as a method of evaluating the stability of testing and intervention procedures (Fink, Wang, Visaya, & Niparko, 2007). Children within the Hd group still varied in their hearing experience and type of device(s) used, thus a single subject design was used in the present study to examine changes in AWC and CTC across study conditions for mothers and their children with bilateral hearing loss, in greater depth. Single subject designs can serve as a preliminary step in exploring the functional viability of newly developed interventions in real-life settings and describing individual-level effects (Cohen et al., 2014). The effects of the interventions on AWC and CTC were explored in light of individual characteristics, such as level of family participation, for the Hd group, which could provide insights for future iterations of LENA feedback and/or the use of the Daily Vroom App.

6.5 Changes in Adult Word and Conversational Turns Counts from Baseline

Family characteristics may have contributed to fluctuations in baseline counts observed within the home language environments, nonetheless, the high degree of variability in AWC and CTC observed for each dyad in this sample could have been viewed as a favourable opportunity for promoting potential change in parental language behaviours (Gilkerson & Richards, 2009). In the LENA Natural Language study, within-family variation illustrated that some families were already capable of providing a large quantity of talk and high adult-child conversational turn counts at times in their child's day to day language environment (Gilkerson & Richards, 2009). It was proposed that providing parents with feedback measured using LENA technology could facilitate parents in avoiding low word count and conversational turn times/days, by consistently exposing their child to greater amounts of talk and engaging them in more verbal interactions, to enrich their child's cumulative language experience (Gilkerson & Richards, 2009). Therefore, the substantial variability in the overall range of AWC and CTC recorded at the beginning of the present study reflect the potential for positive change(s) in maternal language behaviours with intervention.

Given the dynamic nature of mother and child interactions, both conversational partners are recognised to influence and regulate each other's behaviours (DesJardin & Eisenberg, 2007). Even though this intervention was directed at changing maternal language behaviours, children may also affect the way mothers talk to them which is a confounding factor. For example, parents may alter their speech to infants and young children depending on their language skills or the use of infant-directed speech (Richards et al., 2018). Gilkerson and colleagues' (2017) demonstrated that the amount of words spoken by adults remained relatively constant over time and did not increase with the child's age, although the frequency of child vocalisations (CVC) on day-long recordings was reported to increase with the age of a typically developing, normal-hearing child up until 26 months of age (Gilkerson et al., 2017). A similar pattern of LENA-generated estimates for the number of adult-child conversational turns were observed to increase in the first and second year of life before plateauing (Gilkerson et al., 2017). It was proposed that the associated increase in CTC could be due to more child vocalisations which therefore elicited more turn-taking interactions with their caregiver (Gilkerson et al., 2017). The steady increase in CVC in their study was likely to have been influenced by the reduction in sleep and nap times over the first 26 months of age, resulting in greater opportunities for engagement in verbal interactions and thus more child vocalisations in recordings at older ages (Gilkerson et al., 2017). In order to control for variations in sleep times/ duration the present study excluded data from nap or sleep times as indicated by zero AWC and CTC within the same time intervals on LENA recordings, and as reported on the Daily Activities Diary.

6.5.1 Evaluating LENA Feedback as an intervention approach

Addressing the second aim of the present study, results supported the hypothesis that there would be significant changes in group mean percentages for AWC and CTC from baseline after the mothers received feedback based on LENA generated information (LF condition). There were significant percentage changes in AWC and CTC from the dyads' baseline counts in both intervention conditions (LF and LFA) as a whole, relative to when only LENA recordings were taken (LO condition). In the LF condition when only LENA feedback was provided to mothers, there was a 19.9% increase from baseline in words spoken by adults and a 22.1% increase in conversational turns from baseline in the present study.

The present study findings were consistent with previous parent-implemented intervention studies which suggested that automatic language counts generated by the LENA software could be used as a language pedometer to monitor progress and support parents in their efforts to enhance language environments at home (Gilkerson et al., 2015; Wang et al., 2017b). Recent studies conducted on different populations (e.g. age groups, disability types, languages spoken) have used quantitative linguistic feedback as a method of educating parents or caregivers with real-life, tailored information based on LENA estimates of AWC, CTC and CVC and percentile ranks of the child's early language environment in comparison to LENA normative data (Gilkerson et al., 2017; Leffel & Suskind, 2013; Pae et al., 2016; Sacks et al., 2014; Suskind et al., 2016a; Zhang et al., 2015). Mixed findings regarding the effect of quantitative linguistic feedback were nevertheless reported due to differences in study design and measurement parameters (Wang et al., 2017b). The present study examined group changes in parental language behaviours based on the child's hearing status, rather than stratifying participants based on their baseline LENA scores relative to normative data. Several studies have noted that families who started with lower than average baseline counts were able to significantly increase their daily adult word counts (Zhang et al., 2015) and daily total conversational turns (Gilkerson et al., 2017) after receiving feedback based on LENA-generated estimates, with less impact for families who had above average baseline counts. Sacks and colleagues (2014) also included quantitative linguistic feedback as a key strategy and implemented a methodology which was more aligned with the present study. Their sample consisted of 11 parents of children with hearing loss, from less socioeconomically advantaged backgrounds or who spoke English as a second language at home (Sacks et al., 2014). Sacks and colleagues (2014) found significant increases in CTC, and no evidence of significant increases in AWC per hour between pre- and post-intervention LENA recordings. They proposed that the pilot study required a larger sample size to detect the intervention effect on AWC (Sacks et al., 2014). Even though LENA-generated estimates were used as a primary outcome measure in both Sacks and colleagues' research and the present study, differences in duration of sample intervals used could have affected measurement sensitivity. The present study examined the AWC and CTC recorded per 5-minute intervals across all recordings in the trial, as opposed to prior studies which relied on hourly counts (Sacks et al., 2014) or total daily adult word and conversational turn counts (Gilkerson et al., 2017; Zhang et al., 2015). Using percentage change in AWC and CTC from the participants' baseline counts was another outcome parameter of the present study which could have contributed to measurement sensitivity.

The present study found significant group mean percentage increases in AWC and CTC from baseline after receiving LENA Feedback, which concurred with another exploratory intervention study (Suskind et al., 2013) which used quantitative linguistic feedback and educational sessions with 17 non-parental caregivers of typically developing, normal-hearing children. In the present study's analysis of six mother-child Hh dyads, the mean increases in AWC between recordings taken in the LENA Feedback only condition compared to baseline was 25.3%, and 24.9% for CTC. Similar results were found in Suskind and colleagues' (2013) study, who reported significant and prolonged mean percentage increases from baseline in caregiver AWC of 31.6% and caregiver-child CTC of 24.9% post-intervention.

Feedback serves to deliver information about an individual's performance so as to create self-awareness of the target behaviour and consider the impact of the behaviour in context (Hermsen et al., 2016). The present study's group findings demonstrated the use of LENA feedback as an effective behavioural change strategy to increase adult language input and adult-child verbal interactions with children who have normal hearing and children with hearing loss. In this instance, LENA-generated estimates offered objective measurement of adult language input and verbal interactions as opposed to parental self-perceptions (Richards et al., 2017). Previous research has shown that parental subjective self-evaluations of the quantity of talk with their children was only weakly correlated with the objective, LENA-generated estimates (Richards et al., 2017). Parents tended to overestimate the amount of talk due to the lack of a benchmark (Richards et al., 2017). Consequently, parents who perceived that they were already engaging adequately with their child were unlikely to initiate behavioural change (Richards et al., 2017). If parents perceive that their amount of talk is high without any means of assessing the accuracy of their beliefs, they may be less responsive to intervention attempts or prompts to talk more (Richards et al., 2017). It is suggested that when direct feedback on performance is provided to parents, their self-calibration of talk may become more accurate. This is an important first step towards enhancing performance (Richards et al., 2017).

As person-to-person discussions were limited by geographical distance, LENA feedback in the present study was delivered by the researcher using a combination of different mediums (either face-to-face or remotely through email or mobile communication) to accommodate both the participants' preferences and availability. All participants were provided with personalised feedback based on LENA estimates and contextual information provided in each dyad's Daily Activities Diary, but it is possible that the effects of feedback in this study were confounded by the range of delivery methods. Despite non-face-to-face delivery of feedback in some cases, the present study still demonstrated significantly increased quantity of adult talk around the child, and significantly increased adult-child conversational turns for dyads in both the Hh and Hd groups after feedback compared to when feedback was not given. This highlights the potential role of remote delivery of feedback, particularly in the Australian context, where distance creates challenge for families in rural areas to access specialist services (McCarthy et al., 2012). Families of children with hearing loss often travel great distances to attend appointments and/or elect to receive support services at early intervention centres in their nearest regional city (McCarthy et al., 2012). Recent research has demonstrated telepractice to be a viable method to complement traditional face-to-face service provision as it can overcome barriers of geographical distance to facilitate regular interactions between clinicians and families of children with hearing loss (McCarthy et al., 2012). The successful delivery of LENA feedback to remotely-based families in the present study, via various telecommunication methods has added to this emerging body of work. Internet bandwidth however, should be included as a key consideration before implementation, as it remains to be a critical limitation in general telepractice applicability.

The second aim of the present study explored whether changes in maternal language in response to the interventions could be observed for both Hh and Hd groups. Previous literature has suggested that there is an added layer of complexity when attempting to study the communication experiences and auditory-language development in young children with significant hearing loss who receive CIs, compared to typically developing and hearing children (Fink et al., 2007; Kral et al., 2018; Pisoni et al., 2018). Although aided with hearing devices, children with hearing loss born to hearing mothers, may have the additional challenge of navigating more lack of synchronies in mother-child interactions (Lam & Kitamura, 2010).

The duration of hearing device experience for children with significant, bilateral hearing loss could also affect the quantity of verbal interactions (Sacks et al., 2014). That is, intervention effects would be more pronounced in mother-child dyads with normal hearing due to their extended length of listening experience. In the present study there was a suggestion of greater mean increase in AWC of 25.32% and 24.91% in CTC for the group of six hearing dyads after LENA feedback, compared to a change of 9.91% in AWC and 16.57% in CTC for the four dyads in the Hd group. The differences between the Hh and Hd groups were not statistically tested but could be the aim of future studies with larger samples.

Both quantity and quality of language (e.g. lexical diversity of adult language input and the reciprocity of parent-child communication exchanges) of language input underpin the richness of a child's early language environment (Decker & Vallotton, 2016; DesJardin & Eisenberg, 2007; Golinkoff, Hoff, Rowe, Tamis-LeMonda, & Hirsh-Pasek, 2018; Suskind et al., 2016a; Suskind et al., 2016b). Although it is not within the scope of the present study, it is possible that other aspects of mother-child language behaviour, such as types of words used by parents, may have been more sensitive to the effects of LENA feedback. Suskind and colleagues' recent research, for example, used quality of adult language input measures of parental vocabulary (word tokens and types) as outcome measures in two parent-implemented interventions with children with normal hearing (Suskind et al., 2016b) and children with hearing loss (Suskind et al., 2016a); both groups having relatively less socioeconomic advantage. Results from Suskind and colleagues' (2016a) intervention study with children with hearing loss found significant increases in the amount of adult word types used, word tokens and MLU in the treatment group after feedback was given, as opposed to the control group, but no significant changes in LENA-generated counts of AWC and CTC were detected. On the contrary, findings of the randomised controlled pilot with parents of children with normal hearing indicated significant increases in parent-child linguistic interactions characterised by both a greater amount of AWC and CTC, and a greater diversity and amount of word types and tokens used by parents who received feedback in the prescribed intervention (Suskind et al., 2016b). Given the breadth of factors which make up a child's home language environment, it would be a strength of future research to include quality of language input parameters, such as the diversity of parental vocabulary used at home and amount of child-directed speech, as a complement to quantity of language input measures.

6.5.2 Evaluating LENA Feedback and the Use of the Daily Vroom App

In addition to LENA generated feedback as a strategy to catalyse and track maternal quantity of input, it was hypothesised that mother's use of the Daily Vroom mobile app would have significant positive effects on the amount of AWC and CTC. The present study found significant group mean percentage increases in AWC and CTC in the Daily Vroom App and LENA feedback condition (LFA condition) compared to baseline and the no feedback, LENA-Only condition (LO condition). Parent-focused apps, such as the Daily Vroom App, encourage caregivers to be their children's positive agents of change, by encouraging engagement in behaviours which foster early language development (McClure et al., 2018). Given the increases in AWC and CTC after LENA Feedback (LF) was provided to participants, further increases in AWC and CTC with the addition of the Daily Vroom App (LFA) were anticipated. Despite statistically significant mean increases in AWC and CTC from baseline in both the LF and LFA conditions, changes were greater for LF (+22.1%), compared to LFA (+13.6%). It was not known whether providing mothers with two intervention strategies; both LENA feedback and asking mothers to use of the Daily Vroom app in the same condition; produced a research fatigue effect, or whether the potential effects of the Daily Vroom app were masked by the LF condition, or whether ceiling levels of AWC and CTC had already been reached with the LF condition. It is possible that there was simply no more room to increase AWC and CTC after using the Daily Vroom App.

It was an acknowledged study design limitation to introduce the LENA feedback and Daily Vroom app as one condition, without isolating the Daily Vroom App (without LENA feedback) as its own condition. In the development of the present study protocol, the decision to exclude the potential fourth condition, i.e. use of the Daily Vroom App alone, was consciously made, taking into account the research participants' time commitment and their potential attrition.

Nonetheless, the inclusion of the Daily Vroom App in addition to LENA feedback was unique in the present study and overall group findings demonstrated the potential use of this parent-implemented approach. The present study findings that CTC were significantly higher in the LF condition compared to the LFA condition may suggest that asking mothers to complete suggested app activities with their children is more didactic and less child-led. Research has demonstrated that parent-child interaction strategies which followed the child's lead, compared to parental directiveness were successful at promoting back and forth verbal exchanges compared to scenarios where the parent directed the conversation (Girolametto, Weitzman, Wiigs, & Pearce, 1999; Shanley & Niec, 2010).

Objective measures, such as AWC and CTC, cannot provide us with the underlying reasons for intervention efficacy or the lack thereof. Study 2 examined the end-user's perspectives of the Daily Vroom App to facilitate understanding of which app features were associated with behavioural change. In the four Hd dyads, there were idiosyncratic mean percentage changes following LENA feedback and the use of the Daily Vroom App, from -61.8% to +34.3% for AWC and -48.4% to +16% for CTC. Possible sources of variability related to these differences include: the choice of app activities, the time of the day the app was used, whether the dyad's routine could accommodate the suggested activities, the impact of multi-tasking, participants' receptivity and compliance with using the app, family participation in the intervention, likeability of the app and individual maternal interaction styles.

The completion of different app activities was a source of uncontrolled variance which could have affected the amount of AWC and CTC elicited from the activities. Although the dyad's interest in the app activity was not directly measured in the present study, it is proposed that increased parent and/or child interest would lead to increased duration of interactions, resulting in increased CTC. However, if the app activity failed to capture the parent or child's interest, shorter durations of interaction would be likely to occur, leading to lower CTCs in some LFA conditions compared to others.

Mothers' choice of activity types and self-reported frequency of app use were not measured. Parents could select from a range of different activities on the app and could choose not to complete the suggested tip of the day. Although this variability was a study limitation, it conferred a higher degree of autonomy to participants. The Daily Vroom App operates on the premise that parents are able to turn everyday moments with their young children into opportunities for dialogue and hence, provided a range of activity types to suit different scenarios including meal time, bath time and bed time routines (Galinsky et al., 2017). The suggested app activities or tips also ranged by time of day and setting, from the time a child wakes up in the morning through to bedtime, taking into consideration different contexts, including: being at home, in cars, supermarkets, being outdoors, on public transport or while waiting for appointments (Galinsky et al., 2017). Past research has demonstrated that the amount of adult talk and child vocalisations varied depending on types of activities which the caregiver-child dyad were engaged in, due to factors such as competing needs for attention to the task at hand and the amount of background noise present (Soderstrom & Wittebolle, 2013). To illustrate the former, meal time could be argued as a potential language interaction opportunity, however the amount of talk recorded was found to be low especially if the adult-child dyad is more focused on the task of feeding or learning how to eat instead of engaging in talk (Soderstrom & Wittebolle, 2013). It is not clear if the language counts were affected for participants who gravitated towards only selecting meal time activities from the Daily Vroom App, or tasks which required shared attention/ multi-tasking, hence raising an important question for future consideration.

The usual routine for each dyad on LENA recording days also differed. The ability for mothers to incorporate suggested app activities within each dyad's usual routine could have affected the number of Daily Vroom App activity completions, resulting in the wide variation of language counts seen in the LFA condition. In the present study, participants completed app activities voluntarily during the weeks when they were asked to use the DVA. There were not any restrictions on the number of app activities which participants could complete in a day during the LFA condition, hence some dyads completed more activities than others in the trial, whereas mothers who were pressed for time might have only completed one app activity per day. The positive effects of app use on maternal language behaviours could have been diluted across the recording day if rate of app activity completion was low. The lack of objective Daily Vroom App usage metrics and individual user analytics was a shortcoming of the study.

Additionally, some dyads were also able to set aside more organised play time in their daily routine than others, which allowed for more adult-child language interaction opportunities through joint engagement. Previous research has shown that story time and organised play time were activities where the most amount of AWC and CVC were recorded, relative to travel time and outside play (Soderstrom & Wittebolle, 2013). In the case of mother-child Dyad B (Lucy and Charlie), going out and travelling to attend frequent appointments in the late mornings and mid-afternoons on recording days were a priority in their schedule which inevitably limited the amount of time they had to focus solely on play. Watching television also featured regularly as an activity in Lucy and Charlie's recording day(s). Organised play time and story time generated high rates of adult-child talk as they are largely one-to-one interactive activities, as opposed to watching television at home which ranked as a low AWC activity, where the television programme was the central focus (Soderstrom & Wittebolle, 2013).

The case findings could also be further informed by the dyad's family participation rating. The present study utilised a clinician rating to reflect the family's participation in early intervention for the young children with hearing loss in the Hd group. Family participation emphasised a strong focus on promoting early language skills in the family context (Decker & Vallotton, 2016). Among the four dyads in the Hd group, Lucy and Charlie (Dyad B) received the lowest rating of three (average participation) compared to the other three dyads who had an ideal family participation rating of five.

Families with an average participation rating may have busy schedules which impact on their ability to optimise language learning opportunities with their children (Moeller, 2000). In Lucy and Charlie's case, family participation could have affected how the dyad responded to the intervention, particularly when self-directed mobile app usage was involved. Furthermore, the use of the DVA as a self-administered intervention strategy might not be suitable for families with an average participation rating as these families may require more intensive ongoing support and professional guidance in order to foster language interactions with their children. Given that there was a heavy reliance on the part of participants to engage actively and independently with the Daily Vroom App in the present study, larger scaled studies focusing on levels of family participation and the use of mobile app interventions for families of children with hearing loss is warranted.

Research has suggested that the likeability factor of a particular technology has an influence on individuals' compliance with its usage, and thus, its effectiveness in facilitating behavioural change (Alluhaidan, Chatterjee, Drew, & Stibe, 2018). Some variance in the four Hd cases' responses to the DVA may be attributed to subjective likeability. Participants who liked the Daily Vroom App may react more positively and increase their amount of talk and/or verbal interactions and the converse may also be true. Lucy and Charlie (Dyad B) reported in the single case findings that the app was not personally useful, and decreased AWC and CTC were seen for this dyad after its use.

It was possible that individual maternal interaction styles affected AWC and CTC in the LFA condition. Past research has found that mothers vary in their contingent responsiveness to their child's vocalisation attempts (Taumoepeau, 2016). Daily Vroom App activities are focused on fostering parent-child interactions (Galinsky et al., 2017) but LENA generated CTC is not an adequate measure maternal responsiveness or contingency. Given that a LENA-estimated conversational turn is defined as an alternation of talk between a child and adult speaker, the CTC measure provides an indication of the amount of child participation in communication experiences (Richards et al., 2018). CTC changes across study conditions was a proxy for observing maternal language behaviours in response to the child's talk. Past research demonstrated that hearing mothers of children using cochlear implants who employed a more responsive interaction style were able to adapt their communication by using different linguistic strategies to maintain their children's engagement in free play and storybook reading activities (DesJardin & Eisenberg, 2007). It is suggested that completing an app activity facilitated dyads in initiating back-and-forth verbal exchanges around a topic, but a mother with more responsive interaction style may already demonstrate these skills which build and extend her child's learning. Dyad D (Wilma and Fred) demonstrated increases in adult-child CTC from baseline during both intervention (LF and LFA) conditions, but the same increases were not evident in AWC. Whilst LENA-generated AWC estimates word exposure, the proportion of speech which the child actually attends to, is unclear (VanDam et al., 2012). CTC may be the more sensitive measure because it involves a verbal exchange between the adult and child, thus has a higher probability of including child-directed speech (Richards et al., 2018). In Dyad D's case, increases in CTC indicated greater back and forth verbal interactions in the LF and LFA conditions compared to baseline. Further research is needed to confirm whether mothers with more responsive interaction styles are more suited for one intervention approach versus another.

6.6 Overall Strengths and Limitations of Study

6.6.1 Strengths of Study

This study presented a novel caregiver-implemented approach to maximising the quantity of AWC and CTC in the home language environment of young children using the LENA system and the Daily Vroom App. Before recent technological advancements offered researchers the option of automated language processing, investigations into the language activity in children's early environments were restricted to short language samples, involving either a static audio recording device or a live investigator presence in the child's home, coupled with the need to manually transcribe the audio data (Smyth & Brinkman, 2014). In Hart and Risley's (1995) longitudinal study of children's language experiences, eight hours of transcription were required for one hour of audio recording. Six years of transcription and analysis ensued after data were collected for the 42 families (Smyth & Brinkman, 2014). In contrast, the LENA software uses complex algorithms to automatically generate data from audio recordings of up to 16 hours (Smyth & Brinkman, 2014). The portability of the LENA Digital Language Processor (DLP) facilitated unobtrusive data collection across a wide range of dyads' activities thus better representing real-life scenarios (Smyth & Brinkman, 2014). All 10 children in the present study, aged between six months and three years tolerated the small LENA DLP.

The LENA system was used successfully as both a primary outcome measurement tool for measuring the effects of the study interventions on participants, and as a mechanism to create feedback which was shared with mothers about their language behaviours. Significant group findings (for the entire cohort of 10 participants, and for the Hh and Hd groups) highlighted the potential of sharing LENA-generated auditory-linguistic information with mothers to increase the amount of AWC and CTC. Each of the dyads acted as their own baseline, hence enabling the visualisation and description of changes across study conditions. The single subject case description method used for the Hd dyads was important in the development of new interventions as they provide room for understanding the child, parent and family in-context of their lives (Moodie, 2018). It was not a focus of this study to examine dyads in the Hh group using the single case descriptions, however a single case design approach to investigating changes in AWC and CTC for hearing dyads could be explored in future research. At the end of the study, the majority (9 of 10) of the participants reported that they would be interested in continuing to use either the LENA system, the DVA, or both in the future. Participation attrition has also been recognised as a common challenge in intervention trials (Eysenbach, 2005), but in the present study all enrolled participants in the present study completed all study conditions which was a strength of the study.

6.6.2 Limitations of Study

The findings of the present intervention study should be interpreted with caution when applying these results to a wider population of typically developing, hearing children or children with severe to profound, bilateral hearing loss. Recruitment of participants for the present study was based on voluntary participation which could have biased the resultant sample of mothers. It is possible that highly motivated mothers would be more likely to agree to participate. With just 10 dyads, statistical analyses to examine the contribution of family, maternal, and child variables on outcomes and uptake of intervention were not possible. Participant demographics were skewed towards higher relative socio-economic advantage, older median age of the mothers and higher levels of maternal education compared to census population data, hence observations might not be generalisable without further recruitment of participants from a wider demographic pool.

With monitoring devices, it is possible that simply their presence can influence participants to alter the behaviour under study (Suskind et al., 2013). This Hawthorne effect with the use of the LENA DLP was contested by Smyth & Brinkman (2014) who found no significant differences in AWC when parents were consciously aware of the DLP, and parents who were not consciously aware. The present study attempted to control for the Hawthorne effect by completing multiple, day-long recordings in each study condition to facilitate participant acclimatisation to the presence of the LENA DLP. There was a limit, however, to the possible length of such an acclimatisation phase as extending the length of the intervention trials could contribute to research fatigue and attrition. Counterbalancing efforts were made to control for carryover effects from the intervention conditions, however this solution was not ideal given that there were some participants who were unable to complete their prescribed order of conditions. A different experimental study design using separate comparison groups with different treatment arms would address both problems of carryover and Hawthorne effects.

6.7 Future Directions

A challenge for behavioural intervention studies is the generalisation and maintenance of intervention effects. Suskind and colleagues' (2016a and 2016b) found that providing quantitative linguistic feedback created short-term change for parents with less relative socio-economic advantage, but outcomes were not maintained at four months post-intervention. In the LENA Natural Language Study, families who demonstrated initial increases in their AWC and CTC then demonstrated slight decreases, suggesting that behavioural change requires continual evaluation and reinforcement (Gilkerson & Richards, 2009). Significant mean increases in AWC and CTC from baseline for both Hh and Hd groups of dyads during the LF condition were observed, but measurement of long-term maintenance was not within the scope of the present study.

Parent-implemented interventions also largely depend upon parental involvement, and the extent to which parents are able to implement the protocol in real-world circumstances (Moore, 2017). Full compliance with the prescribed weekly conditions over the course of the trial was not observed for any of the participating dyads in the Hd group which impacted on the amount of usable data. Ongoing outcome monitoring and greater engagement with parents in shared decision-making regarding agreed intervention strategies are proposed to lead to better adherence to parent-implemented intervention plans (Moore, 2017).

Current research appears to indicate that variance in the CTC (and not AWC) is key to maximising child language (Wang et al., 2017b). CTC had greater predictive value than AWC on long-term child language and cognitive outcomes in typically developing children at six (Romeo, et al., 2018a) and 14 years of age (Richards et al., 2018). Whether this holds true for children with hearing loss is not known. Regarding the description of changes in AWC and CTC across conditions for each of the cases in the Hd group, the use of visual inspection could have been further complemented with formal statistical methods. Shadish (2014) proposed the use of a multi-level regression model, Bayesian analyses and standardised effect-size estimation to extend the rigor of single case experimental design. The use of parametric analyses in experimental single-subject studies would require full participant compliance and adherence to the prescribed study phases and conditions. The use of inferential statistics could be factored into the design and reporting of future prospective single-subject interventions. Lastly, longitudinal studies with larger samples of dyads (mothers with young children with significant bilateral hearing loss using cochlear implants and/or hearing aids) could examine the relative impact of AWC and CTC on child's language outcomes in these populations (Suskind et al., 2016a; Suskind et al., 2016b).

7 STUDY 2: SURVEY METHOD

Chapter 7 describes the methodology for Study 2 which involved the development and implementation of the Designing eHealth For Clinicians And Families (DeCAF) survey. Understanding factors which shape an individual's intentions about the use of technology in a specific context has been recognised as a pivotal step in promoting technology use and acceptance (Holden & Karsh, 2010). By adopting a user-focused approach, the key aim of the DeCAF survey was to explore mothers' and clinicians' perspectives on the use of LENA and mobile technology to support early child language development.

7.1 RECRUITMENT AND STUDY CONSENT

Study 2 was conducted with the approval of the Royal Victorian Eye and Ear Hospital (RVEEH) Human Research Ethics Committee (HREC) approved project reference 15/1250H and in accordance with the Australian government's National Statement on Ethical Conduct in Human Research (2007; updated 2018). A purposive sampling approach was undertaken as participants for Study 2 were comprised of mothers who had participated in Study 1, and clinicians who had previous experience working with paediatric populations in early intervention or early educational settings.

Clinicians were recruited via calls for Expressions of Interest. An Invitation to Participate was circulated via professional networks; the Speech Pathologists In Deaf Education (SPIDE) Special Interest Group; and HEARing CRC member sites in Australia. Participants provided consent either by returning signed, scanned copies of the Participant Information Consent Form (PICF; Appendix 12) or when they initially accessed an online copy of the DeCAF survey. Participants were prevented from proceeding with the survey unless they had provided consent in the first section of the survey, which included a link to the PICF and a participant declaration (Figure 29). The first section also included a short introduction to the DeCAF survey and instructions for downloading and using the Daily Vroom App (Figure 30).

Wearable Technology and Mobile Application: Clinician and User Perspectives

Participant Consent

* 2 **Please download and read the Participant Information Sheet.**

Please sign and send the completed Consent Form to dawn.choo@unimelb.edu.au.

Alternatively, by selecting the first checkbox option below, you are providing electronic consent to to participating in this online questionnaire.

Declaration by Participant

I have read the Participant Information Sheet or someone has read it to me in a language that I understand.

I understand the purposes, procedures and risks of the research described in the project.

I have had an opportunity to ask questions and I am satisfied with the answers I have received.

I freely agree to participate in this research project as described and understand that I am free to withdraw at any time during the project.

I understand that by ticking the "I provide electronic consent to participating in this online questionnaire" option, I'm agreeing to participate in the questionnaire.

After using the app, you may delete or keep the app from your mobile. Please refrain from sharing the name or details of the mobile app with families who may be potential participants.

- ◯ **I provide electronic consent to participating in this online questionnaire and wish to proceed.**
- ◯ **I do not wish to continue.**

Prev Next

Figure 29: Participant Declaration for the DeCAF Survey

Wearable Technology and Mobile Application: Clinician and User Perspectives

This questionnaire is part of a study looking at the use of digital technologies to optimise the linguistic environment for young children with significant hearing loss. The information collected will provided a rich background for the study researchers to understand the use of wearable LENA technology and the mobile app from your perspective.

Before you begin, please ensure that you are either a current user/have previously used the Daily Vroom App.

Otherwise, please download and trial the Daily Vroom App for at least 10 minutes (click here for more instructions on downloading Daily Vroom).
If you are a clinician, it is your choice whether or not to remove the app from your mobile device after trialing it.
The app download links are as follows:

- For Apple Smartphone Users
- For Android Smartphone Users

This questionnaire will take approximately 20 minutes to complete. Questions marked with an * are compulsory and will require an answer. By selecting the "Next" button, you are agreeing to continue with completion of this questionnaire.

Prev Next

Figure 30: Introduction to the DeCAF Survey and Instructions

7.2 Participants

There were 27 respondents (9 mothers; 18 clinicians) who participated in the DeCAF survey. Their responses consisted of 22 (81.5%) full survey completions and the remaining 5 (18.5%) were partially complete. There were two participants who completed a paper version of the survey while the other 25 participants completed the online version on SurveyMonkey. The respondents were predominantly female (96.3%), lived in Victoria (85.2%) and were between 25 and 34 years of age (44.4%).

7.2.1 Mothers

There were nine mothers who participated in the DeCAF survey after completing Study 1. No further inclusion/exclusion criteria were applied to this group given their prior experience with using the Daily Vroom App and the LENA system as part of the intervention protocol. In this group, two of the nine mothers (22.2%) were between 25 and 34 years of age and the other seven mothers (77.8%) were aged between 35 to 44 years. The majority (n=8) resided in the state of Victoria except one mother who lived in New South Wales.

7.2.2 Clinicians

Recruited clinicians (n=18) were asked to use the Daily Vroom App for at least 10 minutes prior to completing the DeCAF survey. In Study 2, the term ‘clinicians’ is used to refer to speech pathologists, auditory verbal therapists and early intervention professionals who have had previous or current experience working with young children and their families in early intervention and/or early educational contexts. The age ranges of the clinicians varied, with 10 in the 25 to 34 age group, one clinician was under 25 years of age, two clinicians were between 35 to 44 years, four clinicians were in the 45 to 54 years age group and one clinician was over 54 years of age at the time of survey completion. Responses were received from clinicians in Victoria (VIC=15; 83.4%), Queensland (QLD=2; 11.1%) and New South Wales (NSW=1; 5%). Of the 18 clinicians who responded to the DeCAF survey, 10 (55.6%) had worked for 10 or fewer years in healthcare and the remaining 8 (44.4%) had over 10 years of experience in the health workforce. Further information about the participants’ clinical experience and work contexts are detailed in Table 10.

Table 10: Clinician characteristics (n=18)

Clinician	Age Range	Gender	State	Years of Clinical Experience	Work Setting(s)	Age Range of Clients/Patients	Years worked at Present Organisation
1	25 to 34	Female	VIC	Between 6 to 10	Early intervention	2 to 12 years	Less than 6 months
2	25 to 34	Female	VIC	Between 3 to 5	Early intervention and at a Specialist school	4 to 18 years	More than 5 years
3	55 to 64	Female	VIC	30 years and more	Early Education	3 to 6 years	More than 5 years
4	45 to 54	Female	VIC	30 years and more	Hospital and Research	Birth to 5 years	More than 10 years
5	35 to 44	Female	VIC	Between 10 to 20	Hospital	3 months to 99 years	More than 10 years
6	18 to 24	Female	QLD	Between 3 to 5	Early intervention	Birth to 6 years	More than 2 years
7	45 to 54	Female	NSW	Between 20 to 30	Early intervention	Birth to 17 years	More than 5 years
8	25 to 34	Female	VIC	Between 3 to 5	Hospital and Early Intervention	Birth to 7 years	1 to 2 years
9	25 to 34	Female	QLD	Between 6 to 10	Early intervention	Birth to preschool years	1 to 2 years
10	45 to 54	Female	VIC	Between 20 to 30	School	4 to 18 years	More than 10 years
11	25 to 34	Female	VIC	Between 6 to 10	Research	Birth to 7 years	More than 2 years
12	25 to 34	Female	VIC	Between 6 to 10	School and Hospital	Not currently working clinically	N/A
13	25 to 34	Female	VIC	Between 10 to 20	Research and Private Practice	Birth to 12 years	More than 5 years
14	45 to 54	Female	VIC	Between 20 to 30	Early intervention	Birth to 6 years	More than 10 years
15	25 to 34	Female	VIC	Between 3 to 5	School	Primary school years	6 months to 1 year
16	25 to 34	Female	VIC	Between 3 to 5	School	4 to 18 years	More than 2 years
17	35 to 44	Male	VIC	Between 10 to 20	Private Practice	4 to 75 years	More than 5 years
18	25 to 34	Female	VIC	Less than 2 years	Early intervention	Birth to 6 years	Less than 6 months

7.2.3 Development of the DeCAF Survey

The structured, self-administered DeCAF survey (Appendix 13) included a questionnaire comprised of closed-ended items specific for these two target user groups (i.e. clinicians and mothers of young children). Two pre-existing measures found in the research literature were also included either in their original forms or adapted for the purpose of this study (outlined below). In total, the questionnaire consisted of 52 items grouped within five sections as follows: instructions and consent; participant background and demographic information; an eHealth Literacy Scale (Norman & Skinner, 2006a); Mobile App Rating Scale (Stoyanov et al., 2016); perceived impact of the Daily Vroom App and the LENA System (adapted from Stoyanov et al., 2016). The readability of the DeCAF survey was calculated to be at a grade nine reading level with a Flesch Kincaid Reading Ease score of 55.5 (where a higher score on a 100-point scale indicates greater reading ease). All participants in this study had high school level of education or greater which surpassed the indicated grade-level of reading ease. The questionnaire was completed by participants either in paper form or electronically. Participant responses provided online were collected using SurveyMonkey Inc (www.surveymonkey.com). The self-paced questionnaire took approximately 15 minutes to complete.

7.3 Materials and Survey Measures

7.3.1 eHealth Literacy Scale (eHEALS)

The eHEALS (Norman & Skinner, 2006a) is a reliability-tested 8-item instrument of perceived eHealth literacy which was incorporated as the third section of the DeCAF survey. Each of the eHEALS items are rated on a 5-point Likert scale, ranging from *1= strongly disagree* to *5= strongly agree*. The items target a combination of factors including knowledge, comfort and self-assessed skills at searching, evaluation and using electronic health information to address health conditions (Norman & Skinner, 2006a). This tool has also been used as an aid to determine an individual's capacity for engaging with eHealth initiatives, in a variety of health settings, across a range of age groups (Chung & Nahm, 2015). The overall mean eHEALS score was calculated out of five and higher self-assessed ratings indicated a greater personal awareness at applying eHealth information to decision-making.

7.3.2 uMARS: Mobile Application Rating Scale

The User Version of the Mobile Application Rating Scale (uMARS) is an Australian validated rating tool designed for end-users to provide evaluations on the quality of mobile health applications (Stoyanov et al., 2016). Specifically, participants in this study were asked to trial the Daily Vroom App for at least 10 minutes, to determine its usability, functions and purpose before responding to questions on the uMARS. Each of the 20 items on the uMARS is rated on a 5-point Likert response scale. The first 16 items measure objective app quality on four dimensions: app engagement (5 items), functionality (4 items), aesthetics (3 items) and information quality (4 items). Mean scores for the items pertaining to engagement, functionality, aesthetics and information quality are tallied. An overall app quality mean score is calculated by averaging the sum of mean scores on the four dimensions. The remaining four subjective quality uMARS items were scored as individual items so as to reflect value judgements which the participants may have about the Daily Vroom App, including a subjective app star rating out of five, which is consistent with the format of app store star ratings (Stoyanov et al., 2016).

7.3.3 Perceived Impact of the Daily Vroom App and the LENA System

This section on the DeCAF survey was adapted from Stoyanov and colleagues' (2016) 6-item subscale to the uMARS. This supplementary uMARS subscale was used to obtain information about the perceived impact which an app could have on its target users (Stoyanov et al., 2016). Participating clinicians were asked to consider the best interest of families on their paediatric caseload when responding to the statements. The perceived impact items were related to the influence which the app could have on the target health behaviour such as awareness, knowledge, attitudes and intention to change. Participants responded to the six statements that aimed to understand the participants' perception of impact after using the Daily Vroom App by using a 5-point Likert scale ranging from 1=strongly disagree to 5=strongly agree. The response choices were subsequently collapsed into three categories of positive/negative agreement and neutrality (outlined in greater detail in the next section of this chapter). The first set of six statements in this section aimed to understand the participants' perceived impact after using the Daily Vroom App. The six statements were modified from the uMARS to include participant responses about the use of the LENA system. Taking into consideration that some participating clinicians were not very familiar with the LENA system, the response, 'I haven't had sufficient experience or am not familiar with the LENA system' was also included as an option. The six perceived impact items which were related to the LENA system were excluded for participants who selected this response option.

7.4 CONTEXT OF THE STUDY AND APPROACH TO DATA ANALYSIS

Study 1, as described in Chapter 4, aims to provide objective, measurable insights into the changes in language behaviours associated with a parent-implemented digital intervention trial using the LENA system and Daily Vroom App. To complement this investigation, Study 2 presents an analysis of subjective information based on the participants' experience which could add to the effective implementation and uptake of technology in early language interventions. By recruiting target user groups (mothers from Study 1 and clinicians) who would be using the technology, Study 2 focuses on addressing the following research aims:

1. To determine whether there were relationships between background attributes of the survey participants and their maternal characteristics and their self-assessed eHealth literacy ratings;
2. To report on the participants' evaluation of app quality for the Daily Vroom App and to measure mean ratings of perceived impact of using LENA and the Daily Vroom App on early child language; and
3. To explore relationships between the participants' DVA quality ratings and perceived impact ratings of using the DVA.

The questionnaire responses derived from rating scale measures and multiple-choice questions were tabulated numerically. To inform the analysis for the first aim of Study 2, summarised data collected on maternal characteristics, based on the measures described in Study 1, were compiled for the 9 participants who also completed the DeCAF survey.

Using a descriptive and correlational survey research design, data analysis was conducted using Minitab Statistic Software Version 17. For the first aim, participants' age was treated as an ordinal variable and survey responses were collected based on multiple-choice options reflecting five age ranges. A Kruskal-Wallis Test was used to analyse whether the age of participants had a substantive influence on their mean overall eHEALS rating of self-perceived eHealth literacy skills. Additionally, a correlation matrix was used to analyse associations between mothers' attributes collected in Study 1 and their self-reported skills of eHealth literacy.

For the uMARS sections of the survey, mean and median overall response ratings out of five were reported based on the participants' Daily Vroom App evaluation of app quality and the perceived impact of the evaluated app and use of LENA. To address the second aim of the Study 2, the 5-point Likert scale options were collapsed into three categories: neutral, positive (*agree* and *strongly agree*) and negative (*disagree* and *strongly disagree*) response choices. The degree of agreement (positive, negative or neutral) which represented the largest proportion of responses towards each perceived impact statement were described as an indication of consensus by the survey participants. Lastly, correlation analysis was used to explore relationships between the participant responses to the uMARS items pertaining to the Daily Vroom App; specifically, the measures of app quality and perceived impact statements.

8 STUDY 2: SURVEY RESULTS

Results from the Designing eHealth For Clinicians And Families (DeCAF) survey are reported in this chapter for the 27 participants (9 mothers; 18 clinicians) who had trialled the Daily Vroom mobile app before completing the questionnaire. To address the aims of Study 2, the participants' perceived eHealth literacy skills are described in section 8.1. The degree of correlation between the background attributes of mothers and their perceived eHealth literacy skills are detailed in section 8.1.2. Participant evaluations of the quality of the Daily Vroom App (DVA) and their perceived benefits (impact) of using the DVA and LENA for supporting children's early language development are detailed in sections 8.2 and 8.3. The degree of correlation between participant ratings of app quality and perceived impact of the DVA measured using the user version of the Mobile Application Rating Scale (uMARS) are outlined in section 8.4.

8.1 DESCRIPTIVE STATISTICS FOR EHEALTH LITERACY SCALE (EHEALS) RATINGS

All 27 participants completed the eight items on the eHEALS section of the DeCAF survey. The overall mean eHEALS score was 3.83 (*SD* 0.51), which ranged from 3.15 to 5, with a median of 4 (*IQR* 0.75). Whilst the group of 9 mothers had an overall mean eHEALS rating of 3.6 (*SD* 0.52; *Range* 3.13-4.38) and a median of 3.25 (*IQR* 0.94), the group of 18 clinicians had a slightly higher overall mean eHEALS rating of 3.95 (*SD* 0.48; *Range* 3.13-5) and a median of 4 (*IQR* 0.82), this difference was not significant, $U = 93.0$, $p = 0.09$.

Higher eHEALS scores indicate greater self-perceived eHealth literacy skills. The mean eHEALS ratings for this sample of 27 participants were skewed towards the higher end of the 5-point Likert scale, but an Anderson Darling test indicated no significant departure from normality. Descriptive statistics for the participants are shown in Table 11.

Table 11: Descriptive statistics for eHEALS ratings by the 27 participants

eHEALS items	All (N=27)				Mothers (n=9)				Clinicians (n=18)			
	Mean	Median	SD	Range	Mean	Median	SD	Range	Mean	Median	SD	Range
1. I know how to find helpful resources on the Internet.	3.89	4.00	0.93	1- 5	3.67	4.00	1.23	1- 5	4.00	4.00	0.77	2- 5
2. I know how to use the Internet to answer my health questions.	3.93	4.00	0.78	1- 5	3.56	4.00	1.24	1- 5	4.11	4.00	0.32	4- 5
3. I know what health resources are available on the Internet.	3.56	4.00	0.85	1- 5	3.11	3.00	1.05	1- 4	3.78	4.00	0.65	2- 5
4. I know where to find helpful health resources on the Internet.	3.63	4.00	0.74	2- 5	3.56	4.00	0.53	3- 4	3.67	4.00	0.84	2- 5
5. I know how to use the health information I find on the Internet to help me.	3.85	4.00	0.77	2- 5	3.67	4.00	1.00	2- 5	3.94	4.00	0.64	3- 5
6. I have the skills I need to evaluate the health resources I find on the Internet.	4.04	4.00	0.71	3- 5	3.67	3.00	0.87	3- 5	4.22	4.00	0.55	3- 5
7. I can tell high quality from low quality health resources on the Internet.	4.07	4.00	0.62	3- 5	3.78	4.00	0.44	3- 4	4.22	4.00	0.65	3- 5
8. I feel confident in using information from the Internet to make health decisions.	3.70	4.00	0.67	2- 5	3.78	4.00	0.44	3- 4	3.67	4.00	0.77	2- 5
Overall mean eHEALS rating	3.83	4.00	0.51	3.13- 5	3.60	3.25	0.52	3.13- 4.38	3.95	4.00	0.48	3.13- 5

8.1.1 Age range and perceived eHealth literacy skills

Of the 27 participants, a majority of participants (12; 44.4%) were aged between 25 and 34 years. There were nine participants (33.3%) between 35 and 44 years, four participants (14.81%) between 45 and 54 years, one participant (3.7%) was aged between 55 and 64, and one participant (3.7%) was aged between 18 and 24 at the time of survey completion. Figure 31 displays the proportion of mothers and clinicians in each age group. There was no statistical evidence of an effect of age of participants and their self-perceived rating on the eHEALS [$H(4)$=1.65, p= 0.8].

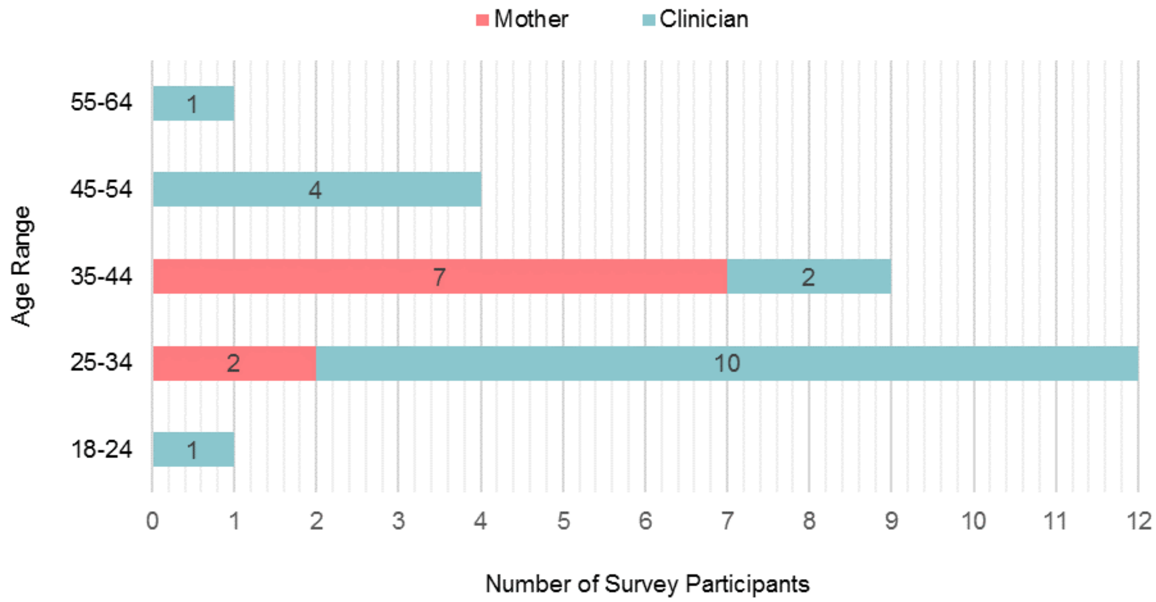


Figure 31: Reported age ranges of mothers and clinicians who participated in the DeCAF survey

8.1.2 Maternal characteristics and perceived eHealth literacy skills

In this sample of nine mothers who had completed both Study 1 and 2, significant relationships were found between maternal occupational skill level, maternal receptive vocabulary as measured using the PPVT-4 and mothers' ratings on three of the eight eHEALS items. More specialised maternal occupational skill levels were significantly correlated with higher agreement ratings on eHEALS item 5 'I know how to use the health information I find on the Internet to help me' (r_s= -0.7, p<0.05) and eHEALS item 8 'I feel confident in using information from the Internet to make health decisions' (r_s= -0.68, p<0.05). Higher maternal vocabulary standard scores on the PPVT-4 were significantly correlated with eHEALS item 4 'I know where to find helpful health resources on the Internet' (r_s= 0.73, p<0.05) and eHEALS item 8 'I feel confident in using information from the Internet to make health decisions' (r_s= 0.76, p<0.05). No statistically significant relationships were found between self-ratings of parenting competence or parenting knowledge and self-assessed eHealth literacy on the eHEALS for this sample.

8.2 Descriptive Statistics based on user version of the Mobile Application Rating Scale (uMARS) Ratings

8.2.1 uMARS App Quality Ratings for the Daily Vroom App

A total of 22 of the 27 participants completed the uMARS section of the DeCAF survey which contained items evaluating the quality of the Daily Vroom App. Their overall mean quality rating for the Daily Vroom App was 3.85 out of 5 (*SD* 0.51), with a range of 2.3 to 4.5, and a median of 3.92 (*IQR* 0.62). Both clinicians and mothers showed similar mean and median ratings on the first four app quality subscales (engagement, functionality, aesthetics and information quality) for the Daily Vroom App. A Mann-Whitney test suggested that there were no significant differences between the group ratings assigned by mothers and clinicians for overall app quality, U= 99, p= 0.79.

Results from the subjective quality subscale showed that 8 of the 22 participants (35%) responded with a rating of 4 when asked if participants would recommend the Daily Vroom App to people who might benefit from it. Mothers (n=9) had a mean rating of 3.89 (*SD* 1.27), with a range of 2 to 5 and a median of 4 (*IQR* 2.5) which corresponded with the description of 'there are many people I would recommend this app to' as compared to the clinicians (n=13) who had a mean rating of 3.39 (*SD* 0.65), with a range of 2 to 4 and a median of 3 (*IQR* 1) which corresponded with the description, 'maybe, there are several people I would recommend this app to'. Half (n=11) of the participants reported that they would use the app between 10 to 50 times in the next 12 months and 10 (46%) of participants reported that they may pay for the app. On the final item of the subjective quality subscale 'What is your overall (star) rating of the app?', 10 of the participants (46%) gave the Daily Vroom App an overall star rating of 4 (good). This subscale aimed to mirror the format of app store star ratings, with an indicative scale of 1 star (inadequate) to 5 stars (excellent). Mothers had assigned the Daily Vroom App a mean star rating of 3.78 (*SD* 0.97), with a range of 2 to 5 and a median of 4 (*IQR* 1.5) reflecting a *good* app quality rating, whereas participating clinicians had a mean star rating of 3.39 (*SD* 0.65), with a range of 2 to 4 and a median of 3 (*IQR* 1) reflecting an *acceptable* app quality rating. A Mann-Whitney test suggested that there were no significant differences between the group ratings assigned by mothers and clinicians for overall star rating of the Daily Vroom App, U= 119.5, p= 0.26. Descriptive statistics for the participants' uMARS ratings have been detailed below in Table 12.

Table 12: Descriptive statistics of uMARS ratings by 22 survey participants

uMARS App Quality items	All (n=22)				Mothers (n=9)				Clinicians (n=13)			
	Mean	Median	SD	Range	Mean	Median	SD	Range	Mean	Median	SD	Range
Engagement (5 items)												
Entertainment	3.68	3.50	0.89	2- 5	3.89	4.00	0.93	3- 5	3.54	3.00	0.88	2- 5
Interest	4.00	4.00	0.69	3- 5	4.00	4.00	0.87	3- 5	4.00	4.00	0.58	3- 5
Customisation	2.86	3.00	0.83	1- 4	2.78	3.00	0.97	1- 4	2.92	3.00	0.76	2- 4
Interactivity	3.05	3.00	1.09	1-5	3.00	3.00	0.71	2- 5	3.08	4.00	1.32	1- 4
Target group	3.86	4.00	0.99	2- 5	3.78	4.00	1.09	2- 5	3.92	4.00	0.95	2- 5
Overall mean engagement score	3.49	3.00	0.62	2- 4.4	3.49	3.60	0.63	2.6- 4.4	3.49	3.40	0.63	2- 4.4
Functionality (4 items)												
Performance	4.23	4.00	0.87	2- 5	4.11	4.00	0.78	3- 5	4.31	5.00	0.95	2- 5
Ease of Use	4.46	4.50	0.60	2- 5	4.56	5.00	0.53	4- 5	4.39	4.00	0.65	3- 5
Navigation	3.96	4.00	0.65	3- 5	4.00	4.00	0.71	3- 5	3.92	4.00	0.64	3- 5
Gestural design	4.14	4.00	0.64	3- 5	4.00	4.00	0.71	3- 5	4.23	4.00	0.60	3- 5
Overall mean functionality score	4.19	4.25	0.53	3- 5	4.17	4.00	0.50	3.5- 5	4.21	4.25	0.57	3- 5
Aesthetics (3 items)												
Layout	4.23	4.00	0.75	3- 5	4.22	4.00	0.83	3- 5	4.23	4.00	0.73	3- 5
Graphics	3.96	4.00	0.79	3- 5	3.89	4.00	0.78	3- 5	4.00	4.00	0.82	3- 5
Visual appeal	3.59	4.00	0.67	2- 5	3.56	4.00	0.53	3- 4	3.62	4.00	0.77	2- 5
Overall mean aesthetics score	3.92	4.00	0.63	3- 5	3.89	4.00	0.65	3- 4.67	3.95	4.00	0.64	3- 5
Information (4 items)												
Quality of information	3.77	4.00	0.97	1- 5	3.78	4.00	0.83	2- 5	3.77	4.00	1.09	1- 5
Quantity of information	3.82	4.00	0.85	1- 5	4.00	4.00	0.71	3- 5	3.69	4.00	0.95	1- 5
Visual information	3.83	4.00	0.86	1- 5	3.88	4.00	0.35	3- 4	3.80	4.00	1.14	1- 5
Credibility of source	3.73	4.00	0.77	2- 5	3.78	4.00	0.67	3- 5	3.69	4.00	0.86	2- 5
Overall mean information score	3.79	4.00	0.71	1.2- 4.6	3.84	4.00	0.47	3- 4.5	3.76	4.00	0.85	1.2- 4.6
Overall mean app quality rating	3.85	3.92	0.51	2.3- 4.5	3.85	3.90	0.43	3.2- 4.5	3.85	3.95	0.58	2.3- 4.53
Subjective subscale (4 items)												
Would you recommend this app	3.59	4.00	0.96	2- 5	3.89	4.00	1.27	2- 5	3.39	3.00	0.65	2- 4
How many times would you use this app in next 12 months	3.68	4.00	0.84	2- 5	3.56	4.00	0.88	2- 5	3.77	4.00	0.83	2- 5
Would you pay for this app	3.09	3.00	0.92	1 -5	3.22	3.00	1.09	2- 5	3.00	3.00	0.82	1- 4
Overall star rating of the app	3.55	4.00	0.80	2 -5	3.78	4.00	0.97	2- 5	3.39	3.00	0.65	2- 4

8.3 Perceived Impact ratings for the Daily Vroom App and LENA system

8.3.1 uMARS Perceived Impact Ratings for the Daily Vroom App

Regarding participants' perceived impact of using the Daily Vroom App, 14 of the participants (63.6%) agreed/strongly agreed that the Daily Vroom App increased their awareness of how language input and exposure affected their child's early language development. The sample (n=22) had a mean agreement rating for awareness of 3.64 (*SD* 0.79), with a range of 2 to 5 and a median of 4 (*IQR* 1). Participants had a mean knowledge rating of 3.4 (*SD* 0.85), ranging from 2 to 5 and a median of 4 (*IQR* 1), with 12 of them (54.6%) agreeing/strongly agreeing that the DVA increased their knowledge of how language input and exposure affected their child's early language development. There were 14 of the participants (63.6%) who agreed/strongly agreed that the DVA changed their attitudes towards improving the amount of language input their child receives. A mean agreement rating of 3.68 (*SD* 0.72) and a median of 4 (*IQR* 1) were assigned to attitudes; the participants' ratings ranged from 2 to 5. A majority of participants (n=18; 81.82%) agreed/strongly agreed that the DVA increased their intentions/motivation to address the amount of language input their child received. Participants had a mean intention to change agreement rating of 3.82 (*SD* 0.59), with a range of 2 to 5 and a median of 4 (*IQR* 0). Half (n=11; 50%) of participants agreed that the DVA encouraged them to seek further help to address how language input and exposure affected their child's early language development. They had a mean agreement rating for help-seeking behaviour of 3.36 (*SD* 0.73), with a range of 2 to 4 and a median of 3.5 (*IQR* 1). Most participants (n=16; 72.7%) agreed/strongly agreed that the use of the DVA affected the amount of language input their child received. A mean rating of 3.69 (*SD* 0.9), with a range of 1 to 5 and a median of 4 (*IQR* 1) was found for the behaviour change item. Results of Mann-Whitney testing suggested that there were no differences between the perceived impact ratings reported by mothers and clinicians for the Daily Vroom App (descriptive statistics are outlined below in Table 13).

Table 13: Descriptive statistics of perceived impact ratings after using the Daily Vroom App by 22 survey participants

uMARS Perceived Impact items (DVA)	All (n=22)				Mothers (n=9)				Clinicians (n=13)			
	Mean	Median	SD	Range	Mean	Median	SD	Range	Mean	Median	SD	Range
Awareness	3.64	4.00	0.79	2- 5	3.89	4.00	0.78	3- 5	3.46	4.00	0.78	2- 4
Knowledge	3.41	4.00	0.85	2- 5	3.67	4.00	0.87	2- 5	3.23	3.00	0.83	2- 4
Attitudes	3.68	4.00	0.72	2- 5	3.56	3.00	0.88	2- 5	3.77	4.00	0.60	3- 5
Intention to Change	3.82	4.00	0.59	2- 5	3.78	4.00	0.44	3- 4	3.85	4.00	0.69	2- 5
Help-seeking	3.36	3.00	0.73	2- 4	3.56	4.00	0.73	2- 4	3.23	3.00	0.73	2- 4
Behaviour Change	3.68	4.00	0.89	1- 5	3.89	4.00	0.93	2- 5	3.54	4.00	0.88	1- 4

8.3.2 uMARS Perceived Impact Ratings for the use of LENA

Following the exclusion of participating clinicians (n=7) who had selected response options indicating that they not heard of, were not familiar with, or had not had sufficient experience with the LENA system, 15 participants' responses (9 mothers, 6 clinicians) were analysed for the perceived impact of using LENA. Most (n=13; 86.6%) of the participants agreed/strongly agreed that the use of LENA had increased their awareness of how language input and exposure could affect their child's early language development. The overall mean agreement rating for awareness was 4.07 (*SD* 1.16), with a range of 1 to 5 and a median of 4 (*IQR* 1). There were 12 participants (80%) who agreed/strongly agreed that the use of LENA increased their knowledge of how language input and exposure affected their child's early language development and increased their intentions/motivation to address the amount of language input their child received. The overall mean agreement rating for knowledge was 4 (*SD* 0.85), with a range of 2 to 5 and a median of 4 (*IQR* 1). The overall mean agreement rating for intention to change was 3.93 (*SD* 0.8), with a range of 2 to 5 and a median of 4 (*IQR* 0). Two-thirds (n=10; 66.7%) of participants agreed/strongly agreed that the use of LENA changed their attitudes towards improving the amount of language input their child received. The overall mean agreement rating for attitudes was 3.67 (*SD* 0.98), with a range of 1 to 5 and a median of 4 (*IQR* 1). There were 11 participants (73.3%) who agreed/strongly agreed that the use of LENA encouraged them to seek further help to address how language input and exposure affected their child's early language development, and the use of LENA affected the amount of language input their child received. The overall mean agreement rating for help-seeking was 3.6 (*SD* 0.83), with a range of 1 to 4 and a median of 4 (*IQR* 1). The overall mean agreement rating for behaviour change was 3.87 (*SD* 1.06), with a range of 1 to 5 and a median of 4 (*IQR* 2). Results of Mann-Whitney testing suggested that there were no differences between the perceived impact ratings reported by mothers and clinicians for the use of LENA (descriptive statistics are outlined below in Table 14). Figure 32 illustrates the survey participants' mean and median agreement ratings on the 5-point Likert scale to each of the six perceived impact items pertaining to both the Daily Vroom App and LENA.

Table 14: Descriptive statistics of perceived impact ratings regarding the use of LENA by 15 survey participants

uMARS Perceived Impact items (LENA)	All (n=15)				Mothers (n=9)				Clinicians (n=6)			
	Mean	Median	SD	Range	Mean	Median	SD	Range	Mean	Median	SD	Range
Awareness	4.07	4.00	1.16	1- 5	4.56	5.00	0.53	4- 5	3.33	4.00	1.51	1- 5
Knowledge	4.00	4.00	0.85	2- 5	4.22	4.00	0.67	3- 5	3.67	4.00	1.03	2- 5
Attitudes	3.67	4.00	0.98	1- 5	3.78	4.00	0.67	3- 5	3.50	4.00	1.38	1- 5
Intention to Change	3.93	4.00	0.80	2- 5	4.11	4.00	0.60	3- 5	3.67	4.00	1.03	2- 5
Help-seeking	3.60	4.00	0.83	1- 4	3.78	4.00	0.44	3- 5	3.33	4.00	1.21	1- 5
Behaviour Change	3.87	4.00	1.06	1- 5	4.11	4.00	0.78	3- 5	3.50	4.00	1.38	1- 5

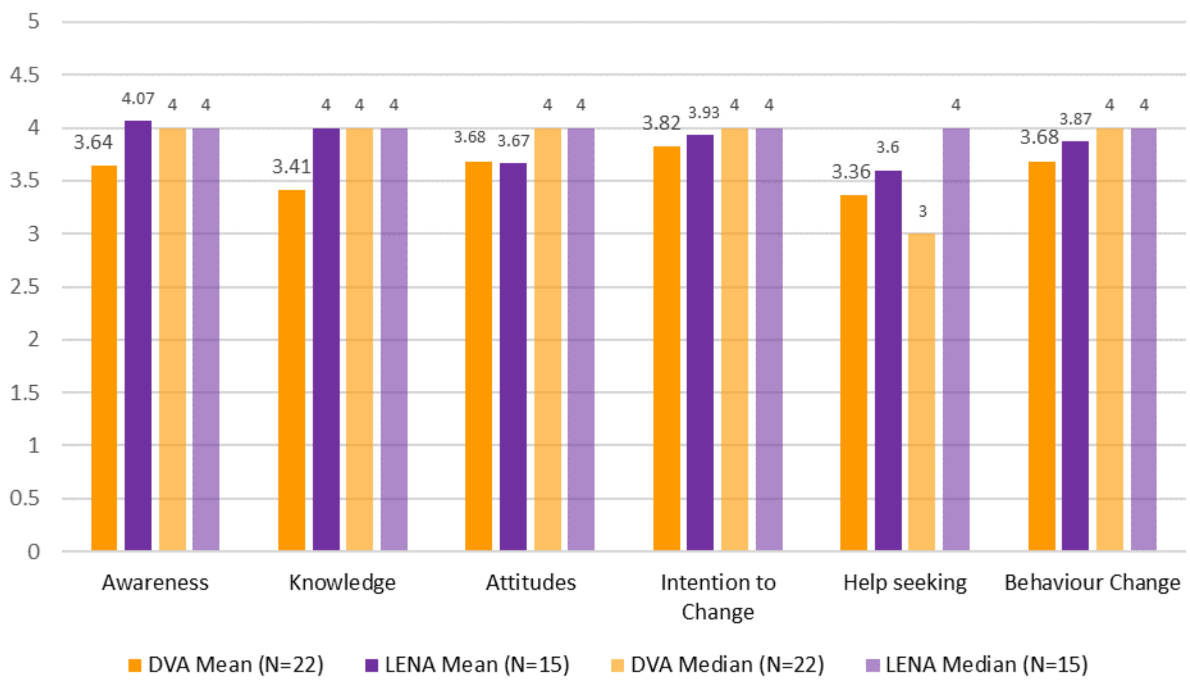


Figure 32: Perceived impact mean and median agreement ratings for the use of the LENA and DVA

8.4 Relationships between app quality ratings and perceived impact ratings after using the Daily Vroom App

Spearman correlation analysis identified associations between users' feedback on the DVA, and the perceived benefits of the DVA on child language. Given the number of comparisons made between app quality and perceived impact statements, the significance level was set to $p<0.01$. Correlational findings are reported in Table 15 below.

Higher ratings of agreement to the awareness statement, 'This app has increased my awareness of how language input and exposure affects my child's early language development' were significantly correlated with higher participant ratings of information: i.e. visual information; credibility of source; quality and quantity of information (r_s= 0.56, $p<0.01$). There was a significant positive correlation between agreement ratings to the behaviour change statement, 'Use of this app will increase the amount of language input my child receives' and app engagement (r_s= 0.58, $p<0.01$). Higher participant ratings of the Daily Vroom App's aesthetical quality were significantly associated with greater agreement with the help-seeking statement, 'This app would encourage me to seek further help to address how language input and exposure affects my child's early language development'.

The overall star ratings assigned by participants were correlated positively with higher agreement on the intention to change (r_s= 0.59, $p<0.01$) statement, 'The app has increased my intentions/motivation to address the amount of language input my child receives'. Participant ratings on the subjective item, 'Would you pay for this app?' were significantly correlated with the most number of perceived impact statements, including: intention to change (r_s= 0.58, p<0.01); help-seeking (r_s= 0.54, p<0.01); and behaviour change (r_s= 0.69, p<0.01); suggesting that participants who were hypothetically willing to purchase the Daily Vroom App also reported greater perceived benefits from using it. The remaining comparisons between app quality items and perceived impact ratings were not significant.

Table 15: Matrix of Spearman correlations between survey participants' mean app quality ratings and mean perceived impact ratings

N.B. Significant correlations (p<0.01) are in bold. Spearman correlation (rs) value (above) and p-value (below) are provided for each correlation.

Perceived Impact Items	**App Quality (Objective)**				**App Quality (Subjective)**			
	Engagement	Functionality	Aesthetics	Information	Would you recommend this app	How many times would you use this app in next 12 months	Would you pay for this app	Overall star rating of the app
Awareness	0.41	0.45	0.32	**0.56**	0.25	0.19	0.13	0.36
	0.06	0.04	0.14	**0.007**	0.26	0.39	0.55	0.10
Knowledge	0.34	0.22	0.44	0.44	0.14	0.04	0.34	0.35
	0.12	0.32	0.04	0.04	0.53	0.86	0.12	0.11
Attitudes	0.31	0.30	0.20	-0.04	0.13	0.21	0.09	0.28
	0.17	0.17	0.38	0.87	0.58	0.34	0.70	0.21
Intention to Change	0.39	0.43	0.26	0.37	0.41	0.52	**0.58**	**0.59**
	0.08	0.05	0.24	0.09	0.06	0.01	**0.005**	**0.004**
Help-seeking	0.28	0.17	**0.56**	0.36	0.24	0.15	**0.54**	0.34
	0.21	0.46	**0.007**	0.10	0.29	0.50	**0.009**	0.12
Behaviour Change	**0.58**	0.28	0.45	0.17	0.38	0.40	**0.69**	0.49
	0.005	0.21	0.04	0.45	0.08	0.07	**<0.001**	0.02

9 Study 2: Survey Discussion

This chapter discusses the Designing eHealth For Clinicians and Families (DeCaF) survey findings for Study 2. The DeCAF survey investigated the use of the Daily Vroom App (DVA) and LENA technology from the perspectives of mothers and clinicians. Mothers of young children who had participated in Study 1, and clinicians with previous or current experience working with young children completed the DeCAF survey. Section 9.1 of this chapter summarises associations between participants' attributes, their self-ratings of eHealth literacy (eHEALS rating), and their views (app quality and perceived impact) on the Daily Vroom App and the use of LENA on child language. The following sections (9.3 to 9.5) discuss Study 2's findings with regard to the present research aims, existing literature on technology designed around the user's experience, and the chapter concludes with future research directions in section 9.7.

9.1 Study 2: Summary of Results

Three aims for Study 2 were centred around factors influencing the end-user experience of the Daily Vroom App and LENA technology. The first aim examined relationships between participant characteristics and their eHEALS rating. The first hypothesis (1.1) for Study, that participant age would be associated with eHEALS ratings, was not supported (Kruskal Wallis test). In contrast, Study 2's second hypothesis (1.2) was supported with significant correlations between mothers' occupational skill level, maternal receptive vocabulary and their eHEALS ratings. Mothers with higher eHEALS ratings, specifically for their ability to find health information on the internet and confidence in using information from the internet to make health decisions, also had more specialised occupations. Additionally, mothers with higher ratings on the ability to find online resources, confidence using information from the internet to make health decisions and knew where to find helpful health resources on the internet, were found to have higher receptive vocabulary scores on the PPVT-4.

Using the user version of the Mobile Application Rating Scale (uMARS), the second aim of Study 2 explored participants' DVA quality ratings, and perceived benefits of using LENA and the DVA on early child language. The overall mean DVA objective quality subscale score was 3.85 out of 5 (which was derived from four dimensions of objective app quality; 3.5 for engagement, 4.2 for functionality, 3.9 for aesthetics, and 3.8 for information quality). On the subjective subscale of the uMARS, participants assigned the DVA an overall star rating of 3.55 out of 5, which was indicative of an average to good quality mobile app. Ratings provided by mothers (n=9) and clinicians (n=13) on the uMARS objective and subjective subscales did not differ significantly.

Regarding perceived impact of using the DVA, 'Intention to change' received the highest rating with 18 of 22 survey participants (81.8%) agreeing that the DVA increased their intention to use more language with their child. Regarding perceived impact of using LENA, 'awareness' was the highest rated item with 13 of 15 survey participants (86.6%) agreeing that LENA had increased their awareness of how language input and exposure could affect their child's early language development.

The third aim of Study 2 addressed relationships between app quality and the perceived impact ratings for the DVA. This hypothesis was supported as significant positive associations were found between app engagement, overall app star rating and the perceived impact on behaviour change. Additionally, there was a significant positive relationship between aesthetical app quality and the perceived impact on help-seeking behaviour, and between information quality and the perceived impact on awareness. Additionally, significant Spearman correlations suggested that participants with higher agreement ratings about the intention to change, help-seeking and behaviour change after using the DVA, indicated they would be more willing to purchase the app.

9.2 Sociodemographic factors and Perceived eHealth Literacy skills

In Study 1, mother-child dyads used the LENA, received remote feedback using communication technology and completed activities suggested on a mobile application (Daily Vroom App; DVA). While changes across study conditions have been discussed in Study 1 (Section 5.3), it is important not to assume (when deploying eHealth initiatives) that the intended users all have the skills to work with technology and participate optimally in these interventions (Norman & Skinner, 2006a). There is little value in eHealth tools and resources if intended users lack the skills to effectively engage in digitally-driven interventions (Norman & Skinner, 2006a). In Study 2, mothers and clinicians completed the eHEALS (Norman & Skinner, 2006a) to measure their self-ratings of eHealth literacy. This component of Study 2 determined whether mothers (i.e. intended end-users) and clinicians (i.e. intended service providers) had the capacity to either promote, and/or engage with LENA and the DVA. The overall mean and median eHEALS ratings for mothers (n=9) were 3.6 and 3.3, and 3.9 and 4, respectively for clinicians (n=18) in the present sample, reflecting high eHealth literacy abilities.

In addition to self-ratings of eHealth ability, measured by the eHEALS, mothers and clinicians needed to also demonstrate readiness to use eHealth tools. Lennon and colleagues (2017) determined that readiness was a key factor enabling implementation of digital health to support service provision for clients. eHealth literacy skills are also known to be influenced by personal characteristics, including education, employment of the intended users, and age (Choi & DiNitto, 2013; Venkatesh, 2012). Neter and Brainin (2012) showed, for example, that younger adults (mean age of 38 years of age compared to 44 years of age), with higher educational attainment (i.e. academic degrees), and higher socioeconomic status, had more access to more digital resources and demonstrated higher eHealth literacy (Neter & Brainin, 2012).

9.2.1 Age and Perceived eHealth Literacy skills

In contrast to Neter and Brainin's (2012) findings, the present study found no significant differences between age groups for eHEALS ratings. No apparent relationship between age at eHEALS completion and ratings was also found by the original developers of the eHEALS instrument, Norman and Skinner (2006a). The present study's small sample size of 27, and the small number of participants (n=5) aged 45 years and above may have made it difficult to demonstrate an age effect. Most of the present survey participants were aged between 25 to 34 years. Regardless of age, clinicians who volunteered to participate in the present study could have had a predisposed interest in mobile apps, or a greater inclination towards using digital technologies. All but two participants, for example, opted to complete the DeCAF survey online instead of the paper version. It is proposed that their greater familiarity with other technology may be associated with their use of eHealth technologies (Norman & Skinner, 2006a). Conversely, persons with less self-efficacy with regard to technology may be less likely to utilise it (Lasslo, Anthony, Reif, & Bell, 2017).

Another shortcoming of the present study was the inherent requirement that all participants had to trial the Daily Vroom App on a mobile device to participate. This may have precluded non-mobile device users from participation if they did not have ready access to a device, thus resulting in selection bias. Future studies would benefit from having either a representative sample of survey respondents with a more even age distribution, or a comparison group of participants who opted to complete paper versions of the DeCAF survey.

9.2.2 Maternal characteristics and perceived eHealth literacy skills

There is a growing recognition that eHealth literacy is a distinct, composite skill which encompasses six main abilities: language; information; media; health; computer; and scientific literacy (Norman & Skinner, 2006b). However, little has been published about the eHealth literacy skills of participants in language intervention studies which use information communication technologies for service delivery. Within the present sample of nine mothers who had participated in both the intervention trial (Study 1) and completed the DeCAF survey, significant associations were identified between maternal receptive vocabulary and self-ratings on the eHEALS. Mothers with higher receptive vocabulary abilities, were more knowledgeable about where to find helpful online health information, and more confident about using online health resources in their decision-making. Receptive vocabulary skills are a key component of literacy (Snow, 2016), and prior research studies highlighted the impact of language on eHealth literacy (Norman & Skinner, 2006b; Werts & Hutton-Rogers, 2013). Individuals with low literacy were more reluctant to seek out web-based health information and demonstrated more difficulty interpreting online information (Birru et al., 2004). The present study also found that having the ability to apply knowledge from electronic sources to address health issues, was positively correlated with having a more specialised, higher skilled occupation. It is proposed that eHealth literacy is not a static participant attribute, that is, there is the potential for participants to achieve greater levels of fluency if they develop abilities in one or more of the six underlying components of eHealth literacy (Norman & Skinner, 2006b). Evaluation measures, such as the eHEALS, provide a method of gauging fit between eHealth initiatives and the self-appraised skills of the intended users, but are limited in measuring skill levels based on actual performance (Norman & Skinner, 2006a). Findings from eHEALS self-ratings in the present study suggested that there is merit in identifying specific participant characteristics which may affect engagement with eHealth tools and/or interventions.

9.3 Daily Vroom App Quality

The user version of the Mobile Application Rating Scale (uMARS) was used by mothers and clinicians to evaluate the quality of the Daily Vroom App on an objective subscale which extended beyond the star rating system commonly used in app stores. The proliferation of mobile apps makes it difficult to locate high quality apps and presents a risk for users to select apps based on popularity, such as high star ratings, due to the lack of information about the quality of apps (Stoyanov et al., 2015). The present sample's uMARS mean app quality rating was 3.85 which was lower than the star ratings provided on two widely-used app stores: Google Play and Apple Store. The DVA (Vroom Version 2.0.28; updated 10 August 2018) received a 4-star review on the Apple Store and a 4.6-star rating on Google Play (Vroom Version 2.0.22; updated 12 February 2018). The lower scores for the app in the current study may be due to more stringent criteria outlined by the four app quality indicators of engagement, functionality, aesthetics and information which participants had to consider, whereas there was a lack of review criteria for the star ratings on the app stores.

The effectiveness of eHealth tools lies in their ability to convey the appropriate information, be interactive, easy to use, engaging and accessible to an array of diverse users (Kreps & Neuhauser, 2010). Health professionals are proposed to focus on clinical effectiveness of apps, while patients are proposed to focus on user experience and ease of use as important features (Hingle & Patrick, 2016; Krebs & Duncan, 2015). The uMARS in the present study, however, did not indicate significant differences in opinions of the DVA across quality indicators of engagement, functionality, aesthetics and information. Apart from the star rating reviews available on mainstream app stores, there have been no further published app quality ratings for the DVA in the research literature to enable more comparisons to be made.

As the uMARS is a relatively new instrument, the present study drew on Furlong, Morris, Serry and Erickson's (2018) appraisal of 132 mobile apps (for the treatment of speech disorders) using the Mobile Application Rating Scale (Stoyanov et al., 2015), for the interpretation of descriptive app ratings for the DVA. The present study's DVA mean objective quality score (average of the four quality indicators) was 3.9 out of 5 (*SD* 0.5; *Range* 2.3 to 4.5) which was slightly higher than the mean of 3.7 (*SD* 0.3, *Range* 2.5 to 4.6) given to the 132 apps by two Certified Practising Speech Language Pathologists with experience working with children with speech disorders (Furlong et al., 2018).

The present study's DVA mean quality of 3.9, corresponds to an 'average/acceptable' app quality. The majority of speech apps (80%) achieved this level (Furlong et al., 2018). None of the apps reviewed by Furlong el al., (2018) achieved an 'excellent', although 25 (19%) of apps were rated 'good quality' and 2 apps (1.5%) were rated 'poorly' (Furlong et al., 2018). Furlong et al., (2018) also cautioned that app characteristics such as: functionality; aesthetics; whether it was engaging; and whether it was a good source of information did not necessarily translate to therapeutic benefit for intended users. Further development of an evidence-based appraisal instruments emphasising clinical usefulness or effectiveness of mobile apps is warranted.

9.4 Perceived Impact of the Daily Vroom App and LENA

The perceived benefits of an eHealth tool tend to predict its usage among healthcare professionals and clients (Gücin & Berk, 2015). The present study's perceived impact subscales explored app-specific benefits for users (which may not have surfaced with quality indicators), including potential impact on participants' awareness, knowledge, attitudes, intention to change, help-seeking and behaviour change (Stoyanov et al., 2015). The present study's descriptive findings suggested that after using the DVA, 81.8% agreed with the impact statement regarding their intention to change the amount of language input their child received. Intention to change, or an individual's readiness to act, has been described as an important feature of the Health Belief Model, Protection Motivation Theory and Theory of Planned Behaviour (Brouwer-Goossensen et al., 2016). Examining the underlying socio-cognitive factors in these theories, self-efficacy is a strong determinant underpinning intent to change (Brouwer-Goossensen et al., 2016). Although self-efficacy per se, was not directly measured in the present study, another study has demonstrated an increase in families' self-efficacy beliefs following the DVA and Mind in the Making partner initiatives (Galinsky et al., 2017). The present study's findings were consistent with the DVA's goal of inspiring parents to be their children's agents of change (Galinsky et al., 2017). Further investigations would be required to determine any relationships between intention to change following the DVA and actual increases in self-perceived efficacy.

The perceived impact statements were also piloted with 15 participants in the present study regarding the use of the LENA. In previous research (Allen, Crawford, & Mulla, 2016; Sacks et al., 2014; Suskind et al., 2013) and in the present Study 1, quantitative language feedback based on LENA generated data were discussed. The provision of feedback is a well-recognised method to raise conscious awareness about a health behaviour (Glanz et al., 2008) and the present study determined that 86.6% of participants agreed that LENA increased their awareness of how language input and exposure could affect their child's early language development.

In lieu of a standardised instrument for identifying high quality and therapeutically beneficial apps, Furlong and colleagues (2018) developed a rating approach to behaviour change statements, e.g. 'the use of this app will likely increase/decrease (insert target health behaviour)' on the Mobile Application Rating Scale. The present study, using their approach, found mean DVA and LENA behaviour change ratings of 3.7 (*SD* 0.9) and 3.9 (*SD* 1.06), respectively. These values were slightly higher than the average behaviour change score for Furlong et al.'s (2018) reviewed speech apps which was 3.2 (*SD* 0.7) (Furlong et al., 2018). Furlong et al., determined that behaviour change ratings between 4 to 5 would be considered to have potential therapeutic benefit. It was unclear if these guidelines were supported by objective outcome measures of actual behaviour change, necessitating stronger evidence to support potential therapeutic benefits. It was a limitation of the present study that measurement of behaviour change following the use of DVA and LENA was not more directly aligned with descriptors. For example, it was not within the scope of the present study to determine whether a DVA suggested app activity was more or less associated with an underlying focus of the intervention (e.g. turn-taking). Further validation of participants' perceived impact ratings for the DVA and use of LENA and measurement of clinical usefulness and/or therapeutic benefit, are warranted.

9.5 Relationships between Quality and Perceived Impact of the Daily Vroom App

Successful implementation of new technology is predicted by its perceived usefulness (Allen et al., 2016). In the field of human-computer interaction, design and usability qualities may be emphasised at the expense of meaningful benefits for users (Stawarz & Cox, 2015). Developing usable health-related apps without considering efficacy for the intended user, may be counterproductive to intended behavior change (Stawarz & Cox, 2015). Yet, without a strong app design to entice users, health-related apps may be of little benefit, due to poor uptake (McCallum, 2012). The third aim of the present study identified associations between app quality characteristics and the perceived impact of the DVA. The DVA goal was to communicate developmental research evidence, through practical and implementable content, to the families and professionals who could benefit (Galinsky et al., 2017). The present study findings supported this goal. There was a significant, positive relationship between the information quality of the DVA, and the perceived impact on participant awareness of how language input/exposure affected early child language development.

Participants were not asked directly about the perceived usefulness of the DVA in the present study, however the price value placed on the DVA provided a proxy indicator of whether individuals would continue to use the app (Venkatesh et al., 2012). The cognitive trade-off between the perceived benefits versus monetary cost is well-established in the research literature (Hew et al., 2015; Venkatesh, 2012). This phenomenon was similarly observed in the present study where participants higher ratings of willingness to purchase the DVA were significantly correlated with higher ratings of: intention to change; help-seeking behavior; and behavior change with DVA use. The unified theory of acceptance and use of technology in a consumer context (UTAUT2) model suggested that if participants perceive the benefits received from using the app to outweigh the price paid for the app, the likelihood of them using the app is high (Hew et al., 2015; Venkatesh et al., 2012).

User experience and visual design are other important elements associated with user uptake and engagement (McCallum, 2012; Stawarz & Cox, 2015). The present study found a significant positive correlation between ratings of help-seeking behavior and the aesthetics of the DVA (visual appeal, layout and graphics), which supported the importance of visual design within app evaluation.

The present study also found a significant positive correlation between participant ratings of app engagement and perceived impact ratings on the behavior change statement for the DVA. Karapanos, (2015) also found that engagement was associated with likelihood of changing behavior (Karapanos, 2015). Ensuring sustained app engagement however, has been found to be a challenge given the high app attrition within the first six months (Karapanos, 2015). Recent research has found that creating strong app checking habits was a method of sustaining user engagement over a prolonged period of time (Karapanos, 2015). In the case of the DVA, daily push notifications (messages which showed up directly on the user's phone) of activities to promote interactions constituted an information reward to parents, and thus, was proposed to be an incentive to keep checking the app (Karapanos, 2015). Future research could measure participants' app checking behaviours to assess long-term sustained engagement and behavior change with the DVA.

9.6 Overall Strengths and Limitations of Study

9.6.1 Strengths of Study 2

The use of communication technologies and eHealth service delivery is gaining traction in allied health (Iacono, Stagg, Pearce, & Hulme Chambers, 2016). The present Study 2 enlisted stakeholder support from clinicians and from mothers of young children, who stand to benefit from eHealth initiatives. The inclusion of both stakeholders' opinions about the DVA and LENA attempted to complement the quantitative outcome measures reported in Study 1. Effective interventions need to be informed by evidence-based practice, and also need to reflect values and outcomes which are important to parents (Moore, 2017). Previous research indicated that service delivery was less effective when parents perceived that their valued and preferred strategies were not taken into consideration (Moore, 2017). The present study used DeCAF data to understand the end-user's experiences of using the technologies.

Norman and Skinner (2006a) advocated for matching technologies to the skill level of users. Identifying relationships between perceived eHealth literacy and maternal characteristics, such as receptive vocabulary (which underpin literacy), may help profile individuals who are more/less suited to eHealth interventions. Profiling can provide insights into how best to fit eHealth tools for persons who are more challenged by eHealth literacy, and persons who would benefit from receiving more support.

The DVA had not yet been evaluated in terms of its app quality in any published research prior to the present study. The utility of the uMARS was demonstrated in the present study for benchmarking across different groups of raters; its use extended from having just speech language pathologists (clinicians) as raters of mobile apps in Furlong and colleagues' (2018) study to include mothers as a second group of raters to complete the uMARS. App evaluation also enabled the documentation of qualities (engagement, functionality, information and aesthetics) which participants valued in an app, which could inform the refinement process of using mobile technology in parent-implemented home language interventions.

Multi-disciplinary concepts and theories were required in examining associations between app design qualities and the perceived benefits of using mobile and LENA technologies in supporting child language. The present study provided a starting point for understanding eHealth interventions from both a behavioural and a socio-technical perspective.

9.6.2 Limitations

The survey findings should be interpreted with caution given the self-selected sample who volunteered to participate in the study. This recruitment bias could have resulted in a skew towards inclusion of participants with high self-perceived eHealth literacy ratings which may not be representative of the wider population of clients nor service providers. It could be argued that families living in rural or remote areas may benefit from the use of technologies (Iacono et al., 2016), so further efforts would be required to recruit participants from these diverse areas.

Given the small sample size of mothers who had completed Study 1 and also participated in Study 2, the mothers' perceptions of using the DVA and LENA might not be generalisable to broader populations. Although it was beyond the scope of the present work, future research could compare the perceived impact ratings about behaviour change with mothers' actual changes post-intervention in a larger sample.

The use of Likert response scales limited the depth of information which could have been collected from the participants. Qualitative methods may offer the opportunity to expand on understanding concepts raised in the survey, or to facilitate cross verification and interpretation of participant responses on the survey. The combination of semi-structured qualitative interviews, in addition to the quantitative data derived from questionnaire data may be considered in future research.

There were some clinicians who could not respond to the perceived impact statements regarding the use of LENA as they did not have sufficient familiarity or experience with it. Increasing exposure of LENA functions through a demonstration of the clinical applications of LENA, for example providing feedback based on LENA-generated metrics, could be examined in future studies with a larger cohort of clinicians.

9.7 Future Directions

Mobile apps offer the benefits of affordability and accessibility, however the rapid rise of new technologies and proliferation of health-related mobile apps poses an ethical challenge (Furlong et al., 2018). Supporting and guiding families through information-seeking and decision-making regarding app selection is difficult given the present lack of a standardised instrument to assess both app quality and potential therapeutic benefit. There is a need to incorporate measurement of the app's potential for behaviour change while considering evidence-based intervention strategies and principles (Furlong et al., 2018). The development of an appraisal tool which could support both clinicians and families in making informed decisions when engaging with mobile apps could be explored in future investigations.

There is an emerging dialogue between multi-disciplinary streams which are invested in eHealth. Information communication technology (which includes closely linked disciplines such as human-computer interaction) is increasingly being used as a platform for health interventions, which necessitates effective app design. Previous research however, has suggested that available apps are grounded in technical principles, but may lack scientific evaluation and/or lack relevant behaviour change methodology (Diefenbach, 2018). Designing interventions for changing health behaviours draws on principles and theories from psychology, public health, health communication and behavioural sciences. To promote long-term engagement and sustained motivation for behaviour change, there is a need to expand beyond the scope of each discipline when designing technology for health and well-being (Diefenbach, 2018).

10 Conclusion

The present research findings highlight that digital tools can be used to better develop, guide and manage the critical mother-child interactions that underpin early language development. Auditory access with early fitting of amplification devices can facilitate children's participation in verbal interactions. Optimal language development however, requires intervention efforts to shape children's everyday auditory-language experiences. An examination of maternal language behaviour change following the implementation of LENA (Language Environmental Analysis) and Daily Vroom App (DVA) in Study 1 and understanding of the user's experience of the Daily Vroom App in Study 2, were undertaken to address the impact of technologies on early child language.

In Study 1, the LENA system was demonstrated to be an effective tool for assessing the language environment for young children with typical development and normal hearing, as well as for children with severe to profound, bilateral hearing loss. All 10 participating children cooperated with the use of the LENA Digital Language Processor (DLP). LENA technology enabled the collection of day-long audio recordings from their home environments, including sampling in different settings and with unstructured activities. This sampling of typical activities without the presence of a potentially intrusive researcher/clinician differentiated this study from past home observation research (Smyth & Brinkman, 2014).

Child's hearing status was not found to be significantly related to adult word count, conversational turn count or child vocalisation count in these 10 dyads. The present study's findings of significant correlations between the families' entitlement to means-tested government concessions and child vocalisation count at baseline and lower LENA Developmental Snapshot and Parents' Evaluation of Aural/oral performance of Children (PEACH) scores for child communication (irrespective of child hearing status) reinforce growing evidence (Hart & Risley, 1995; McKean et al., 2015; Pace et al., 2017) of the role of socioeconomic factors on child language. Maternal characteristics including the highest level of education attainment, occupational skill level, receptive vocabulary and intelligence were also significantly related to socioeconomic markers in these 10 dyads. These correlation findings related to socioeconomic advantage must be interpreted with caution due to the small Study 1 sample size.

As socioeconomic status is not directly amenable to intervention, directing attention to caregiver language behaviours may be the most effective way to enhance child communication experiences. Provision of LENA feedback in the present study, has been gaining traction as a behaviour change strategy to educate parents about their own adult word and conversational turn counts relative to LENA normative data (Pae et al., 2016; Richards et al., 2017; Sacks et al., 2014; Suskind et al., 2016a; Zhang et al., 2015). Referring to objective benchmarks, promoting awareness of children's early language exposure in the home, and developing parental self-calibration of words spoken towards their children can enrich home language environments (Richards et al., 2017). LENA Feedback, with reference to the Daily Activities Diary, was provided to mothers to increase awareness of language behaviours over the course of a typical day. Study 2 survey results further validated Study 1 intervention findings, with the majority (86.6%) of participants expressing agreement that feedback from their use of LENA increased their awareness of how language input and exposure affected their child's early language development.

Traditionally, parent-focused interventions for families with young children have been limited by access and cost. This study demonstrated the feasibility of providing both face-to-face and remote LENA feedback to parents, thus providing preliminary support for this strategy in telepractice to alleviate inequities of access to services. Mobile applications also offer technology-based solutions which enable content to be shared with parents regardless of geographical location, family circumstances or socioeconomic status (Furlong et al., 2018; Galinsky et al., 2017). The Daily Vroom App, an initiative of the Bezos Family Foundation, was developed to promote executive functioning skills in children using parents as the agents of change (Galinsky et al., 2017). Although the Daily Vroom App was not designed as a language app per se, it provided frequent opportunities for parents to initiate conversations with their children using suggested activities. Home-based interventions should not create additional work for parents and should capitalise on language learning opportunities during naturally occurring everyday activities (Tamis-LeMonda, Custode, Kuchirko, Escobar, & Lo, 2018). The present study demonstrated significant increases in adult word count and conversational turn count from baseline when mothers used the Daily Vroom App in conjunction with receiving LENA feedback, compared to when only LENA recordings were taken. Furthermore, most participants (81.8%) in Study 2 agreed that the Daily Vroom App increased their intention to use more language with their child. Using apps such as the Daily Vroom App, and providing LENA feedback to mothers, may hold promise for positively influencing parental language behaviours, but further research is required to estimate the proportion of parents of young children with sensorineural hearing loss who will access and use digitally-driven interventions.

It was not clear from the present study why the significant increases in conversational turn count for the 10 dyads were observed more consistently in the LENA Feedback (LF) condition, compared to when feedback and the Daily Vroom App were implemented. The addition of the Daily Vroom App to LENA Feedback (LFA condition) showed a significant change from baseline compared to the LENA-Only (LO) condition, but the dual intervention approach did not lead to further increases in adult word count and conversational turn count. Study 2 explored potential factors (user perceptions about the app quality and user experience) which could have contributed to this result. Firstly, the Daily Vroom App's mean quality rating was 3.85 out of 5, which can be described as 'average/acceptable' to 'good' quality. If future modifications to the Daily Vroom App features lead to 'excellent' quality ratings, greater changes to parental language behaviours may result. Secondly, each child's verbal responsiveness contingent on the suggested app activity may mediate parental perception of the app's usefulness. Future studies could examine changes in child vocalisation count before and after Daily Vroom App use. Thirdly, Study 2 examined the potential fit of technology-driven interventions across individuals. Study 2 identified significant, positive correlations between self-ratings of eHealth literacy, and both maternal receptive vocabulary and maternal level of occupational skill. Tailoring content, ease of use and technology design to suit different levels of eHealth literacy could enhance the utility of the digital interventions (Neter & Brainin, 2012).

Early intervention programs, whether evidence-based or not, are unlikely to lead to desirable changes in all parents (Moore, 2017); tailoring language interventions to suit different family contexts is one factor that may improve intervention efficacy. Study 1 examined whether the intervention was suitable for four mother-child Hd dyads and described changes in adult word count and conversational turn count across the study conditions. These four case studies provided unique insights into the daily lives of young children with sensorineural hearing loss and the potential impact of individual differences including: family participation, child duration of device experience, mothers' availability as caregivers, and variations in daily activities on their responses to the intervention conditions. As parent-implemented interventions largely depend upon parental involvement and the extent to which parents can implement the protocol in real-world circumstances (Moore, 2017), future research should consider the mediating effects of family involvement on intervention outcomes. Study 1's four Hd single-subject case studies highlighted the importance of using family-centred approaches, and understanding the parent, child and interaction in context to effectively support and deliver intervention with favourable outcomes (Moodie, 2018).

10.1 Recommendations for Future Research

The findings of the present study have highlighted the following areas for future research: examination of different activity types on language interactions, impact of languages other than English, analysis of non-verbal gesture use and in-depth analysis of quality of spoken language input in conjunction with quantity markers. Long-term adherence to eHealth interventions, maintenance of intervention effects and the related factors of participant motivation warrant further attention.

Finally, expanding the reach of eHealth to address equity issues for families with less socio-economic advantage should be clarified.

Study 1 was not able to determine the proportion of variability in LENA generated adult word count, conversational turn count and child vocalisation count that may be attributed to activity type during each dyad's typical daily routine. Observed parental reports based on the Daily Activities Diary in Study 1 demonstrated that the proportions of structured (e.g. book reading) and unstructured (e.g. outside play) activities varied across participants and across LENA recording days. Recent research has observed that children are exposed to contextually bound language scripts when participating in frequently recurring routines. These scripts assist children in learning to predict and infer word meanings (Tamis-LeMonda et al., 2018). Future research could examine typical home routines and LENA generated metrics to identify which activities affect the amount of parental spontaneous language (Tamis-LeMonda et al., 2018). Future research could focus on closer examination of parental amounts of spoken language and comparisons of pre- and post- Daily Vroom App use. The Daily Vroom App suggested activities based around everyday situations which assist children to map words to familiar actions, objects and people but Study 1 demonstrated that more data is required to demonstrate the actual impact of Daily Vroom App suggestions on adult word and conversational turn count following Daily Vroom App use. The LENA's current algorithms were not able to differentiate between the languages spoken by participants. Whilst encouraging evidence regarding the validity of LENA use with multilingual families is emerging, it is not known from Study 1 whether speaking more than one language at home could have led to greater variation in counts for the present study's 10 dyads. Establishing normative LENA data for families with diverse backgrounds who speak language(s) other than English is warranted.

It was not within the scope of Study 1, and the use of the LENA measurement tool, to capture and analyse non-verbal gestures, including sign language. It is certainly recognised that mothers and children use gestures and/or sign language to communicate. In particular, mothers of very young children, children with hearing loss, and children who are adjusting to their hearing devices (Smyth & Brinkman, 2014) are recognised to employ gesture and use of sign. To address this gap in knowledge, live transcription of interactions, or transcription of sign/ gesture from video recorded samples would be required.

Study 1, and LENA's current algorithms, were not able to address the quality of language input, such as diversity of word types. Other literature, not using LENA, have reported on the importance of quality of parental input on child language skills and communication outcomes (Pan et al., 2005). Further investigation of the predictive value of quality of adult language input, in tandem with the quantity of adult language input is needed to enable a more robust understanding of a child's early language experiences (Rowe, 2012).

Study 1 was not able to determine the long-term sustainability of adult word count and conversational turn out changes over time, nor the potential impact of adult word count and conversational turn count changes on child language. Despite the rhetoric that digital health and mobile phone apps can facilitate behaviour change, Study 1 has not fully addressed long-term participant adherence and usage patterns of self-help applications. The sustainability of behavioural change is a known challenge in digital interventions (Eysenbach, 2005). To address this, a longitudinal, experimental study design could be implemented to determine if significant increases in adult word count and conversational turn count following LENA feedback and/or Daily Vroom App use were maintained over time, and if these were correlated with continuous, enriched early language exposure for the children.

The uptake and use of digital technologies may be affected by the end-user's perspective of the technological tools (Birnbaum et al., 2015). A larger sample of mothers who complete both the intervention trial (Study 1) and the survey (Study 2) could examine individual changes in adult word count and conversational turn count from baseline and match these with each participant's Designing eHealth for Clinicians And Families (DeCAF) survey ratings. Further exploration comparing Study 1 participants' eHealth literacy skills, enjoyment of using the Daily Vroom App and improvement in LENA counts is also warranted.

Study 1 was not able to fully elicit users' motivations and participants' experiences after using the LENA and Daily Vroom App. A mother's intentionality towards meeting intervention goals might be a precursor to behaviour change which mediates intervention outcomes. Appraising maternal motivation for participating in the research at the beginning of the study and whether their needs were met at the end of the study would be a beneficial extension to the present research. It is also crucial to increase end-user involvement in the design of these technologies to develop relevant, usable and effective eHealth solutions (Birnbaum et al., 2015). Linking motivation to actual measures of behaviour change could inform future digital intervention efforts aimed at mothers of young children. One solution could be the addition of semi-structured interviews with participants to extend inquiry into app design, effectiveness, retention and usage. Finally, if lasting increases in adult word count and conversational turn count were demonstrated, future research could examine whether the significant inverse relationships observed between family entitlement to means-tested government concessions (i.e. an SES marker) and the amount of child vocalisations and children's scores on the LENA Developmental Snapshot, are replicated in other populations and in the long-term.

10.2 Implications for Practice

Contemporary research evidence has demonstrated the importance of providing children with early, enriched language experiences to facilitate child language development and later educational outcomes (Golinkoff, Hoff, Rowe, Tamis-LeMonda, & Hirsh-Pasek, 2018; Hart & Risley, 1995; Levine et al., 2016; Richards et al., 2018). Dissemination of advice regarding the importance of adult talk and adult-child conversations in the home, however, needs to be more accessible to families outside of therapeutic settings. An increasing number of families with a child with hearing loss for example, seek resources on the internet and through electronic forms of media, to complement traditional services (Porter & Edirippulige, 2007). Additionally, with the rise in early implanted, paediatric cochlear implant recipients (Lammers et al., 2015), there is an increased need for developing eHealth solutions which shift the emphasis from a clinician-centric, resource-intensive model of care to a patient, self-managed, participatory health approach. A participatory health approach with the aid of advanced communication technology, not only provides families with more control, but also has a service delivery imperative to it (Waegemann, 2010). Emerging eHealth research has highlighted the advantages of digital health tools and mobile phone applications (mHealth) as accessible, low-resource means to equip and empower patients and their families in their healthcare journeys (Birnbaum et al., 2015). With initiatives such as the Bezos Family Foundation's Daily Vroom App, mobile phone communication may be used as a medium to share information with parents and to equip them with skills to carry out language enriching activities with their children. High level evidence is however, still lacking regarding the efficacy of mobile apps to reach at-risk populations organically, and their impact on parental behaviours at a population level is still unclear (McClure et al., 2018). Study 2 highlighted that the appraisal process for classifying available apps on the market, in terms of quality and potential therapeutic benefit, requires further investigation.

At a policy level, as more technology-based applications in healthcare become available, developing fluency in eHealth literacy becomes more relevant. Study 1 and 2 have highlighted the potential for clinicians to assist families with informed decision-making when engaging with mobile apps. Clinicians are well-placed for offering mobile app and eHealth tools recommendations to assist parents in enriching language input to their children in-between therapy appointments. Introducing digitally-driven, evidence-based language interventions and therapeutically beneficial apps to parents in the context of care settings may also provide the legitimacy required to facilitate implementation and uptake (McClure et al., 2018).

Study 1 indicated that maximising early language experiences for children during sensitive learning periods was possible, as demonstrated by the mean increases in adult word count and conversational turn count from baseline post-intervention in this sample of 10 mother-child dyads.

The single-subject case descriptions highlighted the need for parent-implemented home interventions to be adaptable and to cater to the needs of different families. By working with individual parents, the hope is to promote positive short-term changes in parental language behaviours which may in turn, foster more optimal developmental trajectories for children in the future (Hall & Bierman, 2015).

10.3 Concluding Remarks

The present research contributed to empirical evidence that modern technology, as part of a caregiver-implemented home intervention, can both measure and enrich the early language environments for children aged between six months and three years. Hearing status of the children was not found to be related to adult word count or conversational turn count in this small sample which may have been a consequence of effective early audiological intervention and amplification. This study demonstrated that children's early language experiences were influenced by family and maternal characteristics, but many questions regarding the complex nature of how these factors influence variability in the amount of talk in home language environments, remain unanswered.

There was a strong focus in the present research on empowering mothers to support their children's early language acquisition by modifying, and specifically increasing, spoken language in their everyday lives. Participant responses to the use of Daily Vroom App were positive but more varied, which warrants further investigation. On average, the adult word count and conversational turn count increased from baseline following LENA feedback, compared to the LENA-Only condition. Individualised and contingent LENA feedback formed the basis of the personalisation of technology which played a notable role in the present digitally-driven intervention. Synthesis of Study 1 and Study 2 results suggests that the use of technology may add an additional layer of variability to intervention outcomes, which is, in part, due to individual differences in eHealth literacy and user experience with digital tools.

Best practice guidelines and evidence regarding the efficacy of digitally-driven intervention strategies are still emerging. Although there is increasing ability to provide digital tools in early intervention, shifting the focus from implementation to service design appears warranted. Provision of family-centred care, and consideration of the suitability and profile of the family, mother and the child, remains paramount. The present research emphasised the importance of considering the end-user's views, expectations and attitudes towards technology, in order to deliver effective early intervention support.

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Talking to Toddlers: Drawing on Mothers' Perceptions of Using Wearable and Mobile Technology in the Home

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Abstract. ***Background.*** Mother-child interactions often give rise to opportunities for early language learning in the context of everyday life. Persuasive technology has the potential to influence maternal language behaviours in the home and promote mothers' active engagement in the development of their children's communication skills. ***Aim.*** This paper explored maternal perceptions regarding the use of a language tracking wearable (Language Environment Analysis; LENA) device and a parent education smartphone application in an 8-week trial with their young children. ***Methods.*** Mother/child dyads were enrolled in a feasibility trial designed to obtain objective auditory and linguistic data from each child's naturalistic settings (Control Condition), provide feedback to mothers about their child's home language environment (LENA Feedback Condition), and to explore effectiveness of an app designed to promote meaningful parent/child interactions during daily routines (LENA Feedback and App Condition). ***Results and Discussion.*** The majority of mothers (80%) who participated in the trial reported a preference for using the mobile app and/or LENA technology again. Maternal responses during this pilot informed the design of an ongoing, prospective language intervention study for parents and their young children with significant hearing loss.

Keywords. Wearable technology, smartphone app, maternal language behaviour, user experience, child language environment

1. Introduction

During the first few years of life, children undergo a sensitive language acquisition period characterised by the rapid development in communication and linguistic skills [1].

For children with normal hearing, pre-school language experiences/milestones predict trajectories of later language and educational outcomes [1, 2]. In the case of children with hearing loss, disparities in oral language experiences, as compared to their typically hearing peers, may place them at risk of delays in spoken language development [2].

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In the design of interventions to address language delays, the role of the adult caregiver is often emphasised in therapy [2]. Adult caregivers, specifically mothers, naturally spend a substantial amount of time with children and are recognised as the primary contributors of spoken language input, in terms of quantity and content that children receive during the early critical years [2, 3]. Adults generally have little conscious awareness regarding the quantity of talk provided to children [2]. Efforts by early intervention professionals (i.e. speech pathologists) are typically channelled into enhancing partnerships with parents and promoting active parental engagement [4]; that is, parental behaviours which promote meaningful learning and optimal outcomes through purposeful interactions with children [5]. Two interventions warrant attention. Firstly, in parent-directed language interventions, the provision of verbal feedback is used by speech pathologists to enhance parental input to the child [2]. Secondly, therapy may focus on enriching the child's immediate environment; reducing noise, reducing speech in noise, and increasing speech directed to the child. Having a tool which provides measurable feedback on these two factors and the ability to monitor progress over time may potentially complement and increase effectiveness of behavioural interventions [2].

1.1. Language ENvironment Analysis (LENA) Technology

Access to the Language Environment Analysis (LENA) system has enabled parents and speech pathologists to view quantified data about a child's overall audio and speech environment [6]. The hardware component of LENA technology is a small, wearable recording device placed in the front pocket of a child's clothing. Recordings are processed by the LENA software which generates frequency counts including *communicative interaction* data (quantity of adult words spoken to the child, number of turns taken between adult and child, and amount of speech-like sounds the child produces) and *environmental* data (close range speech, electronic media, distant speech, background noise and silence) [7]. Providing parents with LENA-generated feedback can facilitate active parental engagement by opening a dialogue between speech pathologists and parents about a child's home language environment.

1.2. Mobile App Technology

Beecher and Buzhardt [4] proposed mobile applications as another technology-assisted strategy for increasing parental engagement. There has been an increased general acceptance of mobile technology as a feature of everyday life and a notable surge in the adoption of mobile devices across diverse populations [4]. Mobile applications, as virtual platforms, have the potential to provide increased access to information, which can be used to persuade and educate [8]. The continual evolution of app development now includes persuasive design features which can modify the behaviours of users [8]. Dialogue support has been identified as a human-computer persuasive design element which uses feedback as a way of interacting with the user [8]. Feedback to the user includes prompts, suggestions and reminders [8]. Additionally, the use of symbolic visual rewards displayed on the app upon completion of a task or goal has also been found to be a typical feature employed to influence user behaviour [8].

1.3. Aim of Pilot Study

Wearable speech recognition technology and the promise of mHealth (mobile technology) offer potential intervention benefits to parents outside of the clinical environment. Nonetheless, the successful implementation of any novel technology is in part, predicted by the users' experience and perceived notion of utility [9]. Failure to address usability factors could hinder the adoption of novel technology, and could result in dissatisfied users, decreased effectiveness and/or high churn rate [10]. Research is required which ensures that technologies are suitably designed and targeted to the end-users' needs before being implemented in clinical interventions [10].

A key objective of this feasibility study was to provide mothers with the experience of using LENA technology and a mobile app with their children, and to explore their first-hand opinions upon completion of the trial. This paper is focused on exploring participating mothers' perceptions of the pilot with the aim of informing future iterations of using wearable and mobile technology in home-based language intervention research.

2. Method

Participants (5 mother and child dyads) were recruited for an 8-week feasibility trial. All participating mothers were smartphone users who spoke English at home and did not require an interpreter. Child participants were aged between 11 months to 2 years (Mean age=1.28 years; SD=0.45), had normal hearing and no additional special needs.

Mother/child dyads completed an assessment and briefing session at the start and end of the trial. Formal child assessments included a receptive and expressive language test and a cognitive developmental screener. Mothers completed measures of vocabulary and cognitive ability. A 10-minute mother-child play sample was also video-recorded at the start and end of the trial. Parent-report questionnaires were used to collect demographic information, child communication development details, ratings of parental competency and knowledge, as well as written views on the technologies used in the study. This paper used an inductive content analysis approach to explore maternal written comments about the use of LENA technology and the mobile app.

Mothers were given the option of completing either a day-long recording of up to 16 hours per week, or to record for up to 16 hours over 2 consecutive days in a week. Participant awareness of when the recordings were taking place was inevitable, hence the latter option was proposed as a strategy to neutralise the possibility of the Hawthorne effect by promoting acclimatisation to the LENA recordings. Participants were also asked to complete a time-use Daily Activities Diary (DAD) for each recording day which informed the interpretation of LENA data and feedback provided to mothers. None of the LENA recordings were completed on days when the children were in day care as exploring the potential of implementing interventions in the home environment was central to this study.

2.1. Pilot Trial Conditions

The use of the LENA system and mobile app was trialled with participants using a repeated-measures study design. A baseline LENA recording was taken at the start of the trial (week 1) and a follow-up recording was taken at the end of the trial (week 8).

Each mother-child pair completed all 3 study conditions (2 experimental conditions and 1 control condition) between weeks 2 to 7 as described below:

Control Condition. Participants completed 2 weekly 16-hour long LENA recordings and filled in a Daily Activities Diary (DAD) describing types of activities they were involved in, people who were around and settings which they were in on the days of recording.

LENA Feedback Condition. Participants completed 2 weekly LENA recordings and DADs as per the control condition, after each week. An individualised visual language environment feedback report based on the dyad's most recent LENA recording was provided to the mothers. Mothers also had either a face-to-face or over the phone verbal discussion about each week's report with the study researcher lasting approximately 15-30 minutes. The feedback provided to mothers outlined key LENA targeted language counts displayed in the form of graphs (number of adult words, conversational turns and child vocalisations per hour) and a snapshot of the child's overall audio environment.

LENA Feedback and Use of Mobile App Condition. In addition to the weekly recordings and providence of LENA feedback (as outlined in the previous condition), mothers were asked to download the mobile app and incorporate short, parent-child interaction activities as suggested by the app into their daily routine for 2 weeks.

3. Results

3.1. Participant Characteristics

All 5 participating mothers had normal hearing and were aged between 37 and 41 years (Mean age=39; SD=1.58). All mothers reported that they were the primary caregivers of their children and spent an average of 136 hours per week (SD=29.9; Range= 104-168) with their child. All families were intact, with two adult parents living in the home. The average relative socio-economic advantage decile (1=areas of least advantage, 10= areas of greatest advantage) for participants was 7.6 (SD= 1.81; Range= 5-10) as defined by SEIFA (Socio-Economic Indexes for Areas) 2011 census data using household postcode. Participant demographic and family characteristics are summarised in Table 1.

Table 1. Participant demographic and family characteristics.

Mother/child dyad	Mother's age (years)	Child's age (months)	Mothers' highest level of educational attainment	Work/study load	Time spent with child (hours per week)	SEIFA decile
P1	38	12	Postgraduate degree	Mat. leave	168	8
P2	41	11	Bachelor's degree	Full-time	104	5
P3	37	13	Diploma/vocational certification	Self-employed	168	8
P4	40	15	Bachelor's degree	Full-time	120	7
P5	39	24	Postgraduate degree	Part-time	120	10

3.2. Maternal Perceptions on the Use of LENA Wearable Technology and the Mobile App

The role of feedback and perceived usefulness were recurring themes (Table 2) which emerged from mothers' written responses to the open-ended questions at the end of the trial, "What did you like about the use of the LENA system/mobile app?" and "What would you change about the use of the LENA system/mobile app in this study?"

Feedback. Visual representations of LENA data were a salient part of feedback which added to the positive experience. Mothers' commented on the perceived impact after viewing LENA feedback information on their own communicative behaviours which indicated engagement with persuasive technology. Badges which were part of the mobile app's reward system as feedback to the users for completing suggested daily activities were viewed as an excessive feature which could be omitted.

Perceived usefulness. Changes to simplify the LENA recording process (i.e. recording over one day instead of two), altering the size of the LENA device and catering to mothers' information needs by having a short video demonstration to accompany the app activities would help address negative experiences reported by the mothers about the use of the technologies in the trial. A majority of mothers expressed positive sentiments about the ease of use for both the wearable LENA recorder and the mobile app. They reported that the app interface was user-centric and suggested app activities were practical and easy to implement with their children.

Table 2. Positive and negative responses on the use of LENA and mobile technology based on maternal perceptions after the trial.

Themes	**Sub-themes**	**Description**	**Sample quote(s)**
Receiving Feedback			
Feedback (Positive)	Visual value	Accessibility of LENA graphs	"Feedback (objective- based on actual recordings) to visualise amount of talk and vocalisations"
	Influence on parental communication behaviour	Engagement with LENA feedback	"Helped me understand the spoken patterns of the day. Showed me just how important/valuable reading is!"
Feedback (Negative)	Unnecessary features	Mobile app reward system	"Found the badges unnecessary."
Perceived Usefulness			
Usefulness (Positive)	Simplicity/ Ease of use	Wearable LENA device	"Simple, still able to do what we would normally do."
	User-centric	Mobile app dialogue support	"Daily reminders to use the app, ability to return to a favourite activity and completed activities."
	Practical Application	Mobile app primary task support	"Simple easy but interesting activities help our child enjoy communicating with us."

Themes	Sub-themes	Description	Sample quote(s)
Usefulness (Negative)	Process design	LENA recording procedure	"Didn't find Day 2 recordings particularly useful. If possible, have only 1 long recording per week."
	Information needs	Mobile app primary task support	"A short video showing the tips ie. with a caregiver and child."
	Hardware limitation	Wearable LENA device	"Device should be smaller."

At the end of the 8-week trial, 4 of the 5 mothers expressed interest in using the mobile app again, and 3 participating mothers reported that they would use both the LENA system and mobile app again in the future. Participant 1 also commented post-trial: "I have placed the app on my phone home screen."

4. Discussion

This paper investigated the maternal perceptions of incorporating modern technologies into daily mother/child language interaction. Usability and feasibility are key contributors to the success of any parent engagement initiative using technology [4]. The feasibility of the approach was supported as the participating children tolerated the use of the LENA recorder and all 5 mother-child participants who enrolled for the study completed the 8-week trial successfully. The use of wearable LENA and mHealth tools were evaluated based on user perspectives, although limited to mothers who had participated, upon completion of the trial. Access to objective information about language behaviours, ease of recording, as well as having a user-centric app experience facilitated mothers' positive perceptions on the value of LENA feedback and perceived usefulness of the technologies.

Completing a 16-hour recording over two consecutive days during the pilot was implemented as a strategy to control for the Hawthorne effect on maternal language behaviours. It was however, highlighted in the comments made that completing one long day of recording was preferred over two consecutive recording days. Allowing for controlled flexibility in LENA recording procedures is likely to promote participant adherence and retention, which are vital elements in successful prospective trial research. This pilot also adopted a repeated measures study design which allows each mother/child dyad to act as their own baseline and for the comparison of measurements across conditions. Analysis of objective measurements of language data is ongoing and will be reported on in a subsequent publication.

Findings of this pilot demonstrated that participants were willing to use the technologies again in the future although, due to the small subject size characterised by more well-educated and socio-economically advantaged participants, this observation might not be generalisable. The ensuing study has addressed this issue by commencing recruitment on a broader Australian cohort from different early intervention sites dispersed across states and geographic regions. Maternal (user) perceptions of the pilot were considered when developing the methodology for a 12-week trial, which is currently underway, exploring mother's input to children who have significant hearing loss.

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Invitation to Participate

We are inviting families with young children to participate in a new intervention study conducted by The University of Melbourne and The HEARing Cooperative Research Centre.

Children go through a period of rapid learning during the first few years of life. They learn through social interactions and exposure to their environment. The way parents interact with their children can have a significant impact on language development. Early child language development is also linked to later academic success.

This study aims to enhance early language learning for children with significant hearing loss by increasing the amount of words they hear, and by providing parents/caregivers with simple everyday language building strategies. The child and the child's caregiver will be involved with using the **Language Environment Analysis (LENA) system** which measures the child's language environment, and the child's caregiver will be introduced to an **educational smartphone app** for promoting shared caregiver-child interactions through every day routines. Participation in this study will take place over the duration of 12 weeks.

Participation in this study will involve: Caregiver and child attendance at pre-trial and post-trial assessment sessions, 13 16-hour long home LENA recordings, 6 short LENA feedback sessions, the use of a mobile app over 3 weeks and completion of questionnaires.

There will be before and after study caregiver and child evaluations which may provide useful information about your child's progress. The assessments will take place at the Royal Victorian Eye and Ear Hospital, The University of Melbourne or other HEARing CRC partner sites. Participation in the study is voluntary and you will be able to leave the study at any point in time, for any reason.

Your participation in this study will help us understand the benefits of using an app and health technology with your child.

Expression of Interest

We are looking to recruit families with children who are between <u>6 months to 3 years of age</u> for this study using an app and an automatic language processing device and software (LENA) to help parents/ caregivers to encourage language learning in the home.

Please complete the Permission to Contact Form on the next page if you are interested in participating in this study.

If you would like more information, please contact:

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Permission to Contact Form

If you would like to participate in this study, please provide your name, contact number and email address so that we can get in touch with you. By providing your details and signing below, you authorise the project's researchers to contact you.

A Participant and Information Consent Form (PICF) and study questionnaires will be given to you if you decide to proceed with participation in this study. The parent-child intervention study will run for 3 months.

Parent	**First Name:** **Family Name:** **Are you a smartphone user? Yes No**
Contact Details	**Contact Number:** **Email Address:**
Child	**First Name:** **Family Name:** **Date of Birth:** **Does your child have a significant hearing loss? Yes No**
Signature ____________________________	**Date: ___/____/____**

Please complete this form and return it to your case manager.
Alternatively, return the completed form by post (if an envelope has been provided), or by email to dawn.choo@unimelb.edu.au.

Participant Information Sheet/Consent Form – Parent/Guardian

Interventional Study - *Parent/Guardian consenting on behalf of participant*

ROYAL VICTORIAN EYE & EAR HOSPITAL

Title	Going digital: Enabling caregivers to optimise the linguistic environment for children with significant hearing loss
Short Title	OLEC (Optimising the Language Environment for Children)
Protocol Number	15/1250H
Project Sponsor	The HEARing CRC
Coordinating Principal Investigator/ Principal Investigator	Ms Dawn Choo
Associate Investigator(s)	Dr Shani Dettman, Prof Richard Dowell, Prof Robert Cowan
Project Personnel	Dr Mehrnaz Shoushtarian, Ms Alexandra Rousset, Ms Sylvia Tari
Location	Royal Victorian Eye and Ear Hospital, Cochlear Implant Clinic The University of Melbourne, Department of Audiology and Speech Pathology Hear and Say, Queensland The Shepherd Centre, New South Wales

Part 1 What does the child's participation involve?

1 Introduction

You are invited to take part in this research project, *Optimising the Language Environment for Children (OLEC)*. This is because you are the parent or primary caregiver of a young child aged between 6 months to 3 years. The research project is testing a new way to enhance early language development in children, through adult-child interactions in the home environment. Participation in this project will involve both you and your child.

This Participant Information Sheet/Consent Form tells you about the research project. It explains the tests and treatments involved. Knowing what is involved will help you decide if you want you and your child to take part in the research.

Please read this information carefully. Ask questions about anything that you don't understand or want to know more about. Before deciding whether or not the child can take part, you might want to talk about it with a relative, friend or the child's local doctor.

Participation in this research is voluntary. If you, or your child, do not wish to take part, you do not have to. The child will receive the best possible care whether or not they take part.

If you decide you and your child want to take part in the research project, you will be asked to sign the consent section. By signing it you are telling us that you:
• Understand what you have read
• Consent to you and your child taking part in the research project
• Consent for the child to have the tests and treatments that are described
• Consent to the use of the child's personal and health information as described.

You will be given a copy of this Participant Information and Consent Form to keep.

2 What is the purpose of this research?

Children develop their early communication skills with you, the parent or caregiver, through their daily experiences and interactions. Significant hearing loss places young children at a risk of having a speech and language delay and may affect later school performance. Cochlear implants and hearing aids enable children to hear, additionally, you play an important role in your child's early language acquisition and development.

The study aims to find out if health technology tools are useful in helping you to enrich your child's natural language environments. These tools involve an educational app and a small recording device called Language ENnvironment Analysis or LENA.

This research will be completed by the researcher Ms Dawn Choo, for the purpose of obtaining a Doctor of Philosophy, under the supervision of Dr Shani Dettman, Prof Richard Dowell and Prof Robert Cowan.

This research has been funded by The HEARing Cooperative Research Centre (HEARing CRC), in collaboration with The University of Melbourne and the Royal Victorian Eye and Ear Hospital.

3 What does participation in this research involve?

You and the child will be participating in this study. If you agree to participate, you will be asked to sign a consent form for both you and the child to participate. Participants will also be asked to provide some family details and background information. At the start and end of the study, participants will complete language, cognitive and developmental assessments. The assessment sessions should take a maximum of two hours each. The assessment tasks will include tests, questionnaires and 10 minute video recordings of you and your child.

This study will involve the use of an educational smartphone app. This app will provide a tip each day on how to share language development opportunities with your child.

The study also involves using the LENA device to record your child's speech and any other sound in the background, including your own speech. The LENA device placed on the child's clothing (as shown in the picture below). The recordings are performed weekly at home. Use of the LENA device will allow automatic measurement of the amount of talk, conversational engagements and electronic background noise (e.g. from the television) a child experiences at home. Instructions on how to use the LENA device such as turning on the device and fitting it on the child's clothing, will be provided. Getting set up for recording will only take a moment each day. Parents/caregivers will be asked to fill in a log of the day's activities on recording days.

After each recording, you may inform the researchers that only the automatic metrics may be used and that the audio file is to be deleted once the automatic processing has been completed, OR you may choose to allow researchers to retain the actual audio file for transcription and analysis. The difference between these two choices is that (in the second option) the researcher will be able to listen to what has actually been recorded. Only the researchers named in the study will be able to listen to the audio files.

After each weekly recording, participants will return the LENA device and relevant study material and receive a newly charged LENA device for the following week via a courier service provided by the study. Up to 13 regular weekly recordings will be done during the study.

Placing the LENA DLP into the pocket of a child's clothing [Online image]. Retrieved 15 October, 2015 from http://www.lenafoundation.org/lena-pro/

You will be randomly assigned to use the app or the LENA device or both at different times during the study. After using the app and/or LENA device, parents/caregivers will be asked to complete a short developmental checklist and questionnaire.

There are no additional costs associated with participation in this research project, nor will you be paid. All tests and reports required as part of the research project will be provided to the child free of charge.

You may be reimbursed for any reasonable travel, parking, meals and other expenses associated with the research project visit.

4 What do I have to do?

You will be using the LENA Digital Language Processor (DLP) device and the educational app for this study. You will need to put the LENA DLP device on your child for 16 hours recording per week, over a 3 month period. We can provide some more information and tips about this. You will also receive up to 20 minute LENA feedback sessions for 6 weeks. In this 3 month period, you will be using an educational app for 3 weeks which provides daily suggested activities to promote early learning development with your child. We will provide you some more information and tips about this.

You and your child will also need to attend a 2 hour session with a researcher at the start and end of the study.

5 Other relevant information about the research project

An estimated 30 caregiver-child pairs in Australia will participate in this research project.

6 Do I have to take part in this research project?

Participation in any research project is voluntary. If you do not wish to take part, you do not have to. If you decide to take part and later change your mind, you are free to withdraw from the project at any stage.

If you do decide to take part, you will be given this Participant Information and Consent Form to sign and you will be given a copy to keep.

Your decision whether to take part or not to take part, or to take part and then withdraw, will not affect your routine treatment, your relationship with those treating you or your relationship with this hospital, clinic or centre.

7 What are the alternatives to participation?

You and your child do not have to take part in this research project to receive treatment at this hospital. Other options are available; these include receiving standard habilitation and early intervention services provided by the clinic or centre. The researchers and you will discuss these options before you decide whether or not to take part in this research project.

8 What are the possible benefits of taking part?

We cannot guarantee or promise that you or your child will receive any benefits from this research. However, possible benefits may include: evaluations of language skills which will provide more insight into your child's home language environment using advanced technology which is not accessible through other standard services; the provision of educational resources and feedback to parents or caregivers, to encourage early child development.

9 What are the possible risks and disadvantages of taking part?

No additional risks are expected during this study. Wearing the LENA device poses a risk of discomfort to the child. Families will be introduced to the LENA device which weighs approximately 57 grams. You will be shown by a researcher how to use the DLP on recording days and fit it in a sealed pocket on the child's clothing. Families will be provided with an example of clothing which will help minimise discomfort during recording days. If you or your child becomes distressed as a result of your participation in the research, counselling support can be provided. The Social Work department or counselling support services will be contacted if required. At all stages of the study, families will be reminded of participant rights, the right to discontinue and speak with a person who is independent to the study.

10 What if new information arises during this research project?

Sometimes during the course of a research project, new information becomes available about the treatment that is being studied. If this happens, the researchers will tell you about it and discuss with you whether you want the child to continue in the research project.

11 Can the child have other treatments during this research project?

Whilst you are participating in this research project, you and the child may continue to have all of your other regular treatments. However, we ask that you let us know of any private or additional speech therapy sessions that are not a part of the research project.

12 What if I withdraw the child from this research project?

If you decide to withdraw the participant from the project, please notify a member of the research team before you withdraw them.

If you do withdraw the child during the research project, the researchers and relevant study staff will not collect additional personal information, although personal information already collected will be retained to ensure that the results of the research project can be measured properly and to comply with law. You should be aware that data collected by the sponsor up to the time of withdrawal will form part of the research project results. If you do not want them to do this, you must tell them before you and the child join the research project.

13 Could this research project be stopped unexpectedly?

It is unlikely; however the research project may be stopped unexpectedly for a variety of reasons. These may include health reasons of the primary investigator(s) and withdrawal of funding support.

14 What happens when the research project ends?

Once you have completed the project, there are no restrictions on the continued use of the educational app.

At the end of the project, a summary of your child's results and/or the project findings will be given you upon request, after completion of the study.

Part 2 How is the research project being conducted?

15 What will happen to information about the child and me?

By signing the consent form you consent to the researchers and relevant research staff collecting and using personal information about you for the research project. Any information obtained in connection with this research project that can identify you and the child will remain confidential. Prior to the collection of any data, participants will be assigned a unique Study ID. Participants will be identified on forms with their Study ID (e.g. Child A, Child 1). The linkage between the Study ID and the participant's contact details will be known by the researchers only. Data will be collected in paper and digital forms. Paper information will be stored in a locked filing cabinet and digital data will be password protected. Access to participant data will be provided only to the named researchers, or research assistants or students directly under their supervision. Digital information, specifically, any audio files and audio-visual recordings will be de-identified and stored on a secure computer hard drive and locked filing cabinets.

Future access to any study data, for any person(s) is subject to RVEEH HREC Ethics approval. All information will be kept for seven years after the completion of the study, the publication of the results, or until the child turns 25 years of age, whichever is the later. At this point, paper information will be shredded and digital data, including audio and video recordings will be permanently deleted. Your information will only be used for the purpose of this research project and it will only be disclosed with your permission, except as required by law.

Information about the child may be obtained from their health records held at this and other health service clinics and centres, for the purpose of this research. By signing the consent form, you agree to the study team accessing health records if they are relevant to the child's participation in this research project. Relevant information about your child collected during this study may be released to the clinic so as to inform usual care management.

It is anticipated that the results of this research project will be published and/or presented. In any publication and/or presentation, information will be provided in such a way that you and the child cannot be identified except with your permission. Participants will not be identifiable in any reporting of results (either peer reviewed journal articles or conference presentations).

Information about you and the child's participation in this research project may be recorded in the child's health records. In accordance with relevant Australian and Victorian privacy and other relevant laws, you have the right to request access to the participant's information collected and stored by the study team. You also have the right to request that any information with which you disagree be corrected. Please contact the study team member named at the end of this document if you would like to access the child's information.
Any information obtained for the purpose of this research project and future subsequent studies that can identify you or the child will be treated as confidential and securely stored. It will be disclosed only with your permission, or as required by law.

16 Complaints and Compensation

If you or your child has any concerns as a result of this research project, you should contact the researchers as soon as possible and you will be assisted.

17 Who is organising and funding the research?

This research project is being conducted by Ms Dawn Choo, at The University of Melbourne under the supervision of Dr Shani Dettman, Prof Richard Dowell, Prof Robert Cowan. Results of this study will be used as part of a Doctoral dissertation. Funding has been provided by the HEARing Cooperative Research Centre to complete this project. No member of the research team will receive a personal financial benefit from your involvement in this research project (other than their ordinary wages).

18 Who has reviewed the research project?

All research in Australia involving humans is reviewed by an independent group of people called a Human Research Ethics Committee (HREC). The ethical aspects of this research project have been approved by the HREC of the Royal Victorian Eye and Ear Hospital.

This project will be carried out according to the *National Statement on Ethical Conduct in Human Research (2007)*. This statement has been developed to protect the interests of people who agree to participate in human research studies.

19 Further information and who to contact

The person you may need to contact will depend on the nature of your query.
If you want any further information concerning this project or if you have any medical problems which may be related to your involvement in the project (for example, any side effects), you can contact the principal investigator on 03 8344 7802 or any of the following people:

Clinical contact person

Name	Jaime Leigh
Position	Paediatric Services Coordinator, Cochlear Implant Clinic
Telephone	(03) 9929 8666
Email	Jaime.Leigh@eyeandear.org.au

For matters relating to research at the site at which the child is participating, the details of the local site complaints person are:

Complaints contact person

Name	Robert Cowan
Position	Professorial Research Fellow, The University of Melbourne, Chief Executive Officer, The HEARing CRC
Telephone	61 (3) 9035 5346
Email	r.cowan@unimelb.edu.au

If you have any complaints about any aspect of the project, the way it is being conducted or any questions about being a research participant in general, then you may contact:

Reviewing HREC approving this research and HREC Executive Officer details

Reviewing HREC name	Royal Victorian Eye & Ear Hospital
HREC Executive Officer	HREC Secretary
Telephone	03 9929 8525
Email	ethics@eyeandear.org.au

Consent Form – Parent/Guardian

Title	Going digital: Enabling caregivers to optimise the linguistic environment for children with significant hearing loss
Short Title	OLEC (Optimising the Language Environment for Children)
Protocol Number	15/1250H
Project Sponsor	The HEARing CRC
Coordinating Principal Investigator/ Principal Investigator	Ms Dawn Choo
Associate Investigator(s)	Dr Shani Dettman, Prof Richard Dowell, Prof Robert Cowan
Project Personnel	Dr Mehrnaz Shoushtarian, Ms Alexandra Rousset, Ms Sylvia Tari
Location	Royal Victorian Eye and Ear Hospital, Cochlear Implant Clinic The University of Melbourne, Department of Audiology and Speech Pathology Hear and Say, Queensland The Shepherd Centre, New South Wales

Declaration by Parent/Guardian

I have read the Participant Information Sheet or someone has read it to me in a language that I understand.

I understand the purposes, procedures and risks of the research described in the project.
I have had an opportunity to ask questions and I am satisfied with the answers I have received.

I give permission for the child's doctors and other health professionals to release information to The University of Melbourne and The HEARing CRC concerning the child for the purposes of this project. Relevant information about your child collected during this study may be released to the clinic so as to inform usual care management. I understand that such information will remain confidential.

I understand the use of the LENA which records what my child hears in his/her immediate environment, and that I may nominate deletion of any audio files, or parts thereof.

I am aware of my responsibilities as the parent/guardian for the child participant and I understand that I will be assisting the child whilst they are participating in this study.

I freely agree to the child participating in this research project as described and understand that I am free to withdraw them at any time during the research project without affecting their future health care.

I understand that I will be given a signed copy of this document to keep.

Name of Child (please print) ______________________________

Name of Parent/Guardian (please print) ______________________________

Signature of Parent/Guardian ____________________ Date __________

Name of Witness to Parent/Guardian's Signature (please print) ______________________________

Signature ____________________ Date __________

Declaration by Researcher†

I have given a verbal explanation of the research project, its procedures and risks and I believe that the parent/guardian has understood that explanation.

Name of Researcher† (please print)			
Signature		Date	

† A senior member of the research team must provide the explanation of, and information concerning, the research project.

Note: All parties signing the consent section must date their own signature.

the royal victorian eye and ear hospital

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ethics@eyeandear.org.au

HREC Number:	**15/1250H**
Project Title:	**Going Digital: Enabling Caregivers to Optimise the Linguistic Environment for Children with Significant Hearing Loss**
Principal Investigator:	**Ms Dawn Choo**

I acknowledge receipt of the revised Protocol and Participant Information & Consent Form. I am pleased to inform you that the above project has received ethical approval from the Eye and Ear HREC, is consistent with the National Statement and satisfies the Eye and Ear research governance requirements.

The HREC approval date is 3 December 2015, the HREC Number is 15/1250H, and approval is valid for five years.

This research may now commence at the Eye and Ear.

The following documents have been approved:

- Project proposal/protocol, v2 dated 10 Dec 2015
- Participant Information and Consent Form, v2 dated 4 Dec 2015
- Invitation cover letter
- Invitation to Participate Handout and Permission to Contact Form
- Daily Activities Diary
- LENA Digital Language Processor How to Guide
- Questionnaires: FamEd-Q2, Before Study Questionnaire: Use of Digital Tools, Post-trial Use of Digital Health Tools Questionnaire: LENA and Post-trial Use of Digital Health Tools Questionnaire: LENA and VROOM

The following researchers are approved for their described role in this project at the Eye and Ear site:

- Dawn Choo
- Richard Dowell
- Silvia Tari
- Shani Dettman
- Robert Cowan
- Alex Rousset

The Royal Victorian Eye and Ear Hospital HREC is constituted and operates in accordance with the National Health and Medical Research Council (NHMRC) National Statement on Ethical Conduct in Human Research (2007 and as updated) and in accordance with the Note for Guidance on Good Clinical Practice (CPMP/ICH/135/95) and the Health Privacy Principles in the Health Records Act 2001(Vic) and Section 95A of the Privacy Act 1988.

In order to comply with the National Statement and Good Clinical Practice requirements you are required to:

- submit an annual progress report for the duration of the project
- submit a comprehensive final report upon project completion
- notify the Secretariat of the project start date at the Eye and Ear
- submit all proposed amendments to the project
- submit any adverse event reports involving Eye and Ear patients
- report any unexpected developments in the project with ethical implications
- notify any changes of project Principal and all other Investigators
- advise if the project is completed prior to the anticipated date or is withdrawn
- preserve the confidentiality of information and records about research participants and only use information for the purpose specified in the approved protocol

Please note that any researcher named in the application did not participate in deliberations or decision making for this project.

Please use the HREC number in all future correspondence with the HREC Secretariat.

On behalf of the Committee, I wish you every success with your project.

Yours sincerely

K Baker

Kerryn Baker
Secretary
Human Research Ethics Committee

21 December 2015

.../2

LENA Recording Reminder

Your child's **weekly recording day(s) are:**
(please circle)

Mon /Tue /Wed /Thu /Fri /Sat /Sun

Agreed LENA pack exchange (Pick up/Drop off) will take place on:

Day, Date Time: ______________________________

Please contact the study researcher, Dawn on 038344 7802 or email dawn.choo@unimelb.edu.au if you have any questions.

Participant ID* ☐☐☐-☐☐** ***Recording:* _____ *Week:* ___ */12

Daily Activities Diary

Child's Initials ☐☐☐

Weekly Recording: Dates and Durations

Day 1: ___/____/_____ **Duration:** ____hours ____minutes

Day 2: ___/____/_____ **Duration:** ____hours ____minutes
(if required)

Please record for ***at least 10 consecutive hours****. We recommend switching on the device and recording for a full day, from wake-up to bedtime. The device will stop recording after 16 hours and will switch off automatically.*

Dear Parent/ Caregiver,
Please note the length of time which the device was recording and complete the activities log on the next page for the recording day(s).

The LENA Software will process the audio recordings automatically and provide quantitative data on measures of the child's environment. There are options for: (1). the audio recording to be deleted immediately after LENA processing (2). If you would like for the research team to ignore any portion(s) of the day's recording, please indicate on the activity log which hours should **NOT** be saved for further analysis.
Your requests will be respected as documented on the form.

Please return the completed Daily Activities Diary with the device after each recording.

Your comments or notes regarding this recording:

____

____

1

Caregiver-Child Interactions: Daily Activity Log

Day 1: ___/____/_____ **Is your child feeling well today? Yes/ No** If not, please describe: ____

Is this a typical example of your parent/caregiver child talk time? Yes/ No If not, please describe: ____

Time of Day	Hours	Environment 1. Home 2. Daycare 3. Car 4. Outdoors 5. TV/Radio	Activity	Any there other people present? (Please state who)	What time was the App used? (please tick and state which app activity was completed if applicable)	Is the child wearing hearing aids /speech processors?	Is the LENA device recording?	Indicate any time/hour you do NOT want saved for analysis with a 'X'
Morning	5–7 am					Yes/ No	Yes/No	
	7–9 am					Yes/ No	Yes/No	
	9–11 am					Yes/ No	Yes/No	
Almost Noon	11am–12noon					Yes/ No	Yes/No	
After-noon	12–2pm					Yes/ No	Yes/No	
	2–4 pm					Yes/ No	Yes/No	
	4–6pm					Yes/ No	Yes/No	
Night	6–8 pm					Yes/ No	Yes/No	
	8–10 pm					Yes/ No	Yes/No	

Day 2: ___/____/_____ **Is your child feeling well today? Yes/ No** If not, please describe: ____

Is this a typical example of your parent/caregiver child talk time? Yes/ No If not, please describe: ____

Time of Day	Hours	Environment 1. Home 2. Daycare 3. Car 4. Outdoors 5. TV/Radio	Activity	Any there other people present? (Please state who)	What time was the App used? (please tick and state which app activity was completed if applicable)	Is the child wearing hearing aids /speech processors?	Is the LENA device recording?	Indicate any time/hour you do NOT want saved for analysis with a 'X'
Morning	5–7 am					Yes/ No	Yes/No	
	7–9 am					Yes/ No	Yes/No	
	9–11 am					Yes/ No	Yes/No	
Almost Noon	11am–12noon					Yes/ No	Yes/No	
After-noon	12–2pm					Yes/ No	Yes/No	
	2–4 pm					Yes/ No	Yes/No	
	4–6pm					Yes/ No	Yes/No	
Night	6–8 pm					Yes/ No	Yes/No	
	8–10 pm					Yes/ No	Yes/No	

Study Schedule
Weekly LENA Recordings

Your weekly LENA recording day is scheduled for the day(s) listed below.
After each recording is completed, please return the LENA device and Daily Activities Diary by the next day: either by pre-arranged courier (if you plan to be home) or by dropping off a prepaid express post bag (at the Post Office or in a Yellow-street posting box).

Initial Study Appointment:			
LENA Feedback Sessions Please nominate a day and time for a 10-15 minutes discussion	Your child's weekly recording days are: Mon/Tue/Wed/Thu/Fri/Sat/Sun		LENA Packs Pick-up/ Drop-off
-	Recording Week 1 (please note: 2 recordings this week)	Day 1: Fri or Sat Day 2: Sat or Sun	Day/Date/Time:
-	Recording Week 2	Fri, 30th Sept	Day/Date/Time:
-	Recording Week 3	Fri, 7th Oct	Day/Date/Time:
1.	Recording Week 4	Fri, 14th Oct	Day/Date/Time:
2.	Recording Week 5	Fri, 21st Oct	Day/Date/Time:
3.	Recording Week 6	Fri, 28th Oct	Day/Date/Time:
4.	Recording Week 7	Fri, 4th Nov	Day/Date/Time:
5.	Recording Week 8 + App	Fri, 11th Nov	Day/Date/Time:
6.	Recording Week 9 + App	Fri, 18th Nov	Day/Date/Time:
-	Recording Week 10 + App	Fri, 25th Nov	Day/Date/Time:
-	Recording Week 11 (please note: 2 recordings this week)	Day 1: Fri or Sat Day 2: Sat or Sun	Please return LENA packs and clothing items at next appointment (if possible).
Follow-up Appointment:			

It is best for our study design that recordings remain on scheduled days. However, we understand that parents have busy schedules, and you may need to change some recording days. Please contact the researchers as soon as possible if you need to reschedule.

APPENDIX 7: LENA STUDY INSTRUCTION GUIDE FOR PARENTS

LENA™ Digital Language Processor How-To Guide

Instructions for Parents and Caregivers

Version 2

Prepared for The HEARing Cooperative Research Centre Program XR 3.3.1c

For more information, please contact:

Dawn Choo, The University of Melbourne

Department of Audiology and Speech Pathology

Dawn.choo@unimelb.edu.au

+613 8344 7802

LENA™ Digital Language Processor

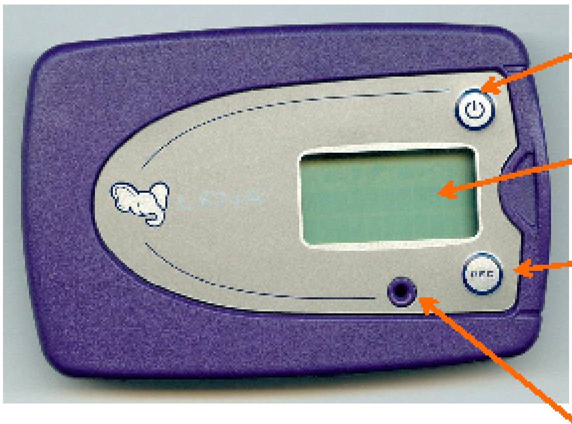
The LENA Digital Language Processor (DLP) is a background (passive) recording device designed to record sounds which your child is exposed to in his/her natural language environment. After recording on the DLP, the stored file is relayed onto a computer and the LENA Software analyses the recording automatically.

Each recording will take place over the course of a day over a maximum duration of 16 hours. You may record over 2 consecutive days if required. We will appreciate your help to record for at least 10 hours straight so that the LENA Software is able to process the recording optimally.

The DLP is delivered to you ready to be used with minimal preparation, although we will require your assistance to turn the device on in the mornings of the recording day(s). You will need to plan what clothing has a suitable pocket for your child to fit the DLP (we can discuss options with you).

- ✓ **Turn the DLP on at the start of each recording day(s) and initiate recording.**
- ✓ **Place the DLP in the pocket of the clothing which your child will wear during the course of the recording days.**
- ✓ **Do a quick check that the DLP has started recording.**
- ✓ **Each weekly recording session will take place over a day (16 hours).**
- ✓ **Ensure that the DLP records for at least 10 hours straight without pausing the recording.**

Getting Started: Using the Digital Language Processor (DLP)



Power Button

Press and hold for 4 seconds to turn on the DLP.

Screen

Shows "Recording" when DLP is on and duration of time.

Record Button

Press and hold for 4 seconds to begin recording.
NOTE: Do not start recording until the morning of recording session.

Microphone

Steps for using the DLP:

1. **Press the top (power) and hold for 4 seconds to turn the DLP on.**
   The screen display will show *'Sleeping'* when first initiated.
2. **Press and hold the Recording 'REC' button until the word '*Recording*' appears on the screen.**
   Note: This button also pauses the recording.
3. **Place DLP into child's LENA clothing.**
   Ensure that '*Recording*' is displayed on screen and not *'Paused'*.
   If recording is on pause, press and hold the REC button again until '*Recording*' appears.
4. **After 10-16 hours of recording or just before bedtime on the first night, press the REC button to pause the recording.** Check that the display screen reads 'Paused'. The DLP will switch off automatically after 15 minutes.
5. **If you are continuing the recording on the next day, if you are recording press the top (power) button to turn the DLP back on and remember to press the REC button again to continue recording.** Check that the display screen says 'Recording'.
6. **At the end of the day, hold the power button down for a few seconds to turn the DLP off.**
7. **After the recording session, place DLP and the Daily Activities Diary in the enclosed envelope. To ensure a quick turnover of the recorder, the items will be picked up on the next scheduled courier day or when you**

Some things to consider…

- If you wish to pause the recording for any reason, or when the child falls asleep on the first night after a 10 hour recording, press the REC button for a few seconds. The screen will read *'paused'* and the timer will stop. Make a note on the diary with the lapsed recording time shown on the screen.
- If the DLP is in *'Paused'* mode and you would like to start recording, press the REC button until the screen shows *'recording'*.
- Leave the DLP on '*Recording*' mode whilst your child is napping during the day. The clothing containing the device may be removed for comfort during your child's nap or whilst he/she is in a car seat, but leave the device near to your child.
- The DLP will automatically turn off after 16 hours of recording. *'Memory Full'* will be displayed on the screen.
- The DLP will be in '*Sleeping*' mode if recording is not activated. The DLP will automatically turn off after 15 minutes in '*Sleeping*' mode.
- If the DLP has turned off after 15 minutes in '*Sleeping*' mode, press the top button for 4 seconds to power on. To begin recording after the DLP is back on, press and hold the REC button until the screen shows *'Recording'*.
- The DLP should not be exposed to liquids or extreme conditions. To ensure the best recording, ensure that the recorder is on the outer most layer of clothing whenever possible.
- Please do not attempt to connect the DLP to any other devices as it may damage the device. The recording can only be analysed using the LENA Software.

Please call or email the study's researchers if you have any questions.

Dawn Choo
Researcher
Email: dawn.choo@unimelb.edu.au
Phone: +613 8344 7802/ +614 34 053 364

APPENDIX 8: FAMILY AND EDUCATIONAL CHARACTERISTICS QUESTIONNAIRE 2 (FAMED-Q2)

Family & Educational Characteristics Questionnaire 2 (FamEd-Q2)

FamEd-Q2 completed on: _____/_____/______ **ID #**

Person completing questionnaire: ___________________________________

Assessment/ Evaluation time point (if applicable):

☐ Initial ☐ Follow-up

☐ Pre-op ☐ Post-op ___________ (duration i.e. 1 years post-op)

How far did you have to travel for today's appointment?
☐ Less than 10 km ☐ 10 to 50 km ☐ 50-100 km ☐ Over 100 km

Child

First Name:	Family Name:
Date of Birth:	Age:
Country of Birth:	Gender:

Age at hearing loss diagnosis (if applicable): ______months _______years

Age that child was fitted with hearing aids/devices (if applicable): ______months _______years

Does the child wear his/her hearing aids/devices for (if applicable):

☐ All waking hours ☐ Most waking hours ☐ Half of his/her waking hours ☐ Less than half of his/her waking hours ☐ Not at all

Cause of hearing loss (if known/applicable):

Does the child have any major health or developmental needs? ☐ Yes ☐ No

If yes, please describe: ____

Do you have any concerns about your child's health? ☐ Yes ☐ No

If yes, please describe: ____

We would like to acknowledge that this questionnaire has been adapted from Geers & Brenner (2003) and revised based on the Family and Educational Characteristics Questionnaire developed by Ms Jaime Leigh and the Cochlear Implant Clinic, The Royal Victorian Eye and Ear Hospital.

Please contact Dawn Choo (The HEARing CRC) regarding the use and distribution of the FamEd-Q2.

Primary Caregiver to Child

First Name:	Family Name:
Year of Birth:	Gender:
Relationship to child:	
Estimated time spent with child per week (hours of care):	
Occupation:	
Employment status (please tick): ☐ Full-time ☐ Part-time ☐ Casual ☐ Self-Employed	
Highest Level of Education Completed (please tick): ☐ Less than 12 years of education ☐ Completed high school ☐ Completed a diploma or certificate ☐ Completed a university degree ☐ Completed a post-graduate degree	
Does the child's primary caregiver hold any Centrelink health care or concession cards? ☐ Yes ☐ No	
Does the child have a secondary caregiver? ☐ Yes ☐ No If yes, please state relationship to child: ______________________________	

Parent(s) and Family

Mother's hearing status: ☐ hearing ☐ has a hearing loss, please state degree of hearing loss: __________	
Father's hearing status: ☐ hearing ☐ has a hearing loss, please state degree of hearing loss: __________	
Mother lives with child: ☐ Yes ☐ No	Father lives with child: ☐ Yes ☐ No
Number of adults who live in household:	
Number of siblings:	Siblings' ages:
Position of hearing impaired child in family (i.e. oldest/middle/youngest):	
Home Postcode:	
Primary Spoken language of the home:	

Please contact Dawn Choo (The HEARing CRC) regarding the use and distribution of the FamEd-Q2. 2

Secondary Spoken language of the home:
Mode of communication used at home (please tick): ☐ Spoken/Oral language only ☐ Spoken language and Sign/ Auslan ☐ Sign/Auslan only

Educational Setting

Does the child attend Early Intervention? ☐ Yes ☐ No

If yes,
Name of centre/program: ______________________ Location: ______________________

How long has the child been receiving EI services? ________ months __________ years

Was there a waitlist for EI services? ☐ No ☐ Yes, please specify how long you had to wait: ___months ___weeks

How do you travel to EI services? ☐ Car ☐ Train and bus ☐ Walked ☐ Other: ___________

How far do you have to travel for EI services? ☐ Less than 10 km ☐ 10-50 km ☐ 50-100 km ☐ Over 100 km

How many hours do you set aside to attend each EI session including travel time?
☐ 1 hour or less ☐ 1-2 hours ☐ 3- 4 hours ☐ More than 4 hours, please specify:__________

Do you have to take time off work to attend EI sessions? ☐ Yes, half a day ☐ Yes, one day ☐ No

Communication mode used in **Individual** therapy (please tick):

☐ Spoken/Oral language only ☐ Spoken language and Sign/ Auslan ☐ Sign/Auslan only

Frequency and duration of Individual sessions: (please tick)	☐ Once a **week**, please state number of hours: ________ ☐ Once a **fortnight**, please state number of hours:_______ ☐ Once a **month**, please state number of hours:_______ ☐ Once every **6 months**, please state number of hours:_______ ☐ **No regular service**, please state number of hours:_______

Communication mode used in **Group** sessions (please tick):

☐ Spoken/Oral language only ☐ Spoken language and Sign/ Auslan ☐ Sign/Auslan only

Frequency and duration of Group sessions: (please tick)	☐ Once a **week**, please state number of hours: _________ ☐ Once a **fortnight**, please state number of hours:________ ☐ Once a **month**, please state number of hours:________ ☐ Once every **6 months**, please state number of hours:________ ☐ **No regular service**, please state number of hours:________

Does the child attend kindergarten? ☐ Yes ☐ No

If yes,

Hours per week: ___________

Communication mode used in kindergarten (please tick):

☐ Spoken/Oral language only ☐ Spoken language and Sign/Auslan ☐ Sign/Auslan only

Does the child attend Childcare/Creche? ☐ Yes ☐ No

If yes,

Hours per week: ___________

Other? Please describe (i.e. Grandmother minds child 2 days per week):

____

____

____

Additional information or notes

Thank you

APPENDIX 9: FAMILY PARTICIPATION RATING SCALE (MOELLER 2000)

Family Participation 5 Point Rating Scale (Moeller, 2000)		
<u>Rating Scale Descriptors:</u>	**<u>Clinician's Rating of Family Participation</u>:** *(Please put a tick or cross in one of the 5 boxes below which best describes this family)*	**<u>Clinician's rating of confidence</u>** *On a scale of **0 (not confident at all) to 2 (very confident)**, how confident are you in rating this child's family participation level?*
<u>Rating of 5 (Ideal Participation)</u> Family seems to have made a good adjustment to the child's deafness. The family is able to put the child's disability in perspective within the family. Family members actively engage in sessions. They attend sessions and meetings regularly and pursue information on their own. They serve as effective advocates for their child with professionals/school districts, etc. Family members become highly effective conversational partners with the child and serve as strong and constant language models. Family members become fluent/effective users of the child's mode of communication. They are capable of applying techniques of language expansion. Extended family members are involved and supportive.		
<u>Rating of 4 (Good Participation)</u> Family members make a better than average adjustment to the child's deafness. Family members regularly attend parent meetings and sessions. Parents take an active role (perhaps not the lead) in Individual Family Service Plans and Individual Education Plans. Family members serve as good language models for the child and make an effort to carry over techniques at home. Some family members have fairly good facility in the child's communication mode and/or in techniques for language stimulation. Efforts are made to involve extended family members.		
<u>Rating of 3 (Average Participation)</u> Family is making efforts to understand and cope with the child's diagnosis. Family members participate in most sessions/ meetings. Busy schedules or family stresses may limit opportunities for carryover of what is learned. Family may find management of the child challenging. Family attends Individual Family Service Plan and Individual Education Plan meetings but may rely primarily on professional guidance. Family attempts to advocate but may be misdirected in some of their efforts. Selected family members (eg, mother) may carry more than their share of responsibility for the child's communicative needs. Family members develop at least basic facility in child's communication mode. Family members are willing to use language expansion techniques but need ongoing support and direction.		
<u>Rating of 2 (Below Average)</u> Family struggles in acceptance of the child's diagnosis. The family may be inconsistent in attendance. They may be inconsistent in maintaining the hearing aids and keeping them on the child outside of school. They may have some significant life stressors that interfere with consistent carryover at home. Management of the child presents daily challenges to the family. Communicative interactions with the child are basic. Family lacks fluency in the child's mode of communication.		
<u>Rating of 1 (Limited Participation)</u> Family faces significant life stresses that may take precedence over the child's needs (eg, domestic abuse, homelessness). Family has limited understanding of deafness and its consequences for the child. Participation may be sporadic or less than effective.		

APPENDIX 10: EXAMPLES OF DESIRED STUDY SEQUENCES A, B, AND C DESIGNED FOR A TRIAL DURATION OF 10 WEEKS

A

Baseline Phase		Experimental Phase																	
Baseline		LENA recording Only Condition			Intervention Condition (LENA FEEDBACK)						Intervention Condition (LENA Feedback + App)								
Week 1a	Week 1b*	Week 2	Week 3	Week 4*	Week 5		Week 6		Week 7*		Week 8			Week 9			Week 10*		
LENA Recording	LENA Recording	LENA Recording	LENA Recording	LENA Recording	LENA Feedback	LENA Recording	LENA Feedback	LENA Recording	LENA Feedback	LENA Recording	LENA Feedback	Use of App	LENA Recording	LENA Feedback	Use of App	LENA Recording	LENA Feedback	Use of App	LENA Recording

B

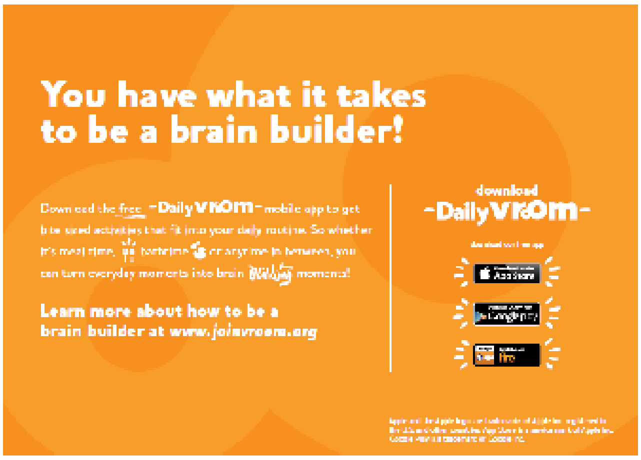
Baseline Phase		Experimental Phase																	
Baseline		Intervention Condition (LENA Feedback + App)									LENA recording Only Condition			Intervention Condition (LENA FEEDBACK)					
Week 1a	Week 1b*	Week 2			Week 3			Week 4*			Week 5	Week 6	Week 7*	Week 8		Week 9		Week 10*	
LENA Recording	LENA Recording	LENA Feedback	Use of App	LENA Recording	LENA Feedback	Use of App	LENA Recording	LENA Feedback	Use of App	LENA Recording	LENA Recording	LENA Recording	LENA Recording	LENA Feedback	LENA Recording	LENA Feedback	LENA Recording	LENA Feedback	LENA Recording

C

Baseline Phase		Experimental Phase																	
Baseline		Intervention Condition (LENA FEEDBACK)						Intervention Condition (LENA Feedback + App)									LENA recording Only Condition		
Week 1a	Week 1b*	Week 2		Week 3		Week 4*		Week 5			Week 6			Week 7*			Week 8	Week 9	Week 10*
LENA Recording	LENA Recording	LENA Feedback	LENA Recording	LENA Feedback	LENA Recording	LENA Feedback	LENA Recording	LENA Feedback	Use of App	LENA Recording	LENA Feedback	Use of App	LENA Recording	LENA Feedback	Use of App	LENA Recording	LENA Recording	LENA Recording	LENA Recording

* Not all participants completed the second LENA recording (1b) at baseline and the third weekly data point for each condition (i.e. weeks 4, 7, 10)

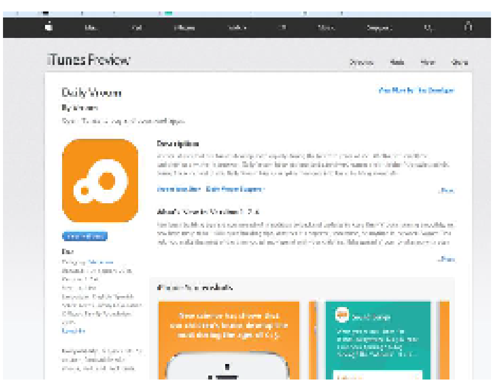
Instructions for getting started with the Daily Vroom Mobile App



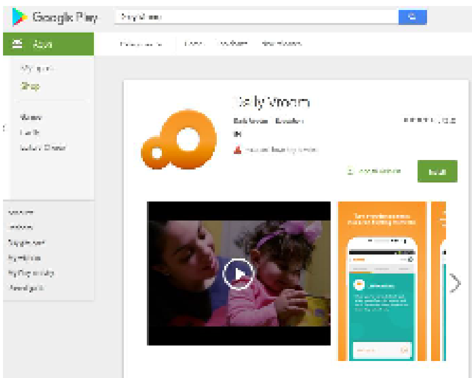
1. How do I get the app?

- You can download it here for iPhone® or here for Android™.
  Alternatively, go to your Mobile App store and search for "Daily Vroom".
- Next, install the application on your mobile phone or tablet/ipad.

Daily Vroom on iTunes for Apple Users



Daily Vroom on Google Play for Android Users

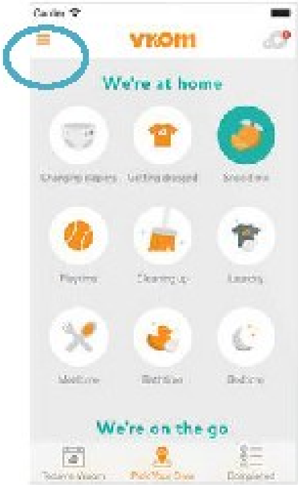


2. Your Daily Vroom Account

- Once the Daily Vroom App has been installed, please open the app.
- You will be prompted to create an account (i.e. email address and make up a password).
- You will also be asked for your child's Date of Birth and Gender as this will help the app to select age-appropriate and suitable activities which your child may be interested in.
- You do not have to enter your child's real name and may use a pseudonym or your child's initials.
- Uploading a photo is optional.

3. App Settings

- Tap on the menu icon on the top left corner of your screen (please refer to example on the right)
- Select "App Settings"



4. Select a Vroom Group

- Scroll down to "Vroom Groups"
- Tick the box next to "Were you referred to Vroom?"
- An additional option to select a group will appear.
- Scroll through the list or use the search function to find "UoM CRC" (as seen below).
- There are 3 UoM CRC options available.
- Please select the group (UoM CRC A, B or C) which your child has been assigned to (the study researcher will provide you with this information).

5. You're ready to begin!

Participant Information Sheet/Consent Form

Health/Social Science Research - *Adult providing own consent*

ROYAL VICTORIAN EYE & EAR HOSPITAL

Title	Going digital: Enabling caregivers to optimise the linguistic environment for children with significant hearing loss
Short Title	OLEC (Optimising the Language Environment for Children)
Protocol Number	15/1250H
Project Sponsor	The HEARing CRC
Coordinating Principal Investigator/ Principal Investigator	Ms Dawn Choo
Associate Investigator(s)	Dr Shani Dettman, Prof Richard Dowell, Prof Robert Cowan
Location	Royal Victorian Eye and Ear Hospital, Cochlear Implant Clinic The University of Melbourne, Department of Audiology and Speech Pathology Hear and Say, Queensland The Shepherd Centre, New South Wales Relevant EI Service Providers

Part 1 What does my participation involve?

1 Introduction

You are invited to take part in this research project, which is called *Optimising the Language Environment for Children*. You have been invited because you are a clinician*. The research project aims to better understand the need and role of using wearable and mobile technology in supporting early intervention service provision from a clinician's and user perspective. Your contact details were obtained from the research team, the University of Melbourne, the Hearing CRC or CRC partner sites.

This Participant Information Sheet/Consent Form tells you about the research project. It explains the processes involved with taking part. Knowing what is involved will help you decide if you want to take part in the research.

Please read this information carefully. Ask questions about anything that you don't understand or want to know more about. Before deciding whether or not to take part, you might want to talk about it with a relative, friend or local health worker.
Participation in this research is voluntary. If you don't wish to take part, you don't have to.

If you decide you want to take part in the research project, you will be asked to sign the consent section. By signing it you are telling us that you:
• Understand what you have read
• Consent to take part in the research project
• Consent to be involved in the research described
• Consent to the use of your questionnaire responses (e.g. age).

You will be given a copy of this Participant Information and Consent Form to keep.

(Clinician in this context refers to as speech pathologists, auditory verbal therapists, teachers, Teachers of the Deaf, teacher aides, special education teachers, counsellors and early intervention professionals.)*

2 What is the purpose of this research?

The use of technology is progressively being integrated into health interventions. Understanding the need and role of technology in supporting service provision from the clinician's point of view will help to provide insight into the practical implications of using wearable, monitoring devices such as the LENA system and the use of a mobile app.

The results of this research will be used by the researcher Dawn Choo to obtain a Doctor of Philosophy degree, under the supervision of Dr Shani Dettman, Prof Richard Dowell and Prof Robert Cowan.

This research has been funded by The HEARing Cooperative Research Centre (HEARing CRC) and is being conducted in collaboration with The University of Melbourne, the Royal Victorian Eye and Ear Hospital and CRC partner organisations.

3 What does participation in this research involve?

If you decide to take part in the research project, you will be asked to:

Step 1. Send this completed Consent Form back to the Primary Researcher:
dawn.choo@unimelb.edu.au
Step 2. Download and trial the free Daily Vroom App for at least 10 minutes.
The app download links are as follows:
For Apple Smartphone Users
For Android Smartphone Users

Step 3. Complete an online questionnaire. A link will be emailed to you after receiving your signed Consent Form.

After trialling the app, completion of the online questionnaire will ask about the use of digital technologies and your perspectives on using wearable devices and mobile apps to benefit early child language development. The online questionnaire includes both closed and open-ended questions and will take approximately 20 minutes to complete.

Step 4. It is your choice whether or not to remove the app from your mobile device after using it. Once you have completed the online questionnaire, there are no restrictions on the continued use of the mobile app, although we **request for clinicians to refrain from sharing the name or details of the mobile app with families who may be potential participants of the intervention trial** until the end of the project in 2018.

4 Other relevant information about the research project

An estimated 30 or more clinicians in Australia from a number of organisations working in collaboration will be taking part in this component of the study. This component of the study takes place concurrently to a parent-directed intervention trial which is testing a new way to enhance early language development in children, through adult-child interactions, in the home environment.

5 Do I have to take part in this research project?

Participation in any research project is voluntary. If you do not wish to take part, you do not have to. If you decide to take part and later change your mind, you are free to withdraw from the project at any stage.

6 What are the possible benefits of taking part?

There will be no clear benefit to you from your participation in this research, although information collected will inform the research area from your perspective as a clinician, in addition to the participating families' perspective(s).

7 What are the possible risks and disadvantages of taking part?

No additional risks of taking part in this project are expected. You may be slightly inconvenienced by having to download and trial the mobile app for 10 minutes before completing the online questionnaire.

8 What if I withdraw from this research project?

If you do consent to participate, you may withdraw at any time. If you decide to withdraw from the project, please notify a member of the research team before you withdraw. If you do withdraw, you will be asked to complete and sign a 'Withdrawal of Consent' form; this will be provided to you by the research team.
If you decide to leave the research project, the researchers will not collect additional personal information from you, although questionnaire data already collected will be retained to ensure that the results of the research project can be measured properly and to comply with law. You should be aware that questionnaire data collected up to the time you withdraw will form part of the research project results. If you do not want your questionnaire data to be included, you must tell the researchers when you withdraw from the research project.

9 Could this research project be stopped unexpectedly?

It is unlikely that the research project is stopped but in the unexpected event, this may be due to the health and personal reasons of the primary investigator(s) or the withdrawal of funding support.

10 What happens when the research project ends?

If you would like a copy of the project findings at the completion of the study, please email the Primary Researcher.

Part 2 How is the research project being conducted?

11 What will happen to information about me?

By signing the consent form you consent to the research team collecting and using personal information about you for the research project. Any information obtained in connection with this research project that may identify you will be replaced with a unique Study ID. Access to de-identified participant data will be provided only to the named researchers, research assistants or students directly under their supervision. Digital information will be password protected, de-identified and stored on a secure computer hard drive and locked filing cabinets. Your information will only be used for the purpose of this research project and it will only be disclosed with your permission, except as required by law.

It is anticipated that the results of this research project will be published and/or presented in a variety of forums. In any publication and/or presentation, information will be provided in such a way that you cannot be identified, except with your express permission.

12 Who is organising and funding the research?

This research project is being conducted by Ms Dawn Choo, at The University of Melbourne under the supervision of Dr Shani Dettman, Prof Richard Dowell, Prof Robert Cowan. Results of this study will be used as part of a Doctoral dissertation. Funding has been provided by the HEARing Cooperative Research Centre to complete this project. No member of the research team will receive a personal financial benefit from your involvement in this research project (other than their ordinary wages).

13 Who has reviewed the research project?

All research in Australia involving humans is reviewed by an independent group of people called a Human Research Ethics Committee (HREC).
The ethical aspects of this research project have been approved by the HREC of the Royal Victorian Eye and Ear Hospital.
This project will be carried out according to the *National Statement on Ethical Conduct in Human Research (2007)*. This statement has been developed to protect the interests of people who agree to participate in human research studies.

14 Further information and who to contact

The person you may need to contact will depend on the nature of your query. If you want any further information concerning this project or if you have any problems which may be related to your involvement in the project, you can contact the researcher:

Research contact person

Name	Dawn Choo
Position	Honorary Speech Pathologist/Clinical Researcher (PhD Student)
Telephone	03 8344 7802
Email	dawn.choo@unimelb.edu.au

For matters relating to research at the site at which you are participating, the details of the local site complaints person are:

Complaints contact person

Name	Adrienne Paterson
Position	Research Program Co-ordinator
Telephone	03 9035 4710
Email	apaterson@hearingcrc.org

If you have any complaints about any aspect of the project, the way it is being conducted or any questions about being a research participant in general, then you may contact:

Reviewing HREC approving this research and HREC Executive Officer details

Reviewing HREC name	Royal Victorian Eye & Ear Hospital
HREC Executive Officer	HREC Secretary
Telephone	03 9929 8525
Email	ethics@eyeandear.org.au

Consent Form - *Adult providing own consent*

Title	Going digital: Enabling caregivers to optimise the linguistic environment for children with significant hearing loss
Short Title	OLEC (Optimising the Language Environment for Children)
Protocol Number	15/1250H
Project Sponsor	The HEARing CRC
Coordinating Principal Investigator/ Principal Investigator	Ms Dawn Choo
Associate Investigator(s)	Dr Shani Dettman, Prof Richard Dowell, Prof Robert Cowan
Location	Royal Victorian Eye and Ear Hospital, Cochlear Implant Clinic The University of Melbourne, Department of Audiology and Speech Pathology Hear and Say, Queensland The Shepherd Centre, New South Wales Relevant EI Service Providers

Declaration by Participant

I have read the Participant Information Sheet or someone has read it to me in a language that I understand.

I understand the purposes, procedures and risks of the research described in the project.

I have had an opportunity to ask questions and I am satisfied with the answers I have received.

I freely agree to participate in this research project as described and understand that I am free to withdraw at any time during the project.

I understand that by sending the signed Consent Form to the Primary Researcher that I am consenting for her to email me a link to the online questionnaire and to completing the steps below.

Step 1. Email this Consent Form back to the Primary Researcher dawn.choo@unimelb.edu.au

Step 2. Download (see links below) and trial the Daily Vroom App for at least 10 minutes:

For Apple Smartphone Users

For Android Smartphone Users

Step 3. You will be given a link to complete the online questionnaire.

Step 4. Delete or keep the app from your mobile. Please refrain from sharing the name or details of the mobile app with families who may be potential participants.

Name of Participant (please print) ______________________________

Signature ______________________ Date ______________________

Designing eHealth for Clinicians And Families (DeCAF)

* 1. Have you downloaded, read and completed the Participant Information Consent Form for this study?

- ◯ Yes
- ◯ No (You will be asked to provide electronic consent on the next page)

1

Designing eHealth for Clinicians And Families (DeCAF)

Participant Consent

* 2. **Please download and read the** Participant Information Sheet.

Please sign and send the completed Consent Form to dawn.choo@unimelb.edu.au.
Alternatively, by selecting the first checkbox option below, you are providing electronic consent to to participating in this online questionnaire.

Declaration by Participant

I have read the Participant Information Sheet or someone has read it to me in a language that I understand.
I understand the purposes, procedures and risks of the research described in the project.
I have had an opportunity to ask questions and I am satisfied with the answers I have received.
I freely agree to participate in this research project as described and understand that I am free to withdraw at any time during the project.
I understand that by ticking the "I provide electronic consent to participating in this online questionnaire" option, I'm agreeing to participate in the questionnaire.
After using the app, you may delete or keep the app from your mobile. Please refrain from sharing the name or details of the mobile app with families who may be potential participants.

◯ **I provide electronic consent to participating in this online questionnaire and wish to proceed.**

◯ **I do not wish to continue.**

Designing eHealth for Clinicians And Families (DeCAF)

This questionnaire is part of a study looking at the use of digital technologies to optimise the linguistic environment for young children with significant hearing loss.
The information collected will provided a rich background for the study researchers to understand the use of wearable LENA technology and the mobile app from your perspective.

Before you begin, please ensure that you are either a current user/have previously used the Daily Vroom App.

Otherwise, please download and trial the Daily Vroom App for at least 10 minutes (click here for more instructions on downloading Daily Vroom).
If you are a clinician, it is your choice whether or not to remove the app from your mobile device after trialing it.
The app download links are as follows:

- For Apple Smartphone Users
- For Android Smartphone Users

This questionnaire will take approximately 20 minutes to complete. Questions marked with an * are compulsory and will require an answer. By selecting the "Next" button, you are agreeing to continue with completion of this questionnaire.

Basic Information

* 3. Please select your age range.

- 18 to 24
- 25 to 34
- 35 to 44
- 45 to 54
- 55 to 64
- 65 to 74
- 75 or older

(Optional) Please specify your age in the box below :

* 4. What is your gender?

- Female
- Male

* 5. Which state do you currently reside in?

6. If you are a clinician, how many years of experience have you had in the health workforce?

7.

If you are a clinician, what type of setting do you work in?
(For example: a hospital, clinic, early intervention, school, community health settings)

8. If you are a clinician, what is the age range(s) of the patients/clients whom you work with?

9. If you are a clinician, how long have you worked at your present organisation?

- Less than 6 months
- 6 months - 1 year
- 1 - 2 years
- More than 2 years
- More than 5 years
- More than 10 years

eHEALS: eHealth Literacy Scale

Acknowledgements:
Norman, C. D., & Skinner, H. A. (2006). eHealth literacy: essential skills for consumer health in a networked world. J Med Internet Res, 8(2), e9.

* 10. I know how to find **helpful resources** on the Internet.

◯ Strongly Disagree
◯ Disagree
◯ Neutral
◯ Agree
◯ Strongly Agree

* 11. I know how to use the Internet to answer my health questions.

◯ Strongly Disagree
◯ Disagree
◯ Neutral
◯ Agree
◯ Strongly Agree

* 12. I know what health resources are available on the Internet.

◯ Strongly Disagree
◯ Disagree
◯ Neutral
◯ Agree
◯ Strongly Agree

* 13. I know where to find helpful **health** resources on the Internet.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

* 14. I know how to use the health information I find on the Internet to help me.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

* 15. I have the skills I need to evaluate the health resources I find on the Internet.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

* 16. I can tell high quality from low quality health resources on the Internet.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

* 17. I feel confident in using information from the Internet to make health decisions.

- ◯ Strongly Disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly Agree

Designing eHealth for Clinicians And Families (DeCAF)

uMARS: Mobile Application Rating Scale

Acknowledgements to:
Stoyanov SR, Hides L, Kavanagh DJ, Wilson H. Development and validation of the user version of the mobile application rating scale (uMARS). JMIR Mhealth Uhealth 2016;4(2):e72.

This section is about the Daily Vroom Mobile App.

Instructions
1. Please use the app and trial it thoroughly for at least 10 minutes.
2. Determine how easy it is to use, how well it functions and does it do what it purports to do;
3. Review app settings, developer information, external links, security features, etc.

18. Entertainment: Is the app fun/entertaining to use? Does it have components that make it more fun than other similar apps?

- ◯ 1 Dull, not fun or entertaining at all
- ◯ 2 Mostly boring
- ◯ 3 OK, fun enough to entertain user for a brief time (< 5 minutes)
- ◯ 4 Moderately fun and entertaining, would entertain user for some time (5-10 minutes total)
- ◯ 5 Highly entertaining and fun, would stimulate repeat use

19. Interest: Is the app interesting to use? Does it present its information in an interesting way compared to other similar apps?

- ◯ 1 Not interesting at all
- ◯ 2 Mostly uninteresting
- ◯ 3 OK, neither interesting nor uninteresting; would engage user for a brief time (< 5 minutes)
- ◯ 4 Moderately interesting; would engage user for some time (5-10 minutes total)
- ◯ 5 Very interesting, would engage user in repeat use

20. Customisation: Does it allow you to customise the settings and preferences that you would like to (e.g. sound, content and notifications)?

- 1 Does not allow any customisation or requires setting to be input every time
- 2 Allows little customisation and that limits app's functions
- 3 Basic customisation to function adequately
- 4 Allows numerous options for customisation
- 5 Allows complete tailoring the user's characteristics/preferences, remembers all settings

21. Interactivity: Does it allow user input, provide feedback, contain prompts (reminders, sharing options, notifications, etc.)?

- 1 No interactive features and/or no response to user input
- 2 Some, but not enough interactive features which limits app's functions
- 3 Basic interactive features to function adequately
- 4 Offers a variety of interactive features, feedback and user input options
- 5 Very high level of responsiveness through interactive features, feedback and user input options

22. Target group: Is the app content (visuals, language, design) appropriate for the target audience?

- 1 Completely inappropriate, unclear or confusing
- 2 Mostly inappropriate, unclear or confusing
- 3 Acceptable but not specifically designed for the target audience. May be inappropriate/unclear/confusing at times
- 4 Designed for the target audience, with minor issues
- 5 Designed specifically for the target audience, no issues found

23. Performance: How accurately/fast do the app features (functions) and components (buttons/menus) work?

- 1 App is broken; no/insufficient/inaccurate response (e.g. crashes/bugs/broken features, etc.)
- 2 Some functions work, but lagging or contains major technical problems
- 3 App works overall. Some technical problems need fixing, or is slow at times
- 4 Mostly functional with minor/negligible problems
- 5 Perfect/timely response; no technical bugs found, or contains a 'loading time left' indicator (if relevant)

24. Ease of use: How easy is it to learn how to use the app; how clear are the menu labels, icons and instructions?

- ◯ 1 No/limited instructions; menu labels, icons are confusing; complicated
- ◯ 2 Takes a lot of time or effort
- ◯ 3 Takes some time or effort
- ◯ 4 Easy to learn (or has clear instructions)
- ◯ 5 Able to use app immediately; intuitive; simple (no instructions needed)

25. Navigation: Does moving between screens make sense; Does app have all necessary links between screens?

- ◯ 1 No logical connection between screens at all /navigation is difficult
- ◯ 2 Understandable after a lot of time/effort
- ◯ 3 Understandable after some time/effort
- ◯ 4 Easy to understand/navigate
- ◯ 5 Perfectly logical, easy, clear and intuitive screen flow throughout, and/or has shortcuts

26. Gestural design: Do taps/swipes/pinches/scrolls make sense? Are they consistent across all components/screens?

- ◯ 1 Completely inconsistent/confusing
- ◯ 2 Often inconsistent/confusing
- ◯ 3 OK with some inconsistencies/confusing elements
- ◯ 4 Mostly consistent/intuitive with negligible problems
- ◯ 5 Perfectly consistent and intuitive

27. Layout: Is arrangement and size of buttons, icons, menus and content on the screen appropriate?

- ◯ 1 Very bad design, cluttered, some options impossible to select, locate, see or read
- ◯ 2 Bad design, random, unclear, some options difficult to select/locate/see/read
- ◯ 3 Satisfactory, few problems with selecting/locating/seeing/reading items
- ◯ 4 Mostly clear, able to select/locate/see/read items
- ◯ 5 Professional, simple, clear, orderly, logically organised

28. Graphics: How high is the quality/resolution of graphics used for buttons, icons, menus and content?

- ◯ 1 Graphics appear amateur, very poor visual design - disproportionate, stylistically inconsistent
- ◯ 2 Low quality/low resolution graphics; low quality visual design – disproportionate
- ◯ 3 Moderate quality graphics and visual design (generally consistent in style)
- ◯ 4 High quality/resolution graphics and visual design – mostly proportionate, consistent in style
- ◯ 5 Very high quality/resolution graphics and visual design - proportionate, consistent in style throughout

29. Visual appeal: How good does the app look?

- ◯ 1 Ugly, unpleasant to look at, poorly designed, clashing, mismatched colours
- ◯ 2 Bad – poorly designed, bad use of colour, visually boring
- ◯ 3 OK – average, neither pleasant, nor unpleasant
- ◯ 4 Pleasant – seamless graphics – consistent and professionally designed
- ◯ 5 Beautiful – very attractive, memorable, stands out; use of colour enhances app features/menus

30. Quality of information: Is app content correct, well written, and relevant to the goal/topic of the app?

- ◯ N/A There is no information within the app
- ◯ 1 Irrelevant/inappropriate/incoherent/incorrect
- ◯ 2 Poor. Barely relevant/appropriate/coherent/may be incorrect
- ◯ 3 Moderately relevant/appropriate/coherent/and appears correct
- ◯ 4 Relevant/appropriate/coherent/correct
- ◯ 5 Highly relevant, appropriate, coherent, and correct

31. Quantity of information: Is the information within the app comprehensive but concise?

- ◯ N/A There is no information within the app
- ◯ 1 Minimal or overwhelming
- ◯ 2 Insufficient or possibly overwhelming
- ◯ 3 OK but not comprehensive or concise
- ◯ 4 Offers a broad range of information, has some gaps or unnecessary detail; or has no links to more information and resources
- ◯ 5 Comprehensive and concise; contains links to more information and resources

32. Visual information: Is visual explanation of concepts – through charts/graphs/images/videos, etc. – clear, logical, correct?

- ◯ N/A There is no visual information within the app (e.g. it only contains audio, or text)
- ◯ 1 Completely unclear/confusing/wrong or necessary but missing
- ◯ 2 Mostly unclear/confusing/wrong
- ◯ 3 OK but often unclear/confusing/wrong
- ◯ 4 Mostly clear/logical/correct with negligible issues
- ◯ 5 Perfectly clear/logical/correct

33. Credibility of source: does the information within the app seem to come from a credible source?

- ◯ N/A There is no information within the app
- ◯ 1 Suspicious source
- ◯ 2 Lacks credibility
- ◯ 3 Not suspicious but legitimacy of source is unclear
- ◯ 4 Possibly comes from a legitimate source
- ◯ 5 Definitely comes from a legitimate/specialised source

34. Would you recommend this app to people who might benefit from it?

- ◯ 1 Not at all I would not recommend this app to anyone
- ◯ 2 There are very few people I would recommend this app to
- ◯ 3 Maybe There are several people I would recommend this app to
- ◯ 4 There are many people I would recommend this app to
- ◯ 5 Definitely I would recommend this app to everyone

35. How many times do you think you would use this app in the next 12 months if it was relevant to you?

- ◯ None
- ◯ 1-2
- ◯ 3-10
- ◯ 10-50
- ◯ >50

36. Would you pay for this app?

- 1 Definitely not
- 2 No
- 3 Maybe
- 4 Yes
- 5 Definitely yes

37. What is your overall (star) rating of the app?

- 1 * One of the worst apps I've used
- 2 **
- 3 *** Average
- 4 ****
- 5 ***** One of the best apps I've used

Designing eHealth for Clinicians And Families (DeCAF)

Perceived Impact of the Mobile App (uMARS)

If you are a clinician completing the following sections of this questionnaire, please respond and comment on behalf of families and children whom you are working with.

Acknowledgements to:
Stoyanov SR, Hides L, Kavanagh DJ, Wilson H. Development and validation of the user version of the mobile application rating scale (uMARS). JMIR Mhealth Uhealth 2016;4(2):e72.

* 38. Awareness – This app has increased my awareness of how language input and exposure affects my child's early language development.

◯ Strongly Disagree ◯ Disagree ◯ Neutral ◯ Agree ◯ Strongly Agree

Comments

* 39. Knowledge – This app has increased my knowledge/understanding of how language input and exposure affects my child's early language development.

◯ Strongly Disagree ◯ Disagree ◯ Neutral ◯ Agree ◯ Strongly Agree

Comments

* 40. Attitudes – The app has changed my attitudes toward improving the amount of language input my child receives.

◯ Strongly Disagree ◯ Disagree ◯ Neutral ◯ Agree ◯ Strongly Agree

Comments

* 41. Intention to change – The app has increased my intentions/motivation to address the amount of language input my child receives.

◯ Strongly Disagree ◯ Disagree ◯ Neutral ◯ Agree ◯ Strongly Agree

Comments

* 42. Help seeking – This app would encourage me to seek further help to address how language input and exposure affects my child's early language development (if I needed it).

◯ Strongly Disagree ◯ Disagree ◯ Neutral ◯ Agree ◯ Strongly Agree

Comments

* 43. Behaviour change – Use of this app will increase/decrease the amount of language input child receives.

◯ Strongly Disagree ◯ Disagree ◯ Neutral ◯ Agree ◯ Strongly Agree

Comments

* 44. Further comments about the app?

Perceived Impact of wearable technnology: LENA (Language Environment Analysis) System

This section is about the use of the LENA (Language Environment Analysis) System.

45. On a scale of 1 (not heard of or used the LENA system) to 10 (very experienced user), how familiar are you with using LENA system?

1 10

* 46. Awareness – The use of LENA has increased my awareness of how language input and exposure affects my child's early language development.

Strongly Disagree Disagree Neutral Agree Strongly Agree

I haven't had sufficient experience or am not familiar with the LENA system

Comments

* 47. Knowledge – The use of LENA has increased my knowledge/understanding of how language input and exposure affects my child's early language development.

Strongly Disagree Disagree Neutral Agree Strongly Agree

I haven't had sufficient experience or am not familiar with the LENA system

Comments

* 48. Attitudes – The use of LENA has changed my attitudes toward improving the amount of language input my child receives.

Strongly Disagree Disagree Neutral Agree Strongly Agree

I haven't had sufficient experience or am not familiar with the LENA system

Comments

* 49. Intention to change – The use of LENA has increased my intentions/motivation to address the amount of language input my child receives.

◯ Strongly Disagree ◯ Disagree ◯ Neutral ◯ Agree ◯ Strongly Agree

◯ I haven't had sufficient experience or am not familiar with the LENA system

Comments

* 50. Help seeking – The use of LENA would encourage me to seek further help to address how language input and exposure affects my child's early language development (if I needed it).

◯ Strongly Disagree ◯ Disagree ◯ Neutral ◯ Agree ◯ Strongly Agree

◯ I haven't had sufficient experience or am not familiar with the LENA system

Comments

* 51. Behaviour change – The use of LENA will increase/decrease the amount of language input child receives.

◯ Strongly Disagree ◯ Disagree ◯ Neutral ◯ Agree ◯ Strongly Agree

◯ I haven't had sufficient experience or am not familiar with the LENA system

Comments

* 52. Further comments about the use of LENA?