PRE-SCHOOL USE OF FM AMPLIFICATION TECHNOLOGY

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Contents

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Abbreviations

AAA	American Academy of Audiology
ACORN	A Classification of Residential Neighbourhoods
ADEX	Advanced Data Extractor
ANSI	American National Standards Institute
ASHA	American Speech Language Hearing Association
AWC	Adult Word Count
BSA	British Society of Audiology
CDI	Child Development Inventory
CE	European Conformity
CI	Cochlear Implant
CLAMS	Clinical Linguistic and Auditory Milestone Scale
CRB	Criminal Records Bureau
CT	Conversational Turns
CV	Child Vocalisations
DLP	Digital Language Processor
FM	Frequency Modulation (transmitter/receiver)
FM+M	Frequency Modulation + Microphone (hearing aid mode)
FMLEC	FM Listening Evaluation for Children (questionnaire)
FRC	Frequency Response Curve
GM ReGroup	Greater Manchester Primary Care Research Governance Partnership
HA	Hearing Aid
IEP	Individualised Education Program
MPO	Maximum Power Output
NHS	National Health Service
NHSP	Newborn Hearing Screening
NRES	National Research Ethics Service
LDS	LENA Developmental Snapshot
LENA	Language Environment Analysis
LTASS	Long Term Average Speech Spectrum
MCDI	MacArthur Communicative Development Inventories
MCHAS	Modernising Children's Hearing Aid Services
PCT	Primary Care Trust
PCHR	Personal Child Health Record
PLS-4	Preschool Language Scale, 4th Ed
R&D	Research and Development
REC	Research Ethics Committee
REEL-3	Receptive-Expressive Emergent Language Test 3rd Ed
SES	Socio Economic Status
SNR	Signal to Noise Ratio
ToD	Teacher of the Deaf
USB	Universal Serial Bus
UKCFMWG	United Kingdom Childrens FM Working Group

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About the author

The Author was amongst the first cohort of students attending the University of Manchester BSc (Hons) Audiology course. He graduated with a 1st class BSc in Audiology with distinction in clinical practice. He was the recipient of an Economics and Social Research Council studentship with which he has pursued this current PhD in Audiology at the University of Manchester. As part of the studentship he completed a Masters in Research Psychology in his first year. He has worked part time for the last 6 years at the Royal Bolton Hospital as a clinical audiologist. More recently he has been appointed as the research co-ordinator at the Ear Foundation in Nottingham where he is directly involved in research projects and overlooks the research programme. The Ear Foundation research is focused on the service user experience (both adults and children) of the technologies associated with hearing impairment (hearing aids/cochlear implants/bone anchored hearing systems/FM systems) by using evidence to inform clinical practice and improve support for users and their families. In his role as research co-ordinator he works very closely with the Collaboration for Leadership in Applied Health Research and Care - Nottinghamshire, Derbyshire and Lincolnshire (CLAHRC-NDL) that is a part of the NHS National Institute for Health Research (NIHR) based at the University of Nottingham.

Abstract

In identifying the importance of early identification of hearing loss in children, very little attention has been given to how advanced FM technology may improve outcomes. Distance, noise and reverberation remain considerable challenges for individuals using hearing aids, more so in really young children. The aim of this present research was to evaluate and explore the benefits of advanced integrated FM amplification technology with pre-school hearing aided children. The research was of a longitudinal prospective design, including both quantitative and qualitative analysis of FM technology use in pre-school hearing aided participants. All participants were provided with the latest hearing aid and integrated FM amplification technology suited to their hearing loss.

An initial study was conducted to validate the 'AutoConnect' feature on the FM technology provided to participants. The manufacturers of the 'AutoConnect' purport the feature removes the need for verifying FM technology 'transparency'. The results indicated the feature did work with the hearing aid and FM combinations used in this study. Three further studies were conducted. The first of these evaluated FM device use via daily diaries, datalogging and questionnaires. Five of the seven families were able to establish regular FM use in a range of environments and settings. The environments where the FM was used most frequently were the home, car, nursery, shopping and outdoors. Listening evaluation measures with FM technology demonstrated the greatest improvements were in noise and at distance. Parents rated the FM technology highly, with all parents reporting 5 out of 5 for 'easy to operate'. Significant improvements in language development were noticed for the three children whose language development was identified as 'at risk' at the start of the study.

The second of the three studies qualitatively explored the views and experiences of parents and carers on their use of FM technology. Eight weekly diaries, seven completed by parents and one completed by pre-school nursery staff of one of the participants, were collected throughout the study period. Seven semi structured interviews were conducted with parents at the end of study participation. Altogether eight cases were included for analysis with seven including both diaries and interviews and one case including diary only. Thematic content analysis sought to acknowledge parents and carers as the experts and place them in the centre of knowledge generation. Six main themes were identified: access to speech, listening, communication, wellbeing, engagement/ownership and practicalities of FM use. More detailed sub-themes were generated under the main six headings. Overall the analysis highlighted the potential benefits, barriers and challenges to pre-school use of FM technology.

The final study used the language environment analysis (LENA) system to compare differences in language environment with and without FM use. The findings indicated the language environment of the children in this study was comparable to their hearing peers. The acoustic environment results suggested the largest portion of children's day was spent in environments where speech was at a distance or in background noise.

The thesis concludes by discussing the findings and implications of this study and highlighting areas for future research. The current study provides a unique contribution to the existing literature and together with future research can be integral to the provision of FM technology as standard for pre-school hearing aided children.

Declaration

No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

Copyright statement

1. Introduction

1.1. Background

The national rollout of the Newborn Hearing Screening Programme in England was completed in March 2006 (www.nhsp.info). This development has been followed up by government sponsored initiatives aimed at raising the standard of early intervention for hearing impaired children identified by the NHSP and appropriate support to their families. The developments in early support services have been matched by rapid technological development in the field of audiology. As a result the national programme providing digital amplification to all paediatric services within England, Modernising Children's Hearing Aid Services (MCHAS), was introduced. Within the framework of social health care this programme enables children identified with hearing loss by the NHSP to have access to the latest digital amplification systems within the first few months of life.

The seminal works of Yoshinaga-Itano et al. (1998), Moeller (2000) and Vohr et al. (2008) stresses the importance of sensitive intervention, demonstrating that where deaf children and their families receive support before six months of age, and Vohr et al. (2008) found before three months, they accrue significantly more benefit in linguistic, social and emotional terms than deaf children identified later in life. Research has further identified the critical role that early auditory experience plays in laying the foundations for spoken communication. Indeed Kuhl and colleagues (1999) propose that speech stimuli is characterised in the form a "perceptual map" by children as young as 6 months of age. For children who are born deaf the acquisition of spoken language and literacy skills still potentially presents a considerable challenge to acquiring age appropriate spoken language and literacy skills (Davis et al., 1997). The principle amplification technology used in early intervention is the acoustic hearing aid. However distance from the speaker, acoustic reverberation and background noise cause adverse effects on listening performance in hearing aid users, especially younger ones (Ross, 1992). FM systems are assistive amplification device used with hearing aids. This device is primarily used in situations where there is a single speaker that the hearing aid user requires listening to e.g. in a classroom situation. The basic components of an FM system consist of two units, the transmitter and the receiver. The transmitter is worn by the speaker. The acoustical signal of the speaker voice is detected by a microphone attached to the transmitter and converted to an electrical signal. This signal is then transmitted to the receiver, which is attached to the user's hearing aid. The transmission occurs on reserved radio frequency bands. The signal is then amplified, converted back to an acoustical signal and delivered to the user through the hearing aid (Ross, 1992). An FM system therefore provides the benefit of a short distance between the speaker and the microphone, which overcomes the challenges of acoustic reverberation and background noise. This in turn improves speech perception and reduces listening effort for the hearing aid user.

FM systems have been widely used in educational settings where there is a well defined situation in which the user wishes to listen largely to a single individual (Boothroyd, 1992). In comparison relatively little use has been made of FM systems in non academic settings. Homes, far from being acoustically friendly, contain many sources of noise as do daily routines of shopping, travel by public transport and playgroups (Berg, 1997). Whilst initially infants are close to the primary carer, increasing independence as children begin to crawl and walk brings increased distance from the primary speaker. For deaf children even early interactions are therefore potentially compromised. Joint attention also presents a major challenge where deaf children are listening to the primary carer but simultaneously looking elsewhere at the object of discussion (Kyle & Sutherland, 1993). It would therefore seem logical to consider the use of FM amplification in children's general environments as well as educational settings in order to maximise benefits. A limited number of studies have addressed the issue of FM use in the home setting but have failed to focus on early identified hearing impaired pre-school children (Brackett, 1992; Moeller et al., 1996). FM systems have previously been unsuitable for young children because of size, weight and accessories needed to link the FM system to the hearing aids. Even the use of smaller wireless ear level receivers attached through the use of FM shoes have been reported to be difficult to use with very young children (Statham & Cooper, 2009). However, the very recent development of fully integrated FM systems incorporated into high performance digital post aural hearing aids (Phonak, 2007) provide an opportunity to overcome these practical limitations.

The present thesis aims to qualitatively and quantitatively assess the use of integrated FM amplification technology with pre-school hearing aided children identified early with hearing loss through the NHSP. In order to gain an insight into the use of FM technology with pre-school children, quantitative measures on: daily use, listening evaluation, technology assessment and language trends was collected. Although the quantitative measures do provide an insight into the use of FM technology with pre-school hearing aided children they cannot provide an insight into the meanings, views and perspectives of the users of the technology. This important aspect, detailing use of FM amplification with pre-school children provides a unique window on the experience of users that can be achieved through qualitative enquiry. Thus a mixed methodological approach was employed to ensure that a holistic view of early use of FM amplification was gained. This research has not been done previously, and the work will develop our understanding of the effectiveness of using different amplification technologies with early identified hearing impaired infants and determine the relevant issues in the use of FM systems with this population.

1.2. Outline of chapters

The next chapter reviews the literature relevant to the current study. The chapter will conclude with the specific aims for each of the four studies to be conducted as part of this research. Chapter three describes the general methodology related to the overall study including, ethics, recruitment, equipment and the overall study procedure. Chapter four describes the first of the four studies which assesses the validity of a new FM technology feature referred to as ‘AutoConnect’. According to the manufacturers this feature removes the need to verify FM systems prior to provision. This chapter will be set out in the format of a peer reviewed scientific journal paper. The chapter will review the literature relevant to the study in the introduction and will present the methods and results in subsequent sections. The final section will appraise the findings from this study with the relevant literature. Subsequent chapters detail the three studies carried out directly with participants. The methods, results and summary of key findings for each study are provided in their respective chapters. The first of these three studies which is described in Chapter 5 provides quantitative measures on the use of FM technology with pre-school hearing aided children. The second of the three studies was a qualitative study providing detailed insight into parents and carers views and experiences of using FM technology with preschool hearing aided children (Chapter 6). The final study describes the language environment analysis (LENA) of pre-school hearing aided children using FM technology (Chapter 7). Chapter 8 brings together the findings from studies two to four in a discussion section and concludes the thesis with the strengths and limitations of the study, implications of the findings and suggestions for future research.

2. Literature review

This review consists of seven sections. The first section will outline the literature on early auditory perception and speech development in normally developing infants. Thereafter, normally developing infant's and children's susceptibility to adverse environmental acoustics compared to older children and adults will be highlighted in the second section. The third section will examine the challenges faced by infants and children with hearing loss to draw attention to the importance of using different forms of amplification technology with this population. The fourth section will critically review the literature on the use of one such amplification technology, the FM system, to understand the limitations present in previous studies evaluating its use with very young children. The progress made so far in the advancement of FM technology will be studied in the fifth section. The subsequent section will provide a conclusion of the literature review and outline the importance of conducting a study using advanced FM amplification technology with young hearing impaired children. The chapter will conclude with a section detailing the aims of the study.

2.1. Early auditory perception and speech development

Prior to the early studies on infant speech perception the widely held view of how infants acquired the phoneme characteristics of their native language was one that emphasised a perception-production relationship. It was assumed that children experimented through babbling and discovered speech sounds through articulations and listening to the resulting sound patterns (Juscyk, 1997). The phenomenon of categorical speech perception was understood in terms of learned equivalence and acquired distinctiveness. In other words, the infant, through auditory exposure and practice of producing speech, would learn to ignore differences from the sounds produced in the same phonemic category and magnify differences in opposing phonemic categories. As a result categorical speech perception was seen to develop through infants' practice of producing and perceiving speech (Fry, 1966).

However other studies have questioned this view (Lenneberg, 1967) arguing that certain linguistic abilities had an innate, rather than experiential basis. Eimas and colleagues (1971) explored this possibility by investigating the speech discrimination capabilities of pre-babbling infants. Eimas et al. (1971) tested infants in two age groups, one and four months, for their ability to discriminate the English voicing contrast observed in the syllables [/ba/] and [/pa/]. The findings demonstrated that infants as young as one month had some capacity to discriminate speech sound contrasts and secondly, like adults, this contrast discrimination was categorical. This highlighted that experience in producing and perceiving one's own speech sounds was not a prerequisite for categorical perception as these were pre-babbling infants.

This study engendered a whole new era of infant-language research and a range of studies followed to investigate the extent of infant speech-discrimination abilities (Jusczyk, 1997). Aspects such as the perception of place of articulation, vowel contrasts, foreign language contrasts, non speech processing, context effects and duplex perception were studied and highlighted infant's innate ability to process speech stimuli from birth (for a review see Jusczyk, 1997). The existing research demonstrates that infants already possess the underlying perceptual capacities to process speech stimuli from any natural language and are well equipped to begin processing speech signals from very early infancy. Studies on the development of speech perception seem to indicate infants begin with a language-general capacity enabling the discrimination of potential phonetic contrasts in any of the world's languages, but following prolonged exposure to their native language the set of contrasts is reduced to those most relevant (Jusczyk, 1997). Jusczyk's (1997) theory explained five processes of categorical perception: enhancement, attenuation, sharpening, broadening and realignment in a particular language environment may modify the ability to discriminate speech sounds.

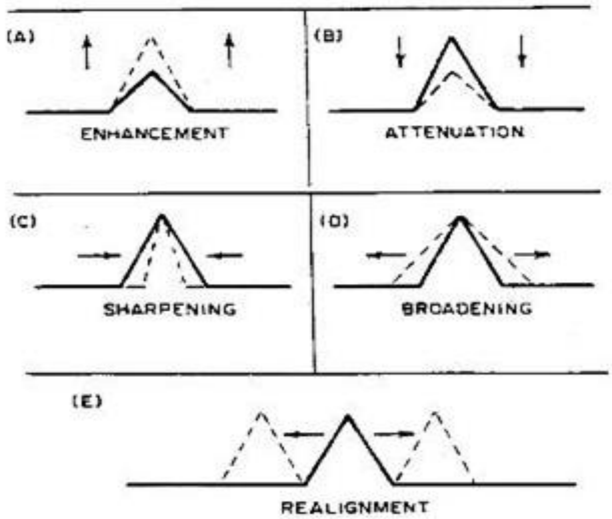


Figure 2.1 Schematised representation of Jusczyk's theory

Infants acquire a substantial amount of information regarding the structural organisation of speech patterns in their native language in a relatively short period of time (Jusczyk, 1997). Research specific to this aspect of developmental data indicates that the first year of life marks a particularly fertile period for learning about specific features of the child's native language (Werker & Tees, 1983, 1984). Infants would appear to be particularly focused on sounds, as sounds constitute the most perceptibly transparent information in the signal. They initially master the sounds of their language to then facilitate the learning of words in their native language (Khul et al., 1999).

The experiential process of learning language may commence before birth as the auditory system begins functioning during the last trimester of gestation (Lecaunet & Granierre-Deferre, 1993; Pasman et al., 1991). The mother's speech is the sound best transmitted to the developing foetus, occurring at a considerably greater intensity then sound in the external environment (Lecaunet & Granierre-Deferre, 1993). Consequently infants have considerable prenatal experience with their mother's speech patterns. This experience may prime infants to preferentially attend to the pitch characteristics and rhythmic patterning of human voices (Lecaunet & Granierre-Deferre, 1993).

2.2. Challenges in auditory perception to children with normal hearing

Given that infants tend to have a systematic progression in language acquisition they are more susceptible to environmental acoustic challenges. In general, young children with normal levels of hearing would experience greater difficulty discriminating speech in noise than adults (Ross, 1992). The concerns over the effects of a noisy environment on the acquisition of language for infants was assessed by Nozza et al. (1990). The study compared speech-sound discrimination in noise for 16 infants between the ages of 7-11 months with 16 adults aged between 19-23 years. The speech-sound stimuli were computer synthesised, consonant vowel syllables /ba/ and /ga/. Variations in performances were taken into consideration for infants and this was determined through pilot data. Infants were tested with the following four SNR's -8, 0, 8 and 16 whereas adults were tested with -12, -8, -4 and 0 SNR. Results showed that although performances varied with SNR for both groups, infants required greater SNR than adults to achieve comparable levels of performance. Overall the results from the study suggested that infants were at a disadvantage compared with adults when processing speech in noise and that concern over the effects of a noisy environment on the acquisition of language was justified.

Other lines of evidence demonstrating the performance difference on speech in noise tasks between infants and adults have emerged more recently. For example, Eisenberg et al. (2000) compared speech recognitions results with reduced spectral cues of two groups of children (5-7 and 10-12 years of age) with that of adults listening to the same materials and conditions. Spectral details of test stimuli was systematically manipulated using a noise band vocoder in which filtered noise bands were modulated by the amplitude envelope from the same spectral bands in speech. Results from this investigation demonstrated that younger children had significantly lower speech recognition scores with reduced spectral cues compared to adults and older children. Analysis of results demonstrated younger children were less skilled then adults and older children in utilising context to recognise words in sentences, however this age difference was not observed for recognition of phonemes in words. The lack of evidence of an age effect in phoneme recognition may have been due in part to the fact that kindergarten level vocabulary was used. If adult vocabulary had been used it would be reasonable to assume an age related difference could have been found for phonemes as well. Overall, results of this research indicate that speech pattern recognition is still maturing in children 5-7 years of age.

Bradley and Sato (2008) measured the speech intelligibility of school aged children in regular classrooms to achieve realistic testing conditions. Altogether 840 children in 41 classrooms in 12 different schools from three age categories were included. The children were in grades 1, 3 and 6 in school and their ages were nominally 6, 8 and 11 year olds. Speech intelligibility scores were obtained using the Word Identification by Picture Identification (WIPI) test. The speech test material was digitally recorded and presented via a small loudspeaker to ensure the same sound levels were used for all test words. Results demonstrated highly significant effects related to SNR and the age of the listeners. The younger children required significantly higher SNR values to obtain the same intelligibility scores as the older children in the classrooms. Model estimates were used to predict the required SNR required for 80% of the children in each age group to achieve (95%) speech intelligibility scores. The required SNR calculated for grade 1, 3 and 6 children was +20, +18 and +15 dB respectively. The findings highlight the increased inability for younger children to understand speech in realistic listening conditions compared to older children. The above studies have established children as young as five with normal levels of hearing are still developing their ability to recognise speech and how acoustically challenging conditions were more detrimental for younger children's auditory perception compared to older children and adults. The subsequent studies highlight the challenges in auditory perception to hearing aid users compared to individuals with normal levels of hearing.

2.3. Challenges in auditory perception to individuals with hearing loss

Even mild to moderate sensorineural hearing losses alter a young child's speech perception in quiet and noise and can impact linguistic development (Moeller et al., 1996). Distance, noise and reverberation are a cause of reduced audibility in normal hearing individuals. However these issues pose an even greater challenge to individuals with hearing impairment. The optimal distance for speech discrimination is within a metre from the listener (Brackett, 1992). In most rooms, at distances of two metres or less the inverse square law of acoustic signals applies. This law dictates for every halving or doubling of distance, the intensity of the acoustic signal would increase or decrease by 6 dB respectively (Ross, 1992). Therefore, once infants and toddlers achieve mobility it would be expected that the optimal distance would not be maintained and that the distance between the child and the speaker would regularly increase.

Distance is not the only challenge for listening. The inverse square law does not apply in rooms where distances exceed two metres due to the presence of sound reflections. In households, noises from common appliances can range from 65 dB SPL to 83 dB SPL with levels as high as 94 dB SPL also being recorded (Ross, 1992). In noisy environments acoustical conditions that are mild or moderately disruptive to normal listeners can result in severely reduced auditory perception in hearing impaired individuals. Similarly, reverberation also adds to the noise effects which increasingly challenge hearing aid users. As sound leaves its source it travels outwards in spherical waves and bounces off all room surfaces, filling the room. For normal listeners reflections received within 30-40 milliseconds of the direct sound are integrated and comprehension and localisation of sound is achieved relatively easily. This phenomenon is referred to as the ‘precedence effect’. However, for hearing aid users reflections are often perceived as separate sound sources that interfere with the perception of direct sound (Ross, 1992).

The effects of reverberation and SNR on hearing aid users compared to normal hearing individuals has been studied by Finitzo- Hieber and Tillman (1978). Table 2.1 below was taken from their study which compares speech scores in different acoustic conditions.

Table 2.1 Speech perception scores comparing a group of normal hearing children and children with hearing loss in different reverberation and SNR conditions taken from Finitzo- Hieber and Tillman (1978).

	Normal				Hearing-Impaired			
R time	Quiet	+12	+6	0	Quiet	+12	+6	0
0	95	89	80	60	83	70	60	39
0.4 s	93	83	83	48	74	60	52	28
1.2 s	77	69	69	30	45	41	27	11

A significant difference between the two groups was observed, with a disproportionately greater effect on the hearing aid users as the acoustic conditions deteriorated. The difference between the two groups highlights the best speech perception score of the hearing aided group was less than the scores for the normal hearing group. Also, the effect of increasing noise was shown to have a disproportionately greater effect on the hearing aided children (83% to 39%) compared to the normal hearing children (95%-60%). Furthermore, when reverberation was added to the noise the cumulative effect was far greater leading to scores as low as 11%.

Very few studies have researched the effects of reverberation on young children with hearing loss. Therefore to further understand the possible effects of reverberation on children using hearing aids, a study on adult hearing aid users is considered next as it raises some important issues relevant to children. The effect of reverberation on adult hearing aid users was investigated by Hawkins and Yacullo (1984). Two groups of adults were included in the study. The first group consisted of 12 normal hearing subjects and the second group consisted of 11 subjects with mild to moderate hearing loss. One of the variables investigated was the effect of room reverberation time (0.3, 0.6 and 1.2 seconds) on 50% correct speech recognition scores using the NU-6 monosyllabic words (Northwestern University Auditory Test No.6). The presentation level of the noise was varied using a best of three adaptive procedure to determine the SNR necessary to determine 50% correct recognition. The results of the study are described in Table 2.2.

Table 2.2 SNR necessary for 50% correct speech tests scores in different reverberation conditions (Hawkins and Yacullo, 1984).

	Normal	Hearing-Impaired
0.3s	-8	+2
0.6 s	-6	+6
1.2 s	-2	+12*

* Only six of the 11 hearing aided subjects were able to perform the task for this condition.

A statistically significant ($p < 0.01$) decrease in performance for hearing aided users compared to normal hearing users was found for each of the reverberation times. Similarly, a statistically significant ($p < 0.01$) decrease in performance as reverberation times increased was noted for all subjects in all three conditions. At 1.2 seconds reverberation time, five of the subjects could not do the task as a result a more representative value for that condition would be higher indicating even poorer performance. The findings highlight how the effects of reverberation have a far greater impact on individuals with hearing loss using a hearing aid compared to normal hearing adults. Similar to the findings from Finitzo-Hieber and Tillman

(1978) the reverberations times had a disproportionately greater effect on the hearing aid users. The hearing loss levels for subjects in this study were described as mild to moderate, as such the effect of reverberation time on individuals with severe- to profound hearing loss would be expected to be greater. As described previously (Bradley and Sato, 2008; Eisenberg, 2000; Nozza et al, 1990), children are more susceptible to adverse listening conditions compared to adults. The studies in this section have described how individuals with hearing loss even when fitted with amplification technology were more susceptible to adverse listening conditions compared to normal hearing individuals. Put together this highlights the increased disadvantage to very young children with hearing loss. The findings from the above studies have implications for the fitting of amplification devices to young children with hearing loss. The primary aim is to ensure children with hearing loss have clear access to the acoustic-phonetic patterns of speech that will form the basis for further phonological and linguistic development. For this the use of optimised device designs and processing characteristics need to be utilised to help ameliorate the extra challenges faced by this population.

More recently Moeller et al. (2007a, 2007b) compared the vocalisations of 12 early identified hearing impaired infants with 21 normal hearing infants in an in depth longitudinal study over 14 months. The mean age of identification of hearing loss for these children was 2.5 months and the mean age of hearing aid fitting was 4.7 months. Thirty minute mother-child interactions were video recorded at 6-8 week intervals in a laboratory playroom setting. Consonantal development and syllable complexity changes were quantified from vocalisations and early verbalisations. Results from this study suggest hearing impaired children despite being identified early were delayed in consonant and syllable structure development compared to normal hearing children. Delayed syllable development may be an indicator of delayed speech development. From the 12 children included in the hearing loss group 10 were identified with hearing loss prior to 4 months of age however two participants were identified at nine and eleven months of age. It would have been useful to exclude the data from these two participants as expectedly this may have distorted the overall results. The only results that were presented for children before 9 months of age was the consistency in use of canonical babbling and these were significantly delayed for the hearing loss group at seven and eight and a half months of age. Overall the findings do suggest children identified with hearing loss prior to 12 months of age had delayed consonant and syllable structure development. The probable causes for this delay were related to the effects of sensori-neural hearing loss on high frequency information. Another major reason suggested for the delay of consonant and syllable structure development by the researchers was the negative effect associated with distance, noise and reverberation in everyday settings.

In summary the above literature has described the early auditory perception and speech production in children with normal hearing. The challenges to early auditory perception for children and their increased susceptibility to environmental acoustic challenges compared to adults were highlighted. The literature further highlighted how individuals with hearing loss were even more susceptible to acoustic challenges compared to their hearing peers. These challenges were shown to affect speech production even in children identified with hearing loss within the first year of life. The negative acoustic effects of distance, noise and reverberation can be overcome for children with hearing loss by the use of FM systems. FM systems transmit speech sounds directly from the speaker to the listener at a greater intensity then the surrounding noise. This enables an audible speech signal to be conveyed to the hearing aid user. FM systems have been widely used in academic settings to overcome problems associated with speaker to listener distance, reverberation and poor signal to noise ratio (Bess et al., 1996; Brackett, 1992). In the same manner FM technology can provide young hearing aided children with an improved signal to noise ratio overcoming many of the above described challenges that they would be expected to encounter in their routine daily activities.

2.4. Pre-school use of FM technology with hearing aided children

As young children with hearing loss begin attending school, the use of FM technology in educational settings becomes routine for them in many countries. However, very few studies have given consideration to the use of FM technology in non academic settings especially with children who have not yet reached school age. Brackett (1992) studied language measures in 19 profoundly deaf children between the ages of two and seven years who had been provided FM systems for personal use alongside their existing cochlear implants. The study compared the phoneme characteristic scores of the children in the study with data reported by Boothroyd (1984) on 120 profoundly deaf orally trained children. The findings suggested the children in the study had better levels of phoneme recognition compared to children with the same degree of hearing loss from the comparison group. Although the study specifically sought children who had been provided with FM technology for personal use outside the educational setting, the participants from the two studies had different primary amplification technologies making it difficult to compare the results. Participants in Brackett's study (1992) were cochlear implant users whereas the children in the comparison study (Boothroyd, 1984) were using analogue hearing aids. Furthermore, data on participant's use of the FM technology were not detailed which could have provided some evidence that the use of the FM systems may have positively influenced the results. Also, the study did not provide individual demographic details on each of the participants making it difficult to establish the number of children who may have been of pre-school age. Although the study did include participants who may have used FM technology in non-academic settings and also children who were of a pre-school age, as the study did not provide any information on FM use or participant's ages it did not provide insight into the potential use of FM technology with pre-school children. As a result the improved speech measures for the children using FM presented in the study cannot be reliably used as evidence for the use of FM amplification with pre-school children.

More recently Gabbard (2003) assessed the benefits and function of FM systems in the Colorado Loaner FM project. The FM device used in this study was an ear level receiver coupled to the hearing aid without the use of cords and body worn devices. Gabbard (2003) did not analyse any objective outcome measures related to speech or language however she was more concerned with the parent's and professional's subjective views. Results were obtained by filling out the FM Listening Evaluation for Children questionnaire (FMLEC; Gabbard, 2003) by both parents and early interventionist providers. This questionnaire uses a five point Likert scale and focuses on parents and interventionist's perception of the child's perceived auditory abilities and also includes a technology assessment section. Completing this questionnaire was a routine requirement of the Colorado Loaner FM Project following three to six months of FM use and quarterly thereafter. Primarily, these results were used to counsel and give technical assistance and training where appropriate for families and providers.

Questionnaires were collected from nine subjects aged between 15 and 30 months of age. In general, hearing aid and FM systems were judged as easy to operate, remained in good working order and were comfortable for children to wear. Gabbard (2003) reported no difference in perceived benefit in listening performance in hearing aids and the FM system. The greatest benefits reported in this study were from comments left by parents at the end of the questionnaire which included: “gives extra boost to hearing aids”, “keeps him focused on the speaker” and “improves attention in noise”. The major finding of this study was many families were able to use and maintain the equipment with ongoing support and information. Similar to Brackett’s study (1992) there was little detail on the study protocol and participant data provided. For example, the actual training provided to parents in the Colorado FM Loaner Project was not described. Similarly, no measures detailing the actual use of the FM device by participants were provided. Finally, the objective changes in language and the scores for participants listening evaluation were not detailed, even though the latter was included as an outcome measure. Although, participants listening evaluation scores reported no perceived benefits of FM use, in contrast the comments by parents reported in the study indicated parents felt there was benefit in FM use. The findings related to the listening evaluation scores were counter intuitive and if these would have been presented this may have helped to understand the differences between the scores and parent reports.

The most recent study on the use of FM in non academic settings with pre-school children was conducted by Statham and Cooper (2009). In their study they offered ear level FM receivers and body worn FM transmitters to five families of children with moderate to profound hearing loss. The families selected for FM provision were those who had raised concerns on their child’s ability to hear speech in difficult listening environments, for example, in the car and in the pushchair. Two of the five participants dropped out of the study as they were beginning the process of cochlear implant assessment. The findings from the other three participants did highlight how the use of FM technology can improve access to speech and enhance quality of family life for young children. However, findings from their study also highlighted difficulties associated with the equipment used. Although the FM receivers were wireless and ear level they were attached to the hearing aids via an FM shoe and the difficulties associated with the functioning, compatibility and maintenance raised concerns and emotional issues for the participants in the study. Like the previous studies (Brackett, 1992; Gabbard, 2003) this study did not include any details on actual FM use and objective measures on language development were not measured. Again this study did include the use of the FMLEC questionnaire in their methods however no results were provided for participants on any of the measures on this questionnaire.

Moeller et al. (1996) overcame some of the methodological limitations in the above mentioned studies. They designed a longitudinal study of FM system use in non-academic settings. Ten children with a mild to moderate hearing loss participated in the two year longitudinal study. The primary participants were eight children with mild-severe hearing loss and were between the ages of two and four at the beginning of the study. The eight subjects were randomly divided into two groups. One group was selected to use the FM system (group I) and the other group was to wear their existing hearing aids (group II). A third group (group III) was created for two 6 year olds who were siblings of one of the participants in group I and upon parental request had been given FM systems six months after the onset of the study. Each subject was assigned an audiological advocate who completed baseline and routine audiological monitoring, monitored device function and provided replacement FM systems when necessary. Although initially groups I and III were to wear the FM system exclusively, observation during the initial parent training revealed problems that would preclude the full time use of these particular systems. Parents of children in the FM groups were provided training regarding FM use. One major goal of the training was to educate and enable parents to make appropriate decisions on which mode of operation to select depending on the situation. Parents were also given both verbal and written instructions regarding care and maintenance of all devices and techniques for assessing equipment functions. All participants were from two-parent, middle- to upper-middle-class homes where one or both parents were employed.

Parents of all subjects were required to complete daily use logs and a weekly observation inventory. Parents were also asked to record factors that affected FM system use, situations where the FM system was preferred or difficult to use, and any perceived differences in their child's auditory performance with the FM system. Audiological evaluations and routine maintenance checks on the hearing aids and FM systems were completed at six month intervals. Word recognition thresholds were obtained on an annual basis using either the Northwestern University Children's Speech Perception word lists (Elliott & Katz, 1980), the Word Intelligibility by Picture Identification test (Ross & Lerman,

1970) or the Phonetically Balanced Kindergarten Word lists (Haskins, 1949 cited in Moeller et al., 1996). Subject's auditory skills were assessed at the beginning and end of the study using the Situational Listening Profile developed for this research. The profile was completed by parents and was designed to monitor children' auditory responsiveness in routine listening environments. Baseline language samples were obtained from all children at the beginning of the study and repeated at 6 month intervals. Language samples were 30 minute sessions videotaped either at their school or at Boystown National Research Hospital. Samples were analysed using Systematic Analysis of Language Transcripts (SALT) and Developmental Sentence Scoring (DSS) (Lee, 1974).

The results of the analyses of language samples from all 10 subjects showed increased developmental complexity and grammatical accuracy of their spontaneous utterances over the duration of the study. By the final test interval six of the ten subjects in the study had closed the gap between chronological and language age for grammatical complexity. Grammar learning rates in selected FM subjects exceeded clinical expectations. However across multiple grammatical measures no statistical difference existed between subject groups. Although the battery of tests used and the detail with which language acquisition was analysed in this study was robust, the small sample numbers in the two main test groups was a major limitation. Due to the small number of subjects a relatively large difference between groups would be required to demonstrate statistical significance. Furthermore, although the study did require parents to complete daily use logs, the results only provide a brief overall percentage of FM use during waking hours for each participant. This percentage was calculated for the first 18 months of study participation. The data does not provide clarity on potential differences in FM use depending on situations or environments or differences in use overtime but simply provides a vague idea of probable FM use dependent on diary entries. As no datalogging feature was present with the equipment used there was no way of ascertaining the reliability of the data. In addition, the results for listening at a distance and in background noise on the situational listening profile developed for the research found no improvements with FM use. This finding was inconsistent with parent's weekly reports and contrary to the expected benefits of FM in general. This highlights the possibility that the instructional set was not clear enough for participants or that the content did not capture the constructs the researchers sought to measure. Also, the results for the weekly observation inventories were presented very briefly and the limited findings presented focussed largely on speech, language and auditory skills rather than the overall views and experiences of FM use in general.

Moeller et al. (1996) found parents did report the number of components and the size of the body worn FM receivers used in their study was one of the biggest deterrents to FM system use. Both parents and children in their study reported the system was bulky, uncomfortable and cumbersome to use outside the home. Similarly, as the receivers were body worn with cords linking to the hearing aid, parents expressed concerns of potential breakage and entanglement when children were climbing or running. Parents did report as the FM system was more visible they received more obtrusive looks and comments from strangers. Likewise the children in their study became more self conscious of the FM technology as they matured and often protested FM device use in public places. By the end of the two year study children were no longer interested in using the FM system outside of the home as a result of this concern. When told about a possible BTE hearing aid which completely housed an FM receiver all parents expressed an interest as this would provide the flexibility to serve as both an FM system and hearing aid. Both the children and parents in the study who had used the FM system agreed unanimously on the benefits of the FM system as an assistive device and the children also reported preferring the FM system in specific listening situations.

Although overall, the above studies did report benefits to the use of FM technology with pre-school children, when considering pre-school use of FM amplification technology the major limitations to these studies were:

- The studies did not include individual children's demographic details which would have been helpful in identifying any potential variables that may have influenced use or non use of FM technology.
- The studies provided little or no data on the actual use of FM by the participants and where usage was reported (Moeller et al., 1996) this was very brief.
- It was difficult to establish the number of pre-school children in the studies of Brackett (1992) and Moeller et al. (1996) as the age range of participants was considerable and individual participant's details were not provided. Participants'

age range in the study conducted by Brackett (1992) ranged from two to seven years and in the study by Moeller et al. (1996) from two to eight years.

- The equipment used, especially in the study by Brackett (1992) and Moeller et al. (1996) was cumbersome and bulky making it unsuitable for younger children. Similarly, Statham and Cooper's (2009) study highlighted even ear level receivers attached to hearing aids via audio shoes raised concerns and emotional issues for parents.

The above studies highlight the lack of empirical evidence available on the use of FM technology with pre-school hearing aided children. The following section will consider recent developments in FM technology that may overcome many of the practical limitations of FM use with very young children. This will then be followed by a conclusion of the literature review which will identify the gap in the current evidence base on the use of FM technology with pre-school hearing aided children.

2.5. Advanced FM technology

A lot of the ergonomic disadvantages mentioned in the above studies if not all are potentially overcome by the recent technological advances in FM amplification. Although various factors can influence the actual FM system arrangement for a given child, the optimal arrangement would be to have a system that provides a transmitter that is:

- easy to use for parents
- not cumbersome
- has the option of boom (head set) and lapel (clip) microphones
- allows for visual monitoring cues of everyday trouble shooting
- provides a datalogging feature showing device use
- rechargeable through direct socket plug
- makes use of advanced digital algorithms similar to those used in digital hearing aids.

Similarly the optimal FM receiver features would include:

- a receiver that was fully integrated with the hearing aid
- a receiver hearing aid combination that was small and suitable for paediatric ears.
- a receiver that made use of advanced digital algorithms.

The most recent advances in FM technology do incorporate the above benefits and include the features listed above. For example, the Phonak Inspiro FM transmitter is a small compact transmitter approximately the size of an average mobile phone (Phonak, 2007). The graphical user interface for the transmitter is a basic and easy to navigate software that someone using a mobile phone would have no trouble accessing. The transmitter has the option of connecting a boom or a lapel microphone, includes an advanced digital platform to process sounds prior to transmission, and is fully rechargeable without having to change batteries. The most recent advances in FM receivers include receivers that can be integrated with digital hearing aids and also use digital signal processing algorithms. The 'mli' series of receivers is an FM receiver fully design integrated with Phonak's latest digital hearing aids. Limitations existing in previous studies such as system bulkiness, device complexities, and cosmetic concerns should be alleviated by the new devices available. Currently the optimal FM system arrangement would be to have a hearing aid integrated with FM receivers with an advanced FM transmitter similar to the Inspiro FM transmitter. This optimal arrangement would offer the latest in advanced FM technology providing an ideal opportunity to build on the current evidence base whilst overcoming many of the limitations faced in previous research.

2.6. Conclusions of the literature review

The aim of this review was to determine the underlying concepts of this study and to establish the possible benefits of FM system use with very young children in their naturally occurring environments. The review of the existing literature has reinforced the need for more attention to be paid to the early use of FM technology with hearing aided children in non academic settings. The apparent paucity of research on the use of FM technology in non academic settings restricts the empirical understanding of the factors that may influence FM technology use with early identified pre-school hearing aided children. To date the only study to provide some level of detail on the efficacy of FM technology use in children's natural environments was done over ten years ago. Furthermore, the FM technology used in the study was inferior to what is available now (Moeller et al., 1996). Whilst there is evidence to demonstrate the acoustic challenges present for infants, most especially those with hearing loss, much research still needs to be conducted relating to the use and benefits of advanced amplification technology with this population. It is therefore important to investigate the efficacy of FM technology use with pre-school hearing aided children. With the improvements in newborn hearing screening resulting in much earlier identification of hearing loss and the continuous advancements in FM amplification technology resulting in improved smaller integrated FM receivers there is a critical need to evaluate this technology for the paediatric hearing impaired population. This present research is therefore both timely and feasible and aims to address the gap in knowledge on FM use with pre-school hearing aided children.

2.7. Aims of the research

This research aimed to quantitatively and qualitatively explore the use of FM technology with pre-school hearing aided children. The focus of this research was on the provision of FM technology to families of pre-school hearing aided children to use in a range of environments and settings. The overarching questions that guided this investigation was

- how parents and carers of pre-school hearing aided children incorporate the use of FM technology into their daily routines?
- what were the potential benefits of FM technology use with pre-school hearing aided children?
- what were the views and experiences of parents and carers using FM technology?

An important precursor to FM technology provision is the verification of FM systems therefore a preliminary study was conducted to assess the 'AutoConnect' function present on the FM equipment used in this study. The manufacturers of the FM equipment described the ‘AutoConnect’ feature removes the need to verify FM systems as the feature would do this automatically.

The primary aim of study one was:

- to assess the ‘AutoConnect’ function to determine whether it performed as described and whether the results would be within the limits described by the American Academy of Audiology (AAA; 2008), Phonak Dynamic Offset Protocol (iPOP; 2009) and the UK children’s FM working group (UKCFMWG; 2008) recommended procedures.

A secondary aim for study one was

- to compare ‘transparency’ levels for each of the five frequencies included in the different recommended procedures.

The subsequent three studies were directly related to the practical use of FM technology in routine everyday settings by parents and carers of pre-school hearing aided children. The first of these three studies focussed on the quantitative measures employed to explore the use of FM technology.

The primary aim of study two was

- to establish quantitative results on the daily usage of FM technology with pre-school hearing aided children including the average duration of FM use, the total hours of FM use, the number of days FM was used and the environments and situations where the FM was used.

Secondary aims for study two were:

- to evaluate situational listening with FM technology for each participant overtime
- to evaluate parents assessment of the FM technology used in this study

- to evaluate children's language development overtime and identify any potential trends related to FM use.

The second of these three studies focussed on the qualitative aspect of FM use with pre-school hearing aided children.

The aim of study three was:

- to explore the views and experiences of parents and carers on the use of FM technology with pre-school hearing aided children.

The final study focussed on objectively comparing the difference in language environments with and without the use of FM technology.

The primary aim of study four was:

- to compare the language environment of pre-school hearing aided children in the home setting and outdoors setting with and without FM technology use.

Secondary aims for study four were:

- to compare the language environment of pre-school hearing aided children with their hearing peers
- to characterise the acoustic environment of pre-school children with hearing loss.

The multi-perspective approach therefore allowed the design and implementation of four studies, which complimented each other by providing a unique insight into the understanding of the use and provision of FM amplification technology in relation to families of pre-school hearing aided children.

3. General Methodology

This primary purpose of this study was to explore parental use of FM systems with hearing aided pre-school children who had been identified very early as having a hearing loss through the NHSP. The research design was a multiple case longitudinal prospective design. The project included a series of case studies leading to an in depth analysis of the use of FM systems by parents of hearing aided pre-school children. The methodological approach was a mixed one, including both quantitative and qualitative measures. The methodology regarding study ethics, recruitment, participants, equipment and overall procedure are discussed in this section.

3.1. Ethics and recruitment

The study was conducted with children currently under audiology care in their local National Health Services (NHS) and therefore required full NHS ethics approval in accordance with the guidelines of the National Research Ethics Services (NRES) (www.nresform.org.uk). To obtain full NHS ethics approval various processes required completing and are outlined below in order. The final approval documents for each process are provided in Appendix A.

- The University of Manchester research office provided sponsorship and insurance cover after reviewing the completed NRES application
- As multiple sites in the Greater Manchester region were to be approached a Pan-Manchester R&D notification form was completed.
- The study was approved by the Sheffield NHS Research Ethics Committee (REC; REC reference: 09/H1308/94).
- The ethics approval was reviewed and approved by the University of Manchester REC (REC number: 09084).
- Thereafter, Research and Development (R&D) approval was registered to the Greater Manchester Primary Care Research Governance Partnership (GM ReGroup) through the central R+D site in Salford (SalfoR+D).

- In accordance with R&D approval, an application for a research passport specific to this study was also sought through the GM ReGroup and a recent CRB from the University of Manchester was included as required.

At this stage all the required documentation for ethics was in place apart from site specific R&D approval which could only be completed once individual departments agreed to participate in the study. An appeal was made to every paediatric audiology department in Greater Manchester by email with details of the study, inclusion criteria and participant information sheet. The participant inclusion criteria for the study were as follows.

- Children should have had full term, uneventful birth histories and meet age appropriate motor and cognitive developmental landmarks.
- Children should have been identified through the NHSP with a moderate (41-70 dB HL) or greater bilateral sensori-neural or mixed hearing loss (British Society of Audiology recommended audiometric descriptors) and aided prior to 6 months of age.
- Children should not be fitted with cochlear implants (CI)
- Children's local audiology departments should consent to fitting Phonak Naida or Nios hearing aids for participants.
- Children must have established use of hearing instruments.
- Children should be of a pre-school age with the minimum age approximately 10 months and maximum age 40 months.

The reason for excluding infants with developmental delays from this study was to limit any potential factors that could influence parental use of the FM device and/or could have an effect on outcome measures. Children with mild, unilateral or conductive hearing loss were also excluded from the study as outcome measures for language and listening may not have been comparable across the different hearing loss groups. Children who had been fitted with cochlear implants were excluded on the basis that FM technology for cochlear implants was not integrated and as a result the comparison of technologies would not have been consistent. One of the main facilitators for this particular research was the development of integrated FM receivers, which considerably reduced the bulkiness of the device and the safety concerns associated with previous FM technology. The latest integrated FM receivers were only compatible with the Phonak Naida and Nios hearing aids and would therefore require audiology departments to upgrade participant's hearing aid technology. Therefore, children whose audiology departments would not consent to fitting this technology had to be excluded. Hearing care professionals (ToD's and audiologists) were asked to consider the child's hearing aid use on the basis that FM system use was only possible with hearing aid use. A minimum age was set to take into account the age when child mobility would begin to pose challenges of distance from the primary speaker and a maximum age was set to encompass the relevant pre-school stage.

Of the 10 paediatric audiology departments approached in the Greater Manchester area two departments agreed to take part in the study and four departments showed an interest but requested more information. Site specific documentation and R&D forms were submitted to the GM ReGroup for the two sites that had agreed participation and approval was obtained for these two sites (Appendix A). The first site had identified three potential participants and the second site had identified one potential participant. Once participants were identified, the audiology professionals were requested to pass on participant information sheets to parents and to provide the parents with the option of a meeting for the parent to request further explanations or answers if needed. All four parents preferred to meet and after discussing the project agreed to participate in the study. However, one of the parents had to cancel participation prior to commencing the study as their child had just been offered to be fitted with cochlear implants.

Where interest from departments had been shown further information was provided and ToD's were included in the discussions. The involvement of ToD's was instrumental in getting two more departments on board and providing potential participants with information on the study. One of the sites had identified three potential participants and the other site had identified one. Site specific R&D forms and accompanying documentation was submitted for the two sites who agreed participation. Once R&D approval had been obtained for these two sites (Appendix A) meetings were offered to parents identified to explain the study and answer any queries.

The fifth site that had shown keen interest in the study found it difficult to identify participants as many of their patients had additional needs. One participant was identified by this site and the participant information sheet was passed on the parent. The father decided not to participate as he was a wheelchair user and felt the study participation was too intensive. A meeting was not arranged for this parent to discuss his concerns. The final site which had shown an interest in the study and had identified three to four potential participants decided to cancel participation as they felt participation was too intensive. The number of participants identified, recruited and the reasons for not recruiting certain potential participants are presented in Table 3.1.

Table 3.1 The number of participants identified, recruited, not recruited and reasons for non-recruitment.

Site	No of participants ID'd	Number Recruited	Reason for Non-recruitment
1	3	3	
2	3	3	
3	3 / 4	0	Department cancelled participation because of waiting lists
4	1	1	
5	1	0	Child was selected for CI's
6	1	0	Father of infant was wheelchair user and felt study participation too intensive
Total	12/13	7	

3.2. Participants

Altogether seven families consented to participating in the study. Demographic details for each of the participants are described in Table 3.2. The developmental status of the children was confirmed using the NHS Personal Child Health Record (PCHR). Every child born in England, Wales and Scotland is allocated a PCHR. From this record, information from the 6-8 week review, the 8 month review and relevant history details was checked for each child. All seven participants had no additional developmental delays noted apart from their hearing loss. Walton et al. (2006) conducted a study on the use of the PCHR in 18 503 children born between 2000 and 2002. The study found 93% of parents (16 917) were able to produce their PCHR on request and 85% (15 813) of mothers showed effective use of the PCHR.

The age in months for the children at the start of the study ranged from 11 months to 32 months of age. By the end of the study the children's age in months ranged from 14 months to 38 months. As can be seen in Table 3.2., two families (P3 and P5) did not complete the full six months of the study and ended participation early. Also, two of the participants (P1 and P2) agreed to carry on with the study after the six month period as they had started the study earlier than the other participants. This was because R&D approval was granted much earlier for their site. As a result these two families (P1 and P2) remained in the study for eight months each.

All participants hearing loss ranged between moderate to severe hearing loss in relation to the BSA recommended audiometric descriptors. One participant's right sided hearing loss (P6) was noted as profound. All the children had been identified through the NHSP with a sensori-neural hearing loss within two months of birth. Similarly, all the children had been fitted with hearing aids within two months of birth except for one child (P1) who had been fitted at three months of age.

Previous literature (Calderon, 2000; Cole & Flexer, 2011; Gilkerson & Richards, 2009) has highlighted the influence of variables such as parents education level, family's socio-economic status (SES), whether families were single or two parent families, the number of siblings in the household and the order of birth. Therefore this information was collected from parents at the start of the study. The parent's education level was noted down and classified into one of five categories:

- 1= secondary level (G.C.S.E's, O levels etc.)
- 2= college level (A levels, NVQ etc.)
- 3= post college (Diploma, equivalent professional qualifications)
- 4= university level (BA, BSc etc.)
- 5= postgraduate level (MA, MSc etc.)

Five mothers' education was at a level 3 and two mothers' education was at a level 2. Paternal education was more varied with four fathers' education at a level 3, one father at a level 1, one father at a level 2 and one father at a level 4.

The SES for families was assessed using the ACORN (A Classification of Residential Neighbourhoods; www.caci.co.uk/acorn) categories. The ACORN provides a geo-demographic segmentation of the UK's population which segments small neighbourhoods, postcodes, or consumer households into 5 categories, 17 groups and 56 sub categories. The categories are based on an in depth analysis of approximately 2 million postcodes including every street in England, Scotland and Wales. In depth analysis of demographics (age, ethnicity, household composition), housing, durables (levels of car ownership etc.), financial (areas typical income), media (most popular newspapers) and leisure (number of holidays, entertainment) are included in the ACORN categorisation. For the purpose of this study the five main ACORN categories were used for participants SES descriptors:

- 1: Wealthy achievers
- 2: Urban prosperity
- 3: Comfortably off
- 4: Moderate means
- 5: Hard pressed

The definitions for the above classification cover a broad range of variables which are described in detail on the ACORN website (www.caci.co.uk/acorn). Two of the participants were in the 'Wealthy achievers' category, four were 'Comfortably off' and one was in the 'Hard pressed' category.

All participants in the study were a 'couple family' where both parents were either married or living together. Two of children had no other siblings, three had one sibling, one had three siblings and one child had four siblings. For the children with siblings one was a first born, three were second born and one child was the youngest of the five children in that family.

Table 3.2 Demographic details for each of the participants taking part in the study

	P1	P2	P3	P4	P5	P6	P7
Age at start of study (months)	21	17	11	24	11	15	32
Age at end of study (months)	29	25	14	30	15	22	38
Hearing loss (R-L)	Sev-Mod	Sev-Sev	Mod-Mod	Sev-Sev	Sev-Sev	Prof-Sev	Mod-Mod
Age of identification	2 months	<1 month	1 month	1 month	2 months	<1 month	2 months
Age of amplification	3 months	2 months	2 months	2 months	2 months	<1 month	2 months
Maternal education	3	3	2	3	2	3	3
Paternal Education	3	3	2	4	3	3	1
SES	3	3	3	1	3	1	5
Family Status	Couple	Couple	Couple	Couple	Couple	Couple	Couple
Number of siblings	1	1	0	3	1	4	0
Order of birth	2nd	2nd	-	2nd	1st	5th	-

3.3. Equipment

Participants were provided with the latest Phonak Nios, Naida SP or Naida UP hearing aids via their NHS audiologist. The models provided to each child were dependant on the child's hearing loss and the request of the paediatric audiology department. Some departments requested more than one model where it was felt the child may benefit from one or the other. However, once the audiologist established the preferred model these were maintained throughout the study period. Manufacturer's warranty applied to all hearing aids and a spare hearing aid was also provided to the audiology department if requested. Participants kept their hearing aids after the study was completed and routine maintenance and repairs of the hearing aids was provided by the local audiology departments. All participants were provided with a Phonak Inspiro FM transmitter and the relevant integrated

FM receiver for their model of hearing aid. These were also left with the participants at the end of the study. The two participants who ended study participation early were given the option of keeping the FM transmitters and receivers or returning them. Both participants chose to keep the FM transmitter and receivers for future use and also chose to keep the receivers on the hearing aids. The manufacturers provided a four year extended warranty for all FM equipment and parents and ToD's were provided with detailed instructions on how to access the free repair and maintenance service after the study period. Table 3.3 details the hearing aid and FM receiver models allocated to each participant.

Table 3.3 Hearing aid and FM equipment models fitted to each of the participants in the study

	P1	P2	P3	P4	P5	P6	P7
Hearing Aids	Naida SP	Naida UP	Nios	Naida SP	Naida SP	Naida SP	Nios
FM Receivers	Ml11i	Ml10i	Ml12i	Ml11i	Ml11i	Ml11i	Ml12i
FM Transmitter	Inspiro	Inspiro	Inspiro	Inspiro	Inspiro	Inspiro	Inspiro

3.4. Procedure

After discussing the overall commitment involved with the study at the initial meeting a second meeting was arranged to discuss the FM technology and the diaries to be kept. The meetings were arranged at a time and location as preferred by the parent either at their homes, local audiology clinics or playgroup sessions arranged by the ToD. Meetings at the audiology clinic and playgroups were held in a quiet room provided by the clinic or the ToD. During this appointment the FM equipment was discussed in detail. Parents were given training and time to practice using the equipment to ensure at minimum: they could activate and use the FM transmitter, subjectively check the FM signal with a stetoclip, assess the microphone positioning with the 'soundcheck' function and synchronise the receivers with the transmitter if and when needed. Parents were also provided with written instructions regarding care and maintenance of the FM device. Parents were given the chance to ask any questions and were also provided with contact details of the researcher if they had any further questions or needed to clarify any details. This initial appointment was attended by each child's ToD who was also given the opportunity to ask questions regarding the technology. The benefit of having the ToD present was parents had an established relationship with them and they were ideally placed to provide support in the use of FM technology.

With the limited theoretical framework available to use as guidance in the use of FM systems with preschool children, parents were made aware of the theory and advantages of FM use (short microphone distance, improved SNR, decreased reverberation). Possible areas where competing noise or distance might interfere with communication were discussed and identified with parents and they were encouraged to make as much use of the FM device as possible in these situations. Similarly, parents were encouraged to identify more situations where they could use the FM device and to make as much use of the FM technology in these situations also. Furthermore, the potential benefits for their child receiving a direct speech signal were also explained to parents to highlight the added potential for FM system use in acoustically favourable conditions. As three separate sites were included in the study, the seven participants were under the care of three ToD's. During this meeting and over the course of the study each ToD did get involved with participants to varying degrees and as they were involved with children's overall hearing care they did provide their own advice on the use of FM to parents.

During this initial appointment parents were also given a parent pack (Appendix B) which was organised in an A5 binder. The binder consisted of four tabs with the following content:

1. Contact: contact details of the researcher and supervisors were included as well as a blank space for parents to include local audiology contact details.
2. Instructions: a brief page summarising the overall instructions for parents was included.
3. Daily log: approximately 100 FM daily diary sheets (Appendix B) were included and parents were informed about how to complete these. Extra daily diary sheets were provided to parents when needed
4. Weekly diary sheets: approximately 30 weekly diary sheets (Appendix B) were included in this section which included seven open ended questions for parents to complete. Extra weekly diary sheets were provided to parents when needed.

Parents understood they would need to attend monthly appointments as part of the study. As the study duration was six months approximate dates were arranged in advance with the parents. However these were confirmed closer to the time and appointments were rescheduled if required. Altogether all parents were asked to attend six monthly appointments. Regular appointments were arranged on request for one of the participant's pre-school nursery as well. Overall, appointments were attended regularly on a monthly basis and the location varied between the participant's home, audiology clinic and/or play group sessions as preferred by the parents. If any equipment (faulty or needing replacement) needed to be picked up or dropped off during the month this would be arranged with parents and as requested by the parents would be either done at the parent's workplace, home or audiology clinics. Daily and weekly diaries were collected and data logged on FM transmitters was downloaded onto a secure password protected laptop during the monthly appointments. Similarly, any language or listening evaluation measures that needed completing were collected during these appointments. On average, monthly appointments would last between 15 to 20 minutes. However, if any troubleshooting or repairs were required appointments could take longer. The final appointment included a semi-structured audio recorded interview and appropriate time was scheduled to take this into account.

4. Study 1: Verification of automatic correction of frequency modulation (FM) gain feature

4.1. Introduction

Children with hearing loss require a much better SNR to be able to access speech compared to their hearing peers (Finitzo-Hieber & Tillman, 1978). FM systems have been well documented to provide a reliable speech signal, in turn overcoming the challenges of background noise, reverberation and distance (Ross, 1992). For an FM system to provide the benefits associated with its use, it is important that:

1) the hearing aid portion of the system has been set to provide appropriate audibility and output for the individual child

2) the fitting of the FM system has been verified (AAA, 2008; Auriemmo et al., 2005; UKCFMWG, 2008).

Verification of the FM system is essential to ensure the device is functioning according to pre-determined targets (AAA, 2008). This is even more important when fitting FM systems to young children who may not be able to give subjective feedback. To date no standards have been published regarding the fitting, verification or performance of FM systems. As such, the verification and fitting of FM systems has been dependant on guidelines issued by special interest working groups and independent research (AAA, 2008; Auriemmo et al., 2005; Evans, 2004; UKCFMWG, 2008). As the technology available both within hearing aids and FM systems has developed rapidly over the last 5-10 years the guidance has reflected these changes.

Previously, the procedure for fitting of FM systems was the "equal output" approach which has been described by ASHA (1994) and Dillon (2001). This procedure was reviewed by Hostler (2004) who found although the "equal output" approach had some benefits when the FM system was being used in an FM only mode but in an FM + hearing aid microphone (FM+M) mode there was very little benefit for the child using it. The teachers voice in competing noise would be "lost" and in practice children had to increase the FM receiver volume to be able to hear the teacher. After consultation an FM advantage approach was recommended where different guidance was given for the fitting of linear and non-linear hearing aids. For linear hearing aids the approach was to obtain a 5 dB FM advantage not a 10 dB FM advantage to avoid distortion (Hostler, 2004).

The nonlinear approach for 'FM advantage' advised an equal gain approach but not a "10 dB FM advantage" approach as recommended by ASHA (2002). Hostler (2004) explained hearing aid compression would make this target unworkable. The FM advantage approach still advised an 80 dB SPL signal be used after equal gain was achieved at 65 dB SPL. The 80 dB SPL signal should show a close match to the 65 dB SPL signal but should be at a higher level. This approach would result in an FM advantage at the child's ear greater than observed by the frequency response curves (FRC). This is because at the precise time that an 80 dB SPL signal was being processed through the hearing aid the small gain given to this signal would be the same gain given to any simultaneous signal at a lower level e.g. 65 dB SPL.

Eiten and Lewis (2008) more recently reviewed both the equal output approach recommended by the 1994 ASHA (ASHA, 1994) guidelines and the equal gain FM advantage approach advised in the 2002 ASHA guidelines (ASHA, 2002). They came to similar conclusions as Hostler (2004) and found the equal output approach when used with hearing aids in FM+M mode resulted in significantly reduced or no benefit in FM use. Similarly, they found the equal gain and 10 dB FM advantage approach advised by ASHA (2002) only worked well with single channel linear hearing aids but was unsuitable for current hearing aids which used more complex processing. They (Eiten and Lewis, 2008) advised a 'transparency' approach to be used to verify FM systems. Auriemmo (2005) also advised a 'transparency' approach which she described in a three step protocol similar to the FM advantage approach described by Hostler (2004). The three-step protocol measured both the 'transparency' and the FM/HA ratio in one measurement session. The FM/HA ratio is described as the difference between the HA 65 dB SPL output and an 80 dB SPL signal presented to the FM microphone.

Although the terminology used in different papers and recommendations are not always consistent, the latest approaches advised by different working groups and scientific papers are very similar. The overall aim is to obtain 'transparency' i.e. both the FM and hearing aid FRC contained the same frequency and intensity characteristics when presented with the same 65 dB SPL stimuli. Provided that audibility is assured with the hearing aid alone a transparent FM system will ensure consistent audibility in FM alone and the FM+M mode when the FM is connected (Auriemmo, 2005). The 'transparency' approach is not invalidated by compression in the hearing aid as this will act on both input signals (Platz, 2004, 2006). Platz (2006) described when the FM is verified in this manner this maintains a 10 dB SNR advantage when the two inputs are presented simultaneously.

In the definition of the AAA (2008), Phonak Dynamic FM offset protocol (Phonak, 2009), Aureiemmo (2005) and Eiten and Lewis (2008) 'transparency' was achieved when the two FRC's were within +/- 2 dB at 0.75, 1 and 2 kHz. The FM advantage approach (Evans, 2004) advised by the UKCFMWG (2008) determines 'transparency' as achieved when the two FRC's were within +/- 2 dB at 0.5, 1, 2 and 4 kHz.

Eiten and Lewis (2008) and both the iPOP and AAA guidelines do not recommend the use of an 80 dB signal for checking FM advantage. However the iPOP protocol advises the use of a 90 dB signal after 'transparency' has been established to make sure the output does not exceed maximum power output (MPO) targets. Auriemmo (2005) and Hostler (2004) both advise the use of an 80 dB signal after 'transparency' has been achieved. The UKCFMWG (2008) has similar advice in accordance with the FM advantage (Evans, 2004) guideline they recommend. Although the FM advantage procedure recommends the use of an 80 dB signal after 'transparency', the guidance highlights that the output may not be different or just slightly higher than the 65 dB signal and not to make any adjustments after checking with the 80 dB SPL input signal.

Recent developments in FM technology have resulted in a feature referred to as 'AutoConnect'. The manufacturers of the FM technology incorporating 'AutoConnect' state this feature would automatically adjust the impedance of the receiver and hearing aid, therefore not having to perform the verification process. Recently, two unpublished studies done by Ward (2010) and Symington (2010) for their respective University dissertations both assessed the reliability of the 'AutoConnect' feature as part of their research. Ward (2010) assessed the 'AutoConnect' feature on the Mlxi receiver with three different manufacturers' hearing aids, the Phonak Nathos, Oticon Safari P and the Siemens Impact M. The Phonak Nathos is the UK National Health Service (NHS) equivalent of the Phonak Naida. She used two different FM transmitters the Phonak Inspiro and the Phonak Campus. The results found the Mlxi when used in combination with the Phonak Campus transmitter did not achieve 'transparency' within +/-2 dB at default setting with any of the 3 hearing aids. Similarly, results with the Phonak Inspiro transmitter found 'transparency' was not achieved with the Siemens Impact M hearing aid at default settings and the Oticon Safari P hearing aid did not achieve 'transparency' at default settings for two of the four measurements. However, when the Inspiro transmitter was combined with the Phonak Nathos and Mlxi receiver, 'transparency' was achieved for all four recordings at default settings. Symington (2010) assessed the cross compatibility of FM system components. As part of the study she initially established the gain settings needed for each hearing aid + FM receiver combination to achieve 'transparency' when paired with a transmitter from the same manufacturer. The FM transmitters used were the Phonak Inspiro and the Oticon T21 and the receivers used were the Phonak Mlxi, Phonak MlxS and the Oticon R2. Symington (2010) found even when receivers were set at default settings recommended by manufacturers for FM verification they still required changes in receiver gain to obtain 'transparency' levels within +/-2 dB. The study's findings indicated that when the using a transmitter produced by the same manufacturer the MLxS and R2 receivers achieved 'transparency' in two and four out of ten aids respectively. The Phonak Mlxi which features the 'AutoConnect' feature achieved 'transparency' for six of the ten hearing aids within +/-2 dB at .75, 1 and 2 kHz at default settings. Both studies raise concerns on the general statement issued regarding the 'AutoConnect' feature and highlight the importance for professionals to verify FM instruments, especially when providing for children who may not be able to give subjective feedback.

The current research is part of a longitudinal study looking at the use of FM systems with pre-school children. As part of the study children were fitted with the latest hearing aid and FM technology. The FM technology the children were fitted with incorporated the 'AutoConnect' function. The purpose of this study was to test the reliability of this function to see if the 'AutoConnect' function performs as described for the hearing aid and FM technology combinations used in this study and whether the results achieved would be within the acceptable limits as described by the AAA, iPOP and UKCFMWG.

4.2. Methods

4.2.1. Hearing aids

Three types of hearing aids were used as part of the study, the Phonak Naida UP, Phonak Naida SP and the Phonak Nios as these were the hearing aids that were fitted to the children in the study (Table 3.3). For the purpose of testing the children's audiology clinics were asked to export and forward the latest digital hearing aid fitting parameters for the children's hearing aids. These fittings were imported into Phonak iPFG 2.5a software. Before testing, each individual child's latest hearing aid fitting was programmed into the corresponding hearing aid instrument. For the purpose of this study the verification was done with the aid as it would be seen by the educational audiologist or teacher of the deaf. Although the recommendation is to disable any advanced features on the hearing aid when verifying FM systems, it would not be routinely expected for teachers of the deaf or educational audiologists to have access to the child's fitting software (Auriemmo, 2005; AAA, 2008).

4.2.2. FM receivers

Each hearing aid was fitted with its corresponding integrated ear level receiver from the Phonak Mli series (Table 3.3). This particular range of receivers were design integrated with the hearing aid and were fitted in place of the battery compartment. The battery compartment was removed and in its place the receiver would be fitted in using the pins provided. The receiver slightly extends the size of the hearing aid but cannot be removed without specific equipment. The receiver swivels open for the battery to be replaced when necessary. For testing the default setting of 0 was used for all receivers. This setting could be adjusted either through the computer or the Phonak Inspiro FM transmitter to a volume range of -8 dB to +8 dB.

4.2.3. FM transmitter

For all testing the transmitter used was the Phonak Inspiro FM transmitter with a lapel microphone as this was the device provided to all parents in the longitudinal study. Initially when testing for verification there was some trouble with recordings. Investigation of this identified that as the Inspiro transmitter used a digital platform the advanced features within the transmitter were reacting to the signals being used for verification purposes. Phonak introduced a verification mode which needed activating before verification commenced and deactivation once verification was complete. The software interface used with the Phonak Inspiro FM transmitter was the FM Successware with the latest updated version being the Phonak FM Successware 4.4.

4.2.4. Measurements

4.2.4.1. Audioscan Verifit

For the verification of FM systems coupled to nonlinear hearing aids, hearing aid analysers with calibrated speech signals are recommended. The use of calibrated speech signals helps bypass many of the complex features like noise reduction and feedback management that are present in digital hearing aids. Many of these features can only be turned off through the hearing aid fitting software which is not always available to the person verifying the FM system. The hearing aid analyser used for the verification of the FM system was the Audioscan Verifit. The reason for testing with the Audioscan Verifit was because it uses actual speech for testing the FRC and readily provides data in numerical format in 1/3 octave bands allowing for easy comparisons of actual values. The Audioscan Verifit is a hearing aid test box that analyses real ear, simulated real ear and coupler measurements of hearing aids and FM systems. Amplified speech is analysed by the Audioscan in 1/3rd octave band to provide the long term average speech spectrum (LTASS). This recording is referred to as the Speechmap and is an Audioscan trademark. The use of Audioscan Verifit in the assessment and verification of FM systems has been supported by Auriemmo et al. (2005) in their FM verification protocol. For testing purposes during this pilot study the male voice Speech-std (1) was used. The system provides a variety of digitally recorded real speech signals (male, female, child) as stimuli for evaluation. Stelmachowicz (1996) and Scollie &

Seewald (2001) verified that the simulated speech signals used for Speechmap were good predictors of real speech output for compression hearing aids.

In the Speechmap fitting environment speech and noise are analysed in 1/3rd octave bands and the stimuli data are presented as 3 curves. The top curve is the speech peaks i.e. the level exceeded 1% of the time. The lower curve shows the level exceeded 70% of the time and the middle curve is the average which is taken as the final frequency response curve. In the multiple curve option the average frequency response curve for each test stimuli is presented. For the Speechmap the 1/3rd octave spectrum is averaged over at least 10 seconds of speech material to provide a stable curve. The speech signals are filtered to provide the long-term average speech spectrum (LTASS) recommended by Cox and Moore (1988) for average vocal effort. The frequency curves are provided in both a graphical display as well as a table that provides information in numeric form on the frequency response for each 1/3rd octave from 250Hz-4kHz + 6kHz. This allows for more accurate comparison of FRC's.

4.2.4.2. FM 'transparency'

The procedure for obtaining frequency response curves was as recommended by the UKCFMWG (2008), FM advantage procedure (Evans, 2004), Platz (2004; 2006), Auremmio (2005), iPOP (2009) and the AAA (2008). After programming the hearing aid with the individual child's fitting provided by their audiologist, the FM transmitter was synchronised to the ear level receiver. The FM system was subjectively checked at this stage to ensure the signal was transmitting to the receiver/hearing aid. Verification measurements were taken in a quiet room with an ambient sound level of 40 dB A. The procedure adopted for taking measurements was as follows:

1. The FM transmitter was muted and the hearing aid was attached to the 2cc coupler in the hearing aid analyser. A frequency response curve was obtained for a 65 dB SPL input signal and recorded as Test 1.

2. The hearing aid and coupler were removed and placed in a closed hollow foam box. The mute function was deactivated on the FM transmitter and the lapel microphone placed in the test box. A frequency response curve was obtained for a 65 dB SPL input signal and recorded as Test 2.

3. Test 1 FRC was subtracted from Test 2 FRC at 0.5, 0.75, 1, 2 and 4 kHz

4. Values obtained at 0.75, 1 and 2 kHz were added and divided by 3 to obtain ‘transparency’ based on AAA (2008) and iPOP (2009) recommendations

5. Values obtained at 0.5, 1, 2 and 4 kHz were added and divided by 4 to obtain ‘transparency’ based on UKFMCWG recommendations (2008)

4.2.4.3. FM advantage-FM/HA ratio

The main purpose was to check for ‘transparency’ in the hearing aids, however in accordance with the recommendations of the UKCFMWG (2008), the FM advantage procedure (2004), Platz (2006) and Auremmio (2005) the FM advantage-FM/HA ratio was also checked. The AAA (2008) and iPOP (2009) do not recommend this procedure. After testing for ‘transparency’ a 75 dB SPL signal was presented when using the AuidoScan verifit as this was the default ‘loud’ speech setting. The FM advantage output was not analysed and compared between hearing aids as it was expected that there would be differences between each hearing aid based on individual fitting characteristics.

4.2.5. Analysis

The FM advantage procedure (Evans, 2004) and the good practice guidelines issued by the UKCFMWG (2008) advise comparing across the main speech frequencies 0.5, 1, 2 and 4 kHz for ‘transparency’. The AAA (2008), Platz (2006) and iPOP (2009) recommend comparing three frequencies 0.75, 1 and 2 kHz. ‘Transparency’ was calculated using both procedures for each individual hearing aid + FM configuration and compared for any differences. Similarly, overall differences for each of the five frequencies (0.5, 0.75, 1, 2 and 4 kHz) were calculated for all the recordings to compare the ‘transparency’ achieved at specific frequencies.

4.3. Results

The advantages associated with the use of FM systems are reliant on the system providing appropriate FM gain level. This is established by electroacoustic verification of the FM system, where the FM FRC and the hearing aid FRC are compared for 'transparency'. In accordance with the protocols recommended by the AAA (2008), iPOP (2009) and the UKCFMWG (2008) a +/-2 dB difference between the FM and hearing aid FRC's would be accepted as a transparent signal. The UKCFMWG established 'transparency' by comparing the mean frequency average for the two FRC's at 0.5, 1, 2 and 4 kHz. The iPOP and AAA established 'transparency' by comparing the mean frequency average of the two FRC's at 0.75, 1 and 2 kHz.

Table 3.3 describes the three hearing aid configurations used to assess the validity of the 'AutoConnect' feature. Of the 14 different configurations of hearing loss tested; 4 were Phonak Nios and ml12i FM receivers (P3 R+L, P7 R+L), 8 were Phonak Naida SP with ml11i receivers (P1 R+L, P4 R+L, P5 R+L, P6 R+L) and 2 were the Phonak Naida UP with ml10i receivers (P2 R+L).

4.3.1. Validity of 'AutoConnect' feature

Table 4.1 shows the difference between the FM FRC and the HA FRC for each individual child's hearing aid fitting once programmed into their corresponding hearing aid at five frequencies 0.5, 0.75, 1, 2 and 4 kHz. Two different averages based on different calculation methods are also presented. Figure 4.1 summarises the data for the two different calculation methods. The eight Phonak Naida SP fittings resulted in 'transparency' levels closest to a desired '0' value with three fittings resulting in 0 'transparency' value for at least one of the calculation methods. All results for the Naida SP + ml11i combination ranged within +/- 0.75 with both calculation methods. The two Naida UP + ml10i fittings were between 0.75 to 1.33 dB for both calculation methods and within the recommended +/-2 dB mean frequency average.

The four Nios + ml12i fittings had varied results. Two of the fittings had mean frequency averages between 0.75 and 1.67 dB for both calculation methods. However the other two Nios + ml12i combinations resulted in a 3 dB mean frequency average at default setting based on the iPOP (2009) and AAA (2008) recommendations. The same two aids resulted in ‘transparency’ levels of 0 and 0.75 when mean frequency average was calculated according to the FM Advantage method as recommended by the UKCFMWG (2008). Overall all 14 hearing aid fittings tested, using the mentioned three FM receiver and hearing aid combinations provided, resulted in ‘transparency’ levels within +/- 2 dB SPL when using the UKCFMWG (2008) calculation method. When using the iPOP (2009) and AAA (2008) protocol 12 of the 14 FM receiver and hearing aid combinations resulted in the recommended +/- 2 dB SPL ‘transparency’ levels. The remaining two FM receiver and hearing aid combinations resulted in ‘transparency’ at 3 dB SPL.

Table 4.1 Differences between HA and FM FRC's for each hearing aid+FM combination at specific frequencies.

HA Fitting	HA + FM Receiver	0.5kHz	0.75kHz	1kHz	2kHz	4kHz	Average @ 0.75, 1 and 2kHz	Average @ 0.5, 1, 2 and 4kHz	FM Advantage
P1R	Naida SP + ml11i	-1	0	0	-1	-1	-0.33	-0.75	2.25
P1L	Naida SP + ml11i	2	0	1	1	-1	0.67	0.75	3.5
P2R	Naida UP + ml10i	0	1	2	1	0	1.33	0.75	2.25
P2L	Naida UP + ml10i	0	1	0	2	2	1.00	1.00	2
P3R	Nios + ml12i	1	2	2	1	2	1.67	1.50	5
P3L	Nios + ml12i	-1	3	3	3	-5	3.00*	0.00	2.25
P4R	Naida SP + ml11i	1	0	0	1	0	0.33	0.50	3.5
P4L	Naida SP + ml11i	0	0	0	2	-1	0.67	0.25	3.5
P5R	Naida SP + ml11i	1	0	0	0	-1	0.00	0.00	2.75
P5L	Naida SP + ml11i	1	0	0	0	0	0.00	0.25	2.5
P6R	Naida SP + ml11i	1	0	0	0	-3	0.00	-0.50	1.25
P6L	Naida SP + ml11i	1	0	0	1	-2	0.33	0.00	2.25
P7R	Nios + ml12i	2	3	3	3	-5	3.00*	0.75	4.25
P7L	Nios + ml12i	3	2	2	1	-3	1.67	0.75	3

*Denotes measurements not within the recommended procedure limits.

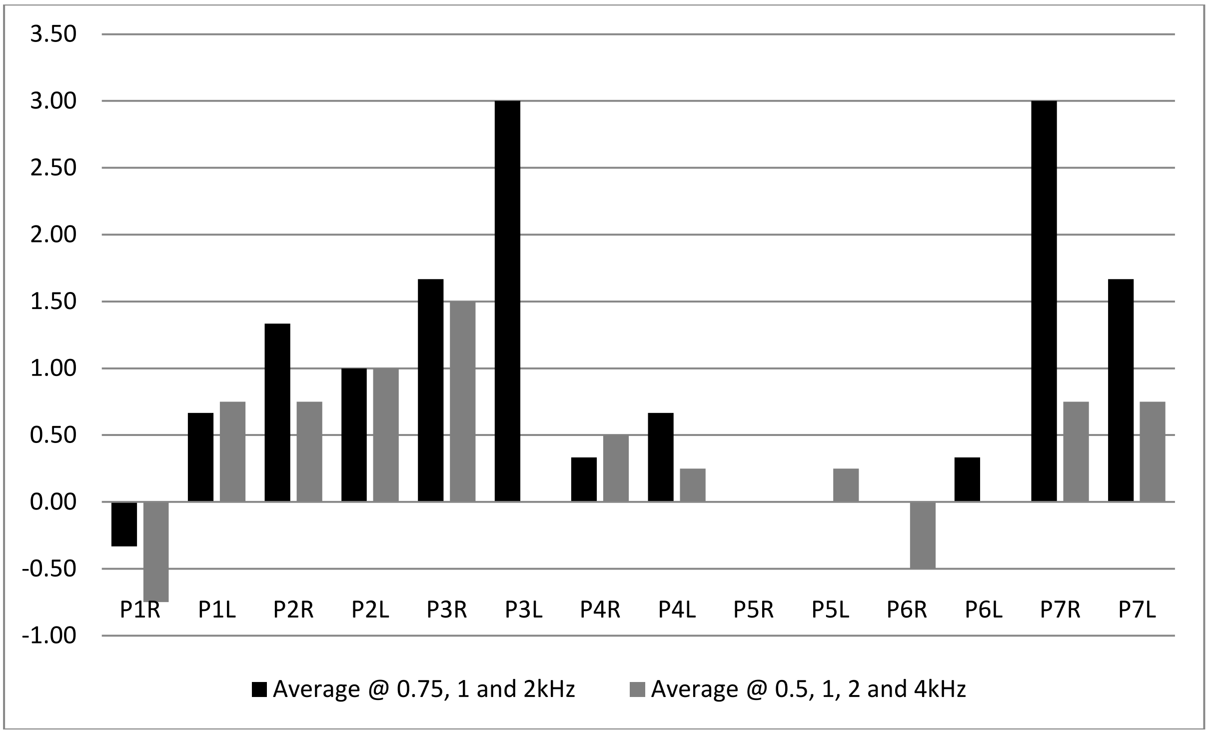


Figure 4.1 Bar graph showing 'transparency' achieved for each hearing aid based on AAA + iPOP recommendations and UKCFMWG recommendations. Black columns= iPOP and AAA calculation method; grey columns= UKCFMWG calculation method.

4.3.2. Comparison of 'transparency' levels for frequencies and calculation methods

Figure 4.2 summarises the mean 'transparency' at each frequency for all 14 hearing aid fittings and the mean 'transparency' achieved for each of the two different calculation methods. The mean difference between FRC's at frequencies 0.5, 0.75, 1, 2 and 4 kHz were 0.79, 0.86, 0.93, 1.07 and -1.29 dB SPL respectively. The 'transparency' levels for 4 kHz revealed 'under balancing' and the other four frequencies revealed 'over balancing'. The range in difference for FM and hearing aid FRC's for frequencies between 0.5 to 2 kHz was between -1 to 3 dB. The difference between FM and hearing aid FRC's at 4 kHz revealed the most difference with a range between -5 to 2 dB. Of the two calculation methods, the UKCFMWG recommendation (0.38 dB SPL) revealed 'transparency' levels closer to 0 compared to the iPOP and AAA recommended procedure (0.95 dB SPL).

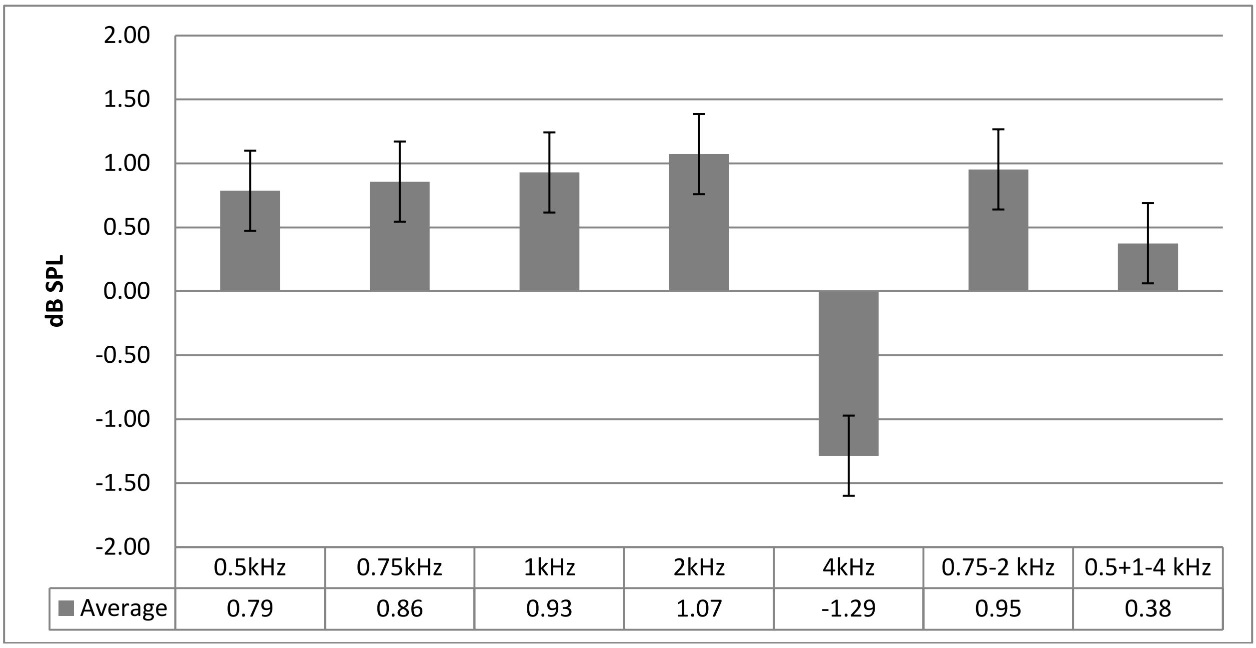


Figure 4.2 Average differences between HA and FM FRC's for all participants' hearing aid fittings at specific frequencies, 0.75-2kHz and 0.5 + 1-4 kHz. Error bars show 95% confidence intervals.

4.4. Discussion

The purpose of electroacoustic verification of FM systems is to ensure that 'transparency' is present between the FM FRC and the hearing aid FRC (Platz, 2004, 2006). The electroacoustic verification procedure is completed with the use of hearing aid analysers by comparing the FRC of the HA and the FM system to ensure both curves have the same frequency and intensity characteristics. When fitting an FM system, routinely the receiver requires adjustments to obtain such 'transparency'. Phonak have introduced a new feature with their FM receivers which they refer to as 'AutoConnect'. They state this feature ensures "an optimal FM level for different hearing instruments, without the need for electroacoustic verification and reprogramming of receivers" (Phonak, 2007).

The results from this study suggest the 'AutoConnect' feature was achieving 'transparency' for the hearing aids + FM combinations tested. When using the FM advantage (Evans, 2004) verification calculation, as advised by the UKCFMWG (2008), all 14 FM configurations provided 'transparency' within +/- 2 dB at 0.5, 1, 2 and 4 kHz at default settings. When using the iPOP (2008) and AAA (2008) recommended procedure for 'transparency' calculation, 12 out of the 14 hearing aid + FM combinations achieved 'transparency'. The remaining two hearing aid + FM combinations were + 3 dB at 0.75, 1 and

2 kHz i.e. they were ‘over-balancing’. However, both these ‘over-balancing’ HA+FM combinations were ‘under-balancing’ by -5 dB at 4 kHz. As 4 kHz is an important speech frequency (Cole & Flexer, 2011) it would not be recommended to reduce the receiver gain in these two particular cases. From a clinical perspective the ‘transparency’ levels for these two hearing aid and FM combinations may not be considered significant. However, this does raise questions on the choice of recommended procedures selected when verifying FM systems, in particular, when studies are employed to evaluate advanced functions of FM technology and different recommended procedures are not reported.

The findings from this study are supported by results from Ward’s (2010) and Symington’s (2010) studies for the specific hearing aid and FM technology combinations used in this study. In Ward’s (2010) study the Inspiro transmitter when combined with the Phonak Nathos and Mlxi receiver achieved ‘transparency’ at default settings. The Phonak Nathos is the NHS equivalent of the Phonak Naida hearing aid. In Symington’s study (2010), consistent with the findings from this study, the Phonak Naida SP was one of the hearing aids achieving ‘transparency’ at default settings. However the interesting result in this study (Symington, 2010) was the Phonak Nios required a change in receiver gain by -6 dB to achieve ‘transparency’. This finding was somewhat consistent with the findings from this study where two of the four Phonak Nios hearing aids with ml12i receivers were over balancing based on the AAA and iPOP recommended calculation methods. However, when using the UKCFMWG recommended calculation method these two hearing aid-receiver combinations were within the recommended +/-2 dB. The other two Phonak Nios hearing aids in this study did achieve ‘transparency’ at default receiver settings within +/- 2 dB for both the AAA+ iPOP and the UKCFMWG recommended calculation methods.

There is the possibility that different calculations for ‘transparency’ could have made a difference with the Phonak Nios hearing aid in Symington’s study, as at 4kHz the overall ‘transparency’ levels for all 14 hearing aid-receiver combinations in this study were ‘under-balancing’ by 1.29 dB SPL. It would have been useful to view ‘transparency’ levels for the five frequencies in both studies (Symington, 2010; Ward, 2010). This would have provided comparisons of the differences in ‘transparency’ based on the different recommendations used. Rejecting advanced technology when a set of results satisfy one particular recommendation whilst the same set of results do not satisfy another recommendation does not provide a robust and reliable measure for assessing advanced technology. A consistent approach regarding verification calculations where all leading professionals and scientists in the field could agree on would benefit practitioners and could provide more reliable interpretations of FM ‘transparency’. Findings from this study suggest the FM advantage procedure (Evans, 2004) provides a more reliable comparison of FRC’s as it includes more frequencies over a wider range. Furthermore, the frequencies used within the FM advantage procedure are the same speech frequencies used in audiology clinics for children’s hearing testing and hearing aid fittings. It would seem appropriate that the same frequencies used for assessing hearing aid fittings be used for FM verification.

Symington’s (2010) study highlights the considerable incompatibility between FM components from different manufacturers. Once gain setting had been set for one FM transmitter, receiver and HA combination, if a different transmitter was used the ‘transparency’ recorded could be greatly variable. Platz (2010) emphasised the issue of system compatibility and the need for manufacturers to adopt a common standard for the design and technology of FM systems. Platz (2010) provides a list of recommendations for manufactures of FM components and hearing aids to ensure ‘essential compatibility’ or basic inter-operability of system components. The non standardisation of systems results in poor cross compatibility questioning FM benefit despite its well known advantages. Bamford et al. (2005) advised DSP hearing aids without low electromagnetic interference processors should not be fitted to clients if personal FM systems are expected to be used. Additionally, it was also recommended that manufacturers use low electromagnetic interference processors in their hearing instrument design. Platz (2010) has suggested an “FM compatible certified” mark could be issued to hearing instruments that obtain ‘essential compatibility’. Although, the prospect of full cross compatibility between manufacturers’ systems would be a thing of the future, basic compatibility would greatly benefit practitioners and users of FM components.

It is important to note the current study was limited to specific models of hearing aids, receivers and transmitters. The FM transmitters and receivers in this study were all from the Phonak ‘Dynamic family’. The findings were in favour of the ‘AutoConnect’ feature working for these particular combinations with various hearing loss configurations. However that does not equate to the ‘AutoConnect’ feature working with different FM transmitters or different manufacturer's equipment (Ward, 2010; Symington, 2010). The findings from Ward (2010) and Symington's (2010) studies highlight the limitations in the 'AutoConnect' feature that when using non-'Dynamic FM' equipment and different manufacturer's equipment the 'AutoConnect' feature cannot be relied upon. Similarly, even when using the 'Dynamic FM' combinations it would still be recommended to obtain FM verification prior to issuing an FM system, most especially in the case of young children who cannot provide subjective feedback. As a large portion of FM users are children FM manufacturers should be more cautious when describing new features and technology available in their equipment. Furthermore, any in-house testing used to determine or assess the reliability of the features should be more readily available and open to review.

The range of equipment tested in this study was limited to the equipment used by the pre-school children included in the longitudinal study. Studies assessing a much wider range of hearing aid and FM equipment would be beneficial to practitioners. Practitioners fitting FM system's would benefit from evidence based results rather than relying on anecdotal feedback from other professionals or generic marketing statements from manufacturers. It would be useful in the future to obtain large scale data from different models and manufacturers' FM technology on the reliability of advanced FM features. Technology is rapidly advancing and it is expected that FM technology will improve and new features carry on being introduced. As such independent research in this field of technology needs to constantly verify and assess the reliability of these advanced features.

5. Study 2: FM technology use with pre-school hearing aided children

5.1. Introduction

In order to gain an insight into the use of FM technology with pre-school hearing aided children, quantitative measures on: daily use, listening evaluation and technology assessment, and language trends were collected and analysed. The next section will detail each of the quantitative measures used in this study. Thereafter the results for each of the separate measurements will be presented. The chapter will conclude with a summary of the key findings from the study.

5.2. Methods

5.2.1. Daily use

5.2.1.1. Data collection

Data on daily FM device use was collected through a parent daily diary sheet and through data logged on the FM transmitter with parental permission. Parents were asked to complete a basic diary sheet (Appendix B) on a daily basis detailing where the FM was used, the times when it was used in a given situation and whether or not the parents felt the system was useful in that situation. Parents had the option of selecting 'yes', 'no' or 'not sure'. Each sheet allowed parents to complete five different situations in which the participant had used the FM device on each day. If parents needed to note down more than five situations this was done on a separate sheet with the date written on the top. Diary keeping is not a widely used method of data collection, because of the challenges to the researcher of ensuring commitment from participants and the inevitable effects this may have on the participants (Willig, 2001). Therefore, to ensure ease of use for the participant the diary was given a rigid structure. This design sought to maximise information but minimise demand and time spent by the participant. The daily diary sheet did not require any form of narrative account as this was to be covered in the weekly open ended questions and the semi structured interview to be held at the end of the study. A separate sheet with pictures as prompts for eight different situations was also provided (Appendix B). However parents did not make use of this sheet and preferred to use the daily diary sheet (Appendix B).

Data collected through the data logging feature on the transmitter was accessed directly through the manufacturers FM Successware (version 4.01 to 4.5) software. The software allows the connection of the transmitter with a personal computer through a USB cable downloading stored data from the FM transmitter onto the computer. The software provides information on the daily usage of the transmitter in a histogram format (Figure 5.1) or in a table format with data saved over 15 minute time frames. The calendar function allows quick access to specific dates and both a 7 day and 31 day tab allows a quick view of daily use per week or month.

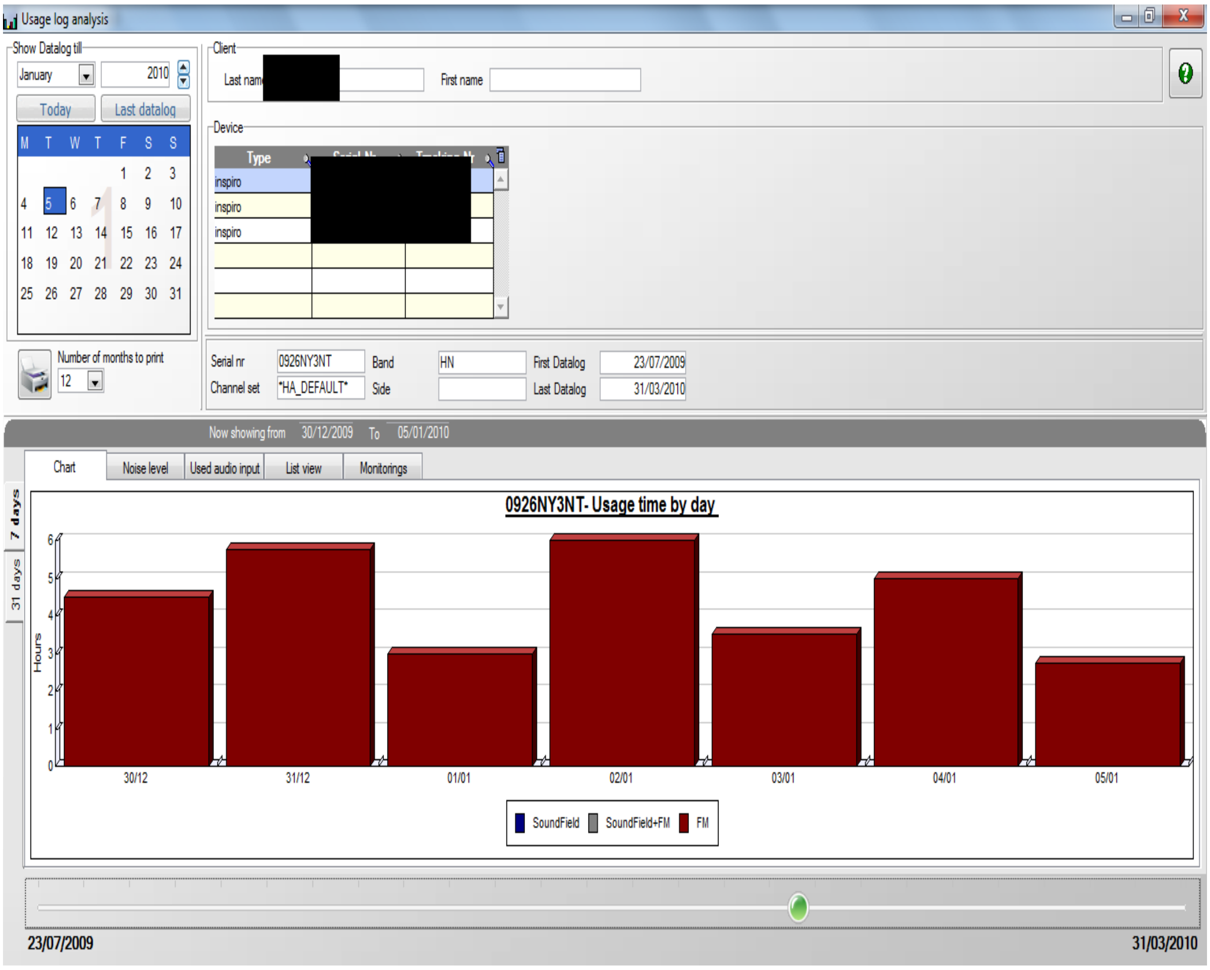


Figure 5.1 Screenshot of FM Successware software version 4.5 datalogging interface. Tabs allow data view over a weekly period (as displayed) or a monthly period.

5.2.1.2. Data analysis

All participants' daily diary sheets were input into Microsoft Excel 2007. Formulas and formatting within Microsoft Excel 2007 specific to time calculations were used to calculate the duration of time the FM device was used in each situation. Initially columns were created for each specific situation parents had noted. However, overtime the situations were narrowed down into seven categories: car, meals, shopping, nursery, outdoors, home and TV. The outdoors and home situations were the most general situations and included many different activities which varied between parents. It was decided to keep meal times separate as some parents noted meals in the home setting whereas other noted FM use during meal times when eating out. Although use in the car and shopping could have been categorised under the outdoors situation it was decided to leave this separate as parents were quite clear in describing shopping and car as situations separate from outdoors. Finally TV was kept as a separate category because the audio input for FM use with the TV was separate. Sound was not input through the lapel microphone during TV plug in but was input using a separate audio input wire, which then transmitted the sound to the receiver.

The total hours FM was used on each day was calculated. Data logging was used to verify daily diaries and overall there was good consistency between the two reports with differences being within 15 minutes of each other. However on occasions the data logged on the FM transmitter showed higher use than that recorded in the diary. This could be a result of the FM device being left on during charge or a result of parents using the mute function, rather than switching the power off, which was logged as use by the transmitter. In these situations the duration of FM device used for analysis was taken from the diary. In some cases where the diary showed more usage than recorded in the FM data log, the data log information was used for analysis for that particular day. This situation could be a result of parents not realising the FM transmitter needed charging or sometimes the diaries were completed at the end of the week and estimates of duration of use were noted. As data could only be logged for a maximum of one month if the time between appointments was over a month some data on the FM transmitter was lost. In this situation the daily diary data would be used. One participant (P2) had ongoing problems with their FM transmitter and as result a master reset was required on a few occasions. Each time the master reset was used all data logged onto the transmitter was lost and for these days the daily diary data was used.

Once the data was verified between the diary and the FM transmitter data log the total hours of FM use overall and in each situation were calculated for each participant. Similarly, the average duration of use in each situation and overall as well as the number of days the FM was used in each situation and overall were also calculated for each participant. The percentage of days the FM was used compared to the number of days of participation in the study was also calculated. Likewise, the number of hours where FM use was noted in dairies to be of benefit, no benefit and not sure of benefit were calculated for each participant and for overall FM use. Statistical analysis was carried out to explore any relationships between the demographic variables recorded (Table 3.2) and FM use for each participant. The Spearman's correlation, a non-parametric correlation analysis, was used to take into account the small number of participants from whom data was collected.

5.2.2. Listening evaluation and technology assessment

5.2.2.1. FM listening evaluation for children (FMLEC)

Data on FM listening evaluation and technology assessment was collected using the FMLEC questionnaire developed by DeConde-Johnson (Gabbard, 2003; Appendix C). The questionnaire can be completed by parents or professional and is structured into four different sections: listening evaluation, technology assessment, situational use and two open ended questions on benefit and challenges of FM use. The latter two sections were not used from the questionnaire as data collected regarding situational use through the daily diary sheets (Appendix B) was more in depth. Similarly, the qualitative feedback from parents through the weekly diaries and interviews was more informative.

The listening evaluation section of the questionnaire consisted of five questions focussing on children's comprehension and receptive language.

1. Child responds to his/her name when spoken to
2. Child attends to person speaking
3. Child distinguishes between words that sound alike (e.g. 'Bay' for 'day', 'sink' for 'think' or 'sun' for 'fun')

4. Child responds accurately to spoken direction and/or questions
5. Child comprehends oral instructions and concepts

Each question had seven situations listed under it, with parents having to rate the child's receptive abilities for each of the seven situations on a five point likert scale. The seven situations were as follows:

a. In a quiet room, within 3 feet
b. In a quiet room, at 10 feet
c. In a noisy room, within 3 feet
d. In a noisy room, at 10 feet
e. Without visual cues
f. From another room
g. Outside/in the community

If parents felt the child was not able to complete any of the questions they would circle NA (not applicable) and the points allocated to that specific situation would not be included in score calculations. Using the answers from the seven situations, scores are calculated on four situational domains: quiet, noise, auditory only (no visual cues) and distance. An overall total score is also calculated using all the responses for each of the seven situations. Two of the seven situations (a and b) were used to calculate receptive scores in quiet totalling a maximum score of 50. Three situations (c, d, and g) were used to calculate scores for noise totalling a maximum score of 75. Similarly, three situations (b, d and f) were used to calculate scores for distance totalling a maximum score of 75. Responses for situation 'd' (in a noisy room, at 10 feet) are included for both noise and distance scores. Finally scores for auditory only were calculated using one situation (e) totalling a maximum score of 25. The overall total possible score was 175 which is calculated using all seven situations for the five questions. Parents were asked to complete all responses based on their child's performance when using FM and not when using hearing aids alone.

The technology assessment section of the questionnaire included five separate questions which were scored on a 5 point likert scale.

1. HA/FM system is easy to operate
2. HA/FM system has remained in good working order
3. HA/FM system is comfortable for child to use
4. Child tries to turn HA/FM system off
5. Feedback (whistling noise) is present with HA/FM system

Parents were asked to respond to all questions only in relation to their FM system and not the hearing aid. Similarly, parents were asked not to complete question number five as this question was more specific to hearing aids. Although feedback can be present when using the FM system as the hearing aid would be on FM + M (hearing aid microphone) mode, the use of an FM system would not be expected to have an effect on feedback.

5.2.2.2. Data analysis

The FMLEC results at the beginning and end of the study were used to consider any changes over the course of the study. The first FMLEC questionnaire was completed after using the FM device for one month. Scores for situational analysis were calculated using the method described above and as set by the questionnaire (Appendix C). Results were displayed in a table and a bar graph was created to illustrate any changes in listening evaluation with FM use overtime. Similarly, the technology assessment ratings for each participant at the beginning (after one month's use) and end of the study were displayed in a table. An overall average score at the end of the study for all seven participants were also calculated and displayed as part of the table.

5.2.3. Language trends

5.2.3.1. LENA developmental snapshot (LDS)

Trends in language development for participants in the study were assessed using the LENA (Language ENvironment Analysis) Developmental Snapshot (LDS; Appendix D). As the LDS is a recently developed language measure the current section will provide details on the questionnaire. The LDS is a 52-question parent survey that assesses expressive and receptive language skills in children 2 to 36 months of age. It provides an estimate of a child's developmental age as a function of chronological age. The LDS was developed by a team of speech language pathologists, linguists, statisticians and other researchers based at the LENA Foundation (Gilkerson & Richards, 2008b).

The question items on the LDS were selected based on experimenter expertise and review of other standard language and cognitive assessments, including: the Preschool Language Scale, 4th Ed (PLS-4) (Zimmerman et al., 2002); Receptive-Expressive Emergent Language Test, 3rd Ed (REEL-3) (Bzoch et al., 2003); Mullen Scales of Early Learning (Mullen, 1995); Bayley Scales of Infant and Toddler Development (Bayley, 2006); Ages and Stages Questionnaires (ASQ) (Bricker et al., 1995); MacArthur Communicative Development Inventories (MCDI) (Fenson et al., 2007); the Child Development Inventory (CDI) (Ireton & Thwing, 1992); and the Rossetti Infant Toddler Language Scale (Rosetti, 1995).

The accuracy of the LDS developmental age estimates and total scores were validated against other standardised measures completed by parents along with results from standardised assessments by a certified speech language pathologist. The standardized language development assessments included for validation were the PLS-4, REEL-3, CDI and the Clinical Linguistic and Auditory Milestone Scale (CLAMS) (Accardo & Capute, 2005). The LDS correlated well with these standard assessments as highlighted in Table 5.1 including a high overall average correlation ($r = .93$; $p < .001$) (Gilkerson & Richards, 2008b).

Table 5.1 Correlation of developmental age from standard language assessments with LENA LDS (Gilkerson and Richards, 2008)

Standard Assessment	N	Pearson's Correlation a
PLS-4 Receptive Language	51	.93
PLS-4 Expressive Language	51	.92
REEL-3 Receptive Language	75	.96
REEL-3 Expressive Language	75	.96
CDI Receptive Language	143	.84
CDI Expressive Language	142	.81
CLAMS	52	.97
Overall Average		.93

Test-retest reliability of the LDS was evaluated with a subset of the participants who completed the LDS on a monthly basis three months after completing their first LDS. The developmental age estimates after three months at the second completion increased by an average of 3.2 points (SD = 2.8), thereafter the average month-to-month increase for subsequent completions was 0.8 points (SD = 2.3). High test-retest reliability for the LDS Developmental Age was reported, as indicated in Table 5.2.

Table 5.2 Test-retest reliability of the LDS developmental age for the normative LENA sample

Completion Month	N	Correlation with Previous LDS Estimate
10/06	308	-
1/07	70	.97
2/07	73	.98
3/07	71	.96
4/07	71	.97
5/07	66	.97
6/07	61	.96
7/07	56	.96
8/07	58	.95
9/07	59	.97
10/07	56	.96
11/07	56	.93
12/07	57	.95

5.2.3.2. Data analysis

The LDS was either completed by parents directly on a laptop or on a hard copy printout and answers were later input into the LDS software (LENA software v3.1.2.). The software automatically analysed children's developmental age and LDS standard scores and charted these on a graph (example graph: Figure 5.2).

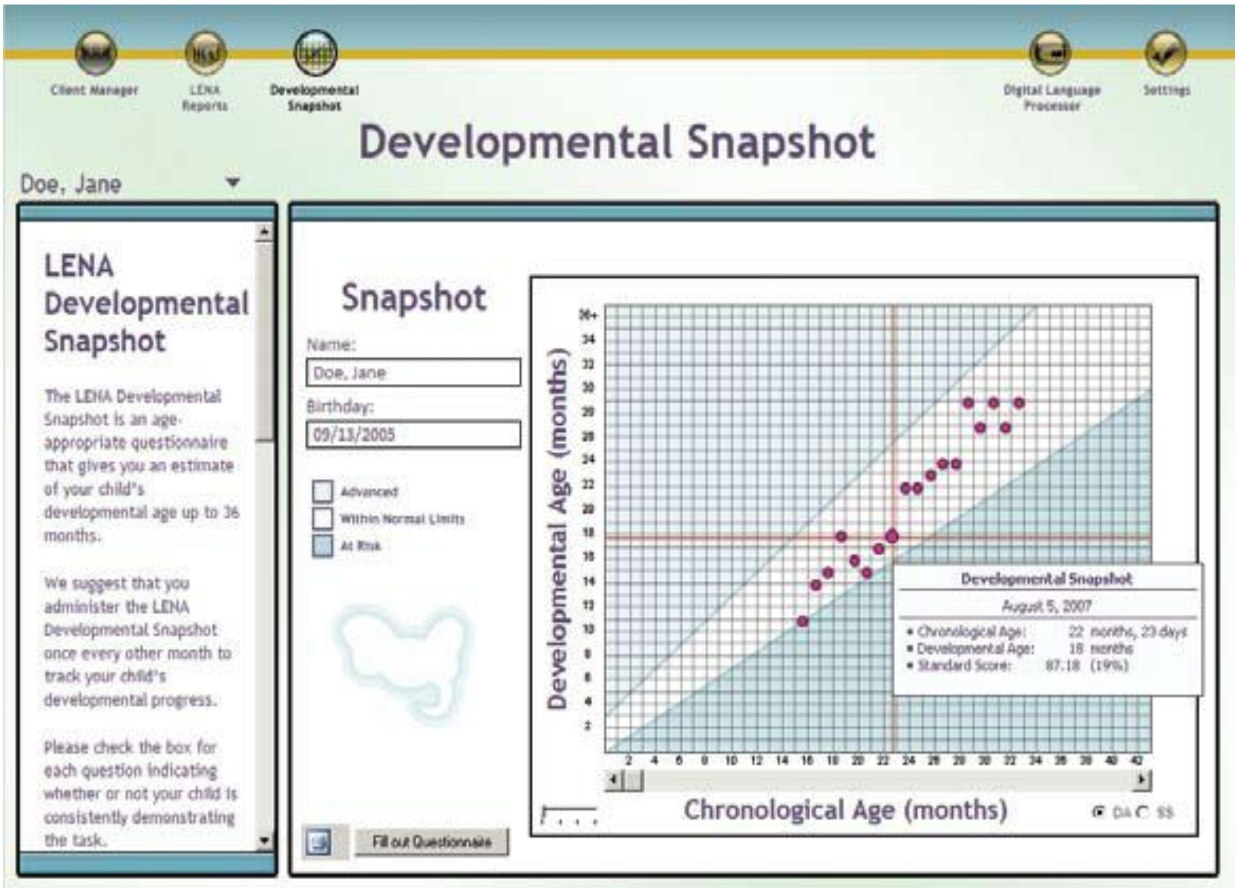


Figure 5.2 Screenshot of LDS screen on LENA software version 3.1. The graph charts developmental age compared to chronological age once the LDS is completed and input into the software.

The graph records the child's developmental trajectory overtime and illustrates whether the child's development is advanced, within normal range or at risk. Results for all participants at the beginning, midway and end of study were summarised into a table and differences between developmental age and chronological age were also calculated. The analysed results for each of the children as plotted on the LDS graph were also included in the results section.

5.3. Results

5.3.1. Daily use

5.3.1.1. Overall use

The data for overall device use by each participant are summarised in Table 5.3. The total number of days involved in the study for all participants was 1198 days, from which 837 days (71%) of recorded FM use was logged. The total number of hours of FM use recorded for all participants in the study was 2874 hours and 15 minutes with an overall average FM use per day of 3 hours and 2 minutes. The daily log options of 'benefit', 'no benefit' and 'not sure' of benefit completed by parents or users of the technology revealed a total of 2801 hours (97%) of usage with 'benefit', 2 hours and 30 minutes with 'no benefit' and 70 hours and 45 minutes (2.5%) where parents were 'not sure' of benefit.

Table 5.3 FM use data for each participant.

	P1	P2	P3	P4	P5	P6	P7	Total
Days in study	251	232	104	187	111	142	171	1198
Days FM used (%)	232 (92)	162 (70)	14 (13)	151 (81)	33 (30)	98 (69)	162 (95)	837 (71)
Total use (hours)	723:15	681:00	23:15	598:00	58:15	244:20	546:10	2874:15
Ave use (hours)	3:13	4:12	1:33	4:03	1:42	2:29	3:22	3:02
Benefit (hours)	687:50	676:30	19:10	582:55	42:20	239:20	544:10	2801:00
No Benefit (hours)	0:15	0:00	0:00	2:15	0:00	0:00	0:00	2:30
Not sure (hours)	35:10	4:30	3:05	12:35	15:25	0:00	0:00	70:45

In considering overall use of FM technology for each participant (Table 5.3), age clusters revealed a possible trend in FM use with three groups emerging. The first group was of the youngest children, which included P3 and P5 who were between the ages of 11-15 months during their time in the study. P3 and P5 were involved in the study for the shortest period of time and used the FM system the least whilst in the study. P3 used the FM system for 14 out of the 104 days involved in the study (13% of days) and P5 used the FM system for 33 of the 111 days in the study (30% of days). Both P3 and P5 had the shortest duration of average FM use per day at 1 hour and 35 minutes and 1 hour and 42 minutes respectively. The second group included the slightly older children P2 and P6. P2 started participation at 17 months of age and P6 started at 15 months of age. P2 and P6 had 70% (148 of 248 days) and 61% (98 of 142 days) of recorded FM use respectively. However, P2 (4:13 hours) had a higher average use of FM per day at 4 hours and 12 minutes compared to P6 whose average use per day was 2 hours and 29 minutes. The final sub category was of the older children who included P1 who started at 21 months of age, P4 who started at 24 months of age and the eldest P7 who started at 32 months of age. P1 (92%), P4 (81%) and P7 (95%) made use of the FM device on most days of their participation in the study. The average use per day for P1, P4 and P7 was 3 hours and 13 minutes, 4 hours and 3 minutes and 3 hours and 22 minutes respectively. Overall five out of the seven participants made consistent use of the FM device over the period of the study.

Further analysis was carried out to explore this relationship between months in age and FM use. Altogether, data collected for children's age in months totalled 27 months ranging from 11-38 months of age. From these 27 months, 12 months (11-15, 16, 19, 20, 23 and 28-30) included data from 2 participants, 8 months (17, 18, 21, 22 and 24-27) included data from 3 participants and 7 months (32-38) included data from one participant. Where participants were not present for a full month, as expected at the beginning and end of their study participation, the number of days present in the study was divided by 30. The figure calculated would be used in place of 1 to provide an overall average use. For example, if a child was in the study for 13 days and had used the FM 11 days for a particular month in age, 13 was divided by 30= 0.43, thereafter 11 was divided by 0.43= 25.5 so the average days of FM use noted for that month was 26. After calculating average days used per month with age of child, a clear trend was observed. Figure 5.3 shows the number of days FM technology was used per month in relation to the age in months. Between the ages of 11 to 14 months the use of the FM device had negative correlation with usage gradually decreasing from an average of 15 days per month down to four days per month. From 15 to 38 months of age a gradual increase in number of days FM was used was observed as children got older.

Statistical analysis was carried out to explore the relationship between children's age in months and number of days FM was used. A non-parametric correlation analysis, the Spearman's correlation was used to take into consideration the data for each month was from a limited number of participants. Analysis revealed a significant positive correlation existed for age of child and average number of days FM was used per month ($r = 0.85$; $p = <0.01$; $n=27$) between the ages of 11-38 months. The reason number of months was 27 and not 28 was that 31 months of age was excluded from the correlation as no data existed for this age in month. Taking into consideration the limited FM use for the two participants aged between 11-14 months, further statistical analysis was carried out to explore the relationship between age in months and FM use after excluding data related to 11-14 months of age. A significant correlation still existed once data related to 11-14 months of age was removed ($r = 0.77$; $p = <0.01$; $n=23$).

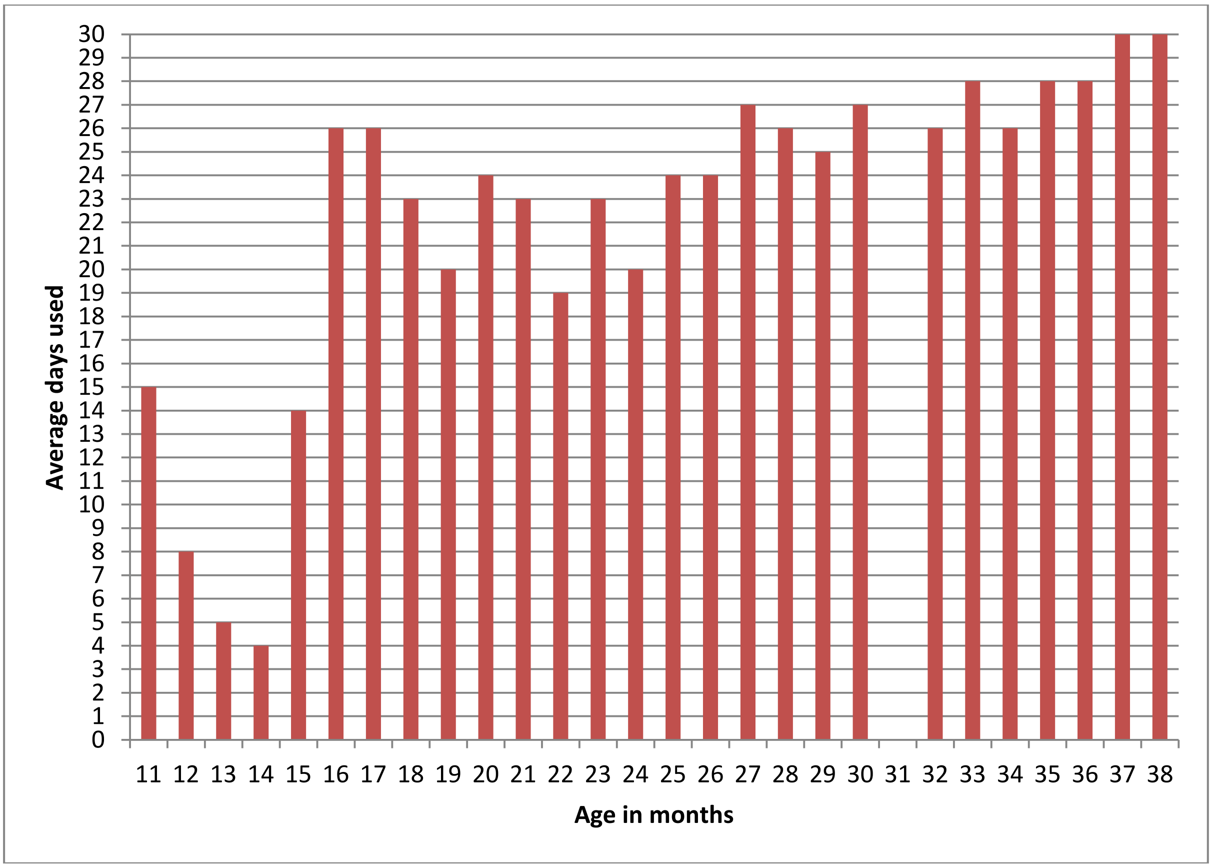


Figure 5.3 Overall average numbers of days FM technology used in relation to participant's age in months.

Similar to Figure 5.3, Figure 5.4 illustrates the number of days FM was used for each month in age however, Figure 5.4 further highlights specific use by each participant over their time in the study. Figure 5.4 provides a clearer description of the number of participant's data included for each age in month and also highlights what age each participant started and ended their inclusion in the study. As the graph illustrates P3 only used the FM one day during months 12 and 13, similar to P5 who only used the FM for 3 days at 14 months of age. However P5 seemed to increase use of FM near the end of their time in the study which was reflected by an increase in number of days used at 15 months in age. For P2 a considerably lower number of FM use days compared to other months of use were noted at 19 and 22 months of age. The reason noted for this in the daily diaries at 19 months of age was the family went on holiday abroad and chose not to take the system with them. Also the considerable decrease in number of days used at 22 months was a result of the FM system being sent in for repair. Apart from them two months the majority of FM use per months in age for all participants, excluding P3 and P5, ranged from 19-30 days. The trend in use for these five participants differed. P6 had no clear trend of increase or decrease in use with usage fluctuating between 20 and 26 days. P2 seemed to have a negative correlation of FM use with age in months where days FM was used decreased overtime, however this can in part be explained by faults with the system and delays in repairs. P1 had steady use overtime with no apparent trends. P4 and P7 both had a positive correlation between age in months and days FM was used, with a steady increase in use over time.

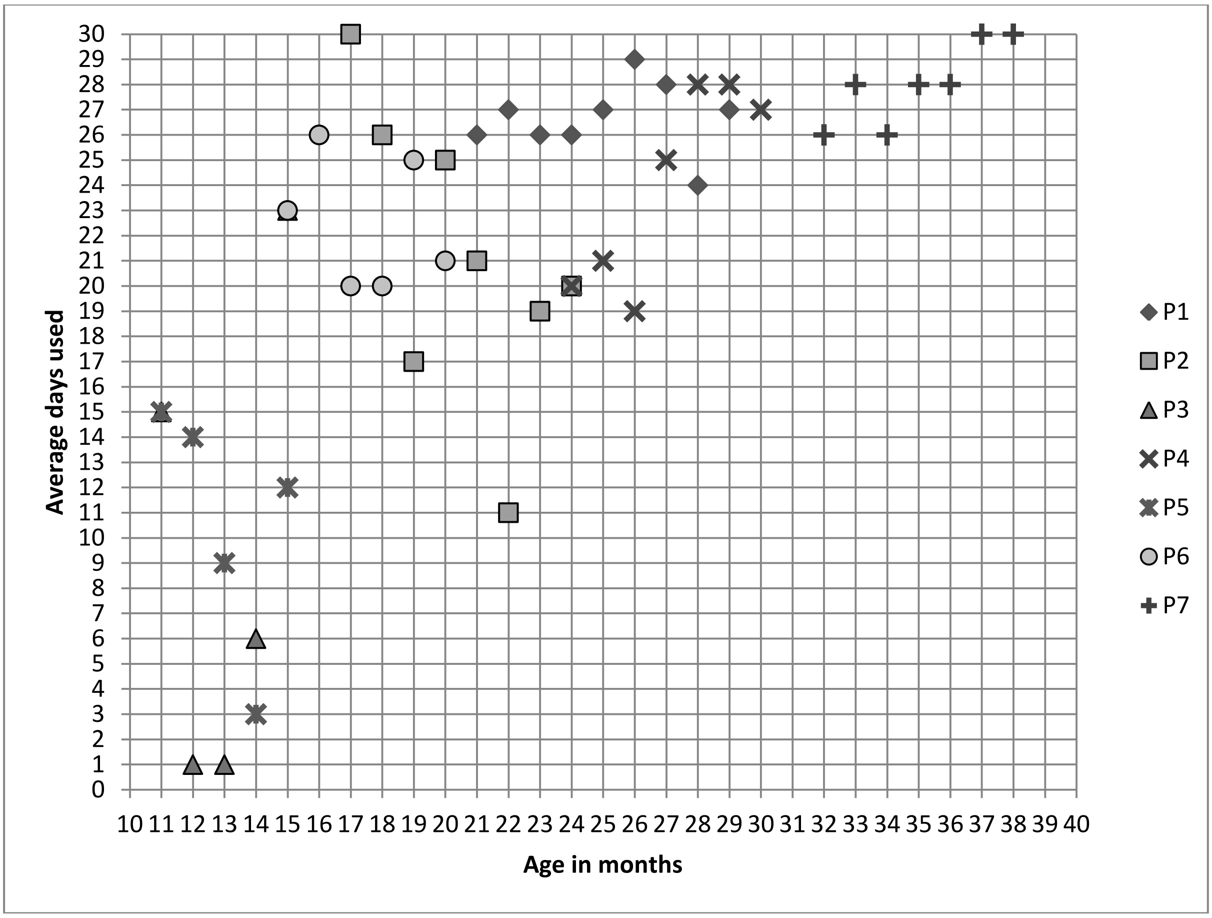


Figure 5.4 The number of days FM technology used by each participant as a function of child's age in months.

Demographics (Table 3.2) were used to observe any further trends in FM use. No observable trends were present for the variables of age of hearing loss identification, age of amplification, paternal education, number of siblings, order of birth and SES. Maternal education showed some trend with the two mothers with 'A-level' equivalent qualification having used the FM device significantly less than mothers (n=5) with 'diploma' level or equivalent qualifications. Taking into consideration the small numbers an independent samples non parametric Mann-Whitney-U test was used to compare total FM use for the two maternal groups (2 and 3). Results indicated a statistically significant difference between the two groups ($p = <0.01$) for FM use.

5.3.1.2. Environments-locations FM used

Daily diary entries of FM use for each participant were summarised into one of seven environment-location categories: car, meals, shopping, nursery, outdoors, home and TV. Table 5.4 summarises the data for all seven participants' FM use in each of the categories. Results for the number of days, number of hours, average hours per day used and the overall percentage of use in each situation are detailed.

Table 5.4 FM use data for each participant as categorised into seven environment-locations. All hours and mean figures are in hh:mm format.

		P1	P2	P3	P4	P5	P6	P7	Total
Car	Days	27	84	2	99	1	4	142	361
	Hours	23:55	77:55	1:55	87:25	0:15	1:30	94:00:00	288:55
	Mean	0:53	0:55	0:57	0:52	0:15	0:22	00:40	00:42
	% Days	3%	12%	8%	15%	0%	1%	17%	8%
Meals	Days	11	31	2	20	2	0	0	66
	Hours	14:25	34:45	0:20	19:15	1:00	-	-	69:45
	Mean	1:18	1:07	0:10	0:57	0:30	-	-	00:48
	% Days	2%	5%	1%	3%	2%	0%	0%	2%
Shopping	Days	41	18	3	37	0	5	32	136
	Hours	98:35	36:30	1:45	48:05	-	6:30	47:05	238:30
	Mean	2:24	2:01	0:35	1:17	-	1:18	01:31	01:30
	% Days	14%	5%	8%	8%	0%	2%	9%	7%
Nursery	Days	113	77	0	39	0	0	80	310
	Hours	325:55	264:40	-	150:35	-	-	240:50	986:00
	Mean	2:53	3:26	-	3:51	-	-	03:02	03:18
	% Days	45%	39%	0%	25%	0%	0%	44%	22%
Outdoors	Days	35	24	5	61	1	34	55	216
	Hours	76:30	48:10	7:30	88:35	1:00	39:15	72:50	336:20
	Mean	2:11	2:00	1:30	1:27	1:00	1:09	01:20	01:31
	% Days	11%	7%	32%	15%	2%	17%	13%	14%
Home	Days	70	75	12	81	32	76	66	415
	Hours	167:10	218:00	11:45	199:35	52:00	183:35	91:25	928:30
	Mean	2:22	2:56	0:58	2:32	1:34	2:24	01:24	02:06
	% Days	23%	32%	51%	33%	88%	80%	17%	46%
TV	Days	15	1	0	7	4	0	0	27
	Hours	16:45	1:00	-	4:30	4:00	-	-	26:15
	Mean	1:05	1:00	-	0:38	1:00	-	-	00:55
	% Days	2%	0%	0%	1%	7%	0%	0%	2%

Figure 5.5 illustrates the total number of days each participant made use of their FM device in each situational category. In terms of number of days the FM was used per situation, use of FM in the home setting overall was the most popular (415) followed by use in the car setting (361) then in the nursery setting (310). Both the outdoors setting (216) and use during shopping (136) also had regular recorded use but FM use in these situations was less frequent. FM use during mealtimes (66) was limited however this was partly to do with differences in parents' diary recording habits. P1, P2 and P4 specifically noted down mealtime usage whereas P6 and P7 described mealtime use as part of home use or outdoors use (if the meal was at a restaurant). Furthermore, P1 mainly noted down mealtime usage when eating out whereas P2 and P4 noted down mealtime usage both when eating out and eating at home. Apart from P1 (17) very few participants made use of the FM system with the TV.

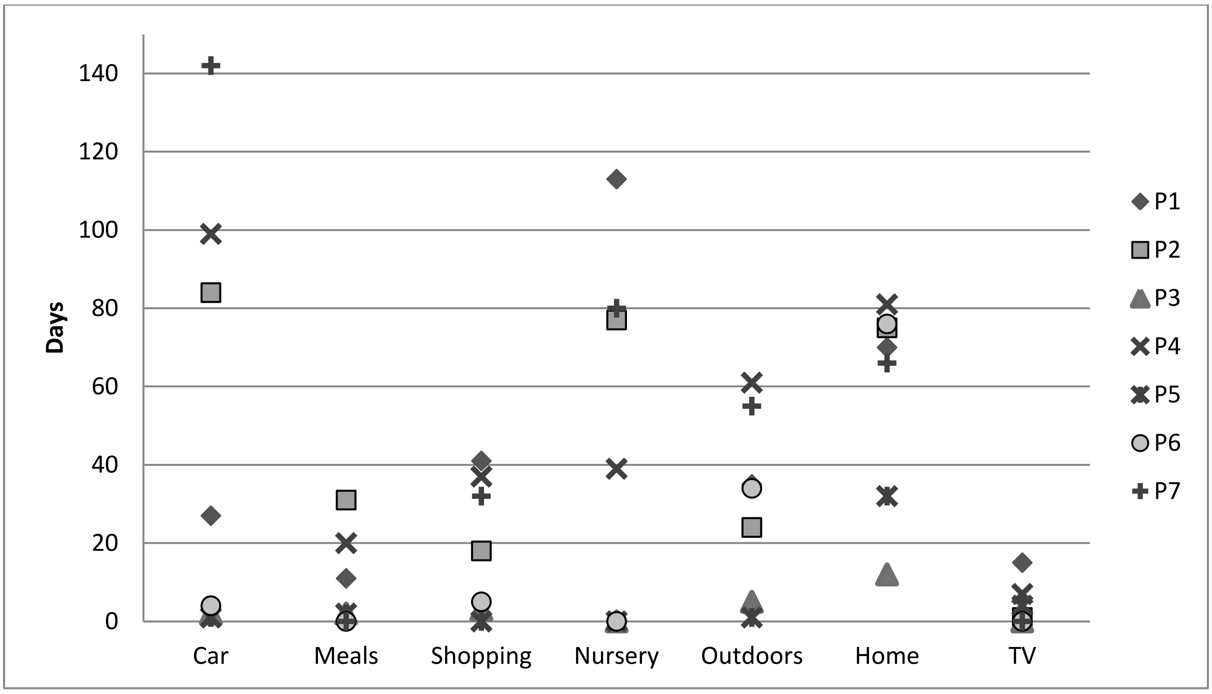


Figure 5.5 The number of days each participant used the FM device per situation. The legend on the side describes which symbols refer to each participant.

P7 (142) used the FM device the most days in the car, with P4 (99) and P2 (84) also making regular use in this situation. In comparison P1 (27) made less use of the FM in the car. P6 (4) P3 (2) and P5 (1) had very limited use of the FM in the car setting. Usage during mealtimes was varied with P1 (11), P2 (31) and P4 (20) noting down use of the FM in this situation. The other participants did not record much use in this situation or simply included this in home use. The FM was used more regularly during shopping by P1 (41), P4 (37), P7 (32) and P2 (18). As expected diary entries for shopping showed a regular pattern of use generally occurring on a weekly basis for these participants. P6 (5) and P3 (3) made limited use during shopping whereas P5 did not use the FM at all during shopping. For the four participants who attended nursery the FM was regularly used in this setting. Of the four participants, P4 (39) had made use the least days however this child attended nursery only 1-2 days a week. P2 (77) and P7 (80) made more regular use in nursery as they attended more often and the most use was recorded for P1 (113) who attended nursery full time. P3 (5) and P5 (1) had made limited use of FM outdoors. P4 (61) had made the most use of FM in the outdoors setting and this was partly because of regular use during horse riding lessons. P1 (35), P2 (24) and P6 (34) also made regular use outdoors and diary entries for outdoors did increase as the warmer months came in. A wide variety of different locations were noted in the diaries for outdoor settings including barbeque parties, fairgrounds, amusement parks, regular walks, picking other siblings up from school, stables and family events. The FM device was used by all participants in the home setting. As expected P3 (12) and P5 (32) had used the FM the least amount of days in this setting. For the rest of the participants home use ranged from 66 to 81 days with a variety of activities noted down for home use including: one to one play, group play, playing in garden, reading, general use, use by siblings during play, use by extended family members and use at family gatherings.

Figure 5.6 illustrates the total number of hours each participant made use of their FM device in each situational category. The trends for total number of hours FM was used were similar to number of days FM was used. However the immediate difference that was apparent in the graphs was with the car and nursery situations. Although the FM was used more days in the car (361) the total number of hours of FM use in the car was 288 hours and 55 minutes. In contrast, the number of days FM was used in nursery was less (310) however the total number of hours was considerably higher with a total 986 hours of recorded use. The home situation had the second highest total use at 928 hours and thirty minutes. FM use outdoors (336:20) and during shopping (238:30) followed, with the least use noted for mealtimes (69:45) and TV (26:15).

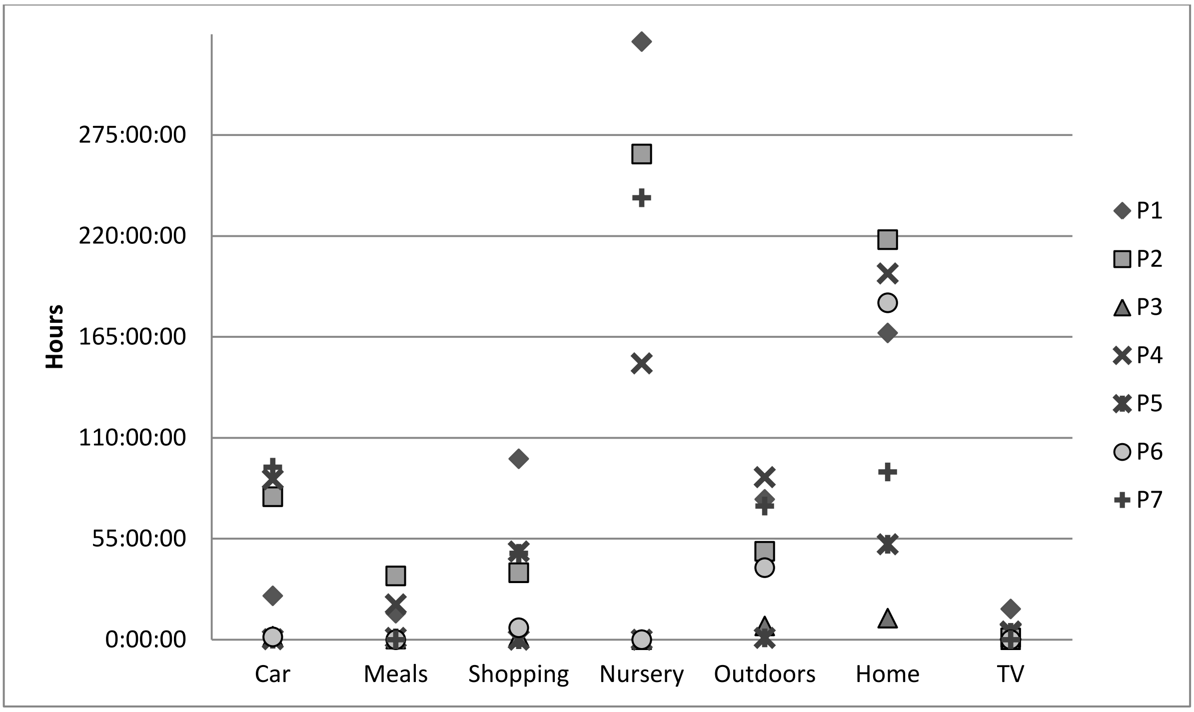


Figure 5.6 The total number of hours each participant used the FM device per situation. The legend on the side describes which symbols refer to each participant.

Similar to number of days, P7 (87) had the highest number of hours for FM use in the car, followed by P4 (87:25) and P2 (77:55). P1 (23:55) did not make as much use of the FM device in the car and P3 (01:55) and P6 (1:30) had very limited use. P5 only used the FM device in the car once for 15 minutes. P7 and P6 had not recorded FM use for mealtimes, however P6 had made mention of FM use during mealtimes in the weekly diaries. This would suggest use during mealtimes for P6 was recorded under home use. P3 (0:20) and P5 (1:00) made limited use of FM during mealtimes. P1 (14:25), P2 (34:45) and P4 (19:15) did make use of the FM during mealtimes. P1 (98:35) made the most hours of FM use during shopping, followed by P4 (48:05), P7 (47:05) and P2 (36:30) who made less than half as much use. P6 (6:30) and P3 (01:45) made limited use with P5 not using it at all when shopping. P1 (325:55) had the highest number of hours with FM use in the nursery setting. Both P2 and P7 followed with 264 hours and 40 minutes and 240 hours and 50 minutes respectively. P4 made use of FM in the nursery setting for 150 hours and 35 minutes. In the outdoors setting P1 (76:30), P4 (88:35) and P7 (72:50) made the most use followed by P2 (48:10) and P6 (39:15). Both P3 (7:30) and P5 (1:00) had limited use in this setting also. All participants had made use of the FM in the home setting with P2 (218:00) having the highest recorded hours of FM use in this setting. P4 (199:35), P6 (183:35) and P1 (167:10) followed with similar amounts of use in the home setting. Apart from P1 (16:45) very little or no use of FM was recorded with the TV for the other participants.

Figure 5.7 illustrates the average duration of use in each setting by each participant. The overall average use for each situation (Table 5.3) highlighted the nursery setting as the setting with the longest duration of use (3 hours and 18 minutes). This was followed by the home setting which had a total average duration of use of 2 hours and 6 minutes. The overall average FM use during shopping and outdoors was 1 hour and 30 minutes and 1 hour and 31 minutes respectively. The overall average duration whilst watching TV and mealtimes was 55 minutes and 48 minutes respectively. The shortest average duration of FM use was for the car setting at 42 minutes.

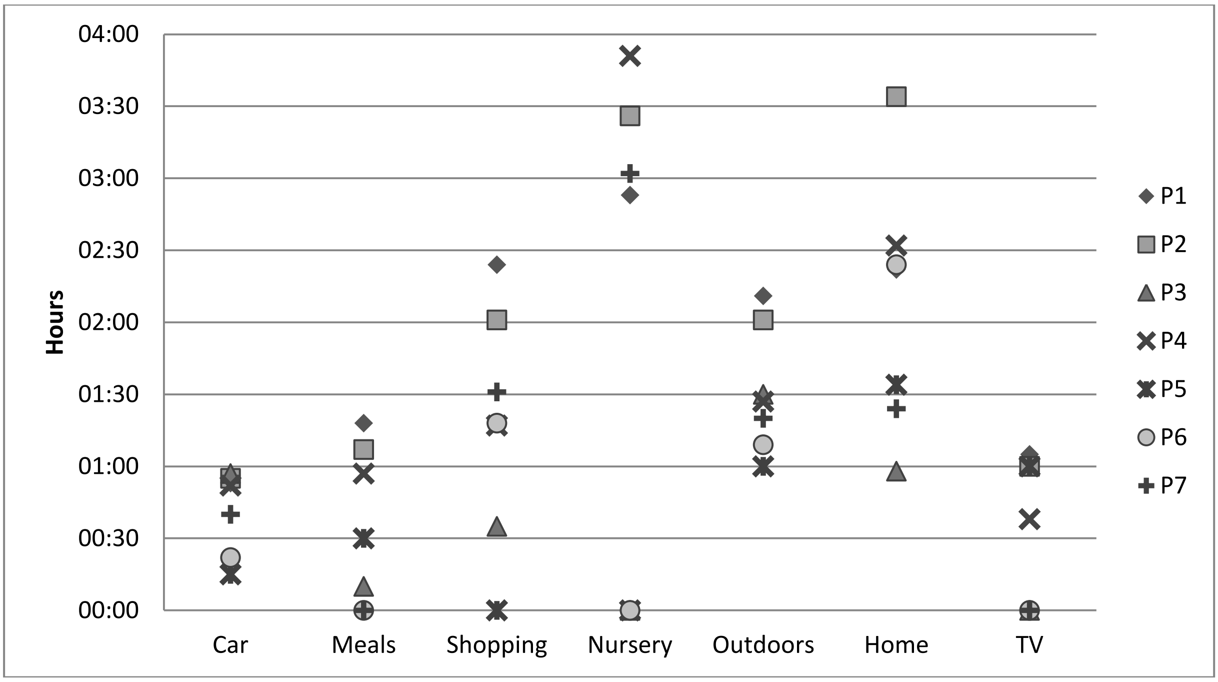


Figure 5.7 The average duration each participant used the FM device per day for each situation. The legend on the side describes which symbols refer to each participant.

The average duration of FM use for each participant in the car did not exceed 1 hour with duration of use ranging from 15 (P5) to 57 (P3) minutes. Mealtimes had a similar duration of use ranging from 30 minutes (P5) to 1 hour 18 minutes (P1). Both P6 and P7 had no recorded use during mealtimes. The duration of FM use whilst shopping ranged from 1 hours and 17 minutes (P4) to 2 hours and 24 minutes (P1). The exception was P3 whose average duration of use in shopping was 35 minutes. P5 did not make use of the FM during shopping. For the four participants who did attend nursery (P1, P2, P4 and P7) the average duration of use ranged from 2 hours and 53 minutes (P1) to 3 hours and 51 minutes (P4). The use of FM outdoors was on average between 1 hour (P5) and 2 hours and 11 minutes (P1). The average duration of FM use in the home was more variable. P3 had an average duration of FM use of 58 minutes. P5 and P7 had an average duration of FM use of 1 hour and 34 minutes and 1 hour 24 minutes respectively. P1, P4 and P6 had a similar average duration of use at 2 hours and 22 minutes, 2 hours and 32 minutes and 2 hours and 24 minutes respectively. P2 had the highest duration of FM use at 3 hours and 34 minutes. The average duration of use with the TV ranged from 38 minutes to 1 hour and 5 minutes.

Figure 5.8 illustrates the percentage of use in each situation for each participant as well as total percentage of use in each situation averaged for all participants. Percentages were calculated using the number of hours FM was used by each participant. The highest percentage of use for all participants was for the home setting at 46%. This was followed by FM use in the nursery setting at 22% and outdoor use which accounted for 14% of total FM use. FM use in the car and shopping accounted for 8% and 7% of total use respectively. The least percentage of use was recorded for mealtimes and TV at 2% each. The highest percentage of FM use for P1, P2 and P7 resulted in nursery setting use followed by home use. In contrast P4 had more percentage of use at home (33%) compared to the nursery setting (25%). For P3, P5 and P6 the highest percentage of use was for the home setting.

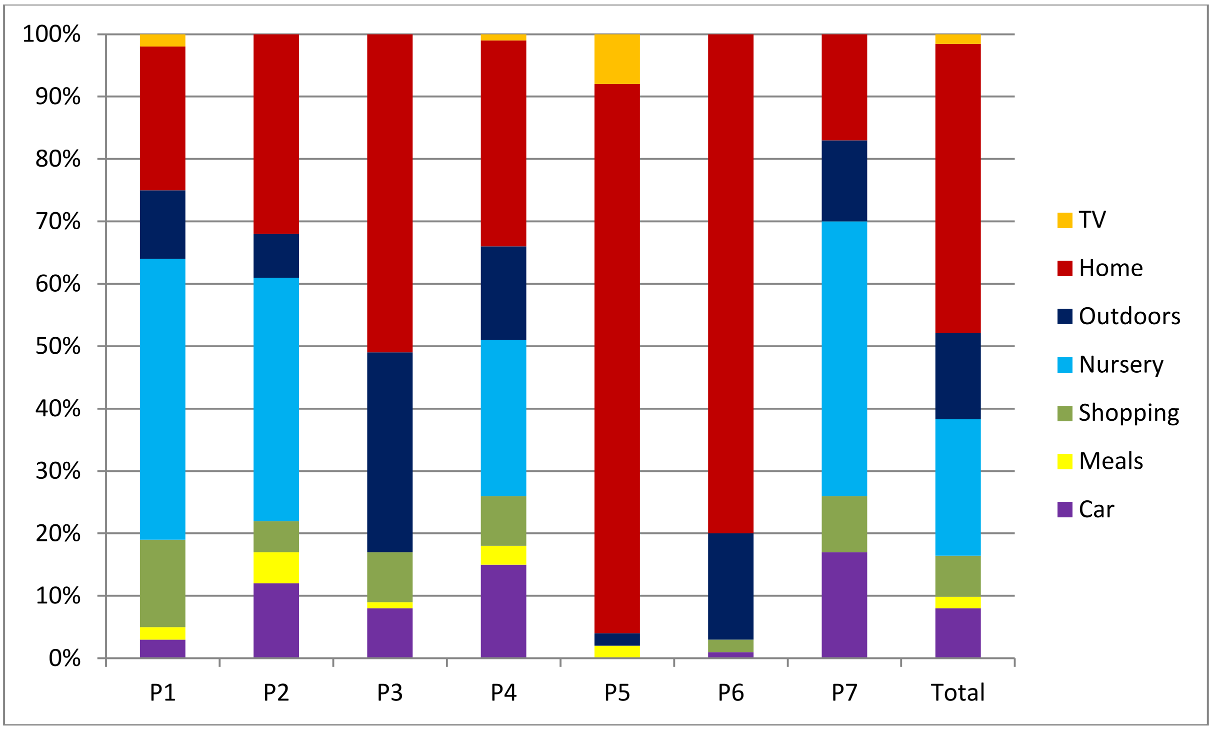


Figure 5.8 The overall percentage use distribution per situation for each participant displayed in stacked columns. The total bar displays the overall usage distribution for all participants.

5.3.2. FM listening evaluation and technology assessment

5.3.2.1. Situational analysis

The results of the situational analysis of receptive language in quiet, noise, distance and when auditory only (no visual cues) with FM use for each participant are presented in Table 5.5. The results illustrate changes in listening skills as reported by parents through the FM listening evaluation for children questionnaire (FMLEC). Changes were recorded using a five-point scale that ranged from "seldom" to "usually". The questions focussed on everyday listening situations and the responses were divided into four categories: quiet, noise, auditory only and distance. Scores were totalled for each listening category and a percentage calculated. All participants overall listening skills with an FM device improved over the duration of the study. Total scores for P3 did not improve overtime. This may be because P3 was in the study for the shortest period of time (3 months), however this may also be because P3 had selected NA for question number 3 which had a score of 35. Therefore, percentages for the beginning and end of study were calculated with different totals. Similarly, question number 3 (distinguishing similar words) was expectedly more difficult for children as receptive language for these children was just emerging and scores on this question were lower than for the other questions for P3. Conversely, the highest improvement was recorded for P5 at 48% who also noted NA for question 3 at the beginning of the study. However it must be noted that P5 had completed the end of study questionnaire at 18 months and not at 15 months when they ended participation in the study. The delay was because of scheduling difficulties as described in the methods section. The other five participants' improvements overtime ranged from 18-34%. Figure 5.9 summarises the overall percentage of improvement in total scores for each participant.

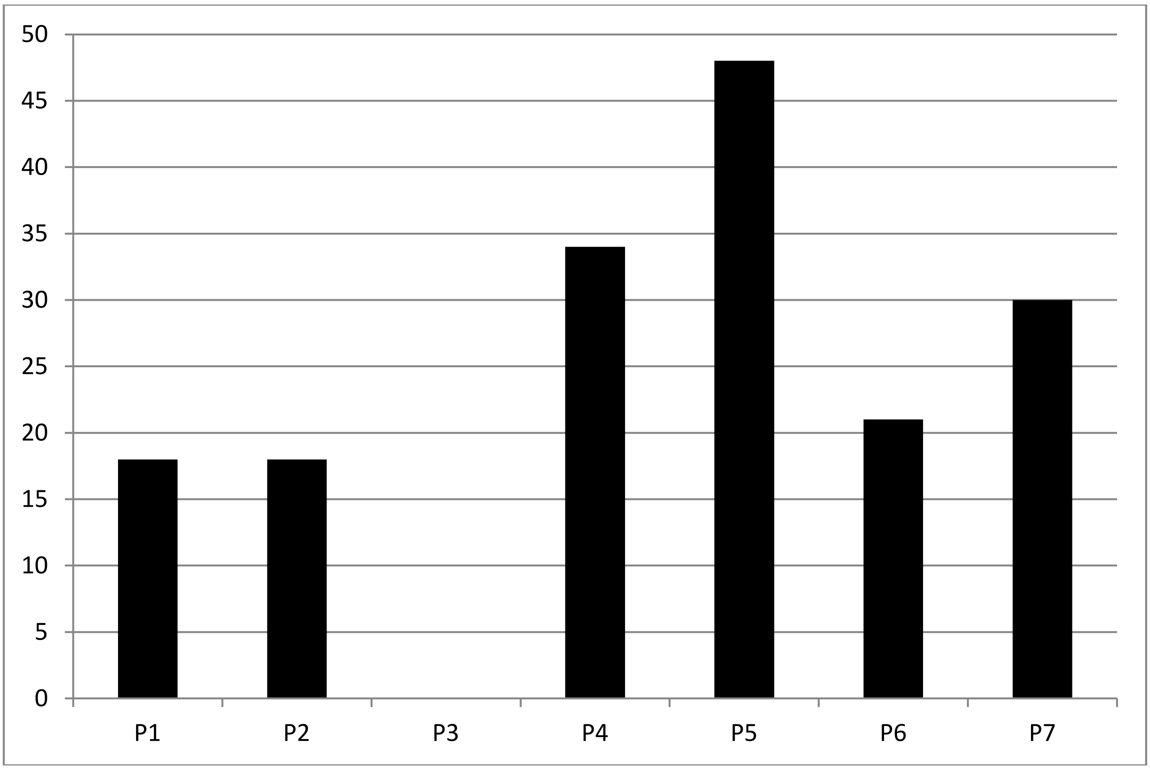


Figure 5.9 Summary of percentage improvement in total situation listening scores for each participant as recorded by parents with the FMLEC. The percentages for total scores at the end of the study were subtracted by the scores achieved after one month of FM use.

From the four listening situations measured, the highest improvements for each participant were observed for listening in noise and at a distance. The two exceptions were P5 and P7 whose highest improvements were observed for auditory only listening at 53% and 52% respectively. As expected P3 had the lowest improvement rates for individual listening situations with no listening improvement in noise and an improvement of 3% in distance. P5 whose results showed the most overall improvement in scores had an improved percentage score of 50% in both listening in noise and distance. The rest of the participants' improvement for listening in noise ranged from 21% to 36%. Similarly, the improvements in listening at a distance for these participants ranged from 18-44%.

Listening in quiet resulted in the lowest improvement scores overtime. P1 reached a 100% for this score at the end, however the improvement overtime was only 2% as the initial scores of listening in quiet were high at 98% to start with. Likewise, P6 also had 2% increase overtime for listening in quiet with a final percentage score of 80%. P7 scores in quiet resulted in 10% improvement by the end of the study. P2 and P4 had improved scores of 18% and 24% respectively over the course of the study. The highest improvement in quiet was scored by P5 at 46% and the lowest by P3 at 1%.

Finally, results for auditory only listening ranged from 8% to 60%. As explained before, both P5 (53%) and P7 (52%) achieved their highest improvements in this listening situation. P1 and P6 both had lowest improvement for auditory only listening overtime at 8%, however, for P1 this was because improvement scores had reached ceiling again at 100%. P6 had a final percentage score of 80% for auditory only listening. Auditory only listening results for P2 and P4 showed an improvement of 16% and 24% respectively. P3's percentage scores for auditory only showed an overall decrease at the end of the study, however this can be explained by the lower scores allocated for question number 3 at the end of the study that were not included at the beginning of the study.

Table 5.5 Results for situational listening with FM for each participant at the beginning and end of the study.

		P1	P2	P3	P4	P5	P6	P7
		Score (%)	Score (%)	Score (%)	Score (%)	Score (%)	Score (%)	Score (%)
Beginning	Quiet (50)	49 (98)	32 (64)	30/40 (75)*	30 (60)	16/40 (40)*	39 (78)	44 (88)
	Noise (75)	51 (68)	38 (51)	37/60 (61)*	23 (31)	15/60 (25)*	39 (52)	41 (55)
	Auditory Only (25)	23 (92)	16 (64)	14/20 (70)*	14 (56)	7/20 (35)*	18 (72)	11 (44)
	Distance (75)	54 (72)	41 (55)	36/60 (60)*	21 (28)	16/60 (26)*	33 (44)	39 (52)
	Total Score (175)	138 (79)	100 (57)	93/140 (66)*	70 (40)	43/140 (30)*	96 (55)	105 (60)
End	Quiet (50)	50 (100)	41 (82)	38 (76)	42 (84)	43 (86)	40 (80)	49 (98)
	Noise (75)	70 (93)	54 (72)	46 (61)	50 (67)	56 (75)	60 (80)	64 (85)
	Auditory Only (25)	25 (100)	20 (80)	17 (68)	20 (80)	22 (88)	20 (80)	24 (96)
	Distance (75)	75 (100)	55 (73)	47 (63)	54 (72)	57 (76)	53 (71)	64 (85)
	Total Score (175)	170 (97)	132 (75)	116 (66)	130 (74)	137 (78)	133 (76)	157 (90)

*Percentages were calculated using different total as NA was selected for some questions.

5.3.2.2. Technology assessment

Participants' assessment of the technology was analysed through the rating scale questions on the FMLEC. Participant's data at the beginning and end of study are summarised in Table 5.6. All participants found the system easy to operate and after 1 month of use the mean rating was 5 out of 5 which remained consistent at the end of the study. P3, P6 and P7 gave a 5 rating for the FM device to be in "good working order" at the beginning and end of the study. P1 gave a rating of 4 at the beginning and end of the study. P5 rated the system as 2 at the beginning of the study but gave a 5 rating at the end. Both P2 and P4 gave a lower rating at the end of the study compared to the beginning.

Questions 3 and 4 assessed the technology from the perspective of the child. P3 rated the device comfort for the child as 3 in the beginning of the study and at the end of the study as 4. All other participants rated the system as 5 for “comfortable to use for the child” at the beginning and end of the study. The overall mean score at the end for child comfort was 4.86. The final question rated was the “child tries to turn the system off” with a mean score of 1.46 at the end of the study. P3 rated this question at 2 at the beginning and end of the study. P2 rated this question as 1 at the beginning but increased this to 4 by the end of the study.

Table 5.6 Results for the four technology assessment questions on the FMLEC. Participants’ scores at the beginning (B) and end (E) of study shown. Scores are based on 1=seldom, 3=sometimes, 5=usually.

	P1		P2		P3		P4		P5		P6		P7		Mean at End
Questions	B	E	B	E	B	E	B	E	B	E	B	E	B	E	
FM system is easy to operate	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
FM system has remained in good working order	4	4	3	2	5	5	5	3	2	5	5	5	5	5	4.14
FM system is comfortable for child to use	5	5	5	5	3	4	5	5	5	5	5	5	5	5	4.86
Child tries to turn FM system off	1	1	1	4	2	2	1	0	1	1	1	1	1	1	1.43

5.3.3. Language trends

LENA Developmental Snapshot (LDS) results for the 7 participants at the beginning, midway and end of the study are shown in Table 5.7. Receptive and expressive language development age and standard scores were calculated by the LDS software and compared with data on the LENA database of children with normal hearing. The ratio of language age to chronological and auditory age is provided for baseline, midway and end of study intervals. The extent of change in language age over the study period is provided for each subject.

Table 5.7 Participants' chronological ages and LDS developmental ages in months and results for each participant's LDS standard score at the beginning, midway and end of study are displayed. Categories of 'at risk' and 'within normal levels' for each test score are shown.

		P1	P2	P3	P4	P5	P6	P7
Beginning	Chronological Age	23	19	11	24	11	17	33
	LDS Developmental Age	13	18	10	13	11	5	23
	Standard Score	66	98	101	<65	106	<65	70
	Category	AR	WNL	WNL	AR	WNL	AR	AR-WNL
Midway	Chronological Age	25	23	12	27	15	18	35
	LDS Developmental Age	20	23	9	16	14	11	23
	Standard Score	82	96	93	<65	102	75	68
	Category	WNL	WNL	WNL	AR	WNL	AR-WNL	AR
End	Chronological Age	29	27	14	31	18	22	37
	LDS Developmental Age	23	25	11	23	18	13	25
	Standard Score	79	91	90	76	100	73	-
	Category	WNL	WNL	WNL	WNL	WNL	AR-WNL	AR-WNL

None of the participants were in the advanced category for the LDS at any of the test intervals. However, P2, P3 and P5 did meet developmental age equivalents and were consistently in the category of within normal level (WNL) scoring close to 100 standard score at all three intervals. No significant changes were observed for these three participants. P3 (Figure 5.10) got 101 at the beginning of the study however this reduced to 93 and 90 for the following two intervals. P5 (Figure 5.11) was the only participant who attained standard scores of 100 or above for all three intervals scoring 106, 102 and 100.

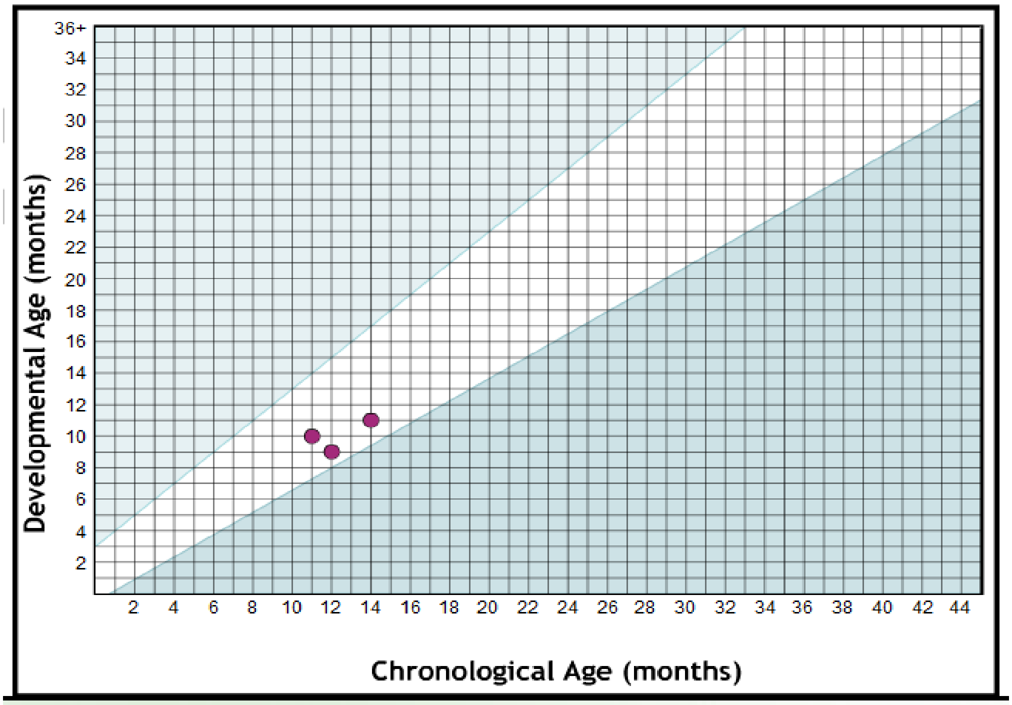


Figure 5.10 P3's standardised scores: 101, 93 and 90. Children's LENA developmental snapshot scores over the duration of the study: the light blue area of the graph displays if the children are 'advanced', the white 'within normal limits' and the blue are 'at risk'.

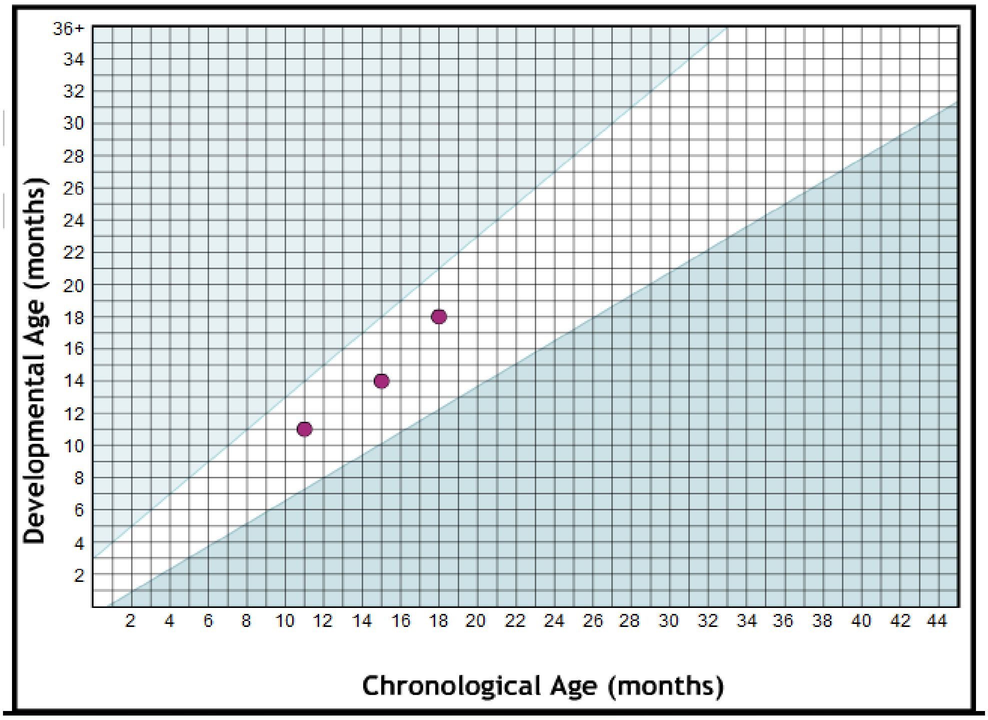


Figure 5.11 P5's standardised scores 105, 102 and 100. Graph display as described for Figure 5.10

P2 (Figure 5.12) attained scores of 98, 96 and 91 for the three intervals. By the end of the study the gap between LDS developmental age and chronological age for P2 and P3 increased by 1 and 2 months respectively but remained the same for P5.

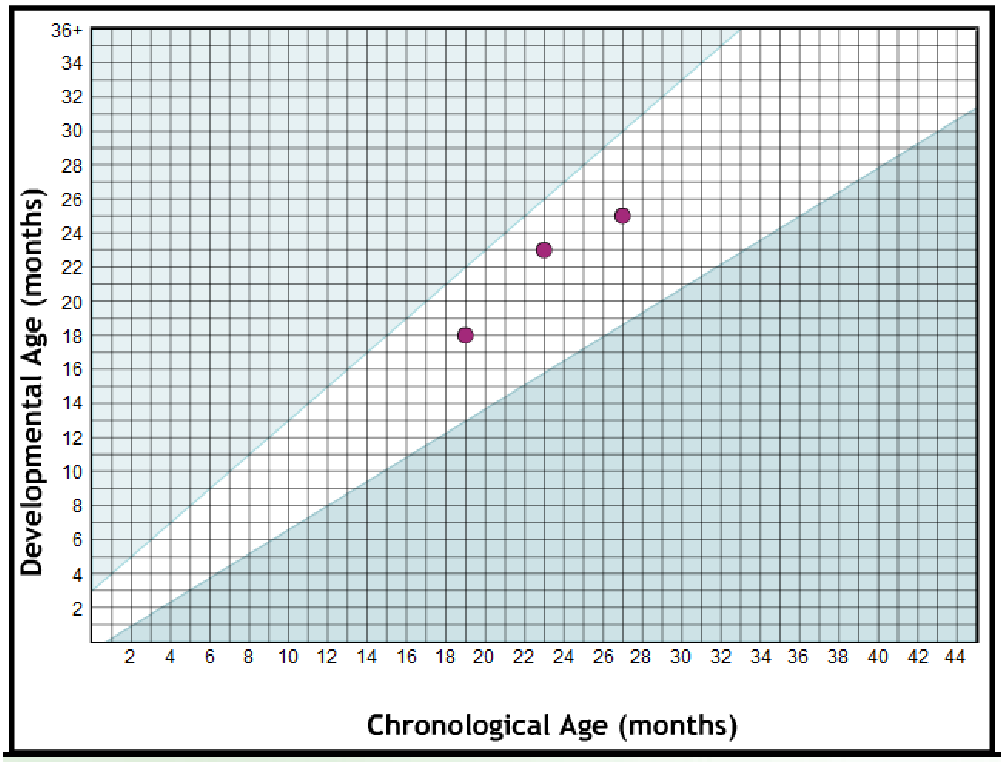


Figure 5.12 P2's standardised scores 99, 96 and 91. Graph display as described for Figure 5.10.

Similarly, there were no significant changes in P7's LDS scores over the duration of the study. P7 (Figure 5.13) remained close to borderline between the "at risk" category and "within normal level" at all three intervals. A standard score for P7 was not provided for the final test interval as the questionnaire goes up to 36 months. For the first two intervals P7 had a standard score of 70 and 68. By the end of the study the gap between LDS developmental age and chronological age increased by 2 months.

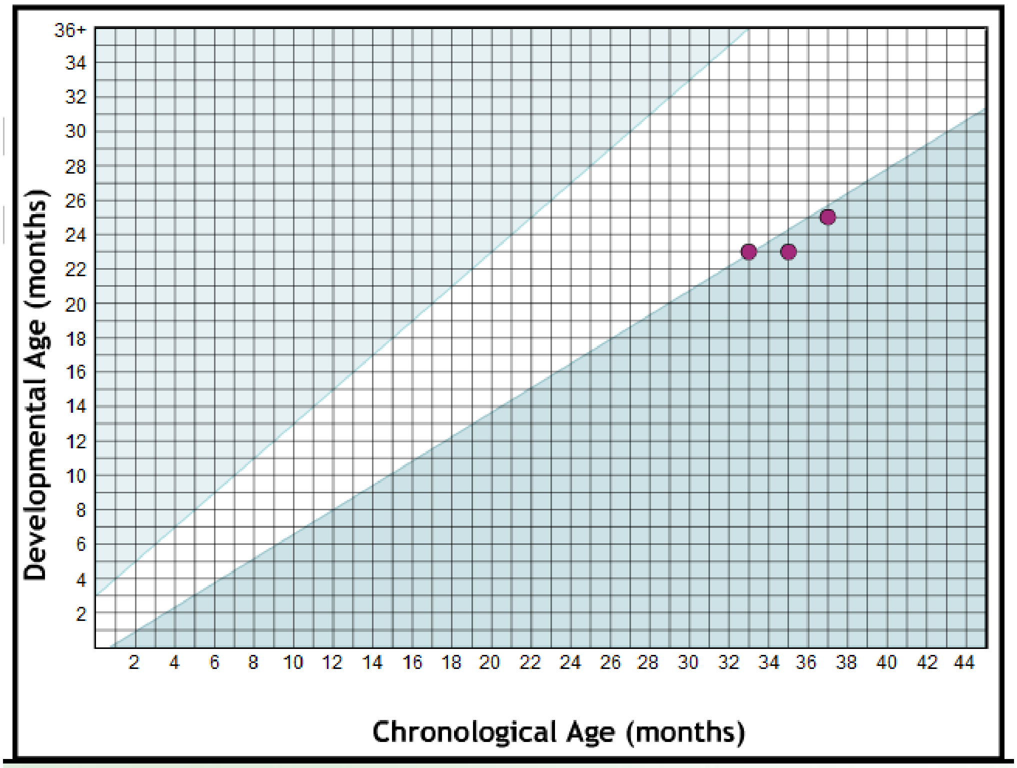


Figure 5.13 P7's standardised scores 69, 65 and no standard score for 37 months. Graph display as described for Figure 5.10.

P1 (Figure 5.14), P4 (Figure 5.15) and P6 (Figure 5.16) all started the study within the "at risk" category. P1 had a standard score of 66 and P4 and P6 both scored <65. By the end of the study P1 and P4 were in the "within normal level" category and P6 was at the borderline of "at risk" and "within normal level". The overall comparison of FM use with LDS scores did not show a clear trend for improved language trajectories for all children. Similarly, individual analysis for each participant shows four of the seven participants (P2, P3, P5 and P7) did not have any significant change in standard scores or narrowing of gaps in developmental and chronological ages. In contrast, standard scores at final interval for P1, P4 and P6 were 84, 76 and 73 respectively highlighting a significant improvement for all three children. The month for month gain in language development and narrowing of the gap between the LDS developmental age and chronological age for these three children suggests the use of an FM system was efficacious for their language development. All three (P1, P4 and P6) had established consistent use of their FM device during the study.

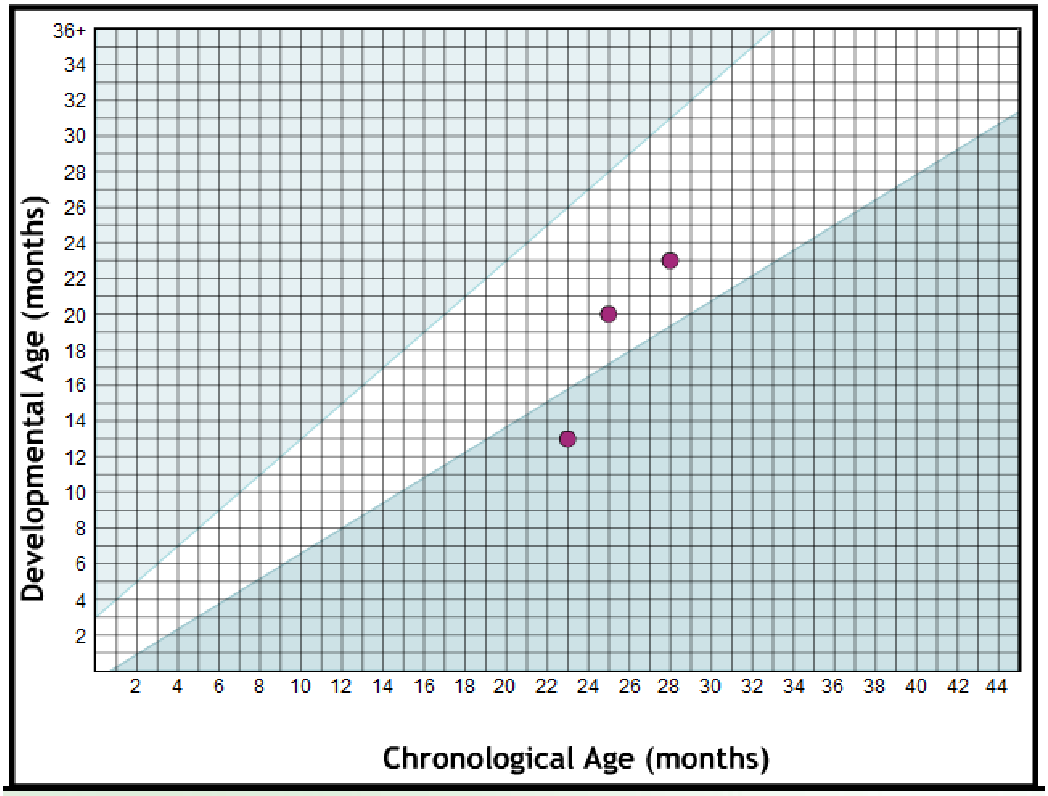


Figure 5.14 P1's standardised scores 66, 82 and 84. Graph display as described for Figure 5.10.

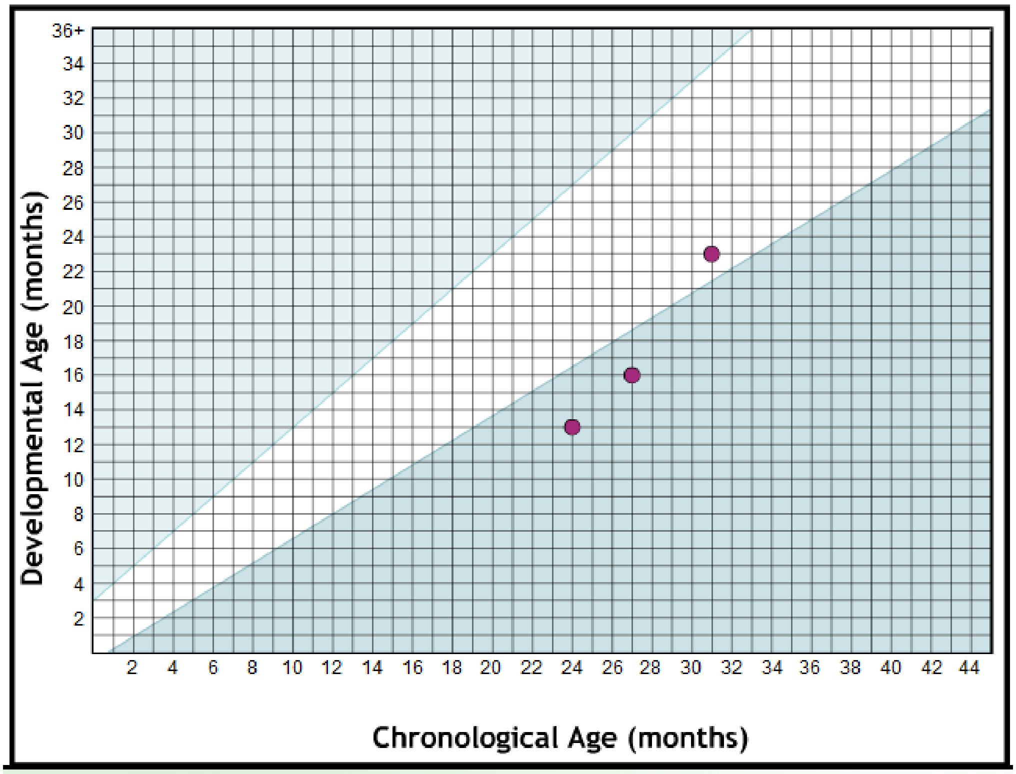


Figure 5.15 P4's standardised scores <65, <65 and 76. Graph display as described for Figure 5.10.

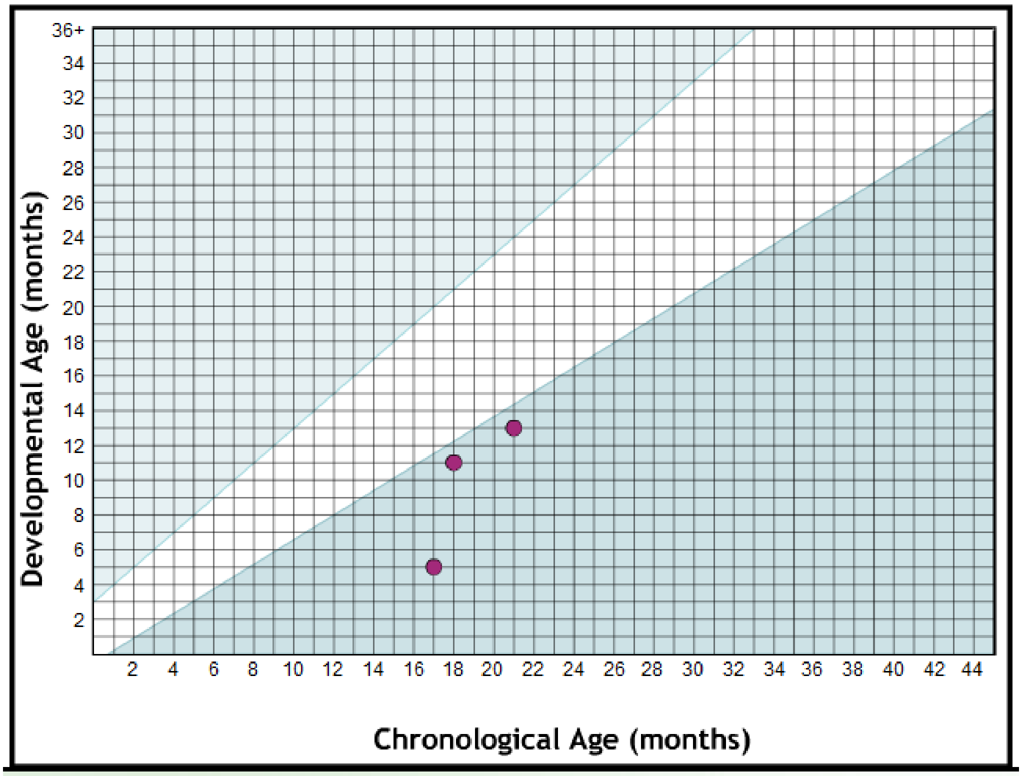


Figure 5.16 P6's standardised scores <65, 75 and 73. Graph display as described for Figure 5.10.

5.4. Summary of key findings

The primary aim of this study was to establish quantitative results on the daily usage of FM technology with pre-school hearing aided children including the average duration of FM use, the total hours of FM use, the number of days FM was used and the environments and situations where the FM was used. Secondary aims for this study were:

- to evaluate situational listening with FM technology for each participant overtime
- to evaluate parents assessment of the FM technology used in this study
- to evaluate children's language development overtime and identify any potential trends related to FM use.

This research study was unique in the level and detail of data captured by participants, both through data logging and daily diaries, on the use of FM technology with pre-school hearing aided children. The key findings for this study are listed below:

- Five of the seven participants were able to establish regular use of FM technology in a variety of settings. For the two participants who did not establish regular use of the FM technology two variables: maternal education and the age of the child (11 months at the outset) were identified as possible reasons that may have affected FM technology use for these two participants.

- On the basis of this sample, maternal education was found to be a significant variable affecting the use of FM technology in this population

- The findings did suggest a significant correlation between age in months of child and the use of FM technology. The two children who did not establish regular use of FM technology were 11 months of age at the beginning of the study. The other five participants were aged between 15 to 32 months at the beginning of the study. A significant correlation still existed between age and FM use once the two youngest participants data was removed.

- Overall the participants were involved in the study for a total of 1198 days from which 837 days (71%) of FM technology use was recorded. The total number of hours of recorded FM use was 2874 hours and 15 minutes. From the total hours of recorded FM use parents reported 2801 hours of FM use were with benefit, 2 hours and 30 minutes of FM use without benefit and 73 hours and 45 minutes of FM use were where they were not sure of benefit. The average duration of FM use was 3 hours and 2 minutes.

- Altogether FM use was recorded for seven environments and settings. Of these the Home, Nursery, Car, Shopping and Outdoors were most popular. Mealtimes were not clearly recorded by all parents and TV use with direct input function was very limited. Although the largest percentage of hours used was recorded for the nursery setting, the highest number of days the FM was used in any setting was the home setting followed by the car then the nursery setting. FM use in the car, during shopping and outdoors was proportionate with the expected duration of time and number of days children would be expected to be in these situations. The increased total hours of use in the nursery setting was a result of the longer duration of time the FM technology was used in this setting. This was highlighted by the nursery setting having the highest average duration of use compared to any other environment/setting. The findings highlight the importance of using all the different forms of data captured (hours used, days used and average duration of use) for each setting to better understand the environments and settings where FM technology was used with pre-school children.

The FMLEC questionnaire results after one month of use and at the end of participants study participation were used to identify any potential improvements in FM situational listening overtime. The questionnaire evaluated children’s listening with FM in four situations: noise, quiet, distance and auditory only. The key findings from the results were:

- The overall total scores for listening in all four environments improved overtime for six of the seven participants. However even this one participant did show overall improvements in all listening situations when one subset of questions were removed. The particular subset of questions was related to the child’s ability to differentiate between similar sounding words. These were marked as not applicable in the first month of the study and completed with low scores three months later at the end of the child’s study participation, lowering overall percentages. The lower scores may have been more related to the child’s skill to differentiate between words still emerging, rather than actual listening with FM.

- Overall, the FMLEC questionnaire was found to be a useful tool in evaluating children’s situational listening with FM technology. The questionnaire was easy to administer and score. The question related to children’s ability to distinguish between similar sounding words was felt to be inappropriate for younger children. Although a clear procedure on how to exclude these scores are provided the overall comparisons were not as accurate overtime. This was experienced in the case of the child who did not show overall improvements.

- As expected the highest improvements from the four listening situations were reported for noise and distance.

The technology assessment questions included in the FMLEC questionnaire were scored by parents to evaluate their assessment of FM technology and to compare for any differences at the beginning and end of their study participation. Each question related to the FM technology was given a score by parents between 1 and 5 (1 indicated a very poor score and 5 a very good score).

- For the question “FM system is easy to operate” the mean rating for all participants in this study was 5 at the beginning and end of the study period.

- For the question “FM system has remained in good working order” the mean rating for all participants at the end of the study was 4.14. One participant’s scores improved from the beginning of the study compared to the end of the study. However two participants score decreased overtime. Both these participants FM technology did require repairs during the study period.

- For the question “FM system is comfortable for child to use” the mean rating for all participants at the end of the study was 4.86. Only one participant reported a score lower than 5 for this question. This participant had made very limited use of the FM technology and reasons for non use were further explored in the qualitative feedback under the theme *barriers to FM use*.

- For the question “Child tries to turn FM system off” the mean score was 1.43. This question implicitly assumes a request to turn the FM system off by the child as a negative behaviour and six of the seven participants understood the question as implied. One participant reported a score of 1 at the beginning of the study but at the end of the study reported a score of 4. This was further explored in the qualitative feedback under the theme of *control of own listening*.

The children’s language development over the duration of the study was assessed using the LDS questionnaire. Results from the beginning, midway and end of the study were compared to identify any trends in language development associated with FM device use. The key findings for these results were:

- Four children whose LDS scores were ‘within normal level’ or border line ‘within normal level’ at the beginning of the study did not show any significant improvements overtime. Of these four participants two had made regular use of FM technology and two had not. The results suggest children with age appropriate or close to age appropriate receptive and expressive language development scores as assessed by the LDS at the start of the study showed no significant changes in language development overtime regardless of FM device use or non use.

- Three children whose LDS results were significantly ‘at risk’ at the start of the study made significant improvements in LDS scores by the end of the study. Two of the participants were ‘within normal limits’ and one close to ‘within normal limits’ at the end of the study. All three of the participants had made regular use of their FM technology. The results suggest pre-school hearing aided children who are significantly ‘at risk’ in their receptive and expressive language scores as assessed by the LDS may achieve significantly better language development with the use of FM technology.

6. Study 3: Parents and carers views and experiences of FM use with pre-school hearing aided children

6.1. Introduction

Although the quantitative methods described above do provide an insight into the use of FM technology with pre-school hearing aided children they cannot provide an insight into the meanings, views and perspectives of the users of the technology. This important aspect can be achieved through qualitative enquiry which was the focus of this study. The following section will describe the qualitative methods used as part of this research. Thereafter the themes identified through parents and carers views and experiences will be presented and considered with relevant literature. The final section of this chapter will summarise the key findings from this study.

6.2. Methods

6.2.1. Methodological approach

The methodological approach for capturing parents and carers perspectives of FM device use with pre-school hearing aided children was a qualitative one. Rather than using a quantitative questionnaire where parents would respond to a set of predefined questions, parents and carers had the opportunity to discuss their own perspectives highlighting events and experiences they felt were meaningful and important to them. The advantage of this approach is that it privileges parents and users of the FM device to evaluate the use of an FM system with pre-school hearing aided children. This does not simply mean to ask parents and users what they think but goes further in the epistemological sense by enabling their accounts to generate concepts, meanings and theories by which the use of FM systems with very young children should be understood and can be further evaluated. Therefore the qualitative approach identifies what is meaningful based on what emerges as meaningful from experience and not by what may be decided as meaningful by researchers when developing a closed set of quantitative questions (Silverman, 2005; Willig, 2001). Furthermore, as the purpose of this part of the study was to explore parents' and carers' in depth perspectives of

FM use with pre-school hearing aided children the qualitative approach was well suited for this as the aim of qualitative research is to understand experiences. The focus therefore in qualitative research is the 'quality and texture' of experience and the meaning attributed to events by the research participants themselves and to describe and possibly explain events, but never to predict (Willig, 2001).

6.2.2. Data collection

Throughout the course of the study parents were asked to complete a structured diary (Appendix B) on a weekly basis. Similarly, one of the participant's nursery staff also participated in diary keeping and kept their own set of weekly diary responses. The structured diary consisted of seven open ended questions and was based on the weekly observation inventory devised by Moeller et al. (1996) for their FM system study. The open ended questions in the weekly diary were:

1. Where did you feel the FM system worked best?
2. Where did you feel the FM system was of little use?
3. Can you see any differences in your child's communication?
4. How did your child show they were listening to you or other sounds?
5. Were there any changes in your child's behaviour when using the FM system?
6. Were there any difficulties or problems in using the FM system?
7. Is there any other information you would like to share?

Although the diary questions were structured the open ended questions did provide flexibility for the parents to capture their own experiences and the final question provided parents with greater flexibility in sharing any of their experiences related to FM use. The benefits of this form of data collection were that diaries provided temporally ordered data revealing how events unfold in real time. They avoid problems associated with retrospective reporting which can be influenced by present circumstances, retrospective interpretation of events or forgetting of details (Willig, 2001). Diaries can also facilitate access to very specific and personal experiences that may not emerge in a face to face interview. Diary responses were also helpful when developing the semi structured interview schedule (Appendix E) and also provided appropriate prompts for individual participants during the interview. As expected with any form of qualitative data collection method certain limitations did exist with diary keeping. The main limitation was the level of commitment required to maintain an open ended diary on a weekly basis throughout the course of the study. Similarly, the level of detail shared and the depth of descriptions were not similar for all participants.

To overcome these limitations and to obtain a more consistent level of in depth perspectives from all parents, semi-structured interviews were conducted at the end of the study. The benefits of using a semi structured interview are that it allows for the interviewer and the parents to develop a 'rapport' (Smith, 2003) during the interview process thus enabling parents to reflect on their experiences and share their personal perspectives of FM use. As the parents had already established extended contact with the interviewer over the duration of the study, developing a rapport, which is a fundamental concept of semi structured interviewing (Willig, 2001), was perceived to occur naturally and parents were felt to be at ease during interviews. Similarly, many parents would share a lot of personal experiences during monthly appointments but had not logged these down in their weekly dairies. The interview process encouraged parents to revisit these experiences and allowed for them to be documented. The combination of diary keeping and semi-structured interview methods of data collection allowed for a form of triangulation (Willig, 2001).

The interviews for four of the seven parents took place at their homes. One parent's interview took place in a separate room provided at the local playgroup where monthly appointments took place. Two parents' interviews took place in a quiet room away from clinics at their audiology centre where again monthly appointments took place. Both parents were present for only one of the interviews with both of them being involved in the interview and contributing to responses. The rest of the six interviews were conducted with mothers only. All interviews were in English as all parents reported they were comfortable communicating in English.

6.2.3. Data analysis

All participants' diary entries and the diary kept by the nursery and all participants' audio recorded interviews were transcribed in full. A thematic content analysis was carried out using the sort and retrieve program QSR NVivo 9. Codes were generated independently by the author and the supervisor. Regular discussions took place and this recursive iterative process lead to the final coding framework. As expected during any qualitative analysis, some codes at times were collapsed into others as it became apparent they were capturing the same overall theme. Cross sectional analysis techniques were used to analyse both within case and cross case perspectives (Silverman, 2005). Each individual was regarded as a 'case' rather than each of the seven interviews and eight diaries. Overall there were eight 'cases', seven of which included data from both diaries and interviews for each participant and the final eighth 'case' referred to the diary kept by the nursery. Participant ID numbers preceding each quote identify which participant's interview/diary the extract is taken from. In the case of nursery quotes a clear label of 'Nursery' was used. The labelling of quotes allows for the tracking of cases and the appreciation of the diversity of responses.

As part of qualitative analysis an acknowledgement and recognition of how the researcher's own knowledge and experiences have influenced the research is referred to as personal reflexivity (Willig, 2001). Nightingale and Cromby (1999) describe this: "*Reflexivity requires an awareness of the researcher's contribution to the construction of meanings throughout the research process, and an acknowledgment of the impossibility of remaining 'outside of' one's subject matter while conducting research*" (p.228). It is important to note the code from which the following analysis is drawn was of particular interest to the researcher who is an audiologist. He has an interest in seeing early amplification options within the broader context of a child with hearing loss, for whom hearing aids may often be the only amplification option offered. He brought to the analysis an appreciation of the wider amplification options available and also a theoretical understanding of the signal processing limitations of hearing aid technology. Therefore the data from parents and carers provided an opportunity to test out the validity of his perception of hearing aids as a baseline amplification option and to understand what role, if any, the use of an FM system had in the amplification options of pre-school hearing aided children. That approach of viewing parents and carers FM technology use brought a reflexive view to the data of an expert outsider who actively used this perspective to interpret parents' and carers' narratives.

6.3. Results and discussion

Parents' and carers' views, as FM users, provide an insider perspective of the potential benefits and challenges of using FM technology with young children. Parental responses in the weekly diaries differed in consistency of responses as well as in the amount of detail described. Some parents updated the diary more regularly but the data entries were more generic and brief, whereas other parent's entries were not as frequent but the entries were more descriptive and rich in detail. As expected parents of the two youngest children had fewer responses as their use of FM was limited. Surprisingly one of the parents who had excellent feedback on using the FM and had established regular and consistent use of the FM device had very little diary input. This parent was encouraged on monthly meetings and did have a lot of feedback to share during these meetings but the diary entries were not something that was undertaken in detail or frequency. The nursery diary was very helpful in obtaining an alternative perspective from those of parents. Interviews produced more narrative accounts of FM use and parents were able to recall issues related to the use of FM on a more general level. Responses from both diaries and interviews were thematically analysed and six main themes were identified:

- Access to speech
- Listening
- Communication
- Well being
- Engagement with technology
- Practicalities of FM use

6.3.1. Access to speech

From a theoretical perspective, it is relatively easy to highlight and identify situations and environments that would benefit from FM use. However, as parents had made use of hearing aids for a length of time, they had a wealth of experience on communicating with their child in a wide range of environments and situations. Therefore, parents' accounts were not simply of experiences regarded as good or bad about the use of FM, but rather a demarcation of what the use of FM had to offer over and above the child's hearing aids. As a result parents experiences did not only offer an objective insight into the increased access to speech provided by the use of an FM system but also highlighted the numerous everyday situations where children with hearing aids were gaining little or no access to speech when using aids alone. Parents own experiences made them compelling experts on the potential provided by the FM technology as they could often compare and contrast between the FM and hearing aid technologies. As such their narratives provide a window on the complex acoustic settings that potentially threaten access to the spoken word for any hearing aided child. Such environments include car journeys, sitting in the pram, walking outdoors and also include situations where distance, noise, reverberation and hearing aid microphones being covered pose considerable challenges.

6.3.1.1. Child position

The ergonomic challenges of direct face to face communication with young children in everyday routine activities proved ever more challenging for children with hearing loss. The majority of parents described many of these activities as key areas where access to speech was difficult, highlighting three situations in particular.

1. child seated in the car behind the parent,
2. child facing away from the parent in a pram/buggy
3. child walking alongside parent (holding parents hand).

With regard to the child seated in a car-seat behind the parents, parents drew attention to not being able to hold a conversation with their child in this situation and also their inability to turn and face their child whilst driving. For the parents the FM provided the opportunity to communicate in the car where previously this would have been difficult to achieve.

P7: "In the car, because I couldn't look at her to speak to her so my voice was trailing off but with the FM it was direct to her ear so she could hear me".

P2: "It is good in the car as well because he is always shouting 'mummy, mummy, birdy, birdy' because he is always pointing out of the car, and I will say to him 'yes' and we do that in the car. I can have a full conversation with him (in the car)".

P4: "In the car I know I've been told from audiologists when she's in the car all she can hear is the drone of the engine really, what I've noticed using the FM in the car she's more responsive, she'll join in with nursery rhymes when we have it on in the car and if I'm in the passenger seat I can just shout and she'll look at me through the passenger mirror and wave to me whereas if she's not got it on she doesn't listen".

Similarly, parents made the point that when the child was seated in a pram/buggy facing away from them, the FM resulted in increased conversation between parent and child.

P1:" She just answers me more because she is in front (in pram) and I am behind her she can't see me but she does answer me".

One mother recounted her father's (child's grandparent) specific experience on how well the child was able to hear in the pram.

P4: "When out in the pushchair my dad was counting aloud to four. He noticed [my daughter] counting on her fingers and then she continued counting out loud to six".

The above two child positions mentioned were common amongst the majority of parents. However the position where the child was walking alongside the parent whilst holding their hand was less common. As the children were still quite young it may simply be for the other parents, the child walking alongside them was not a regular occurrence as the use of a pram was much more frequently cited. Two parents did notice the benefits of FM use whilst walking. One mother made regular comments on the potential access to speech the FM provided in this situation.

P6: "I can talk to him whilst we are walking and point to things and tell him what they are... In the morning on the way in to school we saw a rabbit and I was talking to him about it. He loved it... I also taught him stop, look and listen at the road today".

Access to speech offered by FM use in all the above mentioned scenarios was not just to do with the child being able to hear the parent, but was also emphasised by the opportunities provided for conversational turns. Parents often appreciated the regular occurrences where without any visual cues they were able to hold a meaningful conversation with their child. Nursery staff noted many opportunities for listening during play where the child's position would generally make it difficult to access speech, for example:

Nursery: "[Child] responded well when he was playing inside a box as [he] couldn't see the staff but he could hear them. He had lots of fun in the box playing 'Boo!'"

6.3.1.2. Distance, noise and reverberation

Unsurprisingly, all families who made use of the FM technology valued the increased signal to noise ratio (SNR) achieved by the FM device. As stated previously, increased distance of the primary speaker from the listener, background noise and poor acoustics in rooms would all provide a poor SNR resulting in a less clear auditory signal for the child to access. In the case of children these factors pose a more significant barrier than with adults, as children's neurological immaturity and lack of language experience reduce their ability to perform auditory and cognitive closure (Cole & Flexer, 2011).

The ideal distance for children with hearings aids is between one and two metres however it may be less than this in noisy conditions (Madell, 1992). For families, routine activities such as being outdoors, in the park, garden or out shopping regularly place the parent and child at distances of over two metres, resulting in a decrease of the speech signal as it reaches the hearing aid microphone. When parents described the use of FM in distance, they not only referred to the improved speech reception of the child that the FM offered but also the usefulness perceived by parents using the FM in these situations.

> *P1: "when we are out shopping because she likes to run off and obviously she is too far away but when I have the FM on she can still hear me... when we went shopping I could tell the difference. She would come to me quicker. She is in a pram but she likes to get out and run about".*

> *P7: "Obviously shopping I can shout without being too loud and she can hear me straight away, and when we are outside in the park or shopping centres, it is really useful because without me raising my voice I can just shout her and get her attention and she knows to stop because mummy is calling my name and without it I would really have to scream".*

> *P4: "I found the FM system really useful whilst in the park. [My daughter] was yards away from me and I just spoke normally to her to come over to me and Connie to have a turn on the swing".*

Distance was not only identified as a factor in outdoor settings. Daily routines in the house often place the child in separate rooms or at a distance of more than two metres. Several parents were able to comment on the benefit of FM in distance situations in the home setting.

> *P2: "He can hear you a lot better. I think his hearing aids at close range work as well but it just when he ventures out like when he was at the other side of the room there"*

P4: "Nice to see [my daughter] responding if she goes out of the room and comes back immediately when you call her".

Similarly, the home environment commonly exposes children to widely varying acoustic conditions resulting from internal and external noise sources and poor room acoustics. Everyday appliances, open windows, TV, siblings and noise generated by competing conversations decrease the potential to access speech directly from the primary speaker. Parents were keen to describe the benefit the FM provided them in background noise.

P5: "Oh yes, it was far better using the FM when in high background noise, when the TV is on or a lot of kids being around. We used it a couple of times when we were doing nursery rhymes, she likes nursery rhymes, so we would use it and all the kids would be playing around quite loudly so we use it in that instance".

P6: "[My son] loves me to attend when he is playing (running commentary). It's easier and I get his attention more when I use the FM. My house is noisy in the holidays and using the FM gives me more chance to play with [my son] even though there is a noisy background".

Likewise, nursery staff frequently commented on the benefit provided by the FM device in distance and noisy settings.

Nursery: "[child] was down at the bottom of the outdoor play area. A practitioner who was carrying the radio aid (FM transmitter) called to [child] as it was time to go inside and [child] turned around".

Nursery: "I said [child]'s name from across the room. He was sat down on a chair. He turned to look at me. As it was dinner time there were a lot of other noises going on in the room".

Rooms with hard shiny surfaces such as kitchens and dining room tables and also in some cases living rooms with wooden flooring are prone to reverberation, resulting in poor acoustic conditions. Despite these challenges the reception of speech sounds is relatively straight forward for an adult with normal hearing. This would make it difficult for parents of hearing aided children to appreciate the increased challenges to their child in these settings. It would be useful for the ToD who has regular contact with parents to explain reverberation to help parents understand the challenges faced by their children in many listening situations. There was evidence of only one mother understanding these challenges and using her understanding to inform the use of FM with her child. This was demonstrated by her actively identifying situations where reverberation and room acoustics could pose a challenge for her child and highlighting these to other members of the family.

> *P4: "You just become aware of different situations that you think it might be useful in, like you look at the acoustics of different places. I say to people you should be using it in the kitchen, trying to get the grandparents to use it in the kitchen, trying to explain to them the hard surfaces, so that is what you become aware of – you are aware anyway with hearing aid users but I am now looking for places where I think the FM system would be very useful".*

Although other parents may have observed the benefits of the FM system in a room with poor acoustics, this was not clearly identified in their feedback as benefit in reverberation or in a room with poor acoustics. The real issue of significance for parents in these situations was the observable differences they noticed in their child. One mother, who used to have lengthy one on one play sessions with her child in the dining room, fully appreciated the benefit the FM provided over hearing aid use alone.

> *P6: "In one to one play is really good, even when you think the hearing aids will pick up anyway it is better to use the FM. He just seems to get more"*

6.3.1.3. Reduced access to HA microphone

Parents also observed another situation where use of FM provided them with significant benefit. Parents described basic everyday situations where the hearing aid microphone was covered, resulting in little or no acoustic information reaching the child through the hearing aid. As the FM signal is wirelessly transmitted directly to the receiver, the HA microphone being covered does not affect the quality of the parent's speech signal. There is no evidence within the research of consideration given to this very practical and commonly occurring situation when using amplification technology with children. Parents described how commonly worn garments like winter hats and hoods on coats would reduce access to speech for their child

> *P4: "we had it in the winter, we started off in the winter. Very useful with the hats on. [My daughter] has hats that cover her ears, so when she has the hats on her ears are covered so we notice a big difference using the FM outside. She could still hear you. We found it most useful outside. Very, very useful outside".*

Similarly safety helmets worn for activities like bicycle riding or horse riding was seen as an ideal situation. For one parent the realisation of the potential for FM benefit in this situation was surprising. Although she was not completely sure how the hearing aid could still pick up sound when the microphone was covered, she was convinced it did work in that situation and pleased at the possibilities this offered.

> *P6: "I took [my son] out on his new bike and used the FM. He did turn round when I spoke to him. I'm not sure if he was hearing me though as he had his hat on over his hearing aids. If it still works with the aids covered this would be great".*

> *P4: "Out horse riding she's got a hat on, so obviously it's blocking... a slight blockage from the microphone on the top of her hearing aid, so there it's really really useful"*

6.3.1.4. Perceived limitations of FM technology

Parents were offered the option of identifying situations where the FM system was of little practical value. For all parents such situations were rare and diary entries were on the large completed as “nowhere”, “none” or left blank. However, parent responses did highlight certain situations where they felt the FM offered reduced or no benefit. One such situation reported by mothers was when the FM was used at an event or when the child was excited or pre-occupied elsewhere. Some parents appreciated that this may be due to the child being more interested in his/her surroundings rather than not being able to hear the parent’s speech.

P2: “BBQ party and birthday party: not sure so took off. Lots of people and noise [my son] was very excited couldn’t tell if it was working or if he was just ignoring us... Still not good when he is excited. I don’t think it’s not wanting it as such, it’s just he doesn’t want to listen if there is too much going on!”

P6: “I’m not sure if it was useful in the buggy, but he was watching his brothers and sister on the sledge so he didn’t turn to me much. I think he was preoccupied”.

However not all parents made this association. As the following mother’s diary entry described how a visit to the zoo resulted in reduced responsiveness from the child, resulting in the FM not being used.

P1: not as responsive with FM system. Couldn’t hear when spoke directly into microphone – didn’t use at zoo because of this.

Similarly, two parents made a clear link between no benefit from the FM system and noisy situations. Although in theory this would be consistent with the expected limitations of the technology as the premise of FM technology is to provide an improved SNR. Taking into consideration, average speech levels expected when the FM microphone is placed 10-20 cm away from the speakers mouth would be 72 – 84 dB in most room settings (Ross, 1992), if ambient noise levels were higher in intensity the SNR would be reduced or negative. Consequently, any potential FM benefit would also be reduced. However, in the following two examples mothers identify the complex environments the children were in when the mothers felt noise was the cause for reduced FM benefit. The situations mentioned are both visually and mentally stimulating environments where it was more than likely the child was preoccupied with his or her surroundings.

P2: "It wasn't very useful if it was very noisy, if we went to a party or something like that".

P1: "Only when it was really really noisy. Like Thomas Land, there were too many people there and it didn't seem to make any difference. It is like a small railway but there are just hundreds of people all around and I am trying to talk to her and she just couldn't hear me, but I couldn't hear myself anyway so it is probably that".

As such, a combination of factors could have led to the child's non-response in the above two examples. The first mother (P2) did appreciate her child being excited and not wanting to listen as a potential factor in the previous example where she described her child's behaviour in BBQ and birthday parties. In contrast, the second mother did not make the same inference and attributed this to the child not being able to hear rather than choosing not to listen. Later on in her diary the mother maintains the view that not being able to hear in a very noisy environment being a result of the background noise but describes how the FM can still benefit in these situations.

P1: "With continued use can work eventually in very noisy places".

Overall, parents did feel there were times when children did not attend to parent's speech transmitted via FM technology. Some parents associated this with typical child behaviour of being occupied with his or her surroundings, hence choosing to ignore the parent (this theme will be further discussed under *control of own listening* and *identifying and establishing preferred use*). Others associated this with the potential limitations of FM technology and chose not to use the FM in that situation.

6.3.1.5. Reduced need of FM in acoustically favourable situations

For the majority of parents, the benefit of FM was best perceived when access to speech was achievable in situations where hearing aids were unable to provide this access. In this respect, some parents felt where hearing aids were able to deal with the listening needs of the child and access to the primary speaker's voice was achievable, the need for the use of an FM system was reduced. Two parents identified the home setting as an environment where the general use of an FM system was not needed.

P7: "Mainly at home when it was just me and her".

P1: "If it was quiet (at home) then it didn't make much difference".

However, others felt the benefit of the FM system did extend to the home setting

P6: "When reading a story [my son] sits listening and pointing to find out what things are".

P2: "when we sit at the table with him doing colouring or anything like that, or reading, it is really useful at that point".

For one parent there was gradual shift in opinion regarding the use of an FM system in the home setting in quiet, one to one situations.

P4: In the home when we are quiet and playing. I feel there isn't much need for it in the house... I find it very difficult to assess whether it is useful in the house... Don't feel the need to use inside when it's just me, [my daughter] and [younger daughter]... Close contact whilst playing at a table together (not useful).

Through explanations in the diary a gradual change in opinion was noted for this mother. Where initially she felt she was not sure of FM benefit and did not feel there was a need for the FM to be used in the home setting under good acoustic conditions, she later changed to a more positive view of potential FM benefit in this setting. The mother did acknowledge she had not made much use of the FM in the home setting when her opinion on the use of FM in the home was more reserved.

P4: "I am still not convinced of it in the house, although not really used in the house".

However, on increasing the use of the FM technology in this setting her opinion was more positive.

P4: "I have begun to use it more in the house now and her grandparents have too. We have found it beneficial in the home".

The gradual shift in opinion for this one parent was a direct result of introducing the FM in the home setting even in good acoustic conditions. Her initial viewpoint was taken based on her feeling that her child was accessing speech sufficiently well in these situations and therefore the parent felt no need to introduce the FM system.

6.3.2. Listening

Although the hearing aid may have presented an audible speech signal to the child, simply detecting the presence of speech is not always sufficient for understanding and in some cases even detection of the speech signal was compromised by adverse conditions. Parents appreciated the improved access and intelligibility of speech achieved with the use of the FM system over the basic audibility provided by the hearing aid alone. Similar to audibility and intelligibility, a distinction exists between hearing and listening. Hearing is interpreted as acoustic access to the auditory brain and achieved in a large part by improving the SNR through technology and environmental management. Listening is the sequence that follows once hearing and access to speech is made available and is defined as attending to acoustic events with intentionality (Cole & Flexer, 2011). For parents and nursery staff the improvement in listening skills through the use of an FM system was an overwhelming theme.

P2: "we have noticed a massive change in [my son]'s speech and listening skills"

P7: "[My daughter]'s listening skills are getting better".

Parents/users comments reflected on the overall and specific benefits of FM use for their child's listening skills. Parental accounts did lend themselves to the theoretical models and constructs of auditory skills development and auditory processing models described by Erber (1982), Kuhl (1987) and Musiek and Chermak (2006). Cole & Flexer (2011) summarises the theoretical sequences of the auditory processing models once speech or acoustic information is presented to a child. Initially the child is motivated to *attend* (or to *detect* it) to the sound. Next, some preliminary auditory processing occurs in the brainstem related to *localisation* and separation of competing messages. Finally, once the sound reaches the auditory cortex higher levels of analysis occur, which have been theorised as *discriminating from close cognates* (*identification*, *recognition* and *labelling* of sounds) and *comprehending* as meaning is derived. In that respect, parents/users comments and reflections on their children's listening skills associated with FM use included: attending, locating FM user, recognising and labelling sounds and comprehension.

6.3.2.1. Attending

All parents and nursery staff noted improved responsiveness and attending to sound when using the FM compared to when using the hearing aids on their own. Parents/carers did not always provide lengthy descriptions but numerous diary entries described the child as being "*more responsive*", "*joins in more*", "*turns quicker*", "*quicker reactions*" , "*answered more*", was more "*interactive*"/ "*communicative*" , had "*more eye contact*", "*looking*", going "*quiet*" and "*pausing*" and overall being "*more alert*" when the FM was in use. The improved responsiveness and increased attending meant for most parents that the FM was providing a clear observable advantage for their child compared to when using the hearing aids alone.

> *P4: "The teacher of the deaf commented on how responsive she was outside playing at preschool... We have been in the garden a lot and I can tell if we haven't got the system on as she isn't as responsive".*

> *P3: "I would say when you said his name, called his name, he would obviously respond a lot quicker, he would turn round almost immediately than with just his hearing aids".*

The above narratives from parents describe the access to speech provided through FM use allowing children to attend to the auditory signal and as a result, parents identified an increase in their child's attending to the speaker's voice with intentionality. These descriptions establish the first sequence of listening for the child and set the child up for some preliminary auditory processing related to localisation.

6.3.2.2. Locating FM user

Parents and nursery staff all commented on their positive observance of how "*accurate*", "*quick*" and "*instant*" their child's ability to localise the FM user was. However, in theory as the FM signal is wirelessly transmitted it would not be possible for the child to receive any directional cues from it. In that case children would have had to make use of other cues to accurately locate the FM user. What was interesting in parents'/users' reflections on the child's ability to locate the person wearing the FM was how some parents identified their child actively monitoring who was using the FM.

> *P4: "She looks at who is wearing the device when we swap it over from one person to the next, e.g. mum to carer at nursery".*

Parents' descriptions of children's pre-awareness of the FM user's location provide one possible explanation for improved localisation of the FM user. As children would be aware of where the person using the FM was, on receiving any speech information via the FM signal the child would recognise the sound and associate this with the position of the FM user and turn to the source. For example, in the car the child would be aware of the position each person is seated in and if the person with the FM would speak the child could associate the speaker's voice with their position and turn to them.

P6: "My mum wore it in the car for a bit and she was amazed that when she said his name he looked around".

This possibility is further explained by some parents' descriptions of how their child would actively look for the speaker on receiving speech through the FM system if they were not aware of the parent/user's position.

P3: "Initially when we first used it, he was a bit scared I think because he was looking round and he wasn't quite sure where the sound was coming from, but then when we tried it he would look at me and he found it quite funny that he could hear mummy's voice quite clearly"

P4: "Looks for the person wearing the microphone when they say her name".

P6: "On the way back I started saying 'Hiya [child's name]' and he was looking for me. When he saw me he started walking".

On the other hand, some of the diary entries did seem to point towards auditory localisation. Although in many of the descriptions it could be argued that there was the possibility of pre-awareness of FM user location, it would be difficult to completely ignore the possibility of improved auditory localisation from the descriptions provided by parents and nursery staff.

Nursery: "As I walked into the room I said "Hi [child name]" and he looked at me straight away... Whilst on the slide a member of staff shouted [child's name] and he looked straight at them and waved"

P4: "My mum was very impressed how instant she was to look round at her whilst outside playing"

It is important to note all the children's hearing aids were set to function on the FM+M mode, where both the FM receiver and HA microphone would simultaneously receive input. In this case it is likely the HA microphones will provide additional auditory information that would help with localising sound. Maxon & Brackett (1989 cited in Madell, 1992), in studying the effects of hearing loss and localisation ability, found profoundly hearing impaired subjects using an FM system whilst their HA was set on FM+M mode, were able to localise stimuli placed at 90 degrees right and left and immediately in front of them at normal conversational levels. When subjects with similar hearing losses using a hearing aid alone were presented with the same test setup, they required greatly increased stimulus levels before they were sufficiently aware of the sound to attempt the task. This highlights the important function the FM signal can play in allowing the children access to speech at normal conversational levels and potentially allowing the HA microphone to assist in locating the sound source. Without the FM signal the children would not be sufficiently aware of the sound to be able to locate it. Parents/users recognised this improvement in the children with the FM on and reflected this in their diary entries.

P1: "Turns more accurately to which speaker, and quicker".

Nursery: "[child] is noticeably responding more and more to the radio aid. Every time words are being spoken through the mic, [child] is looking at the person speaking".

6.3.2.3. Recognising and labelling sound

Clearly, speech picked up through the FM and hearing aids will both be processed with higher level cortical activities involving phonetic, phonological, syntactic, semantic and pragmatic/contextual processing (Cole & Flexer, 2011). On that basis, content and descriptions from parents expectedly did not describe any clear differences between FM use and hearing aid use. However parents and nursery staff did describe children's ability to recognise and distinguish between different users of the FM device.

Nursery: "He recognises our voices (different staff) quite easily".

Two parents reported how their child labelled FM use with a particular individual and how a different person using the FM system resulted in a clear reaction from the child. The first parent recalls this with a specific example.

P6: "Today when [my son] was climbing on the slide I said '[child's name] no!' He just looked at me. I then put the microphone piece to [my partner] and he said 'No'. [Son]'s eyes opened really wide and he looked at him".

The second parent reported how another person using the FM caused the child to be upset.

P1: "Got upset when different person spoke through FM".

The above accounts would also appear to include an element of auditory memory and retrieval (Bamford & Saunders, 1991) in that children associated the use of FM with a particular voice and were able to draw on that knowledge.

6.3.2.4. Comprehension

All parents and users of the FM system were able to reflect on their child's improved comprehension and receptive language abilities which they associated with the use of the FM device. Parents reflected upon more general improvements in their child's overall comprehension and understanding.

P4: "Responds and interacts much more – just seems to understand more... The response you get with the FM system it is instant and without the FM you have to ask her a few times".

P2: "He understands nearly everything I tell him"

P1: "getting answers correct more".

P6: "[my son] is understanding a lot more. He is distinguishing different voices. Also stern voices and reading voices".

*P5**:** **"**she responds more accurately to spoken instructions"*

Similarly, parent's and nursery staff were able to reflect upon more specific instances of comprehension displayed by the child when the FM was used.

P6: "He also put the remote control on the window sill and when he was walking back I said 'cheeky boy, where have you put the remote'. He looked at me smiling and then walked back and got it".

Nursery: "[child's name] responded very well to questions asked, e.g. '[child's name] go and find the balloon'. [Child's name] would go and get it".

Parents and users also provided examples of comprehension without visual cues, something they were able to appreciate was a direct benefit of the FM system.

Nursery: "[Child] was under the table. The practitioner said "Mind your head". [Child] responded by patting himself on the head with a frown. The practitioner was wearing the radio aid".

Nursery: "He wanted to show her something. He walked away and the practitioner said "One minute". [Child] turned to wait. She was wearing the radio aid".

P6: "[My son] was watching television and playing with his hearing aid. I asked him if he wanted me to sort it out for him. He looked at me and ran straight over to me".

In the same manner, parents and nursery staff noticed an improved ability to multi task where children would listen and comprehend instructions whilst involved in a physical activity related to the instructions given. From parents and staff's perspective the extra benefit the FM system provided in this situation was appreciated.

Nursery: "His radio aid worked well during creative activity, as [child's name] heard everything [staff name] said and knew what the activity was about"

P2: "when we sit at the table with him doing colouring or anything like that, or reading, it is really useful at that point".

The ability to multi task in this manner requires the ability to perform other actions that require cognitive functioning whilst listening at the same time, resulting in a certain amount of listening effort. Research (Downs, 1982) has shown how it is possible for individuals with hearing loss to attain fairly high speech perception scores under poor acoustic conditions, but only with the expenditure of a great deal of effort and more processing time. Increased listening effort results in reduced energy available for performing other cognitive operations

(Ross, 1992). By providing a clear speech signal during activities that require other cognitive operations whilst listening, the benefits of the FM were clearly observed by parents and nursery staff. This is not a novel concept and is something that has been recognised in education for many years. Ross (1992) described the observable differences in children when taking orally dictated tests with and without the use of FM. With the use of FM, children kept their eyes on the paper and made the required responses. In the situation where FM was not used and children relied solely on their hearing aid, they would observe the teacher, and at the conclusion of the utterance they looked down to mark the paper.

6.3.2.5. Playing at not hearing

As the whole basis of an FM system is to provide recognition of speech in noise, examples of auditory figure ground tasks described by parents can be found throughout this section. It can be argued that the child's ability to recognise speech in noise with the use of an FM system may not be describing auditory figure-ground tasks as defined in auditory processing models but is a result of the FM system performing the task prior to any higher level processing taking place. However, increasingly interesting was parents descriptions of how the child was able to do the complete opposite of auditory figure-ground tasks whilst the FM was in use. Children were able to play at not hearing the person speaking through the FM by intentionally ignoring them. One parent described how their child would tease his sibling by intentionally ignoring him when he repeatedly tried to get his attention through the FM.

> *P6: "When [Eldest sibling] used the FM [child] was ignoring him. [Eldest sibling] kept saying it's not working. [Child] was having him on and after a while [eldest sibling] shouted his name and he turned and smiled".*

Although auditory figure-ground refers to the ability to identify a primary speaker from background noise it also covers the ability to selectively listen. On that note, parents described how they would sometimes feel the FM was not working only to do a check and find the system was working fine and the child was not listening as a matter of choice.

P2: "we have occasionally (checked the system) when he has been ignoring us. [Husband] has gone upstairs with the hearing aid and I have talked and we can tell if it is working".

P7: "If I thought it wasn't working properly or just wasn't responding, which sometimes she doesn't, I just checked that the receivers were working and it wasn't just her deciding she wasn't going to do as she was told!"

One mother described her daughters choosing to not listen when engrossed in another task, as something coming from her daughter rather than any uncertainty around the FM technology not working correctly as described before.

P4: "Not sure if she was listening while doing painting – she seemed to ignore me".

Similarly, another mother explains how her son was able to attend to her when a specific kind of voice was used.

P6: "If I just talk as though I'm not talking to him he carries on with what he is doing. If I shout his name he turns. I have a voice I use when I talk to him and he always turns to me".

6.3.2.6. Control of own listening

Increasingly interesting was parents' descriptions of their child's ownership of his/her listening requirements and needs. The difference between parental accounts here and those described in the section above (*playing at not hearing)* was above children just carried on with whatever they were doing, effectively placing the speech coming through the FM system in the background. However in the current section children specifically requested or gave an indication for the FM to be switched off or on, or for the settings to remain the same. As one mother describes when her daughter was comfortable with the FM settings and she tried to adjust the volume, he daughter clearly voiced her disapproval of this.

P1: "Plugged into car DVD player – [child] said 'no' when I tried to alter volume on it".

One mother explained how her daughter would physically take the FM device off of her and give it to her grandmother when she left her child there.

P4: "I'm not sure if she knew what it was but she was aware of it, because I would be taking her to my mum's in the morning and she would come to me and unclip it off me and go and give it to my mum"

Others described how if the FM was not on the child would tell the parent to switch the FM on.

P6: "After a while he started pointing to his hearing aids because he wanted them in and then he started pointing to the FM. So he would get me to use that... [My son] has started asking for the FM, which tells me that he gets benefit from it".

P7: "If I didn't have the FM on she would point at her hearing aid and say "Mummy can't hear" to let me know she wanted the FM on".

In the same context of child's ownership of his or her own listening requirement one mother described how her child would specifically ask for the FM to be switched off if he did not want it on.

P2: "as he has got a little bit older and he will tell us 'oh, I don't want you to wear that' and we have noticed we don't wear it as much but it still benefits him because we are using it when he wants us to use it, he is very aware of it. He knows if you have got *it on or if you haven't got it on and he will point to it and he will go like that if he doesn't want you to have it on".*

For one child the mother described her son's reaction was to remove his hearing aids, if he did not want to listen to what was coming through the FM device.

P6: "He loves me talking to him but only if I am not disturbing him, like if he is watching Mr. Tumble. If I answer the phone with the FM on, he pulls his hearing aids out or if I have an adult conversation".

On a similar note parents also described how their child's behaviour would enable them to make the decision that their child did not want the FM in a particular situation.

P4: "When playing with other children, didn't want to listen".

P2: "If he is playing no. And the nursery found that as well. If he was off playing inside with all the other children they tended not to have it on, because they found that he wasn't interacting with other kids, not that he wasn't interacting but I think he probably thought oh I can hear what the nursery nurses are saying and he couldn't concentrate on anything else, because he could hear the person who is wearing it in the background you see. So although it is good I suppose when they are really young because they are picking up lots of incidental hearing, but when they are trying to build relationships and friendships with other children. I know they are just playing together at this age, they are still listening to each other aren't they – I suppose it is just getting that balance really".

The above two themes (*playing at not hearing* and *control of own listening*) address a common concern posed by professionals worried about the over use or misuse of FM technology. Parents clearly expressed their child's ability to decide when and where they did not want the FM to be used. Parents also reflected on the times where their child just carried on with the task at hand or chose to play at not being able to hear in the presence of a speech signal through the FM device, identifying children's ability to selectively not listen to the FM input. Likewise, parents were able to effectively judge when their child did not want the FM on based on the child's responses, even if the child did not expressly object to the use of FM. This emphasises both, children's ability to control their own listening environment and parents' ability to effectively determine when the child did not want the FM device on. As described, children as young as 15 months were able to make informed decisions about their listening choices with an FM device on a regular basis. In theory, very little or no acknowledgement has been given to really young children being able to make these subjective choices with early FM use. Although, parents did feel children were very good at being able to express their listening choice, they also acknowledged if the child was occupied and surrounded by company they may not communicate their choices as clearly. However, in these situations parents were quick to realise their child's listening needs and adjust the use of the FM accordingly.

6.3.2.7. Concentration and focus

The skill of listening is underpinned by the development of focussing and attention strategies. In children, listening development has a clear progression as the skill of focussing on an auditory stimulus grows. Carr (1997) proposed five stages of attention control. The first stage, *disengaged* relates to children around 12 months of age and under where children have very fleeting attention control and exhibit extreme distractibility. In the next two stages *single-channelled* and *spontaneous*, children can focus on one thing at a time. At this stage the child takes increasing control over their attention focus but still alternates between engaging in a task and listening. The final two stages of dual-channelled and integrated attention develop at four,-five and six years of age respectively. Of the five children with established FM use in this study, four children ranged from 15 months at the start to 30 months at the end of the study. The fifth was older and started at 32 months and ended at 38 months of age. As such these children's attention skills would be expected to relate to the second and third stages. However, taking the hearing loss into consideration it can be expected that some children may still have been in the first stage of attention control. The mothers of the four children aged between 15-30 months clearly recognised the benefits of the FM system in improving focus on an auditory stimulus. Whilst the FM was in use, parents felt that their child was more focussed and had an increased concentration span. The mother of the child of 15 months described auditory behaviours associated with FM use which indicated the child's progression from being disengaged to focussing on a single auditory stimulus.

P6: "I took him upstairs for his afternoon nap using the FM. He lay listening to me read to him. He usually just fidgets when he is upstairs but he lay still, then I put him in his cot".

P6: "Yes, he would never usually sit for long and listen to a story. Now he always gets me a book at night and wants me to read to him".

P6: "Singing together and with [sister]. He sat nicely listening and watching the actions".

Similarly, the mothers of the three children aged between 17-30 months, noticed a direct improvement in auditory focus which they related to FM use with auditory related tasks such as listening to books being read, watching the television and joining in singing.

P1: "Watches TV more intently when attached... sat watching TV longer, was still... When using in car DVD [my daughter] loved it and smiled more and laughed at Peppa".

P2: "Loves books, singing, even watching TV now".

P4: "When the room was quiet, listening to stories, [my daughter] followed the story from start to finish".

Although, it would be expected that the ability to concentrate and focus would progressively develop with maturational changes in the central nervous system (Shaffer, 1995), the mother's above recognised a more immediate change in children's concentration associated with the use of an FM system. By providing a stronger more clear auditory signal through the FM, children were able to maintain better focus and attention to the signal, something positively received by the mothers. As such, the introduction of the FM did provide an identifiable improvement in attention control for this group of children.

6.3.2.8. Overhearing

Overhearing, allows children access to speech that is not directly addressed to them, providing opportunities for incidental/passive/casual listening and learning (Ling, 2002). Developmental psychology research points to approximately 90% of young children's knowledge of spoken language being acquired incidentally (Cole & Flexer, 2011). Akhtar et al. (2001) found the ability to attend and learn novel words from non directed speech was evident in children as young as two years of age. The experimental context of their study was limited in that children had little distraction during their task, unlike everyday contexts where there is likely to be more than one event competing for a young child's attention. Akhtar (2005) conducted a follow up study which included experimental tasks involving children being occupied in an engaging activity. Her findings demonstrated that children as young as 22 months were equally good at acquiring new words through overhearing when engaged in another activity as when there was nothing to distract them. More recently, Floor and Akhtar (2006) found children as young as 16 months of age were able to learn new words whilst distracted, through overhearing speech without any form of language scaffolding. Unfortunately, hearing aided children have reduced overhearing potential compared to their hearing counterparts. However, parents and users in our study reported increased instances of overhearing taking place with the use of FM system. Parents and users found children copying and learning new words not intended for them and identified this to be a direct result of FM use.

> *Nursery: "[Child] responded well all afternoon with the radio aid, even copying a member of staff saying 'Zak"'.*

P2: "[My son] knows when I'm not talking to him. For example, he may be playing and I may be talking on the phone. I think it's good for him to hear incidental conversations! Sometimes he hears a word he is familiar with and starts saying it then I realise he's listening into my conversation".

P4: "I was telling my eldest daughter off whilst driving to school when from the back seat [child] said 'Shut up, shut up'".

P6: "He was shouting at the football match after I shouted. It was sounding like [eldest sibling name]. At one point it sounded like he said 'kick it'".

For overhearing to take place children need access to intelligible speech over distances, as a result the improvement in distance hearing provided by the use of an FM system highlights the opportunities for overhearing that children with hearing aids can potentially access.

6.3.3. Language

Many references of receptive language have been included in the above themes and this particular theme follows on and focuses on parents reflections on their perceived impact of FM use on children's expressive language. The development of language typically follows a known developmental trajectory, thus it would be expected that children in the study would demonstrate improvements in their overall language abilities over the duration of the study. However, parents and nursery staff's reflections described improvements that they directly associated with FM use.

6.3.3.1. Copying

Many parents and nursery staff described the children's improved ability to copy words and phrases when the FM was in use

Nursery: "He sat having one to one with [nursery staff name] looking at a picture book and copying words [nursery staff name] said. He did very well".

P5: "She now copies words said by us and remembers them in the correct situation".

However what was more interesting was parent's ability to recognise a clear improvement in accuracy and clarity. The improved auditory and linguistic access provided through FM use was acknowledged by parents who felt FM use resulted in increased accuracy and clarity in their child's language.

P1: "Attempting to copy more now and says 'Come here'... Tries to copy more accurately".

P4: "When started talking, smiled at me immediately. Copied phrases. [My daughter] seems to be copying words more, her nursery rhymes are sounding clearer too".

Although the above comments were more general, parents and staff at nursery also reflected on more specific instances of copying, for example during joint shared attention of other objects. Staff at the nursery noted the child's ability to attempt copying sounds whilst reading a book.

Nursery: "When reading a book 1:1, staff showed [child] picture of a snake and made a 'hissing' noise and snake movement with finger. [Child] copied hand gesture and tried to copy the noise".

In a similar manner, the following mother reflects on how she and her child were able to communicate at night and how her child attempted to copy the name of the object they had shared attention of.

P6: "At night when it was just me and him. He likes stars. He was looking at a star and making hand movements to sing, so we sang, then he kept pointing to the star. I was saying it and he was trying to copy".

6.3.3.2. Speech

The perception of improved accuracy and clarity of speech was noted by parents under the current theme of overall improvements in expressive language. In particular the mothers of the three children whose language scores identified them to be in the 'at risk' category (Chapter 5.3.3) for their age group, were more clear and regular in their diary entries in recognising their child's speech improvement. Two of the mothers noticed a clear improvement in the number of words developing and the pronunciation of words.

P4: "Definite improvement. [My daughter] is putting words together and is copying all the time... [My daughter] is developing more spoken language now... [My daughter] range of vocabulary is expanding daily. Every day she says something new, be it either spontaneous or copying".

P1: "Speech becoming more pronounced... Intonation better... Starting to pronounce sounds more clearly... Starting to pronounce more words correctly, more words coming... Developing more words... More words forming".

The third mother of the youngest of the three described the child being more conversational and talkative with the FM.

P6: "Yes it feels like I can have a conversation with him – he looks at me when I talk to him and nods his head... Just more conversation, babbling... While we were out shopping, he was more talkative, pointing at things and trying to say the word, e.g. ball".

All the above three children made significant improvements in their language scores within a few months of consistent FM use and made month by month gains in language age. However improvements in speech was not restricted to above three children but was also noted by parents of children who were progressing at normal developmental levels of language.

P2: "Yes, his speech is much clearer... Speaks much clearer! Words he already uses are pronounced very clear "Hiya", "Bye", "[sister's name]", "Mama"... Yes he talks much clearer and is understanding much more... [My son]'s words are getting much clearer... He seems to be learning more and more new words... Yes, his speech is getting clearer and clearer!"

P5: "Yes, she recognises more words and speaks baby language in a conversational manner".

6.3.4. Well being

The significance of well being and quality of life has been given great importance in psychology (Fredrickson & Joiner, 2002), social care (NEF, 2009) and the health sector (NICE, 2010). Well being has been defined as "positive and sustainable characteristics which enable individuals and organisations to thrive and flourish" (www.cambridgewellbeing.org). Likewise, quality of life has been defined as "The degree to which a person enjoys the important possibilities of his or her life" (www.utoronto.ca). Based on the above two definitions parents' narratives and reflections described many such accounts where the FM provided positive and sustainable opportunities for the child to 'thrive and flourish' and provided 'important possibilities for the child's development'. Many of these possibilities have been described in detail previously however parents did also identify positive emotional and social changes in their children with FM use.

6.3.4.1. Emotional

Positive emotions broaden the scope of attention and cognition and by consequence initiate an increase in emotional well being (Fredrickson and Joiner, 2002). Parents associate many positive emotions within their child with the use of FM. Diaries regularly noted children's positive emotions of "enjoyment", "being happier", "laughing", "smiling more" and of children "loving" the use of the FM device. Although parents and nursery staff noted these positive emotions as a result of children enjoying the access to speech and listening through the FM, other positive emotions were also recognised by mothers. One mother reflected on how she felt her child just seemed calmer and more comforted as a result of being able to hear her voice in the car.

> *P6: "I am starting to see the benefit of using the FM more now and [my son] enjoys it... He left his aids in whilst in the car, something he doesn't do often. He seemed more calm and comforted".*

Likewise, another mother recognised the possibility that the use of an FM resulted in an increase in her child's confidence.

> *P2: "He loves interacting. It's almost given him more confidence, if that's possible for [my son]!! Really confident and vocalising lots".*

6.3.4.2. Social

Three of the four parents whose children attended regular pre-school noted how staff noticed an improvement in the child's ability to engage in activities and join in more at nursery. "*Joining in more*" was a consistent theme in various activities noted down in the diary kept by the nursery.

> *Nursery: "[Child] responded well to the activity. [Child] was sat the furthest away from the staff and he was interacting and joining in with the actions that were being sung".*

Similarly, for children whose nursery staff did not keep a weekly observational diary they would mention this benefit to the parent.

P1: "Joins in more at nursery, doing more nursery rhymes now – loves singing and dancing".

The concept of "joining in" i.e. connecting with one's environment and a sense of social belonging with friends and classmates is an important measure of quality of life. One child was noted to not join in singing activities and furthermore would sit outside her circle of classmates and watch the activities going on in the circle from a distance. With the introduction of an FM device the nursery staff noticed an immediate engagement and involvement in the activity from the child and informed the mother of this.

P4: "At the nursery [my daughter] never joins in with singing. She never sits in the circle just stands and watches from a distance. She sat next to her key worker who was wearing the microphone and joined in".

Although, during monthly visits regular explanations were provided by the mother regarding her child's natural characteristics of being the "*quiet type*" and being more of an "*observer*", it was striking to see whatever barriers were present for this young child seemed to disappear with the introduction of the FM device. On that note, the increased engagement in activities was not just limited to the nursery setting. Two mothers explained how their children would use the FM device as a form of 'security blanket' allowing them to explore their surroundings and engage in activities in play centres which they would not usually do prior to the use of the FM.

P1: "At play centres its very noise a lot of children shouting so [my daughter] was struggling whereas with the FM she can hear me even though she can't necessarily always see me which means she's a bit more confident at playing on her own or playing *with the other children there doing the activities or whatever they have knowing that she can hear mum if she needs to whereas before she would be constantly looking for me. She was very clingy at the beginning because of that and she has got better with the FM because she knows she can still hear me I don't necessarily have to be in view all the time".*

P2: "I suppose it gave him a little bit of like security as well because he could hear me all the time. If we went out to a play place or whatever, because he can't hear a long way around him, if I was sat at a table and he was in the box or ball pool he could still hear that I was about, and I suppose that gave him a little bit of security when we went out to play centres and things. More for his confidence really not for his listening and speech"

6.3.4.3. Safety

As part of the child's well being and quality of life the importance of child safety is paramount. Parents and nursery staff reflected on the FM device being able to provide improved safety for the child. One mother explained how the basic act of trying to speak with her hearing aided child in the back seat whilst she was driving could be potentially very dangerous. For this mother, the act of trying to get her daughters attention or interact with her in the car was compromised and unsafe if she did not have the FM device on.

P7: "It meant that I didn't have to look at her, both really we didn't have to have eye to eye contact, like in the car really it's dangerous to turn round and look at her, so for me personally it was a lot easier so I could speak to her and she could still hear me and we could still chat rather than me and when I say [daughter's name] – when I say it like that (quietly) my voice wouldn't reach her, but with the FM it made it a lot clearer and it was easier for [my daughter] to have a conversation with me in the car".

Another mother highlighted horse riding as a potentially dangerous situation where the need for good clear communication was required to maintain her daughter's attention and alert her to any dangers.

P4: "Obviously there are horses around. There are dangers, and I shout [daughter's name] and she will turn round instantly and a lot of people at the stables have commented – 'how can she hear you from that distance', and then I obviously explain what we are doing so other people notice how responsive she is using it. Just generally being outside, the distances you can get, just by saying [daughter's name] and she will turn round and they all notice it here as well".

Not dissimilar, nursery identified using the FM system to alert the child of potential hazards when outdoors playing.

Nursery: "This morning [child] responded well to his radio aid well when playing outside. When children were going towards him on bikes staff were able to warn him".

6.3.4.4. Parents and users

The use of FM technology was not just seen as a tool to benefit the child and to improve their well being, but many parents explained how the use of the FM device generated positive feelings in them also. The benefits of the FM were perceived as mutual and mothers and nursery staff were able to explain this two way benefit.

P6: "Yes, there was definitely a difference. He was looking at me while I was talking to him while he was about 3-4 metres away from me. It was great for me and for him. Also if I am busy doing something else the odd word while he is playing really contributes. I found it really useful because I knew he could hear me all the time. It made me feel comfortable".

P7: "It has just improved her life as well and mine as well to the point that I don't have to shout any more".

Nursery: "[Child] was near the door in the 1-2's room and I was near to the fence. I asked [child] to come away from the door and [child] responded by moving and smiling at me [staff name]. The radio aid (FM system) proves very useful!"

Furthermore, the positive shared interactions were a source of encouragement for parents who explained the child's improvements motivated them to make more use of the FM device.

P2: "I suppose just seeing how much he came on with it, you know just every day he was like getting better and he seemed now, he is just over 2, and he seems to have really turned a corner, it is like as though language has just clicked with him... I think he gets frustrated when he doesn't know what you mean or he hasn't quite heard you or something. Just seeing him come on made me want to use it more with him".

For one parent of a young child the motivation of wanting to use the FM resulted in the parent wanting to increase her son's use of his hearing aids.

P6: "Using the FM makes me feel motivated to put his hearing aids in more often".

6.3.5. Engagement with technology

Madell (2011) explains how hearing aided children's ability to use audition to develop spoken language relies mainly on parents buying into the technology. For parents to engage with the technology they need to believe the technology will help. The parents who made regular use of the FM technology did identify the benefit of FM use and were able to provide positive feedback. Based on the *broaden and build* theory (Fredrickson, 1998, 2001), positive emotions *broaden* individuals thought action repertoire's encouraging them to discover novel lines of thought or actions. In the case of FM device use the positive emotions perceived by parents resulted in an increase in their personal resources i.e. parents and users were able to increase their knowledge and experience of FM device use and build on their skills to identify different patterns of use. As such, parents and users were able to engage with the technology and through their own experiences create a sense of ownership where they were able to establish for themselves their preferred system of using the FM device.

6.3.5.1. Identifying-establishing preferred use

Establishing and identifying preferred use of the FM system was something all parents and staff using the FM device were able to draw upon. One mother explains how the nursery staff had decided on their preferred use of the FM device after a period of general use.

> *P1: "they (nursery) have identified set times now when they use it, at first they were just using it generally but now they have specific times. They do circle time and they want her to be able to hear so they use it at that specific time every day, and then in an afternoon they do story time, so those specific times that is when they use it. That seems to work really well".*

Similarly, one mother explains how in the beginning she felt the constant use of FM was of benefit but how this gradually changed over the duration of the study. She was able to draw upon her own and her son's experiences and feedback to establish her child's current needs and acknowledge how this was not a set system but something that could change in the future depending and drawing upon her experiences and feedback from the child at the time.

> *P2: "I still think that if anything he benefited at the beginning using it constantly because it got him used to it and then I suppose he realised when it was on and when it wasn't, wearing it at a specific point in the day is better than just having it clipped on the whole time because you do forget about it then and it is not fair on him really because he is obviously listening. It has been like a whole new learning streak for all of us because obviously at first we thought what was the best thing, and it was the best thing when we first got it, when he was just one, that was the best thing to wear it all the time but now it isn't, because he has got to learn the difference with the priorities*

that he has got. When he is 3 he might not want it on all the time. It will be something that will just go with time".

The reduction in FM use was not seen as a negative factor but something positive that was a result of both parent and child having full ownership of the device and discovering between themselves novel lines of action for the use of the FM device. In contrast another mother expressed her method of establishing preferred use of the FM device was to keep the FM with her at all times. However, like other parents she was then able to draw upon her experiences and use these to decide whether she would use it or not.

P7: "I used it every single day, there wasn't a day we didn't use it. I took it everywhere with us and if I didn't use it I just muted it. If I didn't feel the need to use it I just turned it off but wherever we went it came with us".

6.3.5.2. Child understanding FM function

Children also engaged with the FM technology. Many of them were able to recognise the function of the FM transmitter being a means of accessing the voice of the speaker directly in their hearing aids. Many mothers described how their child would talk down the microphone and listen to their own sounds.

P6: "[My son] was sat on my knee in the morning. He kept taking the microphone off my top and trying to clip it on his own top. He was talking down the microphone, then passing it to me. He played with it for at least half an hour".

P7: "When I turned it on I would say can you hear me and she would say yes mummy, but just recently she has started cuddling it to herself and saying mummy can you hear me. So she understands what it is for and the use for it, and she can hear mummy in her ear so it has been really good".

P1: "I put the FM system on [my daughter] and she talked down it, which she found quite funny, plus she could hear her footsteps harder and kept running".

P2: "Yes, he keeps trying to talk down the microphone of the FM".

One mother further described how on another occasion her son would use the FM on his talking toy and appreciate how the sound from the toy was able to transmit to his hearing aid via the FM.

P6: "Today I was playing with his talking Elmo. [My son] was pointing to his hearing aids, so I clipped the FM on to Elmo. [My son] loved it, he was smiling and really pointing to his aids. When he was fed up with him he took the clip off Elmo and put it back on me".

6.3.5.3. Increased use of hearing aids

Engagement with technology was not limited to FM technology but two parents described an increased use an engagement with hearing aid technology as a result of FM use. For one mother in particular the increased consistency of hearing aid use was a very strong theme. At the start of the study her son was 15 months old and there were some concerns on whether the child had established hearing aid use or not. This was cited by ToD's as one possible reason to not include the family in the study. Other family commitments were also reported as a possible reason for participation being difficult for this family. In the end it was decided to let the mother make the decision. The mother opted into the study and immediately after fitting the FM system the mother noticed an increase in hearing aid use:

P6: "After Day one, [my son] seems to be keeping his hearing aids in more. It was the first time he has ever kept his hearing aids in whilst in the car, he fell asleep. It was reassuring for me as well knowing I could sing to him whilst he was asleep"

P6: "He enjoys wearing his hearing aids for longer periods of time"

P6: "Yes. He kept his aids in and we walked to the park with him with his FM on and he kept his aids in, and he looks at me when I say something... He keeps his hearing aids in while we are out when I am using the FM".

A large number of diary entries for this mother were focussed on the increased consistency of hearing aid use and even after the six month study period the mother highlighted the importance of this issue in the interview.

P6: "he has always gone through stages pulling them out and then when we got the FM he started leaving them in".

The second mother who noted an increase in consistency of hearing aid use was at the initial visit visibly upset with mould troubles and the fact that her daughter was not keeping her aids in. She was also told that her daughter was on the border line for her current model but that she may require power aids which were a larger model. This was a very sensitive issue for the mother who preferred to stick with the smaller model. At the time the mother was in a dilemma as the child's hearing loss was border line and although she wanted to stick to the smaller model she did not want to potentially compromise any hearing benefit. Once the mother started using the FM she noticed significant improvements in her child's overall listening and development as has been highlighted in comments related to P4 previously. Also not only was her daughter keeping her aids in more but she had begun to start requesting for them.

P4: "[My daughter] has begun to ask for her hearing aids to be put in now".

For the two younger children the concept of inconsistent hearing aid use and age were seen as barriers to FM use discussed in more detail below. The use of the FM device for these two children was very minimal so it was difficult to determine the possibility of increased HA use for these children. The parents of the other three children had established hearing aid use in all situations and as a result this topic was not discussed by them.

6.3.6. Practicalities associated with FM technology

As with any new technology, practical issues related to the device use and functions would be expected. In that respect parents did discuss ease of use, barriers to using the FM device, daily management, practical problems and finally challenges associated with FM use.

6.3.6.1. Ease of use

Surprisingly, one theme that was consistent with all parents regardless of established use or not was how easy the technology was to use.

P4: "No problem at all, I think it is really very straightforward".

P1: "In terms of the usability it was very easy and we could put the lock on, and it wasn't too hard for her either".

P6: "its fine ... I don't think there were any challenges. I found it really easy to use".

P3: "It was easy enough to use... It was fairly easy, quite self-explanatory, you know the up and down and obviously the soundcheck".

Some parents likened the FM transmitter to a mobile phone and as a result felt the size and functions were easy to deal with and manage.

P7: "Fine. Actually it was just like having a little mobile phone fitted on your belt, it was tiny so you didn't know you had it on".

P5: "Yes, straight away, same as mobile phones, so it is not too hard... it was quite easy"

Nursery, also described how overtime different staff got used to the FM device and were confident in using it.

Nursery: "Head of room is on holiday but the other staff in the room are much more confident with it now".

6.3.6.2. Barriers to FM use

Although the actual device was described as easy to use, mainly the mothers of the two children (P3 and P5) who did not make consistent use of the FM device described a range of factors that lead to the inconsistent use. In summary, the parents explained any factor that would lead to the hearing aids not being used as a barrier to FM use. This included ear moulds not fitting properly, ear infections and also the child not keeping the hearing aids in the ear.

P3: "[My son] started with an ear infection on the Sunday so we haven't used it since... Not used as [my son] isn't keeping aids in long enough, only 10 minutes at a time as ear moulds are too small... I would say especially with [my son], the problems we have had is with earmoulds, getting them back to us quick enough, they have been taking 2 or 3 weeks by which point he will wear them for about a week and then they will be too small again".

P5: "Nothing major – it was just to do with actually wearing the hearing aids. We couldn't use it if she wasn't using the hearing aids, she was pulling them out and the moulds wouldn't fit, her ears grow so the moulds need changing every 3 or 4 weeks and the process of that takes a bit of time so she wouldn't wear the hearing aids for a couple of weeks or she will wear them for a minute or two and then take them out, so we will turn the FM on to use it but the moulds will be out in the next 5 minutes so we wouldn't get the proper use out of it".

The same parents also felt the age of the child (both children 11 months at the start of the study) played a significant part in their limited use of the FM. One mother described her reasons for why she felt age was an issue for her son.

P3: "He is still at that stage, and obviously being so young he falls asleep a lot. We have used it in the pushchair as well but again it is a similar thing, depending on what time of day he very often falls asleep. I think being such a young age obviously he is only saying odd words at the moment, and probably in the car was the same. I just think that because of his age it would have been better in say another 6 months or 12 months, then definitely it would be a lot more beneficial. He was 11 months. I just think at that age I don't think, other people might find it different, but I just feel that as he gets older and his language improves and then places like in the pushchair he can point things out and say mummy what's that over there and he will be able to hear your response much clearer, whereas at the moment quite often in the pushchair or in the car he just sits and he is just busy looking and watching but yes, yes, I will definitely think it will be useful".

The parents of the second child also identified age as a reason in their non use of FM but felt the age of the child was one factor in a combination of factors for which barriers to the use of the FM device existed.

P5: "At the time more her age and the moulds going, and her not wearing the hearing aids – that would be the main thing that would stop us and sometimes she would keep the aids in and then take the aids out after a minute or two and we would think what's the use".

One mother, who had established FM use with her child, described how for her a barrier to extended FM use was getting others to use the FM device. The mother consistently made reference of this in the weekly diaries and the topic held a lot of importance for her.

P4: "I think my main challenge was getting other people to use it... People like carers, my mum, [husband's] mum, getting them to use it... Getting other people to use it and getting other people to use it appropriately... She has moved into a new class who aren't familiar with her aids yet"

However overtime there was an improvement as demonstrated by comments during the interview.

P4: "the nursery were very good at using it and they also found it extremely useful",
Researcher: "*So how did you find that with the grandparents, have they managed to get used to it*".

P4: "Yes they have, yes".

For other mothers the use of FM by the extended family was not a significant topic and diary references for some parents pointed to various people making use of the FM.

P2: "It works really well whenever I wear it or others".

P1: "My 3¾ year old son can use the system effectively".

P6: "It was good when [eldest sibling] used it today... [child] knew it was different. I let [second eldest sibling] wear the FM whilst he reads a book... Yes, when [eldest sibling] wore the FM [child] really enjoyed it. He was really excited".

6.3.6.3. Daily management

Similar to ease of use all parents were confident and comfortable with the daily management associated with the FM device. Parents were able to describe their own daily routines.

P2: "Mainly in the evening actually just to plug in to charge it, it needs charging every day, so basically it is just, you know, if someone hasn't got the FM on then obviously one of us will check that it has been put for recharging. When I get back from nursery on a Wednesday, Thursday or Friday, because I will have had it on in the car, I tend to just take it off and plug it straight back in".

P4: "Charging it. It was charged every night and then just did sound checks every morning".

Even the mother who had limited use of the FM was able to recall her daily management for when she had used it.

P3: "Mostly to check that it was charged up. I switched it on then I did a sound check to obviously check the sound. A couple of times I would have to redo it depending where I was. Then I used to lock it obviously because it was usually in my pocket. That was it really, and generally check that everything was still attached and not been pulled off".

One mother whilst describing the routines associated with the FM device also identified a difference in daily hearing aid management.

P7: "With the hearing aids the batteries needed to be changed a lot more often than without the FM. I just checked that it was switched on and checked that the receivers were on but that is it really there wasn't much to do. I had to check the receivers were being received by that, just checking basically that [my daughter] could hear me, just listening to it, just simple really, nothing hard. I charge it up every night, just plug it in and leave it every night".

All parents were confident with making use of features such as sound check and a few parents were able to access further options on the menu. Three of the parents described how they were able to make use of the FM direct link with the TV and mp3 option.

P1: "If have a twin screen DVD player for the car, can attach FM individually – [my daughter] and her brother could both enjoy a DVD... it was easy to change (channels) back and it was good that it showed me how to put in the MP3 because I tried to do it and it was easy, it showed me where it was on the software so that is better".

P5: "I found the wire which connected to the audio device was quite useful and we connected it to the TV, and it works absolutely fine. The volume is done by the TV as well so we can use that"

P4: "Although we have now got the system working on the TV, I find it hard to tell if it is of any benefit to her as she just sits and watches the TV. She joins in with songs she knows on the TV so I'm sure it is of benefit".

Two of the mothers described how they were able to manually change the channels on the transmitter/receiver.

P1: "It had gone off channel to HO3 – managed to change back and reschedule".

P6: Just when we were at the group because there was another woman who had the same channel so I felt more comfortable turning it off because I didn't want her child to hear me but then you showed me how to change it.

6.3.6.4. Challenges and faults

With extended use of the FM many parents did find challenges and faults did arise. Although two families did not mention repairs required in their diaries or interviews, their FM transmitter did require sending back to manufacturers for repair. One transmitter had to be sent back more than once. Another child's receiver on the aid needed replacing but again there was no mention of this in the parent's diaries or interviews. It seemed parents just accepted basic repairs and faults would arise with daily use in the same way as it does with hearing aids. However, parents did reflect and identify problems associated with the design of the device. Parents regularly found the back clips of the transmitter were unstable and increased use would at times lead to it unscrewing and falling off.

P6: "It just keeps unscrewing at the back (the clip)"

P1: "Yes, the clip keeps coming away from the FM. It keeps undoing at the back".

P2: "It is fine apart from the clip keep breaking. It did keep falling off a lot. When you have it on and it keeps twizzing round, it comes off, the back clip"

Similarly, mothers also described how the microphone positioning was not always easy and how this was highly dependent on the type of clothing worn at the time.

P1: "The microphone turns over when used with light clothing. The wire could do with coming out more in the middle... the clip and wire on the microphone fit better with mic to skin".

P6: "It's fine except on certain items of clothing, you know when it doesn't hook on or the microphone isn't in the right place. That was the only thing. You just adjust to that".

One mother explained how at times she would find the positioning of the microphone difficult as she regularly wore a scarf.

P5: "I found it difficult with the clothes, I wear a scarf".

Two mothers described incidents of interference. What was surprising was only these two instances of interference were commented on in the diaries and no mention was made during interviews even though interference is normally seen as a regular limitation with FM devices. One mother described how she noticed interference coming through the hearing aids.

P7: "I noticed some interference in [my daughter's] aids (crackling noises). This didn't seem to bother [my daughter] which surprised me as it was quite loud".

The lack of mention of interference by parents may be a result of parents not noticing any interference that may have occurred and therefore were not able to note this down or could be evidence of improvements in technology. One other parent did note down troubles with 'interference' when visiting a cochlear implant centre, however the mother's description explained voices coming across the same FM channel rather than white noise interference.

P6: "We went to the Cochlear Implant Centre a couple of months ago. [My son] was having speech therapy and we could hear voices coming through his hearing aids. He kept taking his hearing aids out and throwing them".

This may have been due to university audiology students or technicians from the Ewing Foundation, who both share the same building as the cochlear implant centre, using their FM system at the same time. In this case the mother could have changed the receiver channel through the FM transmitter, or an easier option may have been to switch the program to hearing aid only mode.

Parents did identify remembering to mute the FM device as a challenge with using FM technology. Mothers described how this was something they had to take into consideration.

P4: "Remembering to mute it at the times you are supposed to mute it, if you went into another room, the telephone rang", *P2: "Sometimes I will forget that I will have the radio aid on and [my husband] will have taken [our son] upstairs and will be able to hear the television upstairs in his radio aid, so that sometimes you have to be really careful".*

P1: "Only forgetting you have it on... Just remembering to turn it off"

P5: "Sometimes we forgot to turn it off but then we got used to it"

P6: "When I forgot to turn it off for half an hour!! I was upstairs in the house talking to [partner], my mum was in the car with [my son]. She said [he] went quiet and she could hear me talking through his hearing aids".

The importance of overhearing is critical in language learning however this needs to be balanced with effective use. Parents did not leave the FM system on intentionally and were able to identify isolated incidences and acknowledge the need to be more aware of this challenge. As discussed before between the parent and child on the whole they were able to identify and establish effective FM use.

Another challenge described by parents of the three youngest children (11-15 months) was their child would pull at the microphone when the parents had the FM on.

P5: "if I was holding [my daughter] she would pull on the wire so that would come off sometimes and she would pull off the mic".

P6: "sometimes when he came to sit on my knee he would pull at the microphone and try and put it in his mouth".

P3: "I had a couple of problems, only the fact that if he saw it on me he wanted to mess with it so I had to try and sneak it in my pocket or... I did find the clip used to untwist itself and sometimes fall off so I would actually put it in my pocket or obviously being a woman if you are wearing a dress you would have to wear it round your neck, which is a bit awkward because he would try and grab onto it".

6.3.6.5. Advice to other parents

In conclusion at the end of the interviews, on a practical note parents were asked what advice they would give to other parents in a similar situation regarding the use of FM technology. Four of the five parents who had made regular use of the FM were very positive and gave strong encouragement towards using the FM device.

P4: "I would say use it. Just use it because it is very advantageous".

P6: "Just to use it as much as they can even if they feel it's not working in one to one. In one to one it does work".

P7: "Go for it. It is just brill. I have never seen anything like it. Considering that she doesn't have to physically wear anything it is a lot easier because children don't like wearing things like that so it is in her ears, she doesn't know, she thinks it is a new hearing aid and she can hear my mummy, so it is just the parent. I just put it in my handbag and put it on me, you don't know it's there. It is really good. I would just say go for it, there is nothing else I can say really".

P1: "Go for it".

The fifth mother was also very positive and encouraging but was more reserved in her advice to others in a similar position.

P2: "Definitely give it a go. It has been brilliant for [my son] but that is not to say it will be great for somebody else. I suppose it depends on the child and also the parents, all different circumstances. Definitely give it a try because you can't say it is going to be beneficial or not until you have tried it".

Surprisingly, even the two parents who did not establish consistent FM use were in favour of using the FM and did share some practical advice which they felt would benefit parents of children at a similar age.

P5: "Be patient and use it when you can use it. Don't get frustrated when you are not using it, and if there is a noisy situation use it there because it will be of benefit".

P3: "just to keep on top of your earmoulds. Just to try and make sure they are regularly fitted, because that has been a major issue anyway. That definitely hasn't helped I think because it was stop, start, stop start with it all overall I think it is worth a go. Yes, definitely worth a try. It will help them with their hearing and speech, so yes"

6.4. Summary of key findings

The primary aim of this study was to qualitatively explore the views and experiences of parents and carers on the use of FM technology with pre-school hearing aided children. The key findings for this study were:

- The improved access to speech FM technology provided was highly valued, especially in situations where the child was not facing parents, for example in the car or pram, in noisy situations, at a distance and when hearing aid microphones were covered.

- Improved listening behaviours in the child were noted when using the FM, including improved attending, locating of FM user, comprehension, improved concentration and reduced listening effort.

- The use of FM technology allowed access to intelligible speech over distances, in noise and more challenging listening situations. This provided more opportunities for overhearing which is important for children to acquire language and learn novel concepts.

- A theme of child control of own listening and FM use as well as parent ability to identify when their child did not want FM device used emerged. A clear sense of ownership and ability to establish preferred use of FM was found. The qualitative feedback from the parent who scored 4 for the FMLEC question “child tries to turn FM system off” reported the child’s behaviour was beneficial as this guided them to use the FM device in situations where their child identified benefit in its use. This contradicts the question’s implicit assumption of a child trying to turn an FM system off as negative behaviour.

- Improvements in language as a result of FM use were reported, with more copying, more accurate intonation and increased clarity of speech being described.

- Improved well being was a strong theme where children were noted to be “loving” the use of FM technology resulting in positive emotions for the children such as “enjoyment”, “being happier”, “laughing” and “smiling more”. Children were also reported to have been calmer and more comforted with FM technology use. An increase in engagement and participation in activities at the child’s nursery and outdoors was also noted with children described to have an increased sense of social belonging. Parents reported children being more confident when parents used the FM device and of children using the technology as a ‘safety blanket’ when engaging in new activities.

- Parent’s of two children who had not established consistent use of their hearing aids found it difficult to introduce FM technology into their regular routines. These parents highlighted age of the child, ear infections, earmould troubles and the child not keeping hearing aids in as reasons for not establishing hearing aid use. However, in contrast two other participants reported how the introduction of FM technology overcame the difficulties associated with the child not keeping hearing aids in. This resulted in an increase in hearing aid use by the child to the extent that the children started requesting their hearing aids. This finding suggests the use of FM technology can help to increase the use of hearing aids in children.

- The technology was reported to have been “easy to use” and parents were able to establish daily FM management routines with ease. The FM transmitter was likened to a simplified ‘mobile phone’ and the advanced features were accessed and used by parents.

- The challenges associated with FM use were described and parents of younger children described how children kept pulling at the microphone wire. More specifically many parents noted how the back-clip of the transmitter kept coming loose pulling the whole back plate off with it. This challenge was more specific to the current model of FM transmitter rather than a more general challenge of FM use.

- Remembering to mute the FM device was also identified by parents as a challenge with using FM technology. Overall parents were able to identify situations where they forgot to mute the FM system and were able to acknowledge the need to be more careful when using the technology.

7. Study 4: Language environment analysis (LENA) with pre-school FM use

7.1. Introduction

The current study was the first UK based study to make use of the LENA technology and the system is still relatively new in the UK. For this reason the current section will detail the background of the LENA technology. Thereafter the following section will describe the methods used in this study. Subsequently, the results for each of the analysis conducted will be presented. The final section will summarise the key findings from this study.

The LENA system's fundamental purpose is to encourage carer-child interaction for very young children. Previously, Hart and Risley's (1995) influential research highlighted the relationship between the amount of adult communication and interaction with children and children's language development and also their IQ's and future success at school and work. A novel method to obtain measures of early speech development through automated analysis of massive quantities of day-long audio recordings collected naturalistically in children's homes forms the basis of the LENA system (Oller et al., 2010). The LENA system uses advanced signal processing strategies to monitor the natural language environment of children. The current recorder can hold up to 16 hours of data and the developers of the system recommend a minimum of 12 hours of recording (Xu et al., 2008). As the signal processing is based on data modelling longer samples provide a more accurate analysis. All sounds in the child's environment are recorded and included in the analysis however as the natural language of a child is highly variable the processing of such data at the micro-level (for example every 5 seconds, 1 minute etc.) can be difficult. Such accuracy is not the purpose of this system but rather the overall quality of the language environment and the general development status of the child are the focus (Oller et al., 2010; Xu et al., 2008b). The main goal of the system is to provide an estimation count at the macro-level (for example per hour or per 12 hour recording) which make it possible to achieve a high standard of analysis. The accuracy and reliability of the analysis has shown high levels of agreement with human transcriptional analysis (Gilkerson et al., 2008; Xu et al., 2009). The system was developed by a team of specialists lead by Professor Oller, University of Memphis. He has been involved in infant vocal development for over 30 years (Oller & Eilers, 1975) and has developed a widely utilised categorisation scheme for early infant sounds (Oller, 2000) as well as conducted extensive research in phonetic transcription and acoustic analysis of infant and child speech (Oller & Griebel, 2008; Oller & Ramsdell, 2006). He is extensively involved in the training of students and professionals in categorisation of speech and speech related vocalisations and in phonetic transcriptions (Oller et al., 2010). Prominent researchers in the field of early language acquisition for children with hearing loss have incorporated the use of the LENA system in their research including, Yoshinaga-Itano (2010), Stremel-Thomas (2010) and Vohr (2010).

7.2. Methods

7.2.1. Participants

Four of the seven participants from the overall longitudinal study were included in this study. P1, P2, P4 and P6 took part in this study and detailed demographic information for each of these participants can be found in Table 3.2 in the general methodology section (Chapter 3). P3 and P5 were excluded from this part of the study as they had not established consistent use of the FM device. The comparison of language environments with FM compared to without FM was an important part of this study and as a result of their difficulties with using their FM technology (infections, ear moulds, non use of hearing aids) they were excluded. P7 was not actively excluded from the study and on two different occasions LENA recordings were attempted. However as the child did not cooperate with the LENA recording procedure it was decided to not include P7 in this study.

7.2.2. Recording device

The LENA digital language processor (DLP; Figure 7.1) is a battery powered all-day recorder weighing less than 60 g that can be securely snapped into the chest pocket of children’s specially designed clothing (www.lenafoundation.org). Naturalistic sampling is initiated by an adult pressing the record button and can be turned off only by holding the record button for several seconds making it child proof. Once in place and fully charged the device records in completely natural environments. The device has a single microphone which remains 7-10 cm from the child's mouth whilst it is in place in the child's chest pocket.

Figure 7.1 LENA digital language processor (DLP).

7.2.3. Recordings

At the beginning of the study, parents were given detailed explanation on the use of the LENA and were shown the DLP, clothes and how to charge and start/stop the recording. Parents understood four recordings were required, with two recordings on days where the parent and child were pre-dominantly at home and two recordings where the parent and child would spend an extended period of time outdoors. For each paired days parents were asked to wear their FM system on one of the days. The FM and non-FM days were randomly allocated to avoid any order effects. Based on these instructions parents were requested to identify specific days where the recording conditions could be as evenly matched as possible. On each of these days the primary carer and the person using the FM system was the mother.

Table 7.1 The age in months (m), duration and recording conditions for the four participants' LENA recordings.

	1st Recording			2nd Recording			3rd Recording			4th Recording		
	Age (m)	Condi-tion	Dura-tion	Age (m)	Condi-tion	Dura-tion	Age (m)	Condi-tion	Dura-tion	Age (m)	Condi-tion	Dura-tion
P1	24	Without FM outdoors	12:14	25	With FM outdoors	12:05	28	Without FM at home	12:15	29	With FM at home	12:20
P2	19	With FM outdoors	12:00	20	Without FM outdoors	12:11	31	With FM at home	12:02	31	Without FM at home	12:35
P4	31	Without FM outdoors	12:03	31	With FM outdoors	12:02	31	With FM at home	12:08	31	Without FM at home	12:15
P6	21	Without FM at home	12:54	22	With FM at home	12:18	22	With FM outdoors	12:47	22	Without FM outdoors	12:36

Table 7.1 describes the order and duration of recordings for each participant. The two recording days to be compared were kept within a maximum of two weeks of each other to avoid any age related effects. Parents were asked to keep a brief hourly diary of the recording days so that the activities for the two days could be compared. Parents were instructed to begin recording when their child woke up in the morning and to ensure a minimum of 12 hours recording was obtained. During recordings parents were instructed to only remove the device during naps and baths but to keep it in as close proximity to the child as possible during these times. For each of the second of the paired recordings parents were instructed to start at a similar time to the first recording and to have it on for a similar duration. Any recording that was not broadly similar for time and duration or the parents recorded very different activities, was not taken for analysis purposes and the recording was repeated.

7.2.4. Software

7.2.4.1. LENA software v3.1.2

The automated language analysis software used for basic recording of data was the LENA Research v3.1.2. This software provides a graphical user interface between the recorded data stored on the recorder and the measures of language environment that are calculated through the pre-set analysis parameters. The recording is transferred via USB cable to the computer and downloaded onto the LENA Research v3.1.2 software. Once the data is downloaded the software begins analysis which can take anywhere between 4-8 hours. The audio recording is analysed through an iterative modelling process which segments data into categorical components including, male and female adult, key child, other child, overlapping speech, noise, electronic noise and silence with a very low inter-unit signal variation (Ford et al., 2008). The analysis produces detailed reports on screen from the full recording including information on adult and child word counts, conversational turn counts, time specific information, audio environment and language specific measures for the key child including estimated mean language utterance. The data is also presented in the form of histograms and can be displayed in month, day, hour and 5 minute segment views (Figure 7.2).

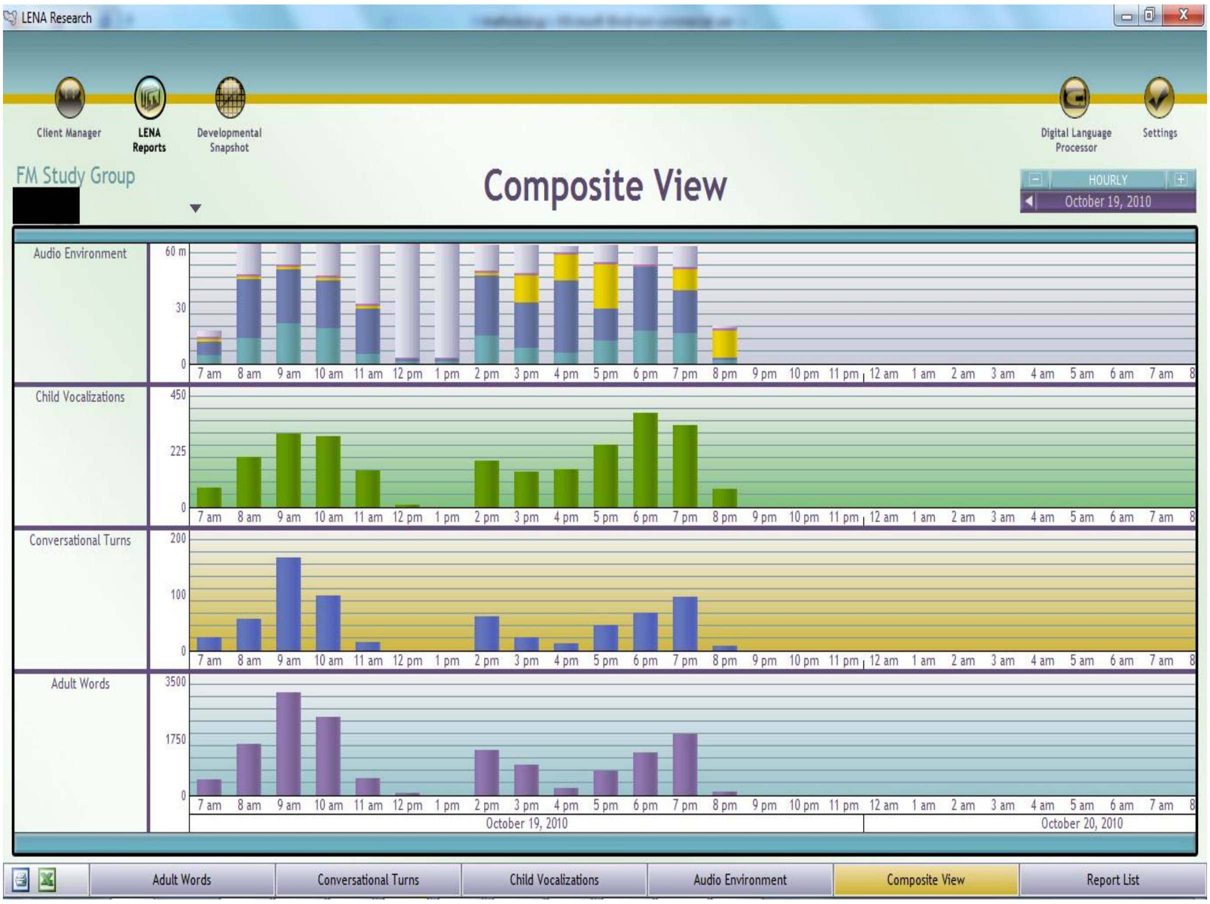


Figure 7.2 Screenshot of composite view on LENA software.

The report list tab (bottom right of Figure 7.2) provides raw counts for adult words, conversational turns and child vocalisations and also has the option for the data to be displayed in percentiles. Gilkerson et al. (2009) provide detailed information on the LENA report count measures. The adult word count (AWC) measures the quantity of adult words spoken to and in the vicinity of the child during the course of the recording day. The measure of language input quantity is that of any adult not just the parent. The software does not differentiate between child directed speech or non directed speech but counts all words spoken near the child. The child vocalisation (CV) count measures the number of meaningful vocalisations made by the child. A child vocalisation is defined as segments of meaningful key child speech of any length surrounded by a vocal break or pause longer than 300 milliseconds or more of non speech or silence. This excludes child non speech and fixed signals like cries or vegetative sounds. The conversational turns (CT) count measures the total number of vocal interactions the key child engages in with an adult. This is defined by the number of times a speaker changes within a single conversation, for example a conversation consisting of child-adult child-adult would be counted as two conversational turns. For a successful conversational turn to take place a vocal sound from the child such as a coo, squeal, babble or word is initiated with a subsequent response by an adult within five seconds, or vice versa. Sounds that do not contribute to the conversational turn count include overlapping speech segments, coughs, cries, and other vegetative and fixed signals.

7.2.4.2. Advanced data extractor (ADEX) software

For more detailed analysis with more focussed parameters on report counts the Advanced Data Extractor (ADEX) software was used (Figure 7.3). The ADEX software is a standalone utility that provides extended access to data from processed audio recording files (.its file: Xu et al., 2008a) that have been exported from the LENA Research software (Gilkerson et al., 2010). The ADEX exports analysed data directly as comma-delimited plain text (.csv) files that can be accessed with widely available spreadsheet software like Microsoft Excel. The ADEX extends the scope of the basic LENA language indices (e.g. Adult Words, Conversational Turns, Key Child Vocalisations) allowing examination for word count data separately for male and female adults and can retrieve data specific to non-key child vocalisations, overlapping speech, TV, noise, silence and more. Furthermore the data can be analysed to pre-filtered output data based on type of speech or interaction allowing for example the export of vocal exchanges specifically between key child and adult female. In addition the ADEX provides a range of selection options, from highly detailed segment level data (ranging from less than one second to a few minutes) to summary views of full recordings (12 hours plus).

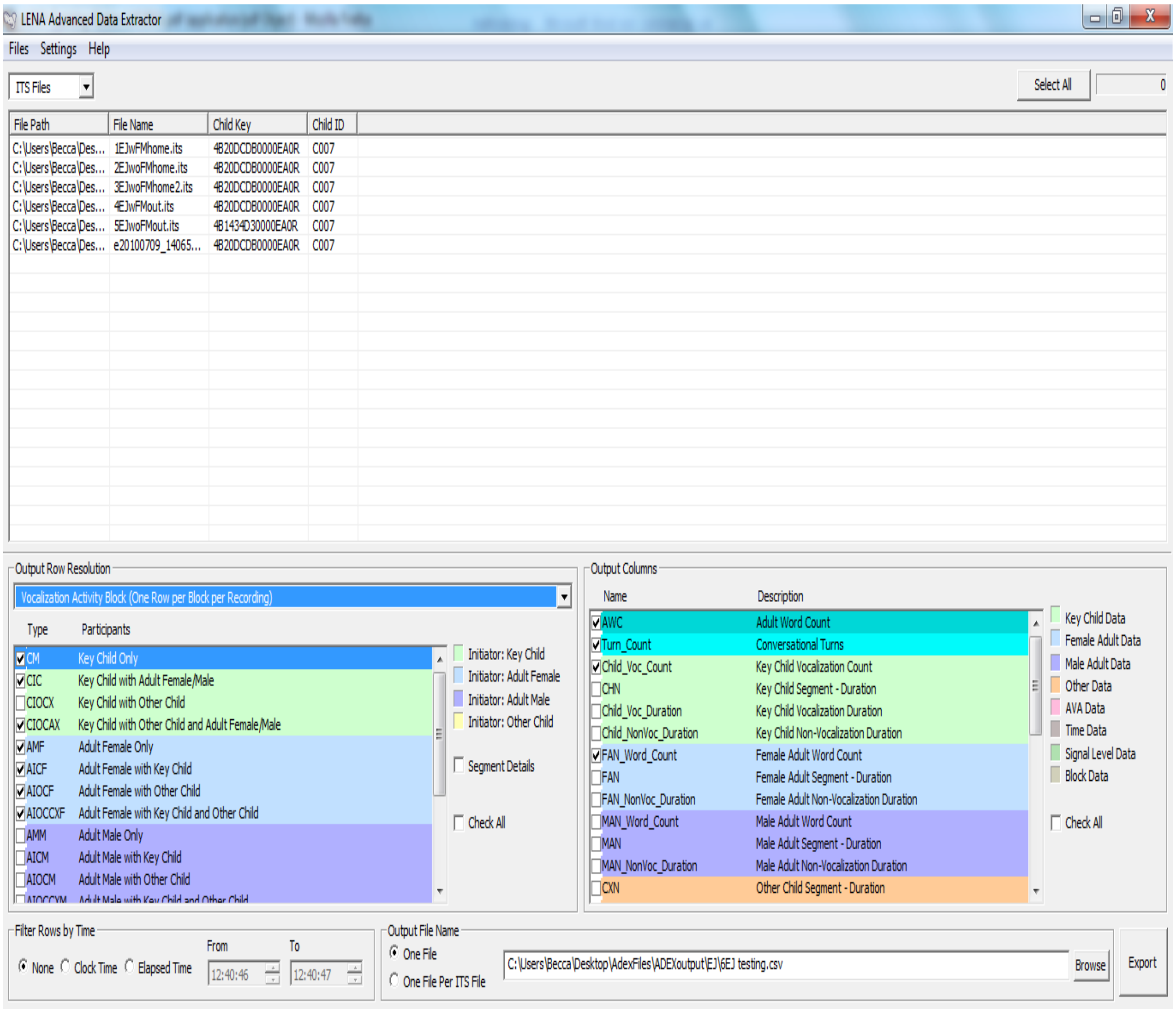


Figure 7.3 Screenshot of ADEX software.

The top half of the screen (Figure 7.3) is dedicated to processed LENA recording files that have been imported into the ADEX software. The left hand side of the bottom half allows for selection of output rows which will determine the amount of data to be used for the advanced analysis. For example, in Figure 7.3 all vocalisation blocks that include information relating to the key child and an adult female have been selected. Although not all the selection options have been captured in the screen shot, some of the selections can be seen. The bottom right half of the screen allows for the selection of the variables of interest. For example in Figure 7.3 Adult Word Counts, Conversational Turns, Key Child Vocalisation Counts and Female Adult Word Count were selected. The bottom right of the screen ‘output file name’ is used to export the analysed data.

7.2.5. Outcome measures and data analysis

7.2.5.1. Comparison of language environment with and without FM

As part of the current study protocol, the vocalisation activity blocks selected for analysis were only those related to the key child i.e. the child participating in the study and female adults. The vocalisation activity blocks selected are described in Table 7.2.

Table 7.2 List of vocalisation activity blocks included and excluded from the ADEX analysis.

Included:	Excluded:
Key Child Only Key Child with Adult Female/Male Key Child with Other Child and Adult Female/Male Adult Female only Adult Female with Key Child Adult Female with Other Child Adult Female with Key Child and Other Child Other Child with Adult Female/Male Other Child with Key Child and Adult Female/Male	Key Child with Other Child Adult Male Only Adult Male with Key Child Adult Male with Other Child Adult Male with Key Child and Other Child Other Child Only Other Child with Key Child

The restriction of vocalisation activity blocks to the ones detailed in Table 7.2 reduced noise by excluding vocalisation blocks related solely to other child or male adult vocalisation activity blocks.

The outcome measures selected from these vocalisation blocks for comparison were

- female adult word count (FAN_word_count),
- key child vocalisations (Child_Voc_Count)

- conversational turns (Turn_Count).

These were the only measures of interest for the purpose of this study as the use and non use of FM systems variable was specific to mother-infant dyads. Based on the defining parameters (Table 7.2) it is expected that some noise would be present for the analysis of female adult word counts as these would include counts from other adult females other than the mother who may be in the vicinity of the child. Similarly, some noise would be expected when measuring conversational turns as the possibility for the conversational turns between ‘adult female’ and ‘other child’ and ‘key child’ and ‘other child’ to be included in the analysis still remained. However, by removing the vocalisation activity blocks related to ‘other child’ that were included in the analysis, would have resulted in removing data related to female adult word counts.

Once data was analysed using the ADEX software, reports for each recording were exported into Microsoft Excel 2007 to calculate total counts for each of the three outcome measures. The totalled counts with and without FM for home and outdoors were compared and bar graphs were used to illustrate any differences. Non parametric related samples Wilcoxin signed rank tests were used to establish any statistical differences between outcome measures with and without FM use. A non parametric test was used due to the small numbers.

7.2.5.2. Comparison of language environment with hearing peers

The percentiles generated by the LENA software v3.1.2 were gathered from a ‘Natural Language Study’ (Gilkerson & Richards, 2008a) using recordings from 329 children between the ages of 2 and 48 months. The children were from mono-lingual English speaking families. Families with children who had been diagnosed with a language or developmental delay or disability were excluded from the original development study, as the data were collected for the purpose of establishing normative information about a typically developing population.

The LENA software v3.1.2 automatically calculated AWC, CT and CV percentiles for each recording taken from the participants in this study. The percentiles for participants’ recordings were compared and bar graphs generated to illustrate any difference. An average percentile for the four recordings was calculated for each participant and was used to compare the AWC's, CT's and CV's for the participants in this study with normative data from their typically developing hearing peers.

7.2.5.3. Characterisation of language/acoustic environments

The audio environment for each recording was analysed by the LENA software v3.1.2. The analysis would break down the audio environment into percentage of time spent in one of five categories: meaningful, distant, TV, noise and silence and background. Table 7.3 provides descriptions for each of the categories and provides detailed 'speaker' ID segments included in each of the categories.

Table 7.3 Descriptions of each acoustic category as analysed by the LENA software (LENA Research v3.1.2)

Acoustic Category	Description	Speaker ID's included
Meaningful	Usable, distinguishable audio that is included in the reported information.	MAN (male adult near), FAN (female adult near), CHN (child near) CXN (other child near)
Distant	Audio typically coming from six or more feet away from the DLP.*	MAF (male far), FAF (female far), CHF (child far), CXF (other child far), OLF (overlap far), OLN (overlap near)
TV	Audio from television, radio and other electronic noise	TVN (TV near)
Noise	Rattles, bumps and other non-human signals	NON (noise near)
Silence and Background	Quiet or vegetative sounds or silence	SIL (silence), NOF (noise far), TVF (TV far)

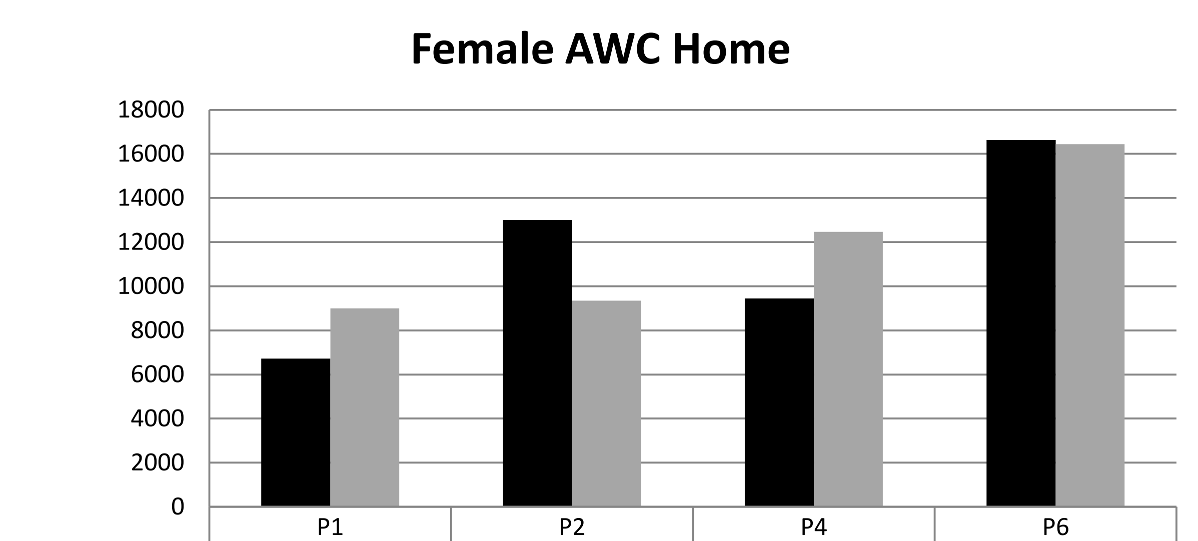
*Speech in the category of Distant Recording is not included when generating report counts

It is important to note the only category that is used by the LENA software for analysing AWC, CT and CV report counts is the data included in the 'meaningful' category. Similarly, the distant category did not only include 'speaker' ID segments that were at a distance but also included overlap near (OLN). The overlapping sounds referred to any speech that simultaneously had a competing sound 'overlapping' it. 'Overlap' had to consist of at least one human sound so had to be either human + human, human + noise, or human + TV. Averages for audio environments were calculated for the two outdoor recordings and separately for the two home recordings. The averages for the two settings were compared in a within subject manner. An overall average for all participants' recordings was also calculated to characterise the audio environment of pre-school children with hearing loss.

7.3. Results

7.3.1. Comparison of language environments with and without FM use

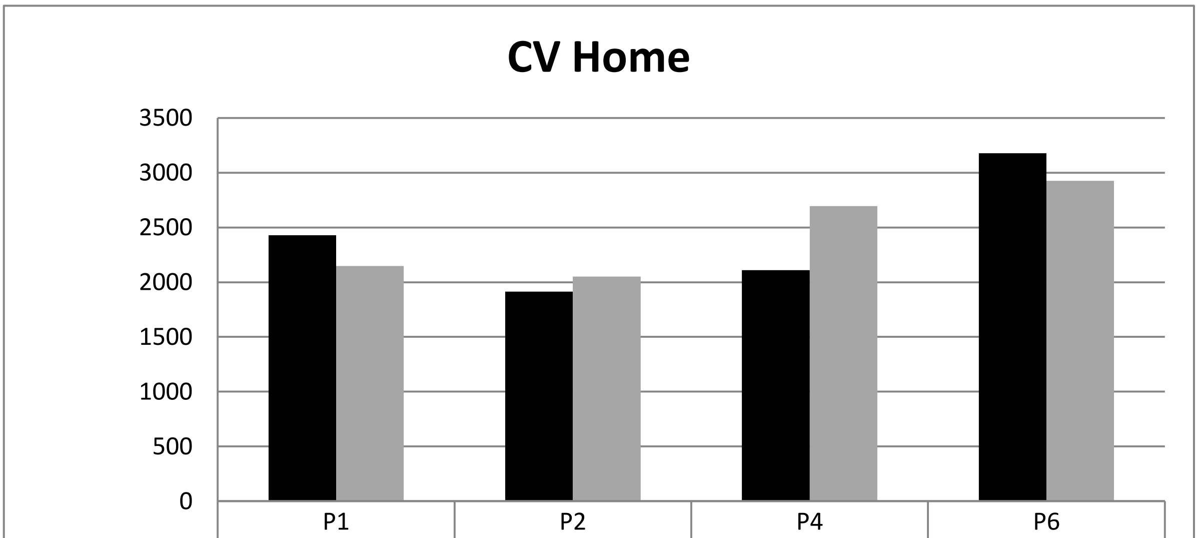
The female adult word count (AWC) results for the four participants in the home setting are detailed in Figure 7.4.



	P1	P2	P4	P6
With FM	6719	13010	9443	16626
Without FM	9000	9339	12462	16443

Figure 7.4 Bar graph displaying differences in female AWC's in the vicinity of the child for each participant with and without FM device use in the home setting. Table below graph details raw counts.

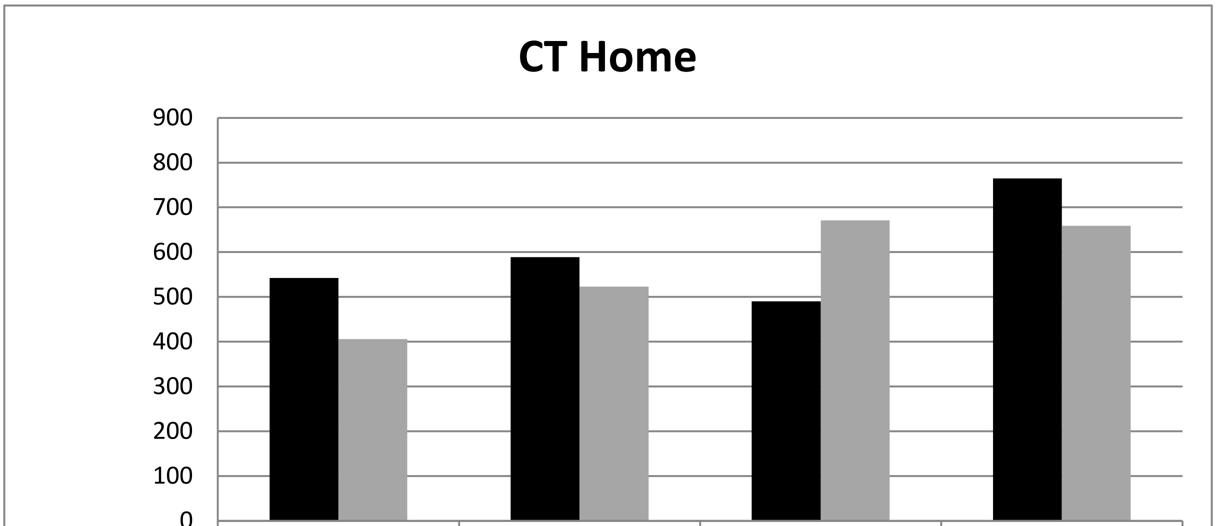
The number of female AWC’s with FM use exceeded the AWC’s without FM use for P2. In contrast both P1 and P4 showed an increase in female AWC’s when the FM device was not used. P6 had a similar amount of female AWC’s with and without FM device use. No clear trends related to FM use were observed for female AWC’s in the home setting. Non parametric related samples Wilcoxin signed rank test revealed no statistically significant difference at the 0.05 level between FM and non FM use for female AWC’s in the home setting (p=1.00).



	P1	P2	P4	P6
With FM	2429	1915	2109	3176
Without FM	2148	2052	2695	2927

Figure 7.5 Bar graph displaying differences in CV’s within the presence of a female adult (or possibly when the child was on their own) for each participant with and without FM device use in the home setting. Table below graph details raw counts.

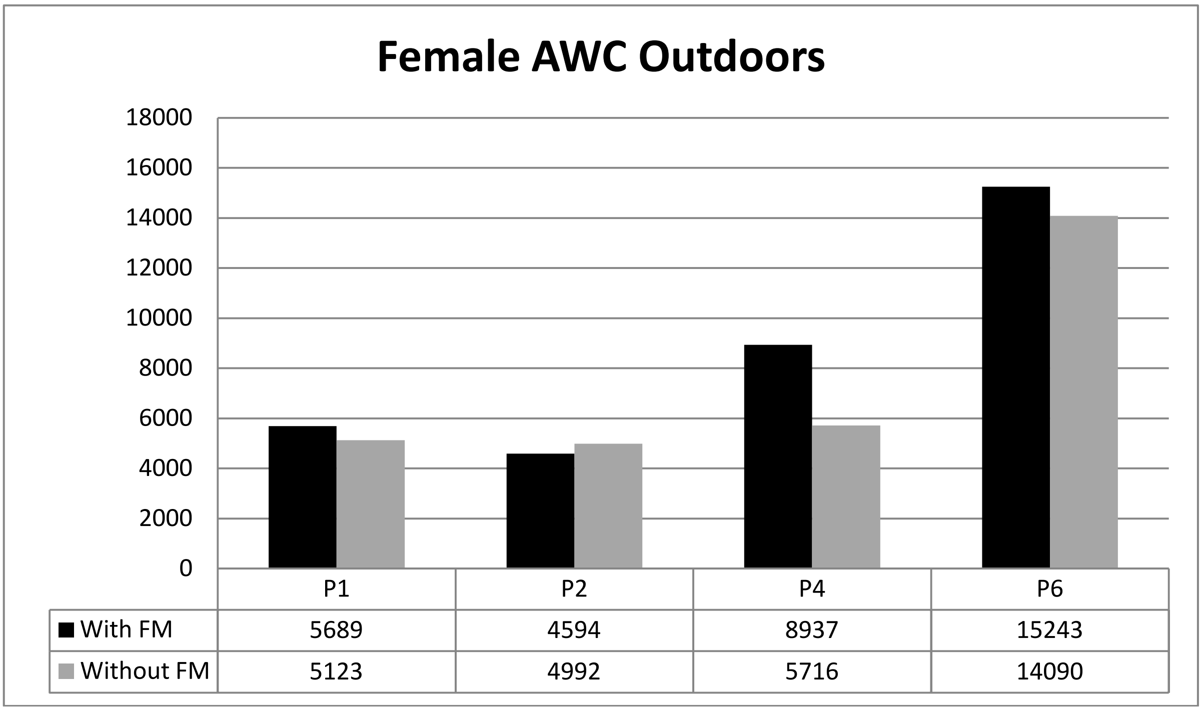
Results for the number of child vocalisations (CV) in the presence of a female adult in the home setting are detailed in Figure 7.5. Similar to the results for female AWC’s, the number of CV’s for P4 and P6 in the home setting without FM use exceeded the number of CV’s with FM use. In contrast P1’s and P2’s CV results contradicted the AWC results in Figure 7.4. P1 showed an increase in CV’s with FM use and P2 showed an increase in CV’s without FM use. The results did not suggest any clear trends associated with FM use and number of CV’s in the home setting. Similar to the female AWC’s a non parametric related samples Wilcoxin signed rank test revealed no statistically significant difference at the 0.05 level between FM and non FM use for CV’s in the home setting (p=1.00).



	P1	P2	P4	P6
■ With FM	542	589	490	765
■ Without FM	406	523	671	659

Figure 7.6 Bar graph displaying differences in CT’s with a female adult (or possibly with another child) in the presence of a female adult for each participant with and without FM device use in the home setting. Table below the graph details raw counts.

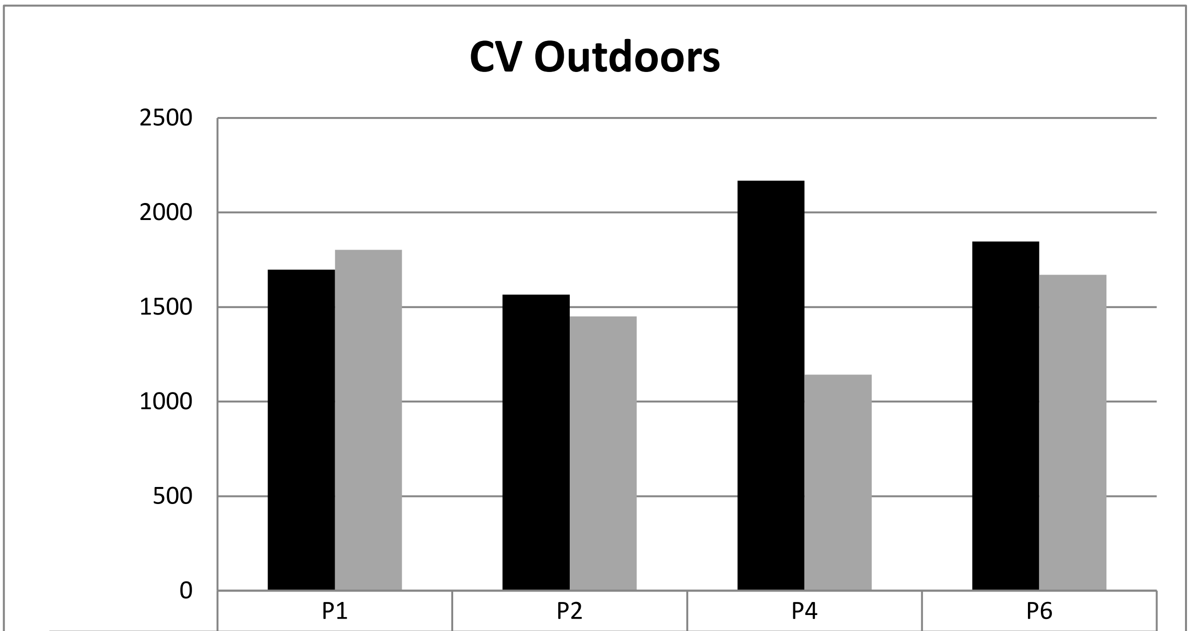
The results for the number of conversational turns (CT’s) in the home setting with and without FM device use are detailed in Figure 7.6. The CT’s in this condition would largely be with a female adult however as described in the methods, because of the defining parameters of the analysis software there is the possibility that with some children’s recordings CT’s with another child could be included. The number of CT’s for P1, P4 and P6 with FM use exceeded the CT’s without FM use. The results for P4 were consistent with her AWC’s and CV’s in the home setting and showed an increase in CT’s without FM use compared to with FM use. Unlike the AWC and CV results, the results for CT’s in the home setting suggest a possible trend with three of the four particpants resulting in increased number of CT’s with FM use. However, a non parametric Wilcoxin signed ranks test revealed no statistically signficant difference at the 0.05 level between the two recordings (p=0.715).



	P1	P2	P4	P6
With FM	5689	4594	8937	15243
Without FM	5123	4992	5716	14090

Figure 7.7 Bar graph displaying differences in female AWC's in the vicinty of the child for each participant with and without FM device use in the outdoor setting. Table below graph details raw counts.

Figure 7.7 illustrates the results for the number of female AWC's in the vicinty of the child when a portion of the day was spent in an outdoor setting. The raw word counts for female AWC's on the outdoor days were lower for all four particpants with and without FM use compared to those recorded in the home setting. Results for P4 and P6 showed the number of female AWC's with FM use exceeded those recorded on days without FM use. Results for P1 and P2 illustrated similar results for both days, however the number of female AWC's with FM were slightly higher for P1 and slighlty lower for P2. The results did suggest a possible trend in favour of more female AWC's with FM use. A non parametric Wilcoxin signed ranks test revealed no stastically significant difference at the 0.05 level (p=0.144).



	P1	P2	P4	P6
With FM	1697	1565	2168	1846
Without FM	1803	1450	1142	1671

Figure 7.8 Bar graph displaying differences in CV's within the presence of a female adult (or possibly when the child was on their own) for each participant with and without FM device use on a day. Table below the graph details raw counts.

Results for the number of CV's on the days the FM device was used in the outdoor setting for the LENA recordings are illustrated in Figure 7.8. Overall CV's for the outdoor days were lower than for those recorded in the home setting with the one exception being P4's CV's with FM use. Three of the four particpants number of CV's with FM use exceeded the number of CV's without FM use in the outdoor setting. In contrast P1 had a slightly lower number of CV's with FM use compared to without FM use. The number of CV's seemed to indicate a potential trend in increased CV's with FM use on the outdoor days however a non parametric Wilcoxin signed rank test revealed no statistically significant difference at the 0.05 level between the two conditions (p=0.144).

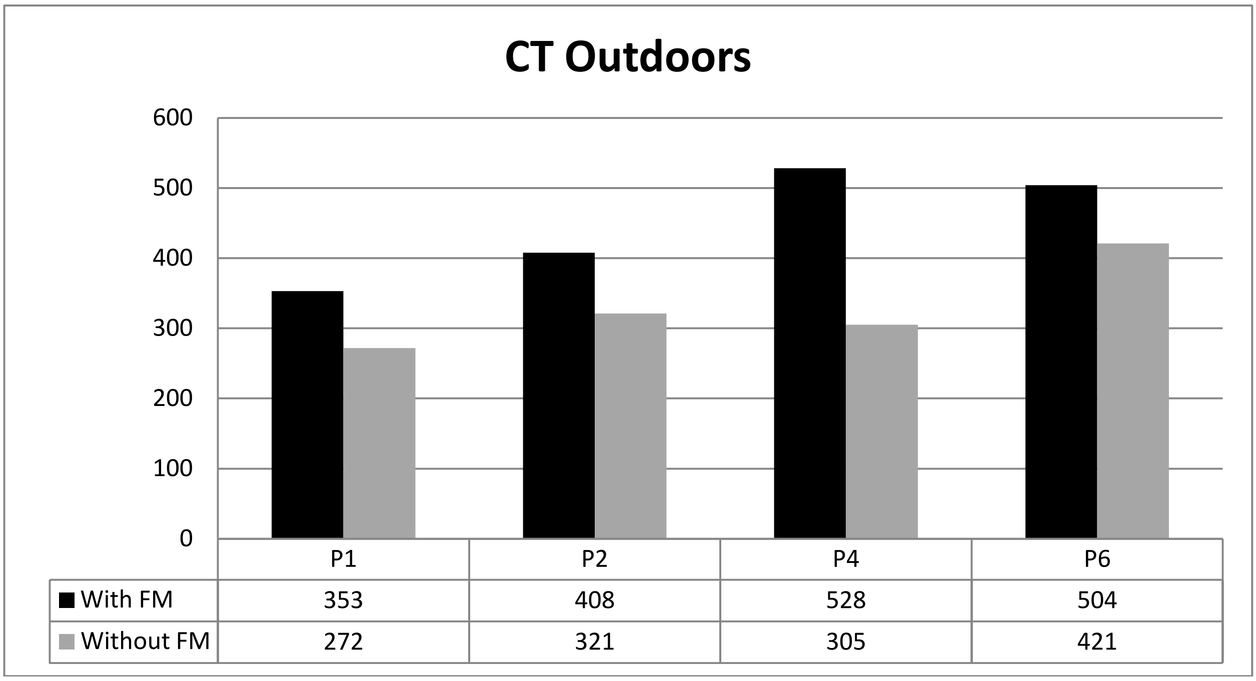


Figure 7.9 Bar graph displaying differences in CT's with a female adult (or possibly with another child) in the presence of a female adult for each participant with and without FM device use in the outdoor setting. Table below the graph details raw counts.

Figure 7.9 illustrates the results for the number of CT's with a female adult or possibly with another child in the outdoors condition with and without FM use. Similar to the outdoor recordings of AWC's and CV's, the number of overall CT's in the outdoor condition were less than the numbers in the home condition. Again the only exception was P4's recording with FM use in the outdoor condition. Results for CT's in the outdoor setting revealed a clear trend for increased number of CT's with FM use for all four particpants. This trend did approach significance at the 0.05 level when tested with a non parametric related samples Wilcoxin signed rank test (p=0.068)

Table 7.4 describes the duration of time the FM was used by participants on the LENA recording days. The average use of FM in the home setting on LENA recording days was 6 hours and 56 minutes. Likewise the average use in the outdoor condition was 9 hours and 48 minutes. The use of the FM device on LENA recording days considerably exceeded the average daily FM use as described previously. The average FM use throughout the longitudinal study duration for the four participants in this LENA study was 2 hours and 43 minutes in the home setting and 1 hour and 42 minutes in outdoor settings. Although on specific day's diary recordings did highlight extended use these were rare. As discussed in the methodology the purpose of this increased use was to gain an insight into potential differences that may exist in the language environment of the child with and without FM use. However the durations of use described for LENA recording days (Table 7.4) are not those that would be considered typical for these parents.

Table 7.4 Duration of FM use for each participant on LENA recording days with FM use.

	Home	Outdoors
P1	6:30	9:15
P2	5:15	8:15
P4	8:45	10:45
P6	7:15	11:00
Average	6:56	9:48

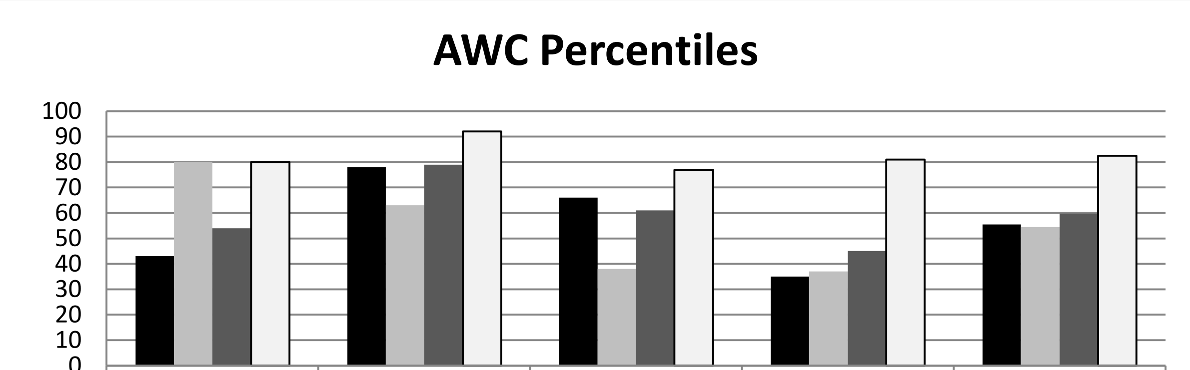
7.3.2. Comparison of language environment with hearing peers

Results for overall LENA report counts for each participant on the four LENA recording days are presented in Table 7.5. The average counts for the four days were also calculated. On their own the raw scores do not give much information to compare with hearing peers. Raw counts were converted to percentiles through the LENA software to provide comparison with hearing peers.

Table 7.5 Overall report counts of AWC, CV and CT's for each participant on each days recording. Average counts over the four days also included in final column.

		With FM Home	Without FM Home	With FM Outdoors	Without FM Outdoors	Average
AWC	P1	11393	17287	14846	10232	13440
	P2	17803	14389	10718	10501	13353
	P4	13001	17478	14075	11665	14055
	P6	17647	22211	16941	18156	18739
CV	P1	2726	2371	2162	2154	2353
	P2	2392	2423	1895	1848	2140
	P4	2479	3441	2574	1336	2458
	P6	3921	3299	1981	2040	2810
CT	P1	558	533	408	313	453
	P2	652	593	505	396	537
	P4	525	723	568	350	542
	P6	800	625	519	437	595

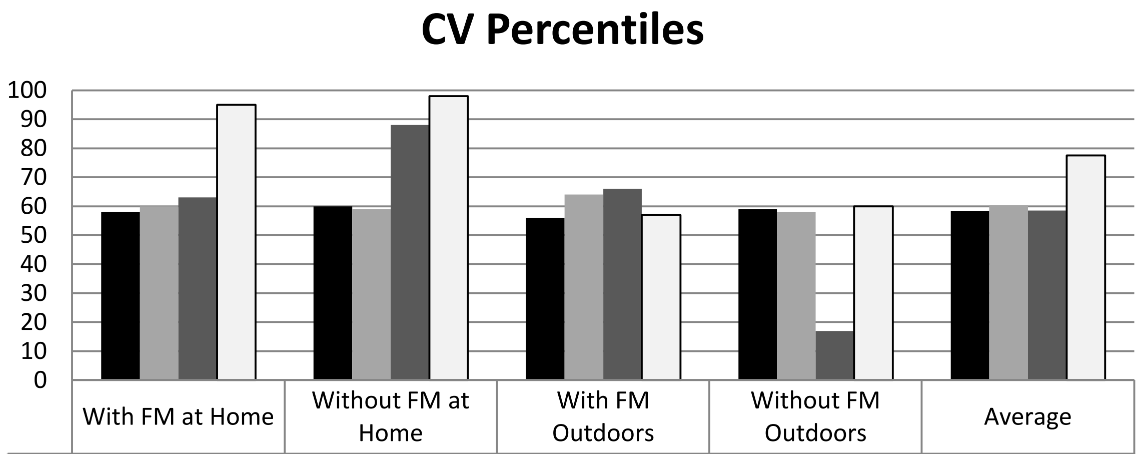
Figures 7.10-7.12 illustrate the percentiles for each of the participants on the four recording days.



	With FM at Home	Without FM at Home	With FM Outdoors	Without FM Outdoors	Average
P1	43	78	66	35	56
P2	80	63	38	37	55
P4	54	79	61	45	60
P6	80	92	77	81	83

Figure 7.10 Bar graph displaying AWC percentiles for each of the four particpants on the four recording days and an average overall percentile. Table below bar graph provides AWC percentile data.

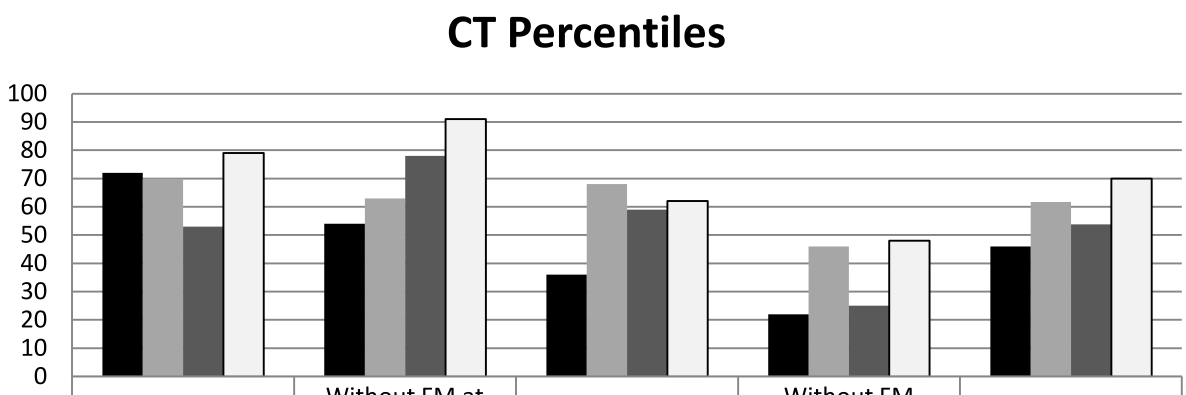
Figure 7.10 illustrates the AWC percentiles for each of the participants on the LENA recording days. For P1, P2 and P4 the day recorded without FM in the outdoors condition resulted in the lowest percentiles. In contrast the day recorded without FM in the home condition resulted in the highest percentiles for P1, P4 and P6. In comparison with hearing peers when the four days were averaged all four participant's AWC's were over the median 50th percentile ranging between the 55th and 80th percentile.



	With FM at Home	Without FM at Home	With FM Outdoors	Without FM Outdoors	Average
■ P1	58	60	56	59	58
■ P2	60	59	64	58	60
■ P4	63	88	66	17	59
□ P6	95	98	57	60	78

Figure 7.11 Bar graph displaying AWC percentiles for each of the four particpants on the four recording days and an average overall percentile. Table below bar graph provides CV percentile data.

Results for CV percentiles are illustrated in Figure 7.11. Both recordings in the home setting resulted in high CV percentiles for all four participants. The CV percentiles in the home condition ranged from the 58th to the 98th percentile. In contrast the outdoor setting days resulted in lower percentiles ranging between the 56th and 66th percentiles with FM and 58th to 60th percentile without FM. The one exception was P4's CV percentile which was considerably lower in the outdoors without FM condition being only in the 17th percentile. However the overall average CV percentiles over the four days for all particpants ranged between the 58th to 78th percentiles.



	With FM at Home	Without FM at Home	With FM Outdoors	Without FM Outdoors	Average
■ P1	72	54	36	22	46
■ P2	70	63	68	46	62
■ P4	53	78	59	25	54
□ P6	79	91	62	48	70

Figure 7.12 Bar graph displaying CT percentiles for each of the four particpants on the four recording days and an average overall percentile. Table below bar graph provides CT percentile data.

Results for CT percentiles are illustrated in Figure 7.12 CT percentiles in the home setting with and without FM use were above the 50th percentile ranging from the 53rd to the 91st percentile. In contrast CT percentiles in the outdoor setting were lower with FM for P1 and P6 being in the 36th percentile and the 62nd percentile respectively. Both P2 and P4 had similar CT percentiles with FM in the outdoor setting which were in the 68th and 59th percentiles respectively. CT percentiles in the outdoor setting without FM were considerably lower for all four particpants ranging from the 22nd to the 48th percentile. The average percentiles for the four recording were above the 50th percentile for P2, P4 and P6 being in the 62nd, 54th and 70th percentiles respectively. The only particpant to have an average CT percentile below the median 50th percentile was P1 whose CT's were in the 46th percentile.

7.3.3. Characterisation of language/acoustic environments

Results for language/acoustic environment data for each of the four participants averaged over the four days recording are presented in Table 7.6. Recordings for all participants were taken during the day and lasted for a minimum of 12 hours with the longest recording being 12 hours and 54 minutes. The data is based on the average time spent in one of the five acoustic categories as assigned by the LENA software. The categories, defined by the LENA software, are described in Table 7.3.

Table 7.6 Percentage of time allocated to each acoustic category for LENA recordings in the outdoor and home settings for each participant. Overall totals for all participants also described. Acoustic categories are as set by LENA software.

	P1		P2		P4		P6		All
Acoustic Category	Out	Home	Out	Home	Out	Home	Out	Home	Total
Meaningful	16.5	20.5	15	19	17	22.5	24.5	30.5	20.5
Distant	55	47	37.5	40	46.5	26	38.5	43.5	42
TV	13.5	14	6.5	10.5	12	3.5	7.5	2.5	9
Noise	3	2	2.5	1.5	1.5	4	4	1.5	2.5
Silence and Background	12	16.5	38.5	29	23	44	25.5	22	26

'Meaningful' speech was defined as usable, distinguishable speech that is included in the reported information. The 'meaningful' category is the only category used to analyse report counts for AWC, CV and CT's (LENA Research software v3.1.2.). The average percentage of time spent in the meaningful category in the home setting for P1, P2 and P4 was 20.5%, 19% and 22.5% respectively. P6 had the highest percentage of time spent in the meaningful category at home with an average of 30.5%. The outdoors setting resulted in 4% to 6% less time in meaningful speech. This can explain the reduced number of AWC, CV and CT's reported for the outdoors setting. Overall the data highlights on average only 20.5% of data recorded was established within the 'meaningful' category and therefore used for data analysis of report counts described in the previous two sections. The results also suggest only 20.5% of the day for children with hearing loss in our sample was spent in an environment where 'meaningful' speech was presented to them, as categorised by the LENA recorder.

The largest proportion of time allocated to any category was the 'distant' category. 'Distant' environment included speech typically coming from six or more feet away from the DLP (digital language processor i.e. the LENA recorder). This included all forms of 'far' speech and ‘far’ noise at a distance. One other key identifier included in this category was ‘OLN’ referring to overlapping speech near the child/recorder. Therefore any speech within six feet of the child but with overlapping noise present would be categorised as ‘distant’ by the LENA system. The amount of time categorised as ‘distant’ in the home setting ranged from 26% for P4 to 47% for P1. Both P2 and P6 had 40% and 43.5% of time spent in ‘distant’ environment respectively. An increase in the amount of time allocated to the ‘distant’ category in the outdoors setting would have been expected and was the case for P1 and P4 at 55% and 46.5% respectively. However, both P2 (37.5%) and P6 (38.5%) had slightly reduced percentages of time allocated to the distant category in the outdoors setting compared to the home setting. Overall, the data describes on average 42% of the recorded day was spent by children in the ‘distant’ environment category. As explained previously this category would not be included in analysis when generating report counts. This would result in a large portion of the potential benefit of distant speech achieved through FM use being overlooked and not included in the data analysis of report counts described above. Furthermore, the data highlights approximately 42% of the speech these children are expected to access on a typical day would be in the ‘distant’ category and not easily accessible.

The percentage of time allocated to the ‘TV’ environment was 2.5% for P6 and 3.5% for P4. Both P2 and P1 had a higher percentage of time allocated to the TV environment at 10.5% and 14% respectively in the home setting. For the outdoors setting the amount of time allocated to the ‘TV’ environment increased to 12% for P4 and 7.5% for P6. This maybe a result of radio/DVD use in the car as the ‘TV’ category includes ‘audio from television, radio and other electronic noise’. The percentage of time allocated to the ‘TV’ category in the outdoors environment was approximately the same for P1 at 13.5%. For P2 the percentage of time allocated to the ‘TV’ category was lower in the outdoors setting compared to the home setting at 6.5%. Overall the average amount of time for all participants in both settings allocated to the ‘TV’ category was 9%. The amount of time spent in ‘Noise’ was very minimal and ranged from 1.5-4% for all participants in both settings. However ‘noise’ here refers to ‘rattles, bumps and other non-human signals’ within six feet of the recorder/child and does not include noise at a distance of 6 feet or beyond.

The average percentage of time allocated to the 'Silence and Background' category in the home setting was 16.5%, 22% and 29% for P1, P6 and P2 respectively. Surprisingly, a very large portion of time (44%) was allocated to 'silence and background' for P4 in the home setting. For P4 this reflected a large difference in the amount of time spent in the 'distant' category at home. It was expected that the outdoors setting days would account for less percentage of time allocated to silence compared to the home setting. Although the percentage of time in 'silent and background' did reduce in the outdoors setting for P1 (12%) and P4 (23%), in contrast for P6 (25.5%) and P2 (38.5%) the percentage of time in the 'silent and background' category increased in the outdoors setting. Overall, for all participants in both settings the amount of time in 'silent and background' accounted for 26% of the children's recorded day.

7.4. Summary of key findings

The LENA device includes a small recorder that is attached to a garment worn by the child over a minimum of 12 hours in their natural environment. The recording is then transferred onto a computer where the specialist LENA software analyses in detail the child's language environment. The analysis includes detailed report counts on the number of adult words (AWC) spoken in the vicinity of the child, the number of conversational turns (CV) taken by the child with another child or adult and the number of child vocalisations (CV) during the day long recording. Furthermore the software also provides detailed analysis on the acoustic environments the child was in during the recording period. The software defines five acoustic categories: 'meaningful', 'distant', 'silence and background', 'TV' and 'noise'. The primary aim of this study was to compare the language environment of pre-school hearing aided children in the home setting and outdoors setting with and without FM technology use. Secondary aims for this study were:

- to compare the language environment of pre-school hearing aided children with their hearing peers, and
- to characterise the acoustic environment of pre-school children with hearing loss

The key findings from this study highlighted:

- Although the primary aim of this study was to compare the AWC's, CT's and CV's with and without the use of FM technology it became apparent the LENA system was not sensitive enough to fully detect potential FM benefits.

- The main finding from this study was related to children's acoustic environment and the amount of time spent by children in the 'meaningful' and 'distant' categories. All report counts (AWC, CV and CT) were generated using only the 'meaningful' category which referred to speech occurring within six feet of the child without any 'overlapping' noise or competing speech present. All speech that may have occurred at a distance of over six feet or with 'overlapping' noise or competing speech present was categorised in the 'distant' category. The other categories of 'TV', 'silence and background' and 'noise' referred to environments where no human speech was present. Approximately only 20% of children's acoustic environment on a typical day was in the 'meaningful' category whereas over 40% was spent in the 'distant' category. As the main benefits of FM use are associated with accessing speech in noise and at a distance any potential benefit was not analysed by the LENA system.

- The study's finding of 40% of children's acoustic environment being spent in the 'distant' category highlights the importance and increased need for FM use with pre-school hearing aided children. This also suggests participants in our study could have benefited from further use of the FM technology on a daily basis.

- Surprisingly, the comparison of report counts for the different settings resulted in a significant difference in CT counts for the outdoor setting. This finding highlights that although no differences were detected in the 'meaningful' category for other report counts and in other situations, the benefits of FM use for this particular setting and report count were picked up within the 'meaningful' category. This may be a result of increased conversations in the car and pram settings where the child may be within six feet of the parent.

Although 'overlapping' noise may be expected in these settings they may have been at a minimum.

- Children with hearing loss in this study had language exposure that was near the 50th percentile or better when compared to their hearing peers. This finding was contrary to the suggestions of previous literature where it was expected that children with hearing loss may have less exposure to language. However it needs to be noted that it is possible as distant speech was not included in the LENA counts, this may have had a bearing on results from previous literature.

- The language exposure percentiles highlighted the only report count where all four participants percentiles was below the median 50th percentile was for CT's in the outdoors recording condition without FM use. In comparison, with FM use three participants CT counts ranged from the 59th to 68th percentile. One participant's CT's was below median at the 36th percentile. However even for this participant there was an increase in CT's with FM compared to without FM (22nd percentile). This further highlights the potential benefits of FM use in the outdoors setting to facilitate conversations with hearing aided children. As a result of FM use their CT environment in outdoor conditions could increase to similar percentiles as their hearing peers.

8. Discussion

The above three studies were carried out to quantitatively and qualitatively explore the use of FM technology with pre-school hearing aided children. Study two established the duration and frequency of FM technology use for seven pre-school hearing aided children. Each participant's usage was categorised into seven different environments/situations. Parent's evaluation of situational listening with FM technology was recorded and the language development for each of the children was monitored throughout the study period. Study three qualitatively explored the views and experiences of parents and nursery staff on the use of FM technology through weekly diary entries and semi-structured interviews conducted with parents at the end of each participant's involvement in the study. Study four made use of the very recent innovative language environment analysis (LENA) system and was the first UK based study to make use of this system. Four of the seven participants were included in study four and their language environment with and without the use of FM technology was compared. Additionally, the language environments for these four participants were also compared with their hearing peers.

The findings from each of the studies will be synthesised and discussed under four sections. The first section will focus on the general use of FM systems with pre-school hearing aided children including overall quantitative results, more specific qualitative results and issues related to the recruitment phase of the study. The second section will discuss pre-school children's listening environments both in the context of the results for listening with FM technology and also in the context of the results for the LENA language and acoustic environments. The third section will discuss the language development for the children in this study using the LDS assessment results as well as the qualitative findings. The fourth section will discuss parents' evaluation of the technology including their qualitative feedback and the quantitative results from the FMLEC technology assessment questions. The chapter will end with a conclusion section that will discuss the strengths, limitations, implications to practice and theory and future scope for research.

8.1. The use of FM systems with preschool hearing aided children

8.1.1. Daily use

There has been little exploration of FM technology use with very early identified hearing impaired children. Three previous studies exploring FM use with pre-school children (Brackett, 1992; Gabbard, 2003; Statham, 2009) did not report any data on daily usage of FM technology. One study (Moeller et al., 1996) did require parents to complete daily use logs, which documented device function and hours of amplification use (FM use, HA use and no amplification). In their study, Moeller et al. (1996) assigned 10 families into one of two groups: one group (six children) was instructed to use FM systems at home as often as possible and the second group (four children) only used their hearing aids. The children were monitored for a period of two years and although parents were required to complete daily logs over the two year period the data reported on daily usage was brief. An overall percentage of waking hours per day that each subject used amplification (excluding time spent in school) for the first 18 months of the study was described. Moeller et al. (1996) found five of the six participants used their FM device between 40-60% of their waking day in the home setting and one participant used their FM approximately 20% of their waking day in the home setting. There was no way of ensuring reliability of participant's usage reports as datalogging was not present in the equipment used in the study (Moeller et al., 1996). Furthermore, it was not clear how many days from the 18 month period were used to calculate this overall percentage of FM device use. Similarly, it can be understood the daily amplification use percentages calculated were limited to use in the home setting, however qualitative feedback from parents did suggest the FM device was used outdoors as well. A clear definition of the 'home setting' was not provided and if the 'home setting' included all daily activities excluding the school setting the results from the daily use data failed to capture the range of listening environments the FM was used in.

This study was unique in that it looked in detail at daily usage of FM technology, capturing not only data related to the duration and frequency of FM use but also the varied and complex listening situations young children live and learn in. The detail with which usage data was captured, including the number of days the FM was used, how long it was used, where it was used and whether parents felt it was useful in that situation or not has previously not been reported. Similarly, demographic information was used to explore any potential variable that may influence the uptake of FM technology with pre-school children. In doing this an in depth insight into the use of FM technology with seven pre-school hearing aided children between the ages of 11-32 months was captured. Five of the seven participants within this study were able to establish regular use of the FM technology. Daily use data recorded for these five participants showed the FM device was used for 69% to 95% of the days these children were involved in the study. The average duration of daily use for these five participants ranged from 2 hours and 29 minutes to 4 hours and 12 minutes. The quantitative results suggested two possible variables, age and maternal education, may have had an effect on FM use for the two participants who had not established consistent use of the FM technology. The maternal education levels for the seven participants fell into two categories: college level and post college level. The two participants who had not established consistent FM use were the only participants in the 'college level' of maternal education. As a result non parametric group comparisons suggested a significant difference between the two groups. Although the results were significant, this finding should be treated with caution as the numbers in the study were small and the variable of child's age suggested a clearer trend with a significant correlation between age and daily FM use when including data for all participants. The findings for the correlation between age of child and number of days the FM device was used suggested the older the children were the more days the FM device was used per month. This correlation remained highly significant ($r = 0.77$; $p = <0.01$) even after data related to the two youngest children who did not make much use of the FM device were excluded. While the value of early access to well fitted and verified amplification has been established, both in relation to hearing aids (Yoshinaga-Itano, 1998; Moeller, 2000) and CI's (Sharma et al., 2002), there is little understanding of 'early' in the use of FM technology. Logically, it can be argued that once a child reached the developmental phase of crawling, close microphone distance is potentially lost. Given the importance of access to speech in the first years of life (Moeller, 2009; Cole & Flexer, 2011) any distance between the speaker and the microphone will degrade the quality of the signal. Integrated FM technology, which overcome the ergonomic restraints of traditional FM systems, both in respect of body worn and audio shoe based FM technology, potentially offers significant benefits. It is unclear at what developmental point it is most appropriate to introduce FM technology from the perspective of children and their families. Future studies would benefit from including a more representative sample of the population to help understand and define ‘early’ in the use of FM amplification.

All seven participants reported very few hours of use where they felt the FM device was not helpful. Although a very high percentage of benefit with FM use was reported by parents (97%), this finding is more indicative of parents being able to recognise where they would prefer to use the FM and where they were finding most benefit. Once this was established for parents in their set routines they made regular use of the FM in these particular situations, resulting in highly positive feedback. It would be counter intuitive for parents to carry on using the FM in settings where they felt minimal or no benefit was being achieved. As a result the feedback in diaries for “no benefit” and “not sure of benefit” was very minimal compared to the overall device use. The qualitative feedback from both parents and nursery staff further clarified these results where under the theme of ‘identifying-establishing preferred use’ parents and nursery staff were able to gradually adapt their use of the FM device over the duration of the study as a result of their own and the children’s experiences and feedback. Initially the use of the FM technology was more general however overtime the use of the FM device reduced to more specific situations. The reduction in FM use was not perceived by parents and staff as something negative but was felt as a positive step in establishing better use of the FM device. The qualitative feedback from parents and nursery staff further highlighted the improved access to speech the FM technology provided, especially in more challenging listening situations such as noise, distance, when hearing aid microphones were covered and when the children were not facing parents, for example in the car or pram. The improved access to intelligible speech over distances was identified by parents to allow their child to overhear conversations and learn new words which they may not have accessed with hearing aids alone. Parents and staff also reported improved listening behaviours in children when using FM with children being described as having improved ability to localise the speaker, improved attention, comprehension, concentration and reduced listening effort.

It was surprising to note the two participants who had not established consistent use of the FM technology had not noted a single occasion where they felt the FM was not beneficial. Although they had noted down when they felt they were not sure of benefit, the majority of their recorded FM use was logged as beneficial. The results seem counter intuitive in that these two participants were finding the use of the FM device beneficial, yet their recorded use of the FM technology was so low. Both parents did identify their child's age as a barrier to the use of FM. One mother clearly explained how she felt as her child was pre-verbal the benefits of the FM were limited as it was not possible to establish a conversation with her child. This was an important point and suggests the value and importance of contingent language was not fully understood. It is natural for anyone instigating a conversation with an 11 month old child to expect some reaction. However it is unclear whether this specific mother was sensitive to her child's non-verbal responses. This is an important area that could be a focus of parent guidance by their ToD. This parent was provided feedback on this particular concern, however as this concern was only raised by the parent during the interview at the end of the study, any changes in FM use could not be monitored. The second parent also mentioned age as a barrier to FM use but related age more with barriers to hearing aid use. Both parents explained how ear moulds not fitting properly, ear infections and the child not keeping the hearing aids in, resulted in inconsistent use of the hearing aids and both parents perceived this to be a major barrier to FM use. Although the poor take up of hearing aids would directly impact FM use, the more pressing concern was to consider the findings of poor hearing aid use by the youngest participants with other research.

8.1.2. Consistency of hearing aid use

Recent research conducted by Moeller et al. (2009) has studied the consistency of hearing aid use in infants with early identified hearing loss. Participants were mothers of seven infants who had been identified with mild to moderately severe hearing loss at a mean age of 1.64 months and the mean age at fitting of amplification was 5.0 months. The seven families were a highly motivated group who were all committed to participation in an ongoing longitudinal study of word learning in infants with normal and impaired hearing (Moeller et al., 2007a, 2007b). This group had frequent contact with a paediatric audiologist and regular support from parent-infant teachers. The study aimed to examine the consistency of HA use across eight different situations. Consistency of use was judged by mothers on a five point Likert scale: 0=never, 1=rarely, 2=occasionally, 3=frequently, and 4=always. The eight situations where consistency of HA use was examined included the child: a=riding in the car, b=interacting with a daytime caregiver, c=eating at mealtime, d=playing with parents, e=playing alone, f=looking at books with parents, g=playing outside and h=going on family outings (zoo, store, etc.). The ratings were completed by mothers as part of a structured interview that was administered at 4-6 month intervals to sample a range of infant developmental periods. The interviews were conducted when the children were 10-12, 16, 22 and 28 months old.

Findings from the study suggested the consistency of HA use, on average, improved with age during the second year of life and by 28 months of age reached between frequent to always for most situations listed. This finding may provide an explanation on the reasons why FM use was highly correlated with age. If the consistency of HA use gradually increases with age it would be expected FM use would follow a similar pattern. Findings from Moeller at al.'s (2009) study suggested maternal reports on consistency of HA use placed the situations into two individual patterns of use. The first pattern of use was where mothers felt they could closely monitor their child's HA use and this included play together, mealtimes and book reading. The second pattern of use was where mothers felt it was difficult to supervise situations and included outside play, outings and the car. For situations where HA use could be closely monitored mothers reported regular use (ratings between frequent and always) by 16 months of age. This further highlights the importance of the age variable with device use and does provide some insight into possible trends of FM use in the current research where children under 15 months of age had not established FM use. Moeller et al. (2009) further highlighted the consistency of HA use in situations where mothers found it difficult to supervise situations fell short of ideal (frequent or always) for four out of the seven participants even once the child had reached 28 months of age. Notably, mothers described the car as the most challenging situation. Two out of the three families who had eventually established consistent HA use in these difficult to monitor situations had established early FM device use. The study (Moeller et al., 2009) further highlighted how four out of seven highly motivated parents of early identified hearing aided children had not established consistent use of their HA device in all situations by 28 months of age. Although consistency of HA device use was not monitored as part of the current study, future studies looking at FM device use with pre-school children would benefit from measuring this very important underlying variable. A detailed understanding of realistic expectations of early hearing aid use would help in understanding how support and technology can be adapted to meet the needs of very early identified hearing impaired children.

When parents from the study (Moeller et al., 2009) were probed on reasons for inconsistent use of hearing aids, concerns regarding loss of device and child pulling aids out were reported. One of the two parents from the current study also reported these concerns as a reason for inconsistent HA device use. However, both parents also highlighted concerns regarding poor ear mould fitting, something that was not identified by parents in the study conducted by Moeller et al. (2009). This may be a result of differences in health care provisions. Previously, a study conducted by McCracken et al. (2008) explored parental views on very early audiological management. Their study was part of national evaluation of the newborn hearing screening programme (NHSP) that had been rolled out across England. Forty five parents and caregivers from across England participated in a qualitative narrative study and one of the aims was to identify key challenges generated by the audiological management of very young babies, with hearing loss at home. Parents in the study of McCracken et al. (2008) were very clear about how they felt the weakest link in the amplification chain was earmould provision. 80% of parents reported earmoulds were poorly fitting and how they perceived waits for appointments for impressions and the return of earmoulds were too long and a source of concern and anxiety. Similar concerns regarding earmoulds were expressed by the two parents who had limited FM device use in this study and was explained as one of the reasons why HA's could not be used by these parents.

At the beginning of this study the issue of poorly fitting earmoulds had caused considerable anxiety for one mother (P4) who was visibly upset at the first appointment because of mould and hearing aid related issues and as a result professionals questioned this families participation in the study. Likewise another child's (P6) inconsistent HA use and personal situation was cause for concern for professionals who were not sure whether to include the family in the study. Both families were given the choice to decide whether they wanted to be included in the study and chose to participate. Similar to the findings from the study by Moeller et al. (2009) where the two families who had made use of FM systems had established consistent HA use in all situations at an earlier age, the two families in this study consistently reported increased hearing aid use once the FM device was introduced. One of the mothers described how after using the FM system her daughter had begun to request her HA device. Similarly, the mother of the second child immediately noticed an increase in her son's HA use. Interestingly, the mother described how in the beginning when she used the FM how it was the "first he has ever kept his hearing aids in whilst in the car". Similarly, the mother described how her son would “enjoy wearing his hearing aids for longer periods of time” as a result of FM device use. The findings from this study support those by Moeller et al. (2009) in that the use of an FM system can be a positive tool to establish and increase consistency of HA device use. Although inconsistent HA device use for two participants (P3 and P5) suggested they were unable to establish FM device use, the two participants mentioned (P4 and P6) in this study and the two described in Moeller’s study found the use of an FM device resulted in a positive increase in their child’s HA device use. Both the consistency of hearing aid use reported by Moeller et al. (2009) and the increased use of hearing aids as a result of FM device use has implications for early audiological management. Paediatric audiology services would benefit from closer monitoring of hearing aid device use in the early years and address possible reasons for non use of hearing aids. Similarly the potential for FM technology to increase the use of hearing aids especially in difficult listening situations identifies the need for professionals to consider FM technology provision in the early years. This raises significant issues for professionals who may currently lack the training and expertise required for the early provision of FM technology.

8.1.3. Gatekeeping

As part of a pilot study to this research (Mulla, 2008), professionals’ views on the use of FM systems with early identified hearing impaired children were explored. Surprisingly, none of the ToD approached completed the short open ended questionnaire. The paediatric audiologists who did complete the questionnaire were from both a clinical and research setting. The UK based professionals who completed the questionnaire voiced general concerns over the need for joint appointments with ToD’s, longer appointments, increased training requirements and funding sources for FM provision. More specific concerns related to FM use included parents ability to cope with the extra technology, the potential for misusing or over using FM technology and the possibility of FM technology use affecting children’s localisation abilities. Although this small group of professionals were open with their concerns, it must be noted some of them were the first to get involved in the study and were supportive throughout the research. Unfortunately, through the course of the research and most especially during the recruitment phase, the above concerns raised by paediatric audiologist were mirrored by many paediatric audiologists and ToD’s. The reluctance by some professionals involved directly with pre-school hearing aided children to consider the use of FM technology with this population, especially as in this case funding of equipment was not an issue, raised the possibility of 'gatekeeping'. This may have been a result of professionals pre-existing views on FM use with pre-school children, the potential level of commitment being requested by parents within this research or because of concerns related to their own time. During the recruitment phase of the research, the approach to contacting parents which relied on working within pre-existing professional systems, brought with it its own challenges.

Firstly, of the ten departments approached four did not provide any answer to why they would not want to participate, closing down what could have been useful dialogue between professionals and the researcher. Thereafter, of the six departments who did show an interest in the study, one department after reading the research protocol and holding a meeting with the researcher decided not to participate in the study. The final reason for not participating communicated to the researcher was they as a department did not have the time to participate in the study. Although, from a departmental perspective this may have been a valid reason and may have also been the case for the four departments who did not answer, this reluctance was unfounded as paediatric audiology involvement with participants specific to this study was very minimal. Paediatric audiologists were required to changeover the children's hearing aids to a newer model at the beginning of the study, thereafter there was no further involvement specific to the research required. During the meeting with this department concerns regarding the levels of parental commitment involved were voiced. Although the study did require a high level of commitment from participants, if this concern was instrumental in their decision to not participate, it would have been more beneficial to discuss these concerns with the parents directly. Similarly, another department explained how the one potential participant they had identified had decided for himself that as a wheelchair user study participation may be too difficult for him. Again, in this case a meeting with the parent was not offered, closing down the chance to address the parents concerns. It can be suggested the use of an FM system could have provided more benefit to a parent using a wheelchair as issues related to distance from speaker may be a more regular occurrence. Previously, Tattersall and Young (2006) conducted a qualitative study exploring parental views of the diagnostic process of newborn hearing screening. They expressed similar concerns where they had several instances of professionals involved with families making decisions that it was too early for parents to receive information about the study, or that it would be distressing or would make pre-existing stressors worse. Tatersall and Young (2006) argued that on the one hand professional's views and actions could be seen as an example of responsibly exercising professional judgement for the benefit of families but on the other hand can also be seen as an example of professional paternalism. Thus, controlling what the parents are allowed to know and making the decision on what is best for them. Tattersall and Young, (2006) clearly expressed their view on this:

> "all parents should be allowed in the same way to make their own decisions about what they think of the research study and whether they wish to be involved. If that entails parents throwing the information in the bin, never reading it, leaving it to come back to, discussing it with professionals, forgetting all about it, or getting in touch in their own time, then all of these are valid responses, but ones that parents can only make if they actually know the possibility exists for them to contribute in the first place. Also if only the parents deemed to be coping or in some way capable are the ones who are routinely informed of the study then this greatly reduces the likelihood of capturing a heterogeneity of experience" (page 37).

As part of this study it was felt, if initially parents were given a demonstration of the equipment, explained its theoretical potential and given the opportunity to ask questions and have their concerns answered they would have been in a better position to make an informed choice on study participation. Thereafter, similar to the views of Tattersall and Young (2006), whatever decision was made by the parents would be a valid one. For example, during the recruitment phase of this project, professionals were concerned regarding the participation of two individuals (P4 and P6) and were considering excluding them from the study. However in the end professionals decided to leave the decision with the parents and arranged a meeting for parents to ask questions about the research. In both cases the parents chose to be included in the study and were very positive about the use of FM technology and by the end of the study had established consistent use of their FM device. In contrast, professionals were confident with regards to study participation for two other participants (P3 and P5) yet both these participants did not make much use of the FM technology. This highlights how the level of involvement from families cannot always be correctly predicted, even by professionals with extensive contact with them.

With regards to the some of the other concerns expressed by professionals on the provision of FM technology to pre-school hearing aided children, the concerns could be divided into two categories. The first category included the more general strategic concerns such as increased appointment times, joint appointments with ToD, increased training requirements and whether the FM systems would be funded by health services or educational services. All of these concerns raise genuine questions on the feasibility of FM technology provision for pre-school hearing aided children. The AAA (2008) are very clear in their opinion that audiologists are the single qualified professional to fit all forms of amplification including hearing aids, FM systems and other hearing aid technology. However, the care and fitting of FM technology has traditionally been the job of ToD's and educational audiologists in the UK (Hostler, 2004). Either way, the training, equipment and funding requirements for the provision of FM technology in pre-school years need to be addressed. In order to meet the quality standards provided by the UKCFMWG, where every child with a hearing loss should be considered as a potential candidate for an FM system, some conformity needs to be established to develop a more child and family focussed approach. Examples of successful partnerships between health and education in the provision of FM technology to pre-school children within the UK do exist (Statham and Cooper, 2009) and these models can potentially be used by other departments.

The second category of concerns raised by professionals included more specific issues related to the possibility that FM technology may affect children's localisation abilities, parent's ability to cope with the extra technology and the potential for misusing or overusing the technology. The qualitative results discuss the concerns related to localisation abilities in detail under *Locating FM user* (6.2.2.2). Although, in theory as the FM signal is wirelessly transmitted it would not be expected for children to receive any directional cues from it, all parents and nursery staff commented on how "accurate", "quick" and "instant" their child was able to locate the FM user. The possibility of children's pre-awareness of the FM user's location provided one possible explanation of improved localisation of the FM user. However, the hearing aid setting of FM+M was also discussed, as on this setting the hearing aid receiver and FM receiver would simultaneously receive audio input. In this case it is likely the hearing aid receiver would provide additional auditory information that would help with localising sound. As mentioned previously, Maxon and Brackett (1989 cited from Madell, 1992), highlighted how in their study hearing aided children were able to localise sounds at normal conversational levels when using an FM system. However, without the FM signal children were not sufficiently aware of the sound to be able to locate it. Also parents' use of FM technology highlighted on average the FM was used between two to four hours, resulting in the majority of the child's day wearing only their hearing instrument. During those times children would receive input from all directions, unless they were using directional microphones which also could impact localisation. Professionals concerns on parents' ability to cope with the extra technology were also addressed by the findings from this research as five of the seven parents were able to establish consistent use of the FM technology. Although the inconsistent use of FM technology for the other two parents may be a result of not being able to cope with the extra technology, the findings suggest this was more related to the child not having established consistent use of the hearing aid which would directly impact the opportunities for FM technology use. Finally, professionals concern over misuse or overuse of FM technology were addressed by the qualitative findings described under *control of own listening* and *identifying-establishing preferred use*. These two sub themes described how children and parents were able to establish *ownership* of the FM technology to address the child's listening requirements and needs.

8.1.4. Ownership

To date, there is very little or no acknowledgement in the published literature of pre-school children controlling the use of FM systems and being active partners in identifying and establishing preferred use of FM technology with their parents or carers. The findings from the qualitative data suggests a clear sense of ownership displayed by children and how parents and carers were led by children's request to use or not to use the FM device. This was interpreted as a highly positive reaction from the children as they were seen to be in control of their listening environment and subjectively choosing the amplification they preferred in specific environments. In contrast, the Likert scale question of "Child tries to turn FM system off" included in the FMLEC questionnaire (Gabbard, 2003) implicitly assumes that a request to turn the FM device off is a negative behaviour. The majority of the participants in this study understood this question as implied and the scores were low for six of the seven participants on this question. However, one parent (P2) reported high scores here but the qualitative feedback clearly explained how the child chose in which situations he did not want the parent to use the FM. The parent reported how this was beneficial for them as it guided them in using the FM device in situations where their child wanted it. Similarly, another parent (P6) explained how her child would inform her if he wanted her to switch the FM device off, however when responding to the FMLEC question this parent did not score high on the "Child tries to turn FM system off" question. All parents noted how their children would request to have the FM device on or off highlighting the level of ownership and understanding of the FM technology these children had. The children's appreciation of FM technology was further explored under the theme *Child understanding FM function*. Many parents described how their child would talk down the FM microphone or place it near a talking toy and listen to the sounds. Similarly, another parent described how the child would actively remove the transmitter from one carer's belt and pass on to another carer when it was time to change carer's.

On a similar note the level of ownership described by parents under the themes of *identifying-establishing preferred use* and *control of own listening* highlighted parents ability to actively monitor the benefits of FM device use. Parents were able to establish when the child would choose not to attend to the speech signal, whether this was because the child was occupied with another task or whether the child simply chose to play at not hearing. Similarly, parents were also able to identify when the child did not want the FM on judging by the child's physical responses, even if the child did not expressly object to the use of the FM device. In both cases parents were able to adjust their use of the FM device accordingly and felt although the children were able to express their listening choices, in some situations where the child was occupied or in a group of children they may not communicate their choices as clearly. The themes of *playing at not hearing, child understanding FM function, identifying-establishing preferred use* and *control of own listening* answer in part the concerns expressed by professionals worried about the over use or misuse of the FM technology. Parents and children were able to jointly monitor the use of FM technology and adjust the use of the technology accordingly. Parents and children were not passive users of the technology who simply used the FM equipment because it was required or because they were told it was good to do so. They were active users who constantly monitored the use of the technology and in accordance with their perceived benefit of the system made use of the technology. Overall the qualitative findings highlighted a new area of study on the high levels of ownership and appreciation of FM technology for parents as well as children as young as

15 months of age. It would be useful to monitor the theme of ownership in children provided with FM technology in pre-school years as they got older. Currently, as the provision of FM is limited to educational settings children do not own the device. As a result it can be expected the sense of ownership of their FM technology is limited. Recent ongoing research conducted at the Ear Foundation (Archbold et al., Unpublished) exploring long term cochlear implant use in young people fitted with cochlear implants for 15 years or more, found the uptake and use of FM technology was poor. It can be expected that levels of attachment and ownership will be far greater for the children who own the FM technology from a young age and who have adapted to using it in a variety of situations. It would be useful to explore the attitudes and perspectives on FM technology use for children who have been provided FM technology from pre-school years compared to those using the technology only in educational settings and do not own the technology. Furthermore, a larger study exploring the views and perspectives of professionals on FM use with pre-school hearing aided children is required. It would be beneficial to know what barriers to the use of FM currently exist for these professionals and whether these were mainly strategic, related to funding or more related to their theoretical understanding of the topic. Over the last 20 years many leading professionals and researchers in the field (Brackett, 1992; Cole & Flexer, 2011; Madell, 1992; Moeller et al., 1996; Ross, 1992) have advocated the use of FM amplification with pre-school hearing aided children. It is unfortunate, even with the latest technological advancements that overcome many of the previous limitations associated with FM use the uptake of FM technology in the UK has been very slow to advance. Parents and carers in this study not only highlighted the ability to incorporate FM technology into their daily routines but also valued the improved quality of life the FM technology offered to them and to their children.

8.1.5. Wellbeing

Improvements in quality of life as a result of using hearing aids (for example, Gatehouse, 1999; Gatehouse & Noble, 2004), bone anchored hearing aids (for example, Dutt et al., 2002) and cochlear implants (for example, Stacey et al., 2006; Summerfield et al., 2002) have been researched in great depth. In comparison very little research has explored the quality of life benefits that may be associated with the use of FM technology. Moeller et al. (1996) did include qualitative data collection where parents completed weekly diaries throughout the study period. However, as seemed to be the main focus of the study, the analysis of the diaries was centred on language specific outcomes rather than overall benefits. As a result very little non language/communication benefit of FM use was reported. The findings described the benefits of FM technology were not limited to communication and language but parents regularly reported children's positive emotions of "enjoyment", "being happier", "laughing", "smiling more" and of their children "loving" the use of the FM system. Furthermore, parents and nursery staff described how the use of FM resulted in an increased sense of social belonging where children were "joining in" more and "participating" in activities where previously they would have remained as outsiders. Statham and Cooper (2009) reported similar results from their study where they found the three participants from their study who had used the FM device found the use of the technology increased children's involvement in activities. The nursery staff for the children in the current study also reported how the children became more active participants. Parents also described how the use of the FM resulted in an increase in confidence for their child allowing them to explore their surroundings without having to constantly look for their parent. The FM device was used as a 'security blanket' in outdoor settings like play centres allowing the children to engage in activities they would not usually get involved in without the use of the FM device. This finding was also reported by Moeller et al. (1996) who found the three younger subjects in their study reported preferences for using the FM device in situations where the carer was not visible because it made them feel more secure.

Although the security benefits explained were more related to the feelings of the child, parents and nursery staff explained the safety benefits of FM use in alerting children to any potential hazards when playing outdoors. Similarly, one mother explained how useful the FM device was when the child would be at the stables or horse riding so she could maintain her daughter's attention and alert her to any dangers. Parents also reflected on how children were much calmer and more comforted when using the FM device especially in the car. One mother described how she found the simple act of communicating whilst driving, with her daughter in the back seat of the car, potentially very dangerous and unsafe. This mother appreciated with the FM how communication in the car became so much easier and safer. The improved child safety provided through FM device use was greatly valued by parents. Overall, the parents acknowledged how the use of the FM did not simply relate to improved well being for the child but also positively influenced parents and carers wellbeing. Parents and nursery staff perceived the benefits of FM device use as a two way benefit where although the child was gaining benefit the users of the device also benefited. This two way benefit seems logical as the use of the FM would require less effort from the parent and reduce the difficulties associated with communicating in difficult acoustic environments. Research on family member's perception of quality of life following early identification of hearing loss in their children suggested low satisfaction ratings in the area of emotional wellbeing (Jackson et al., 2010). Findings from the current study have highlighted how the use of FM technology helped to increase parent's perceptions of wellbeing. Furthermore, the wellbeing reported was not limited to easier communication but parents also described how the benefits to their child were a source of encouragement and motivation for them. Future studies would benefit from further exploring the overall quality of life benefits of FM use, especially in the pre-school years. Research on the benefits of cochlear implants has provided in depth analysis of the quality adjusted life years provided through cochlear implant use (Barton et al., 2006a; Barton et al., 2006b, 2006c; Stacey et al., 2006; Summerfield et al., 2002). Although the two technologies cannot be compared, it would be useful to explore similar concepts with the use of FM technology, especially as the cost of an FM device is minimal in comparison to implant technology.

8.2. Characterisation of pre-school hearing aided children's listening, language and acoustic environments

As explained previously the few studies that did explore the use of FM technology with pre-school children (Brackett, 1992; Gabbard, 2003; Statham and Cooper, 2009) did not provide any detail on daily usage of FM technology. The one study (Moeller et al. 1996) that did include daily usage data lacked detail and only presented a very brief overall percentage of waking hours per day that each subject used their FM technology outside the educational setting. Furthermore, the results from the daily use data failed to capture the range of listening environments the FM may have been used in. The data from this research has captured detailed information from parents on the environments and situations they had used the FM device and whether they found FM use beneficial or not. The purpose of this was to characterise the environments and situations where parents felt their child benefited from FM use. Although, in the literature much information can be found on where theoretically the use of FM technology could provide benefit for pre-school children (Ross, 1992). In practice, there was no published data to support this. The current section will first discuss the environments where parents of pre-school children made use of FM technology. Following this, results from the FMLEC situational analysis of FM use in noise, distance, quiet and auditory only will be discussed. The final two sections will focus on the results of the study carried out with four of the seven participants using the LENA device. These two sections will discuss the data on the acoustic and language environments of pre-school hearing aided children, something which has previously been unpublished.

8.2.1. FM listening environments

The results from the daily use diaries included data reported by parents on where they had used the FM device and whether they found it beneficial or not. As there was no previously published data describing practical FM use with pre-school children it was difficult to anticipate where and for how long the participants would make use of the FM technology. As a result diaries were left very open and parents were simply asked to describe any location or environment where they had used the FM, for how long and whether they found the use of the FM beneficial or not. Surprisingly even within the pre-school population the educational setting of pre-school nurseries was where the highest overall percentage of hours (35%) the FM device was used. Of the five participants who had established consistent use of the FM device, three attended full time nursery and one attended part time nursery. Of the four participants who were enrolled in pre-school nursery, three of the participants individual use data reported the highest percentage of hours for FM use in the nursery setting. Similarly, as these four participants had recorded the most total hours of FM use, their results influenced the overall percentage scores. On reflection, the usage trends for these participants can be expected as the majority of these children’s waking hours would have been spent in the nursery setting. Thereafter, the environment where the highest percentage of hours of FM use was recorded was in the home setting. This also can be expected as the majority of waking hours for pre-school children not attending full time nursery would be expected to be in the home setting. Individual trends in FM use highlighted the highest percentage of hours used was in the home setting for four of the seven participants. The one participant who had attended part time nursery had made more use of the FM in the home setting compared to the nursery setting. It can be argued, that nursery attendance may have been an influential factor in parents overall acceptance of FM technology. However, in response to this argument the final participant (P6) had established consistent use of the FM but did not attend a nursery setting. For this participant a high percentage of use (80%) was recorded in the home setting. Similarly, the results highlight how 65% of total hours of FM use was outside of the nursery setting emphasising the range of environments and situations parents found the FM technology useful in.

Although, percentage of use in outdoors settings, in the car and during shopping were not as high as the nursery and home setting the overall hours of usage in these settings was proportionate to the times children would be expected to be in these settings. For example, the majority of car use resulted in short durational use, however the use in the car was very regular and for one participant FM use in the car was reported daily. This emphasises the benefits perceived by parents of using FM technology in this particular situation. However as the majority of car journeys were of very short duration this was reflected in the total hours of use. This does not mean the use of FM in the car setting may be less important than for example its use in the home setting but highlights how the use of FM in any setting can only be established when the child is in that situation. A similar trend can be established for shopping where FM technology could only be recorded when used in this setting depending on parents shopping patterns. Likewise, as the majority of parents had started study participation during the winter months, outdoor use was not recorded as much at the beginning of the study but picked up a lot more during the summer months. The findings emphasise that although the total hours of FM use provide a reliable insight into the actual FM use recorded, to get a more detailed appreciation of overall FM listening environments, the average duration of use in each setting as well as the number of days used in setting are required.

The five settings of home, nursery, car, shopping and outdoors were the most clearly defined for FM use. It is important to note although home, nursery and outdoors were clearly defined they included a wide range of sub settings where parents valued the use of FM technology. These included play time, reading, circle time, listening to music, attending play groups, horse riding and at parks and play grounds. Each of the activities and situations described by parents could be clearly defined into one of the three environments making it easier to compare FM use across participants. In retrospect, the setting of mealtimes was more difficult to define as although FM device use in this particular setting was valued by parents, their interpretation of this setting was noticeably different. For example, some parents included mealtimes in the general description of home use or outdoors use whereas other clearly described FM use in the kitchen during lunch or at a restaurant or cafe. Given the very social nature of mealtimes and the complications of multiple speakers it would have been appropriate to clearly identify this setting for parents. It was interesting to note one parent describing the family Christmas dinner, an important social event, as being an ideal time to use the FM transmitter. Although there was very minimal use of the direct input facility on the FM device with the TV, which was surprising, it was useful to separate the TV setting from the home setting as this highlighted the lack of TV audio input. The lack of FM use with TV may simply be because parents did not feel the children needed it in this situation as the television volume could be adjusted to suit the child. Similarly, it was useful to separate the car and shopping environments from the outdoor setting as this provided more detail on outdoors use.

Overall, the results highlight the importance of collecting a range of measures on FM use to better understand and characterise FM listening environments. Future studies exploring the use of FM technology would benefit from the data captured in this study to possibly pre-print a range of environments in diaries that may facilitate diary completion as well as provide more in depth information on FM use in a range of environments and settings. This would also help to provide some form of conformity amongst participants when comparing results. The current level of data collected, provides good counselling potential for advising parents on their use of FM. Likewise, the data collected in this study on FM listening situations could be used by professionals to advise parents on the situations and expected duration of FM use in the different situations mentioned. At the beginning of the study there was no published data that could be used as a potential reference when advising parents on pre-school FM use. Although general theoretical guidance was present (Ross, 1992; Moeller et al., 1996), nothing specific was available to guide or provide advice to parents with. Finally, as a result of the extended use of FM systems in the nursery setting, future studies would benefit from a more in depth look at FM device use in pre-school nurseries. The detailed reporting from one of the participant's pre-school nurseries provides an example of the rich data that could be gained from a larger study.

8.2.2. Situational analysis

The FMLEC questionnaire was used to further analyse parents listening evaluation for their children in four situations: noise, quiet, distance and auditory only. The FMLEC questionnaire has previously been used by Gabbard (2003) and more recently by Statham and Cooper (2009). Although both studies did include this evaluation tool within their study protocol, they failed to report any of the situational analysis results. Gabbard (2003) did report results for FM technology assessment which is included as a separate section in the questionnaire and these will be discussed under parental evaluation of FM technology (section 8.4). Moeller et al. (1996) developed their own situational listening profile to illustrate changes in listening skills for the participants in their study. Their SLP consisted of 29 questions using a five-point scale that ranged from "almost always" to "almost never". Responses from parents were divided into four listening categories: multiple talkers, distance listening, background noise and clarification requests. Very small differences in observed changes in listening behaviour over the two year period were noticed for the HA group. However, this was expected by the researchers as the SLP was targeting situations where the FM device would be most beneficial. For the FM group, large improvements occurred for categories of multiple talkers and clarification requests however surprisingly there was not uniform improvement for distance listening and background noise. This finding contradicted the findings from the current study where the largest overall improvements for participants were reported for listening in noise and at a distance. Moeller et al. (1996) did explain their findings for distance listening and background noise were inconsistent with many entries in the weekly observation inventories. This discrepancy was identified by the researchers as possibly related to parents not clearly understanding the instructional set for their situational listening profile. This was one of the reasons why their situational listening profile was not used as part of this research. A further explanation provided by Moeller et al. (1996) was that as children matured and became exposed to a more diverse set of listening situations, parents may have expressed an increased awareness of their child's listening difficulties. However, the results from the current study suggested otherwise as six of the seven participants reported overall improvements in listening in noise, quiet, auditory only and distance at the end of the study, ranging from 18% to 48% overall improvement for all four listening situations. The one participant (P3) who did not report overall improvements was only in the study for three months and did not make much use of the FM system. However even for this participant when a subset of questions relating to the child's ability to differentiate between similar sounding words was removed an overall improvement in all listening situations was reported. The particular subset of questions were marked as not applicable in the first month of the study as the child was too young to complete this, however at the end of the study the parent did complete this set of questions but the scores were quite low, lowering the overall percentages. As the child was still young the ability to differentiate between words would have still been an emerging skill and the low scores may have been more related to the child's stage of development rather than listening with FM technology. One of the interesting findings from this part of the study was the results for P5. P5 had, similar to P3, not made much use of the FM and had dropped out of the study at 15 months of age. However, because of scheduling conflicts the final appointment where the FMLEC was completed was delayed to 18 months of age. At this point a considerable improvement in FMLEC scores were reported. This further highlights the significance of the age variable in FM use with pre-school children and suggests as children start developing verbal skills parents start to perceive more benefit in FM use and therefore make more use of it. The findings suggest even where support from early intervention programs is available for hearing aided children parents may need more support and guidance from professionals to appreciate the value of FM amplification with pre-verbal children.

Although the children in this study reported overall improvements in situational listening with FM technology overtime, the one caveat to these results is that developmentally children's listening skills would be expected to mature overtime. Overall, the results do suggest children's listening skills with FM device use do carry on improving and this may be directly related to developmental maturation, use of FM technology or a combination of both. The findings from Moeller's study (1996) on improvements in 'multi talker' and 'clarification requests' categories for the FM group further supports the theory of improvements in listening being related to FM use. It would have been useful to include the measures of multi talker and clarification in the current research however the breakdown of each category scores were not very clear, unlike the FMLEC, making it difficult to replicate these categories. The FMLEC was a very useful tool in evaluating children's listening with FM technology and provided detailed scoring explanations allowing the user to fully appreciate each situation's scoring method and the questions related to it. Although, the questionnaire may have benefitted from including more categories and clarification requests, this has to be balanced with the length of the questionnaire and the time parents took to complete it. In its current form the questionnaire was set out within two pages and the situational analysis questions were brief and easy for parents to complete in a short time frame. The appropriateness of question number 3 (child distinguishes between similar sounding words) for the younger participants was raised during the study, and although a clear procedure on how to exclude these scores was provided, the overall comparisons were not as accurate overtime. This finding in particular may clarify one of the counter intuitive findings from Gabbard's (2003) study. Gabbard's (2003) study reported no difference in listening evaluation between hearing aids and FM systems however parent's comments highlighted benefits. This contradictory finding may have been a result of the way the overall scores for listening evaluation are calculated and identifies the importance for the provision of actual scores rather than a general statement of findings as this would allow for more accurate comparisons of scores overtime and between conditions set out on the questionnaire.

8.2.3. Acoustic environment

Currently, no published data exists that describes the natural acoustic and language environments of pre-school children. The four participants involved in the LENA study completed four days of recordings resulting in over 192 hours of recorded data of their natural acoustic and language environments. The LENA system categorised children's acoustic environments into one of five categories: 'meaningful', 'distant', 'TV', 'noise' and 'silence and background'. The three categories of 'TV', 'noise' and 'silence and background' did not include any human speech within them. If any human speech was present at any point during the day that particular acoustic environment would be categorised into one of two categories: 'meaningful' or 'distant'. The 'meaningful' category included any speech that occurred within six feet of the child without any 'overlapping' noise or competing speech present and was the only category used by the system to generate report counts (AWC, CT and CV). Surprisingly, the longest duration of time spent in any of the categories was the ‘distant’ category, which accounted for 42% of the children’s natural acoustic environment. This would mean pre-school hearing aided children spent approximately 5 hours a day in an environment categorised by the LENA system as ‘distant’. This definition of the ‘distant’ acoustic category included all forms of speech at a distance or in the presence of competing noise. Any speech that was six or more feet away from the digital language processor (DLP) or where background noise was ‘overlapping’ the speech signal was categorised as ‘distant’.

This finding emphasises the increased potential for FM technology use with pre-school hearing aided children. The major benefit associated with FM technology is the short speaker to microphone distance increases the SNR of the speech signal and overcomes the challenges of distance and noise. The results show approximately 40% of pre-school hearing aided children’s day, whether at home or outdoors is spent in acoustic conditions where speech is at a distance of six feet or more or in background noise. This finding suggests for pre-school hearing aided children to gain access to a clear speech signal the FM technology should be used for longer durations of time compared to what was established by the participants in this study. However, at the same time FM use needs to be balanced with the practicalities of everyday life. One of the major limitations of FM technology use is the transmitter is limited to one person, whereas in everyday activities many situations will arise where a multitude of speakers will be present. Recent innovations in FM technology have introduced multi talker functions where multiple transmitters can be used at the same time. However the cost implications and management of multiple systems makes this option highly impractical in the home setting. Ideally, families and parents may benefit with extended support from professionals on the effective management of language environments. Communication especially in groups by its nature is fast and fluid therefore counselling on the importance of turn taking and improved communication tactics may help parents, siblings and extended family members to improve hearing aided children’s acoustic environments. Furthermore, the use of the LENA acoustic categories can be used as an ideal counselling tool where parents can be shown an hour by hour analysis of the acoustic environments their child was exposed to and how they could overcome some of these by either making changes in the acoustic environment and where possible using FM technology. One such example was recently published as a case study by the LENA foundation (Eberlein, 2011). Eberlein (2011) was concerned about her hearing aided child’s kindergarten classroom acoustics. Although she had requested an FM system for her daughter, her daughter’s teacher felt a sound field system would be sufficient. With the permission of the classroom teacher the LENA system was used to distinguish distant speech from meaningful speech to test the quality of the acoustical environment enabled by the sound field system. The hourly audio environment showed a considerable discrepancy between the child's audio environment at home and at the school. The LENA estimates for 7 a.m. to 8 a.m. at home showed 54% of time was in 'meaningful' and 21% was in 'distant' speech. The data for between 10 a.m. to 11 a.m. at the school showed 15% of speech was in a 'meaningful' environment compared to 83% in the 'distant' environment. Eberlein shared the results with the team of professionals who planned her daughter's Individualised Education Program (IEP) to support her request for an FM system for her daughter. The team of professionals were really impressed with the reports and concluded that although the sound field system made the teachers voice louder, the sound was still distant and often drowned out by other auditory input in the room. The information was used to provide the child with an FM system. This case study highlights the counselling potential the LENA system has both for families and professionals.

Finally, the findings from this study also highlight another important issue. The primary aim of the study was to compare pre-school hearing aided children's language environment (AWC's, CV's and CT's) with and without the use of FM technology. However approximately 40% of children's recorded day was spent in the 'distant' environment and the LENA system did not use 'distant' data to calculate report counts. The only data used to calculate report counts was data included in the 'meaningful' category. The difficulty this posed for analysis was the major benefit and potential increases in AWC' and CT's when using the FM device, would be expected at a distance or in background noise. If this data was not included in the LENA reports any potential FM benefits would not be highlighted. This raises implications for the use of the LENA system in any future research comparing language environments with and without FM use. The findings suggest the LENA in its current format is not sensitive enough to analyse any potential benefits of FM device use. Discussions with FM manufacturers have resulted in possible solutions to overcome this with one potential suggestion of placing a third FM receiver within the LENA hardware. However, this would require major collaborations between the two manufacturers and this may not be achieved easily. When technicians at the LENA foundation were approached a possible solution was to provide a second DLP to the mother or primary speaker to keep close to them for example in a top pocket. Thereafter, as all DLP's are set to exact times through GPS (global positioning satellite) technology, the two recordings could be compared. This may be a solution that could be explored in future studies comparing the language environment of pre-school children with and without FM device use. Overall, the LENA in its current format provides very useful acoustic information related to children's environment and can be used as a positive counselling tool. Interestingly, although the LENA system would not be expected to be sensitive enough to identify benefits of FM use in report counts, a significant benefit for FM use was reported for the number of CT's in the outdoors setting. This may be a result of conversations that may have occurred in the car or whilst the child was in the pram within a distance of six feet that may not have occurred without the use of an FM device. Although the current study encouraged parents to use the FM device as much as possible on the LENA recording days this resulted in higher than average FM device use. Future studies would benefit from having parents use the FM device for the duration of time they would normally expect to use it as this would provide a more realistic comparison of potential differences with and without FM device use.

8.2.4. Language environments

The importance of listening experience was explored by Hart and Risley (1999) who found the number of words spoken to children in the first three years of life had a significant impact on language and educational outcomes in later years. Their study was the basis for the development of the LENA system which provides reports on the number of AWC's, CV's and CT's for children in their naturally occurring environments. Some of the literature on hearing loss in pre-school children does suggest a child's hearing loss can have an effect on the interactive relationship between the child and his parents/carers (Cole & Flexer, 2011). Research conducted by Cole (1994) suggests some of the effects on adult talk to young children with hearing loss included: reduced amount of talk directed to child and more frequent rejecting, critical or ignoring responses. As such it would be expected the number of AWC's and CT's for families of children with hearing loss would be lower than normative samples collected for typically developing children with no hearing loss. Data for the four pre-school hearing aided children in this study compared the AWC's, CT's and CV's with the normative LENA sample using the percentiles function on the LENA software. The results from this study suggest after four separate recordings the average report counts for all three measures were above the median 50th percentile for all four participants with one participant's averages between the 70th to 83rd percentiles. Only one participant's average percentile for CT's was reported at the 46th percentile. Although the literature (Cole, 1994; Cole & Flexer, 2011) suggests children with hearing loss may be exposed to less language, the findings from this study suggest the 'meaningful' language environment for participants was close to or well above the average percentiles for their hearing peers.

The language environment of children has been identified as a significant predictor of developmental outcomes in later years for children with normal hearing (Hart & Risley, 1992), highlighting the greater importance of this variable for children with hearing loss. The LENA promises good counselling potential for ToD's or SLT's working with children with hearing loss and their families to improve these children's language environment. The LENA software has an accessible graphical user interface allowing for important data on language environment to be presented to parents in an easy to understand format. Future studies would benefit from assessing the extent to which the language environment of children could be improved overtime. In addition, it would also be beneficial to know how many LENA recordings it would take to influence any consistent change in families. Although it would be expected that this would vary considerably between families, it would be beneficial to explore this variable.

8.3. Language development of pre-school hearing aided children using FM systems

Previous research on the language development of early identified hearing impaired children reported earlier intervention resulted in significantly better language outcomes (Yoshinaga-Itano et al. 1998; Moeller, 2000). More recently, Vohr et al., 2008 found children identified with hearing loss and enrolled in intervention programs prior to three months of age demonstrated significantly better language outcomes than children identified after three months of age. Vohr et al. (2008) also reported children with moderate to profound hearing losses had significantly lower language outcomes compared with children with mild hearing loss and hearing control subjects. The purpose of collecting language development measures during this study was to explore participant's language development trends and to identify any trends that could be associated with FM device use. It was difficult to establish one consistent easy to administer language measure as the previous research studies used different measures of language making it difficult to accurately compare results. For example Vohr et al. (2008) in their study used the MacArthur Communication Development Inventory, Yoshinaga-Itano et al. (1998) used the Minnesota Child Development Inventory and Moeller (2000) used the Pre-school Language Scale measure. For the purpose of this study the LDS measure was used as it correlated well with widely used standard assessments. Similarly, the LDS measure allowed for easy comparison of language outcomes with normative samples of typically developing children. The results from Vohr et al. (2008) suggest it might not be suitable to compare language outcomes of children with moderate to profound hearing loss with their hearing peers. However, both Moeller (2000) and Yoshinaga et al. (1998) found early identified children did achieve language outcomes that approximated those of their hearing peers, regardless of degree of hearing loss.

The LDS results for the children in this study showed four of the seven participants had age appropriate or close to age appropriate language development throughout the study period. No significant differences in language outcomes were reported for these three participants over the study duration. However, a significant improvement in LDS scores was noted for the children whose first LDS assessments placed them well within the 'at risk' category. By the end of the study two of the participants were in the 'within normal limits' category and one borderline. All three participants had established consistent FM device use during their study involvement. This finding suggests the extended use of FM technology had a positive impact on language scores for those children who were at risk of language delay. It is difficult to generalise this finding with the small number of participants in this study and future studies would benefit from assessing the potential for FM use to improve language outcomes. However, the results from this study do provide insights on the potential for FM technology to provide overall language improvements. The qualitative feedback further supported these findings with the three children, whose language scores were in the 'at risk' category, having more regular and detailed diary entries recognising their child's speech improvement. Although, these three reported language benefits more regularly, improvements in speech associated to FM use were not restricted to them but was also noted by the other parents and nursery staff. Parents and nursery staff's diary entries described improvements in language that they directly associated with FM use. The improvements in language reported included improved ability to copy words and phrases when the FM was in use and clear improvements in the accuracy and clarity of speech.

The qualitative findings for language development in children using FM technology from this study support the qualitative findings from the study done by Moeller et al. (1996). The study by Moeller et al. (1996) was insufficiently powered to detect any significant effect of FM use on language acquisition between the FM and HA groups. However, the parents of children from the FM group commented more frequently (at least twice as often) on their child’s language developments and their comments were more detailed, in the weekly observation inventories, than parents of children in the HA group. Findings for expressive language from Moeller’s study found parents of children from the FM group reported improved language complexity compared to the HA group. Parents of the children in the FM group were more specific in their description of perceived semantic changes and also commented more frequently on the overall length of their child’s sentences.

Parents in this study also reported in detail on the improved access to speech and the opportunities for overhearing provided through the use of FM technology. Parents highlighted how the challenges to listening in environments, such as car journeys, sitting in the pram, walking and playing outdoors and also situations where distance, noise, reverberation and where hearing aid microphones were covered (winter hats, hoods, bicycle and horse riding helmets), were overcome with the use of the FM device. Parents acknowledged the potential provided by the FM technology and based on their own experiences with their child they were able to compare between the FM and HA technologies. The parents were experts in their child’s experiences and were able to identify the settings where access to speech was threatened for their child with HA technology use only and where the FM technology was able to overcome such threats. The detail with which parents were able to reflect on these challenges especially in terms of the situations and environments where they experienced difficulties has previously been unpublished. Although the literature (Madell, 1992) does highlight the situations where theoretically FM technology should provide benefit, the detail with which parents reflected on their use of the FM technology in everyday settings provides a more practical insight into the use of FM technology with pre-school children. Furthermore, in terms of precursors to receptive language, parents identified the potential benefits the FM provided for hearing aided children to overhear speech. Cole &

Flexer (2011) has highlighted how developmental psychology research points to approximately 90% of young children's spoken language being acquired incidentally. Children with hearing loss have reduced potential to overhear compared to their hearing peers, however parents in this research reported how children were found to copy and learn new words not intended for them which they identified as a direct result of FM use. The findings suggest the FM technology provides hearing aided children opportunities to overhear which may not be possible with HA use alone. The findings on overhearing reported by parents in this study support the qualitative findings reported by Moeller et al. (1996) on pragmatic overhearing. Comments from the parents of the FM group were very specific and provided examples of language their child used which suggested developments in pragmatic overhearing such as, "suppose I have an idea", "absolutely not" and "get out of my light". This level of reporting was not found for the HA group. The findings on overhearing challenge the traditional approach of FM technology use where the transmitter is muted when not talking directly to the child. This approach assumes overheard speech is of no value, whereas the findings from this study, the study by Moeller et al. (1996) and the important findings on overhearing by Akhtar et al. (2001), Akhtar (2005) and Floor and Akhtar (2009) suggests this approach may need to be modified. The constant muting of FM technology may remove the opportunity for hearing aided children to overhear what hearing children naturally have access to and naturally learn from.

The qualitative findings reported by parents also highlighted improved receptive language abilities reporting improved listening, improved comprehension, improved concentration and focus and reduced listening effort. The improvement in children's listening skills through the use of FM technology was a key theme. Parents and nursery staff's comments reflected on both general and specific benefits of FM use for children's listening skills and their accounts did follow the theoretical models and constructs of auditory skills development and auditory processing models described in the literature (Erber, 1982; Kuhl, 1987; Musiek & Chermak, 2006). Although, the development of attention and focussing skills would be expected to progressively develop with maturational changes in the central nervous system (Shaffer, 1995), parents noticed more immediate improvements in their child's concentration which they associated with the use of an FM system. The findings suggest the clearer auditory signal presented through the FM device enabled children to maintain better focus and attention. Similarly, parents and nursery staff reported improved comprehension in children whilst the FM technology was in use, with parents and nursery staff regularly reflecting on instances where children were able to understand instructions even in difficult listening situations and also where no visual cues were present. Furthermore, parents and nursery staff also described how the use of the FM technology allowed children to effectively multi task and resulted in reduced listening effort for the children. Research on listening effort (Downs, 1982; Ross, 1997) has shown although children with hearing loss can do well in poor acoustic conditions with increased listening effort, this leaves them with reduced energy for performing other cognitive functions. The findings from this study has highlighted the use of FM technology with pre-school children allowed them to more easily perform activities which required multi tasking both in nursery and home settings. This finding suggests the use of FM technology with pre-school children reduces their listening effort, thus effectively increasing the energy available for performing other cognitive functions. The qualitative findings from this study on receptive language and comprehension supported the qualitative findings from the study by Moeller et al. (1996) on comprehension and clarification needs. Moeller et al. (1996) found parents of children in the FM group more frequently reported observed decreases in their children's requests for clarification compared to parents of children in the HA group. The HA group continued to report problems in poor listening conditions. Furthermore, parents of children in the FM group also reported increases in their child's comprehension of conversations with the use of the FM technology compared to HA use alone.

Overall, the LDS scores for the children in this study and the qualitative feedback from parents and nursery staff have provided detailed insight into the potential FM technology provides for the language development of pre-school hearing aided children. As the numbers in this study were small, future studies would benefit from including more children as well as including more detailed language measures to further explore the potential benefits with FM technology use with pre-school hearing aided children. Furthermore, the LDS results for the children in the 'at risk' category of language development suggest clinics could look at introducing FM technology for children whose language development may be falling behind. Two of the three parents whose LDS scores significantly improved after FM introduction were the parents who reported their children's consistency of hearing aid use increased with the introduction of the FM technology. This may have been one of the reasons for the significant improvements in language development noticed in these two participants. This further highlights how children who may be struggling to establish consistent hearing aid use may actually be the ones who could possibly benefit the most with the provision of FM technology. Clinicians may need to rethink how they make decisions for parents in a technological era where the extensive use of technical equipment has become second nature for many parents of young children. The experience with parents in this study was, at times parents' understanding of the FM technology allocated to them was superior to the understanding of many of the hearing professionals working with them.

8.4. Parental evaluation of FM Technology

Previous studies providing FM technology to pre-school hearing aided children varied in the feedback reported by parents. Statham and Cooper (2009) reported initial difficulties with functioning compatibility and maintenance of the equipment and found these difficulties raised emotional challenges for all families involved. However, they did acknowledge these difficulties were more related to the actual equipment used in the study. For example the FM receivers used in their study required audio shoes which would be expected to raise challenges and genuine concerns in the pre-school population. They did feel the introduction of more recent technology, such as the integrated FM receivers used in the current research, would solve many of the technical and compatibility issues. All parents were consistent in their feedback on how easy they found the technology to use, regardless of whether the parents had established regular use of the FM technology or not. Some parents likened the FM device with a mobile phone and explained how the size and functions were easy to deal with and manage. As mentioned previously, the overall acceptance of the technology and ease of use reported by parents may be a result of increased general acceptance of portable technology like mobile phones and mp3 players. In the same way, nursery staff also reported general acceptance of the technology and competence in its use overtime with different staff members. This finding was contrary to the findings in the study by Moeller et al. (1996) where day care staff found it difficult to use FM technology. Furthermore, parents were confident and comfortable with the daily management of the FM technology and were able to describe their own daily routines in managing the technology which included checking advance features on the device. One parent did note the increased use of the FM technology resulted in more regular battery changes in the hearing aids.

As expected with any technology used regularly, the issue of faults and repairs would be expected to arise. Although for the majority of parents no repairs were required throughout the study period, three participants did require repairs to their systems. For one participant, the repair during the study period consisted of replacing a faulty receiver once. The other two participants had more regular troubles with their device and this seemed to be more a result of them being the first two participants in the study. As the technology was very recent at the time, the FM transmitters they received were from the one of the initial batches distributed in the UK. This may be the reason why their transmitters were more prone to requiring repairs. Both these transmitters did require firmware upgrading during the study period, whereas the transmitters for all other participants had the firmware upgraded prior to issue. Surprisingly although, three of the participants did experience faults with their FM technology needing repairs they did not mention this in their interviews or diaries. This may be simply a result of parents accepting basic repairs and faults as something expected with regular device use similar to faults and repairs occurring with hearing aids. However the results of the technology assessment questions for these three parents did reflect the fact that their systems were sent in for repairs under the question “FM system has remained in good working order”. Gabbard’s study (2003) provided mean scores for the three technology assessment questions on the FMLEC questionnaire for the 9 families involved. The mean rating for “FM system has remained in good working order” was 5 for the participants in that study. This score was higher than the average 4.14 for participants in this study. The mean rating results for the scores on the other two technology assessment questions were higher for the participants in this study compared to Gabbard’s study (2003). Participants mean ratings for “FM system is easy to operate” in Gabbard’s study (2003) was 3.88 compared to 5 for this study. This may suggest the newer technology used in this study was easier to operate or, as explained previously, may be a result of parents being more used to technology because of increased availability and general use of devices such as mobile phones and mp3 players. Finally the “FM system is comfortable for child to use” was slightly higher for this study at 4.86 compared to 4.6 in Gabbard’s study (2003). Although this result was similar in both studies, the slightly higher score in this study may be a result of the improved receiver design of newer technology.

Although parents did not provide much qualitative feedback on repair issues, they were more critical and did report concern about the ergonomic design of the FM transmitter model they were using. Many regularly reported the back clips on the transmitters were unstable and with increased use would fall off at times. Likewise, mothers also found the positioning of the microphone was difficult at times and was highly dependent on the clothing worn at the time. Parents of the three youngest children also described how if the microphone wire was not placed under the garments, their child would pull at it. Although interference was a major issue for participants using FM technology in the study by Moeller et al. (1996), only two instances of interferences were ever reported in this study. This may be a result of improved regulations in place for frequency transmission and also overall improvements in FM technology. Finally, parents did report remembering to mute the FM device as challenging and mothers identified this was something they had to actively take into consideration when using the technology. Although, this is not an ideal situation for children to be in, it was not something that was reported to occur regularly or intentionally. As such the challenges with remembering to mute the FM transmitter for parents seemed minimal compared to amount of benefits and effective use reported by parents. Furthermore, parents unintentionally found children were actively using overhearing in instances where speech was not directed at them increasing opportunities for children to acquire language and learn novel concepts. Overall, parents found the FM technology easy to use but did report challenges specific to the design of their model of FM transmitter. Manufacturers of the technology would benefit from taking on board parental feedback as the challenges and practicalities of using an FM system outside an educational setting with pre-school children would be expectedly different from the more general accepted use of FM technology in the school setting. The findings do suggest parents are competent with new technology and both parents' qualitative feedback and technology assessment scores from the FMLEC questionnaire found the technology easy to use. This further stresses the potential for providing advanced amplification technology to parents of children identified early with hearing loss, and for professionals to dispel with the common concerns voiced of families not being able to cope with new technology (Mulla, 2008). The guidance on the quality standards issued by the UKCFMWG (2008) state "every child with a hearing loss should be considered as a potential candidate for an FM system". For this to happen, clinics should be in a position where they can provide clear explanations on FM technology use to parents of children with hearing loss, offer a trial of FM technology to parents requesting it and if and when parents would like to have the technology fitted be able to provide this service.

8.5. Conclusions

The current section will initially summarise the strengths of the research and acknowledge its limitations. Thereafter the implications of the findings for practice are considered and the section will conclude by outlining directions for future research.

8.5.1. Strengths and limitations

This longitudinal study on the use of FM technology with pre-school hearing aided children has made a significant contribution towards a better understanding of pre-school use of FM amplification. The previous chapters have identified a number of strengths and limitations associated with this research which are summarised in this section.

- Key strengths of the present research lies in the combination of qualitative and quantitative approach to the subject as well as the detail with which the quantitative data was captured. The qualitative data in this research contributed considerably to a comprehensive understanding of FM technology use with pre-school children and offered an insight into the views, interpretation and perspectives of participants that could not be achieved through quantitative methods alone. The existing literature and research on FM use with pre-school children do not present practical data related to the daily use of FM technology. Very little empirical attention has been given to the environments and situations where FM technology was used and no studies have investigated the duration and frequency of FM technology use and what this means to parents and users of the technology. Thus, this research has addressed both a critical knowledge gap in the literature as well as highlighted a number of implications for practice and scope for future research in the area of FM technology use with pre-school hearing aided children.
- The use of the LENA system was a further strength of the present research as without it the level of recorded data captured and the detailed analysis possible through the software would have been beyond the scope of this research. There were limitations regarding the LENA system's sensitivity to FM technology

use. However, this only became apparent through the present research as no published data was present to have indicated this.

- Another important strength of this research was the detailed scrutiny of the advanced 'AutoConnect' feature available in the FM technology provided. In considering the various approaches to achieve FM 'transparency' this study established that there are differences in recommended procedures that may impact on research findings when evaluating new technology. This has identified the need for an internationally agreed approach to achieving FM 'transparency' which includes manufactures and actively promotes best practice.
- The majority of findings from this study were not specific to any particular model of hearing aid or FM device but were relevant to the general topic of improved SNR through the use of wireless amplification technology use with pre-school hearing aided children. The provision of the latest technology to participants may be seen as an inducement to study participation and a limitation to the study. However, as the provision of amplification technology is free at the point of delivery in the UK, this argument is not as significant as it would be in countries that do not employ a similar policy. In addition, the present study findings did not reflect the provision of technology as an incentive as the feedback was not all positive and some participants did not make use of the FM technology provided.
- The main limitation inherent to this research was the small sample size making it difficult to generalise the conclusions from this study. Reluctance to participate from departments and the possibility of 'gatekeeping' from professionals, hesitant regarding the potential benefits of FM use, also affected the recruitment of families of pre-school hearing aided children. Furthermore, the participants in this research were self selected and as a result may have been more likely to be engaged.
- As the study was longitudinal it was very time and labour intensive for the participants who required high levels of engagement throughout the research period. However, the study would have benefited from having a longer study time, allowing for a more reliable assessment of FM use over the duration of

pre-school years. As the present study was part of a programme of research the option of a longer study period from initial fitting to school entry would have been preferable but was outside the scope of this study. Similarly, longitudinal studies with very young children in their very nature present difficulties when interpreting results. As children develop naturally it is difficult to tease out and attribute changes resulting from developmental changes and those resulting from an intervention being studied, in this case FM technology.

- Another major limitation of the study was how the research was very reliant on other professionals to provide services essential for the use of FM technology, for example, earmoulds provision and hearing aid repairs.
- There were some limitations with the situational analysis of FM use with the FMLEC questionnaire where any previous answers completed as not applicable could adversely affect comparisons of total percentage calculations in subsequent results. Similarly, as mentioned previously, the LENA system in the majority of situations was not sensitive enough to detect any potential FM benefit. If this study was to be replicated these two points need to be addressed.

8.5.2. Implications

The findings from this research highlight a number of issues that need to be addressed to better meet the needs of early identified deaf children and their families. One of the major concerns raised during the course of the study was the consistency of hearing aid use in children aged below 15 months. Professionals need to establish the consistency of hearing aid technology use in really young children. Many of the children presently identified through the NHSP are fitted with hearing aids within a few months of birth. The current study highlights how children aged between 11-15 months of age, who had been fitted with hearing aids within two months of birth, had still not established consistent use of hearing aids. This identifies the need for clinics to monitor hearing aid use through data logging software and/or possibly also with basic daily diaries, working closely with pre-school services who have more contact and a more personal relationship with the families. Parents described the reasons behind non use of hearing aids included loose earmoulds, ear infections, and child removing aids. Although some of these issues can be addressed more easily than others, professionals need to investigate the reasons for non use and to liaise with co-professionals in helping families to address these issues. One of the findings from the current study was the use of FM technology increased hearing aid use. Professionals working with pre-school hearing aided children can take this into consideration when assessing ways to establish consistent use of hearing aids with families. Also the evidence in this study highlights that paediatric services need to be sensitive to individual families and to try and fast track earmoulds and repairs.

Another important issue raised was the readiness for paediatric services to offer FM technology provision for pre-school hearing aided children. Currently the AAA has very strict guidelines on who can fit an FM system to children and youth (AAA, 2008). The AAA clearly states audiologists are the single qualified professional to fit all forms of amplification including hearing aids, FM systems and other hearing aid technology. However, in the UK the fitting of FM systems has traditionally been the job of the ToD or Educational Audiologist (Hostler, 2004). The latest UKCFMWG guidance on quality standards state every child with a hearing loss should be considered as a potential candidate for an FM system (UKCFMWG, 2008). The position then is to question why a child with a hearing loss should not have an FM system rather than which child should. If this was to be implemented nationwide the fitting of FM systems would rest with pre-school ToD's or the other option would be for paediatric audiologists to take on this responsibility. With the current advances in FM software and technology, both ToD's and paediatric audiologists wishing to fit pre-school children with FM's need additional training to adopt this responsibility. Some form of conformity and joint working needs to be established so that children and their families across the UK are considered as potential candidates for a personal FM system. Examples of successful partnerships between health and education in the provision of FM technology to pre-school children within the UK do exist (Statham and Cooper, 2009) and these models can potentially be used as examples by other departments.

Professionals fitting FM technology should be fully aware of the theoretical benefits of FM use and should work alongside families to help them maximise FM use in as many situations as possible. The anecdotal concerns that remain with many professionals (Mulla, 2008) need to be addressed, for example professional's concerns regarding families not being able to cope with advanced technology was not substantiated in this study. All parents felt the technology was easy to use and were able to make use of advanced functions as well. Also, when fitting younger pre-verbal children professionals may need to work more closely with parents to help them identify listening behaviours in their child. This may help parents of younger children better appreciate the use of FM technology. Any provision of FM technology would benefit from some form of diary keeping, where parents could note down information that is important to them. These reports can be beneficial for professionals to help families structure their use of FM on an individual basis and more generally the reports can be used anonymously with other families to demonstrate potential benefits of FM use.

The use of LENA as part of this research project has highlighted its immense potential for counselling families of very young deaf children. The importance of language exposure on children's outcomes in later years has been reported (Hart and Risley, 1995). The current LENA system is easy to use and provides detailed information where professionals and families can work together to identify the amount of language their child is being exposed to and the acoustic environment of their child. The LENA system could help parents to increase the amount they talk to their child as well as help to identify noisy times and situations during the day where FM use would be beneficial.

Finally, when designing FM technology, manufacturers need to consider the different demands on an FM system from a parent using the device in the home setting. Traditionally the main user of an FM transmitter was a teacher in a classroom setting. The introduction of FM use with pre-school hearing aided children in a range of environments and settings introduces far more physical demands on FM transmitters. Specific concerns regarding the FM transmitter model used in this study was that the back face often came apart after prolonged use. It would be useful for manufacturers to invite parents and families to use and feedback on any new developments. Similarly, families would benefit from manufacturers providing extended warranties and family friendly return services.

8.5.3. Future scope

There are a number of areas of research that could be investigated to further clarify the issues related to the use of FM technology with pre-school hearing aided children. Primarily, future studies should use a larger and more representative sample of the population to consider the breadth of socio-economic, educational, cultural and geographical diversity represented in the real world. Currently, this area of research on the use of FM technology in the early years can be compared with the research related to early identification of hearing loss approximately 15-20 years ago. It was only after findings from larger more representative studies like the seminal work of Yoshinaga-Itano et al. (1998) emerged, that the introduction of universal newborn hearing screening programmes became widespread. At present, the advancements in FM technology and the early identification of hearing loss provide an ideal platform to conduct a larger more representative study that could prove to be instrumental in the widespread introduction and acceptance of FM technology use in the early years. Similarly including all early identified children would mean that those children with additional and or complex needs would be included in the study. This would be more representative of the population of children served but would significantly alter linguistic outcome measures. Deaf children and their families are heterogeneous by nature. The potential use of FM with any early identified deaf child is an area for future research. Given the low incidence of hearing loss and the importance of such a study it is imperative that the research is of a multi-centre approach and include a number of centres. This could be within the UK or could for example involve centres in Australia, Canada, New Zealand and the USA. This would allow for diaries and language measures to be standardised across the study and provide a more varied population base on which to assess early FM usage.

Additionally, the use of FM with pre-school CI users needs to be explored. The FM receivers for CI's are not as discrete and safe for really young children as the integrated FM receivers available with hearing aids are. Recently more improved models of FM receivers have been introduced. However as CI's are ergonomically much more bulky than hearing aids to begin with, the extra size added on by the receiver may affect parent's motivation to accept the technology and practically may not be feasible for very young children. This issue needs to be explored as the potential benefits of FM use for pre-school children should not be limited to hearing aid users.

An important preliminary study to any future research on FM technology use in the early years would be to establish reasons for inconsistency of hearing aid use in younger children. Without the use of hearing aids the use of FM technology would not be possible. Financial implications of providing hearing instruments within the current system are considerable thus understanding the user perspective of non use of hearing aids has social, developmental and economic implications. This would provide a better understanding of the reasons for non use of hearing aid technology and highlight areas where professionals could work with families to improve hearing aid use. This area of study would also provide useful information on situations where children may benefit from FM use and similarly where FM use is contraindicated.

Any future research on the use of FM technology in the early years would benefit from including more detailed measures of language development, and a more detailed look at the quality of life and ownership of FM technology themes. Although the current study did use the LDS measure to assess language development more detailed standardised assessments of language development would benefit future projects. Furthermore, any potential future research needs to draw attention to the wider benefits of FM use as described in the current study. For example, some of the benefits of improved localisation reported by parents raised some interesting points. Future studies may benefit from building on Maxon & Brackett's (1989) study that pointed to the increased localisation benefits associated with the FM+M mode of hearing aids compared to the M mode of hearing aids. A similar study with pre-school children may highlight the wider benefits of FM use.

Moreover, benefits related to improved quality of life including improved participation, enhanced social inclusion, improved safety and other factors important to the overall wellbeing of parents and children need to be explored and prioritised. Studies similar to those conducted regarding quality adjusted life years with cochlear implant use (Barton et al., 2006c; Summerfield et al., 2002) would be beneficial especially as FM technology is much cheaper. In addition, it would be useful to monitor children's sense of ownership of their FM technology as they got older. Presently, the provision of FM technology is limited to educational settings and the device owned by schools. It would be useful to explore differences in attitudes, ownership levels and overall use of FM technology in children provided with FM technology in the early years compared to those who are limited to its use at school. Additionally, a follow up of this cohort after a few years would provide an interesting window on the effect of early FM use on language, social and academic outcomes.

Another important area of research required when considering FM technology use in the early years is a larger study exploring the views and perspectives of professional's that would be involved in the provision of FM technology to children. It would be important to highlight potential barriers that may exist for professionals including the more general strategic barriers as well as any family or child specific concerns that professionals may have. The concerns and views of professionals would need to be assessed and addressed before widespread introduction of FM technology could be feasible. On a similar note, the views and experiences of pre-school nursery staff on the use of FM technology should be explored in more detail. The extended use of FM technology by nursery staff in the current study highlights how mainstream nurseries were able to incorporate the use of FM technology in their everyday routines. As the educational provisions of children with hearing loss is moving much more towards mainstream educational settings, the views and experiences of nursery staff on the use of FM technology would be very important to explore and share with families, professionals and other nursery settings.

The current study highlighted the potential of the LENA system in research related to outcomes for early identified children with hearing loss. Although the findings from the current study suggested the report counts were not sensitive enough to identify potential benefits of FM device use it may be more useful to use LENA in a large scale study for its intended purpose. The LENA system is primarily a counselling tool and future studies would benefit in assessing its potential with hearing impaired children. By using the easy to understand reports professionals can highlight to parents their child's acoustic and language environment broken down into hourly or five minute segments. This would help parents to implement changes in the child's acoustic environment and increase the amount of language they speak to their child in particular settings and at specific times. It would be useful to identify the extent to which the important variable of meaningful language exposure can be influenced and how many LENA recordings would be required to establish any consistent improvements. In addition, the acoustic environment reports can be used to highlight particular times and situations where FM device use would be ideal.

To conclude, research on the use of FM technology with pre-school hearing aided children is both timely and topical. The current research has provided a unique contribution to the existing literature and research base and provides a basis upon which further research in this area can be taken forward. It is anticipated that this work, together with future research, can lead to the provision of FM technology to pre-school children with hearing loss as a standard part of their early intervention program.

9. References

AAA. (2008). American Academy of Audiology: Clinical Practice Guidelines: Remote Microphone Hearing Assistance Technologies for Children and Youth Birth-21 years Retrieved 18/09/2011, from http://www.audiology.org/resources/documentlibrary/Documents/HATGuideline.pdf

Accardo, P. J., & Capute, A. J. (2005). *The Capute Scales: Cognitive Adaptive Test/ Clinical Linguistic & Auditory Milestone Scale*. Baltimore: Paul H Brookes Publishing.

Akhtar, N. (2005). The robustness of learning through overhearing. *Developmental Science, 8*(2), 199-209.

Akhtar, N., Jipson, J., & Callanan, M. A. (2001). Learning words through overhearing. *Child Development, 72*(2), 416-430.

Archbold, S., Mulla, I., O'Donoghue, G., & Wright, N. (Unpublished). *Long term follow up of paediatric cochlear implanted young people*. The Ear Foundation.

ASHA. (1994). Guidelines for fitting and monitoring FM systems. Report of the ad hoc committee on FM systems and auditory trainers. *American Speech-Language-Hearing Association 36*(12), 1-9.

ASHA. (2002). Guidelines for fitting and monitoring FM systems. Retrieved 18/09/2011, from http://www.asha.org/docs/html/GL2002-00010.html

Auriemmo, J., Keenan, D., Passerieux, D., & Kuk, F. (2005). A protocol for using FM with DSP hearing aids. *The Hearing Journal, 5*(3), 30-42.

Bamford, J., Hostler, M., & Pont, G. (2005). Digital signal processing hearing aids, personal FM systems, and interference: Is there a problem? *Ear & Hearing, 26*(3), 341-349.

Bamford, J., & Saunders, E. (1991). *Hearing Impairment, Auditory Perception and Language Disability*. London: Whurr Publishers.

Barton, G. R., Fortnum, H. M., Stacey, P. C., & Summerfield, A. Q. (2006a). Hearing-impaired children in the United Kingdom, III: Cochlear implantation and the economic costs incurred by families. *Ear and Hearing, 27*(5), 563-574.

Barton, G. R., Stacey, P. C., Fortnum, H. M., & Summerfield, A. Q. (2006b). Hearing-impaired children in the United Kingdom, II: Cochlear implantation and the cost of compulsory education. *Ear and Hearing, 27*(2), 187-207.

Barton, G. R., Stacey, P. C., Fortnum, H. M., & Summerfield, A. Q. (2006c). Hearing-impaired children in the United Kingdom, IV: Cost-effectiveness of pediatric cochlear implantation. *Ear and Hearing, 27*(5), 575-588.

Bayley. (2006). *Bayley Scales of Infant and Toddler Development, Third Edition*. San Antonio: Harcourt Assessment.

Berg, F. S. (1997). *Optimum Listening and Learning Environments. In McCracken, W. & Laoide-Kemp, S. (Eds.) Audiology in Education* London, England: Whurr Publsihers.

Bess, F. H., Chase, P. A., Gravel, J. S., Seewald, R. C., Stelmachowicz, P. G., Tharpe, A. M., & Hedley-Williams, A. (1996). Amplification for Infants and Children with Hearing Loss. *American Journal of Audiology, 5*(1), 53-60.

Boothroyd, A. (1984). Auditory perception of speech contrasts by subjects with sensorineural hearing loss. *Journal of Speech and Hearing Research, 2*, 134-144.

Boothroyd, A. (1992). *The FM Wireless link: An Invisible Microphone Cable. In M. Ross (Ed.) FM auditory training systems: Characteristics, Selection and Use*. Timonium, Maryland: York Press.

Brackett, D. (Ed.). (1992). *Effects of early FM use on speech perception. In M. Ross (Ed.) FM auditory training systems: Characteristics, Selection and Use*. Timomium, MD: York Press.

Bradley, J. S., & Sato, H. (2008). The intelligibility of speech in elementary school classrooms. *Journal of the Acoustical Society of America, 123*(4), 2078-2086.

Bricker, D., Squires, J., & Mounts, L. (1995). *Ages and Stages Questionnaires: A parent-completed, child monitoring system*. Baltimore: Paul H. Brookes.

Bzoch, K. R., League, R., & Brown, V. L. (2003). *Receptive-Expressive Emergent Language Test, Third Edition*. Austin: PRO-ED.

Calderon, R. (2000). Parental Involvement in deaf children's education programs as a predictor of child's language, early reading, and social-emotional development. *Journal of Deaf Studies and Deaf Education, 5*(2), 140-155.

Carr, G. (1997). *The Development of Listening Skills. In McCracken, W. & Laoide-Kemp, S. (Eds.) Audiology in Education* London, England: Whurr Publishers.

Cole, E. B. (1994). Encouraging intelligible spoken language development in infants and toddlers with hearing loss. *Infant and Toddler Intervention, 4*(4), 263-284.

Cole, E. B., & Flexer, C. (2011). *Children with Hearing Loss Developing Listening and Talking*. San Diego: Plural Publishing.

Cox, R. M., & Moore, J. N. (1988). Composite speech spectrum for hearing aid gain prescriptions. *Journal of Speech and Hearing Research, 31*, 102-107.

Davis, Bamford, J., Wilson, I., Ramkalawan, T., Forshaw, M., & Wright, S. (1997). A critical review of the role of neonatal hearing screening in the detection of congenital hearing impairment. *Health technology assessment (Winchester, England), 1*(10).

Dillon, H. (2001). *Hearing Aids*. Stuttgard, Germany: Thieme.

Downs, D. W. (1982). Effect on hearing aid use on speech discrimination and listening effort. *Journal of Speech and Hearing Disorders, 47*, 114-122.

Dutt, S. N., McDermott, A. L., Jelbert, A., Reid, A. P., & Proops, D. W. (2002). The Glasgow benefit inventory in the evaluation of patient satisfaction with the bone-anchored hearing aid: Quality of life issues. *Journal of Laryngology and Otology, 116*(SUPPL. 28), 7-14.

Eberlein, L. (2011). LENA Case Study Retrieved 18/09/2011, from http://www.lenafoundation.org/pdf/Case-Study-Deaf-and-Hard-of-Hearing-2.pdf

Eimas, P. D., Siqueland, E. R., Jusczyk, P. W., & Vigorito, J. (1971). Speech Perception in Infants. *Science, 171*, 303-306.

Eisenberg, L. S., Shannon, R. V., Martinez, A. S., Wygonski, J., & Boothroyd, A. (2000). Speech recognition with reduced spectral cues as a function of age. *Journal of the Acoustical Society of America, 107*(5 I), 2704-2710.

Eiten, L., & Lewis, D. E. (2008). FM verification for the 21st century. *Perspectives on Hearing and Hearing Disorders in Childhood, 18*, 4-9.

Elliott, L. L., & Katz, D. R. (1980). Children's pure-tone detection. *Journal of the Acoustical Society of America, 67*(1), 343-344.

Erber, N. P. (1982). *Audsitory Training*. Washington DC: Alexander Graham Bell Assocaition for the Deaf and Hard of Hearing.

Evans, D. (2004). FM Advantage procedures for the setting up of FM radio systems for use with hearing aids Retrieved 18/09/2011, from http://www.connevans.com/information/fmadvantage.pdf

Fenson, L., Dale, P. S., Reznick, J. S., Thal, D., Bates, E., Hartung, J. P., . . . Reilly, J. S. (2007). *MacArthur Bates Communicative Development Inventories, Second Edition*. Baltimore: Paul H. Brookes Publishing.

Finitzo-Hieber, T., & Tillman, T. W. (1978). Room acoustics effects on mono-syllabic word discrimination ability for normal and hearing impaired children. *Journal of Speech and Hearing Research, 21*, 440-458.

Floor, P., & Akhtar, N. (2006). Can 18-month-old infants learn words by listening in on conversations? *Infancy, 9*(3), 327-339.

Ford, M., Baer, C., Xu, D., Yapanel, U., & Gray, S. (2008). lLTR-03-2: The LENA Lnaguage Environment Anslysis System: Audio Specifications of the DLP-0121 Retrieved 18/09/2011, from http://www.lenafoundation.org/TechReport.aspx/Audio_Specifications/LTR-03-2

Fredrickson, B. L. (1998). Cultivated Emotions: Parental Socialization of Positive Emotions and Self-Conscious Emotions. *Psychological Inquiry, 9*(4), 279-281.

Fredrickson, B. L. (2001). The role of positive emotions in positive psychology: The broaden-and-build theory of positive emotions. *American Psychologist, 56*(3), 218-226.

Fredrickson, B. L., & Joiner, T. (2002). Positive emotions trigger upward spirals toward emotional well-being. *Psychological Science, 13*(2), 172-175.

Fry, D. B. (1966). *The development of the phonological system in the normal and deaf child. In F. Smith and G.A. Miller, eds., The Genesis of Language* Cambridge, Mass: MIT Press.

Gabbard, S. A. (2003). *The Use of FM Technology in Infants and Young Children. In Fabry D & Johnson CD Achieving Clear Communication Employing Sound Solutions.* Stafa: Phonak AG.

Gatehouse, S. (1999). A self-report outcome measure for the evaluation of hearing aid fittings and services. *Health bulletin, 57*(6), 424-436.

Gatehouse, S., & Noble, I. (2004). The Speech, Spatial and Qualities of Hearing Scale (SSQ). *International Journal of Audiology, 43*(2), 85-99.

Gilkerson, J., Coulter, K. K., & Richards, J. (2008). LTR-06-2: Transcriptional Analyses of the LENA Natural Language Corpus Retrieved 18/09/2011, from http://www.lenafoundation.org/TechReport.aspx/Transcription/LTR-06-2

Gilkerson, J., & Richards, J. (2008a). LTR-02-2: The LENA Natural Language Study Retrieved 18/09/2011, from http://www.lenafoundation.org/TechReport.aspx/Natural_Language_Study/LTR-02-2

Gilkerson, J., & Richards, J. (2008b). LTR-07-2: The LENA Developmental Snapshot Retrieved 18/09/2011, from http://www.lenafoundation.org/TechReport.aspx/Snapshot/LTR-07-2

Gilkerson, J., & Richards, J. (2009). LTR-01-2: The Power of Talk 2nd Edition: Impact of Adult Talk, COnversational Turns and TV During the Critical 0-4 Years of Child

Development Retrieved 18/09/2011, from http://www.lenafoundation.org/TechReport.aspx/PowerOfTalk/LTR-01-2

Gilkerson, J., Xu, D., Richards, J., Yapanel, U., & Gray, S. (2010). LTR-11-1: LENA Pro Brochure Retrieved 18/09/2011, from http://www.lenafoundation.org/TechReport.aspx/LPB/LTR-11-1

Hart, B., & Risley, T. R. (1992). American Parenting of Language-Learning Children: Persisting Differences in Family-Child Interactions Observed in Natural Home Environments. *Developmental Psychology, 28*(6), 1096-1105.

Haskins, H. A. (1949). *A phonetically balanced test of speech discrimination for children.* . Masters, Northwestern University, Evanston, IL.

Hawkins, D. B., & Yacullo, W. S. (1984). Signal-to-noise ratio advantage of binaural hearing aids and directional microphones under different levels of reverberation. *Journal of Speech and Hearing Disorders, 49*, 278-286.

Hostler, M. (2004). *Fitting FM Systems with Advanced Digital signal Processing Hearing Aids. In D.A. Fabry & C.DeConde Johnson (Eds.) ACCESS: Achieving Clear Communication Employing Sound Solutions 2003. Proceedings of the First International FM Conference.* . Murten, Switzerland: Phonak Communications AG.

Ireton, H. R., & Thwing, E. J. (1992). *Child Devleopment Inventory*. Circle Pines: American Guidance Service.

Jackson, C. W., Wegner, J. R., & Turnbull, A. P. (2010). Family quality of life following early identification of deafness. *Language, Speech, and Hearing Services in Schools, 41*(2), 194-205.

Juscyk, P. W. (1997). *The Discovery of Spoken Language*. Cambridge, Mass: MIT Press.

Khul, P. A., Gopnik, A., & Meltzoff, A. N. (1999). *The Scientist In The Crib Minds, Brains and How Children Learn*. New York: William Morrow.

Kuhl, P. K. (1987). *Perception of speech and sound in ealry infancy. In Salapatek, P. and Cohen, L. (Eds.), Handbook of infant perceptions: from perception to cognition* (Vol. 2). New York: NY: Academic Press.

Kyle, J., & Sutherland, H. (1993). *Deaf Child at Home*. Bristol: Bristol Deaf Studies Unit, Bristol University.

Lecaunet, J.-P., & Granierre-Deferre, C. (1993). *Speech Stimuli in the Fetal Environment. In B. Boysson-Bardies, S. de Schonen, P. Jusczyk, P. MacNeilage and J. Morton eds., Developmental Neurocognition: Speech and Face Processing in the First Year of Life.* Dordrecht: Kluwer Academic.

Lee, L. (1974). *Developmental sentence analysis: A grammatical assessment procedure for speech and language clinicians*. Evanston, Illinois: North Western University Press.

Lenneberg, E. (1967). *Biological Foundations of Language*. New York: Wiley.

Ling, D. (2002). *Speech and the hearing impaired child, 2nd Edition*. Washington DC: Alexander Graham Bell Association for the Deaf and Hard of Hearing.

Madell, J. R. (1992). *FM Systems for Children Birth to Age Five. In M. Ross (Ed.) FM auditory training systems: Characteristics, selection and Use*. Timomium, MD: York Press.

Madell, J. R. (2011). Helping Families Accept Technology. *ENT & Audiology News, 20*(3), 76-77.

Maxon, A., & Brackett, D. (1989). *Children's localization abilities: Effects of age, hearing loss and amplification.* Paper presented at the Convention of the of the American Speech-Language Asoociation, St. Louis.

McCracken, W., Young, A., & Tattersall, H. (2008). Universal newborn hearing screening: Parental reflections on very early audiological management. *Ear and Hearing, 29*(1), 54-64.

MCHAS. Modernising Childrens Hearing Aid Services Retrieved 12/09/2008, from http://www.psych-sci.manchester.ac.uk/mchas/

Moeller, M. (2000). Early intervention and language development in children who are deaf and hard of hearing. *Pediatrics, 106*(3).

Moeller, M., Donaghy, K. F., Beauchaine, K. L., Lewis, D. E., & Stelmachowicz, P. G. (1996). Longitudinal Study of FM System Use in Nonacademic Settings: Effects on Language Development. *Ear & Hearing 17*(1), 28-41.

Moeller, M., Hoover, B., Putman, C., Arbatatis, K., Bohnenkamp, G., Peterson, B., . . . Stelmachowicz, P. (2007a). Vocalisations of Infants with Hearing Loss Compared with Infants with Normal Hearing: Part 1- Phonetic Devleopment. *Ear and Hearing, 28,* 605-627.

Moeller, M., Hoover, B., Putman, C., Arbatatis, K., Bohnenkamp, G., Peterson, B., . . . Stelmachowicz, P. (2007b). Vocalisations of Infants with Hearing Loss Compared with Infants with Normal Hearing: Part 2 - Transition to Words. *Ear and Hearing, 28,* 628-642.

Moeller, M. P., Hoover, B., Peterson, B., & Stelmachowicz, P. (2009). Consistency of hearing aid use in infants with early-identified hearing loss. *American Journal of Audiology, 18*(1), 14-22.

Mulla, I. (2008). *Exploration of different signal processing strategies used in hearing aids with early identified deaf children.* 1st Year PhD Continuation Report, University of Manchester.

Mullen, E. M. (1995). *Mullen Scales of Early Learning, AGS edition*. Circle Pines: American Guidane Service.

Musiek, F. E., & Chermak, G. D. (2006). *Handbook for central auditory processing disorders: satisfyign the 10 cravings for a new genration of customers*. San Diego, CA: Plural Publishers.

NEF. (2009). A guide to measuring children's well-being Retrieved 18/09/2011, from http://www.neweconomics.org/publications/guide-measuring-children%E2%80%99s-well-being

NICE. (2010). Measuring effectiveness and cost effectiveness: the QALY Retrieved 18/09/2011, from http://www.nice.org.uk/newsroom/features/measuringeffectivenessandcosteffectivenesstheqaly.jsp

Nightingale, D. J., & Cromby, J. (1999). (Eds), Social constructionists psychology: A critical analysis of theory and practice. Buckingham: Open University.

Nozza, R., Rossman, R., Bond, L., & Miller, S. (1990). Infant speech-sound discrimination in noise. *Journal of the Acoustical Society of America, 87*(1), 339-350.

Oller, D. K. (2000). *The Emergence of the Speech Capacity*. Mahwah, NJ: Lawrence Erlbaum Associates.

Oller, D. K., & Eilers, R. E. (1975). Phonetic expectation and transcription validity. *Phonetica, 31*, 288-304.

Oller, D. K., & Griebel, U. (2008). *Complexity and flexibility in infant vocal development and the earliest steps in the evolution of language. in Oller, D.K. and Griebel, U (Eds.) Evolution of Communicative Flexibility: Complexity, Creativity and Adaptability in Human and Animal Communication*. Cambridge, MA: MIT Press.

Oller, D. K., Niyogi, P., Gray, S., Richards, J., Gilkerson, J., Xu, D., . . . Warren, S. F. (2010). Automated vocal analysis of naturalistic recordins from children with autism, language delay, and typical development. *Proceedings of the National Academy of Science, 107*(30), 13354-13359.

Oller, D. K., & Ramsdell, H. L. (2006). A weighted reliability measure for phonetic transcription. *Journal of Speech and Hearing Research, 49*, 1391-1411.

Pasman, R. L., Naatman, R., & Alho, K. (1991). Auditory evoked responses in prematures. *Experimental Psychology: Human Perception and Performance, 14*(129-135).

Phonak. (2007). Inspiro: Discover Dynamic FM Retrieved 18/09/2011, from http://www.connevans.com/information/inspiro_technicalbooklet.pdf

Phonak. (2009). iPOP – Phonak Dynamic Offset Protocol. Retrieved 18/09/2011, from http://www.phonak.com/content/dam/phonak/b2b/Pediatrics/campaign_2010/dynamic_fm/ipop_phonak_dynamic_fm_offset_protocol_en.pdf

Platz, R. (2004). *SNR Advantage, FM Advantage and FM Fitting. In D.A. Fabry & C.DeConde Johnson (Eds.) ACCESS: Achieving Clear Communication Employing Sound Solutions 2003. Proceedings of the First International FM Conference.* . Murten, Switzerland: Phonak Communications AG.

Platz, R. (2006). New insights and developments in verification of FM systems. Paper presented at the American Academy of Audiology Convention, Minneapolis, MN. Retrieved 18/09/2011, from http://www.phonak.com/phonak/com/b2b/en/support/eschooldesk/resources.html

Platz, R. (2010). *Standardization of FM systems for assistive listening applications. Proceedings of ACCESS 2 Virtual Conference on FM-2009.* . Murten, Switzerland: Phonak Communications AG.

Rosetti, L. (1995). *Rossetti Infant-Toddler Langauge Scale*. East Moline, IL: LinguiSystems.

Ross, M. (1992). *FM Auditory Training Systems Characteristics, Selection and Use*. Timonium: York Press.

Ross, M., & Lerman, J. (1970). A picture identification test for hearing-impaired children. *Journal of Speech and Hearing Research, 13*(1), 44-53.

Scollie, S. D., & Seewald, R. C. (2001). Evaluation of electroacoustic test signals I: Comparison with amplified speech. *Ear and Hearing, 23*, 477-487.

Shaffer, D. R. (1995). *Developmental Psychology; Childhood and Adolesence*. Pacfic Grove, California: Brookes.

Sharma, A., Dorman, M. F., & Spahr, A. J. (2002). A sensitive period for the development of the central auditory system in children with cochlear implants: Implications for age of implantation. *Ear and Hearing, 23*(6), 532-539.

Silverman, D. (2005). *Doing Qualitative Research Second Edition*. London: Sage.

Smith, J. A. (Ed.). (2003). *Qualtitative Psychology A Practical Guide to Research Methods*. London: Sage.

Stacey, P. C., Fortnum, H. M., Barton, G. R., & Summerfield, A. Q. (2006). Hearing-impaired children in the United Kingdom, I: Auditory performance, communication skills, educational achievements, quality of life, and cochlear implantation. *Ear and Hearing, 27*(2), 161-186.

Statham, C., & Cooper, H. (2009). Our experiences of introducing FM systems in the early years. *BATOD, January*, 18-20.

Stremel Thomas, K. (2010). Determining Pre-Post-Cochlear Implant Outcomes for Young Children with Deaf-Blindness Through LENA Technology Retrieved 18/09/2011, from http://www.lenafoundation.org/pdf/LENA-Conf-2010/Presentations/LENA-Conf-2010-Katherine-Stremel.pdf

Summerfield, A. Q., Marshall, D. H., Barton, G. R., & Bloor, K. E. (2002). A cost-utility scenario analysis of bilateral cochlear implantation. *Archives of Otolaryngology - Head and Neck Surgery, 128*(11), 1255-1262.

Symington, L. B. (2010). *Using Electroacoustic FM Verification Measures to Assess the Cross-compatibility of FM System Components.* AUD Capstone Project, Central Michigan University, Mount Pleasant, Michigan.

Tattersall, H., & Young, A. (2006). Deaf children identified through newborn hearing screening: Parents' experiences of the diagnostic process. *Child: Care, Health and Development, 32*(1), 33-45.

UKCFMWG. (2008). *UK Chidlrens FM Working Group: Quality Standards for the use of personal FM systems: promoting easier listening fro deaf children*. London: National Deaf Children's Society.

Vohr, B. (2010). Studies of Early Language Development in High-Risk Populations Retrieved 18/09/2011, from http://www.lenafoundation.org/pdf/LENA-Conf-2010/Presentations/LENA-Conf-2010-Betty-Vohr.pdf

Vohr, B., Jodoin-Krauzyk, J., Tucker, R., Johnson, M., & Topol, D. (2008). Early Language Outcomes of Early Identified Infants With Permanent Hearing Loss at 12 to 16 Months of Age. *Pediatrics, 122*(3), 535-544.

Walton, S., Bedford, H., & Dezateux, C. (2006). Use of personal child health records in the UK: Findings from the millenium cohort study. *British Medical Journal, 332*(7536), 269-270.

Ward, Y. (2010). *A Critical Evaluation of 'AutoConnect' using the Phonak mlxi dynamic FM receiver.* MSc Audiology, University of Manchester, Manchester, UK.

Werker, J. F., & Tees, R. C. (1983). Developmental Changes Across Childhood in the Perception of Non-native Speech Sounds. *Canadian Journal of Psychology, 37*, 278-286.

Werker, J. F., & Tees, R. C. (1984). Cross-Language Speech Perception: Evidence for Perceptual Reorganization During the First Year of Life. *Journal of the Acoustical Society of America*, *75,* 1866-1878.

Willig, C. (2001). *Introducing Qualitative Research in Psychology: Adventures in theory and method*. Buckingham: Open University Press.

www.cambridgewellbeing.org. The Well-being Institute Retrieved 18/09/2011, from http://www.cambridgewellbeing.org/index.html

www.lenafoundation.org. Retrieved 18/09/2011, from http://www.lenafoundation.org/ProSystem/Overview.aspx

www.nhsp.info. About Newborn Hearing Screening. *NHS* Retrieved 29/10/2007, from http://hearing.screening.nhs.uk/

www.utoronto.ca. An Overview of the Quality of Life Research Unit Retrieved 18/09/2011, from http://www.utoronto.ca/qol/unit.htm

Xu, D., Yapanel, U., & Gray, S. (2009). LTR-05-2: Relaibaility of the LENA Language Environment Analysis System in Young Children's Natural Home Environment Retrieved 18/09/2011, from http://www.lenafoundation.org/TechReport.aspx/Reliability/LTR-05-2

Xu, D., Yapanel, U., Gray, S., & Baer, C. (2008a). LTR-04-2: The LENA Language Environment Analysis System: The Interpreted Time Segments (ITS) File Retrieved 18/09/2011, from http://www.lenafoundation.org/TechReport.aspx/ITS_File/LTR-04-2

Xu, D., Yapanel, U., Gray, S., Gilkerson, J., Richards, J., & Hansen, J. (2008b). Signal Processing for Young Child Speech Language Development Retrieved 18/09/2011, from http://www.lenafoundation.org/Research/PapersPresentations.aspx

Yoshinaga-Itano, C. (2010). The Missing Link in Language Assessment for Children Who Are Deaf or Hard of Hearing Retrieved 18/09/2011, from http://www.lenafoundation.org/pdf/LENA-Conf-2010/Presentations/LENA-Conf-2010-C-Yoshinaga-Itano.pdf

Yoshinaga-Itano, C., Sedey, A. L., Coulter, D. K., & Mehl, A. L. (1998). Language of early- and later-identified children with hearing loss. *Pediatrics, 102*(5), 1161-1171.

Zimmerman, I. L., Steiner, V. G., & Pond, R. E. (2002). *Preschool Language Scale, Fourth Edition*. San Antonia: The Psychological Corporation.

Appendix A: Ethics Approval Documents

MANCHESTER
1824

The University of Manchester

Faculty of Medical and Human Sciences
The University of Manchester
Simon Building
Brunswick Street
Manchester
M13 9PT

www.manchester.ac.uk

Tuesday, 07 April 2009

To whom it may concern

Role of the Research Sponsor under the Research Governance Framework for Health & Social Care and the Medicines for Human Use (Clinical Trials) Regulations 2004 (SI2004/1031)

I hereby confirm that the University of Manchester would be prepared to accept the role of research sponsor as currently defined in the *Research Governance Framework for Health & Social Care Version 2 (DoH 2005)* and the *Medicines for Human Use (Clinical Trials) Regulations 2004 (SI2004/1031),* in relation to the study:

"Exploration of FM system use with hearing aids in the home setting by early identified deaf children"

I have been informed that this study will be conducted by **Mr Imran Mulla** under the supervision of **Mrs Wendy McCracken** of The University of Manchester.

Sponsorship is conditional upon review and approval of the research by appropriate ethics, NHS and regulatory bodies.

To enable the sponsor to meet their responsibilities as listed in section 3.8 of the Research Governance Framework, Chief Investigators are asked to adhere to the responsibilities as outlined in section 3.6 of the Framework www.dh.gov.uk/research. In line with this requirement **Mrs Wendy McCracken** must ensure that all involved in the research project understand and discharge their responsibilities in accordance with the agreed protocol and any relevant management, ethical and regulatory approvals.

Chief Investigators are also reminded that they must register LREC or MREC approval with The University of Manchester Research Ethics Office in order to ensure that their research project has adequate indemnity cover.

If you have any queries about sponsorship of this project then please address them to
Richard Sherburn Tel: 0161 2755436 Richard.Sherburn@manchester.ac.uk

Yours Faithfully,

Dr Richard Sherburn
Faculty Research Practice Co-ordinator

The University of Manchester, Oxford Road, Manchester M13 9PL Royal Charter Number: RC000797

MANCHESTER
1824

The University
of Manchester

Faculty of Medical and Human Sciences
The University of Manchester
Simon Building
Brunswick Street
Manchester
M13 9PT

www.manchester.ac.uk

To whom it may concern

This is to confirm that where appropriate the insurance policies held by the University of Manchester will apply to the research entitled **"Exploration of FM system use with hearing aids in the home setting by early identified deaf children"** which we have been informed is being conducted by **Mr Imran Mulla** under the academic supervision of **Mrs. Wendy McCracken**.

The University of Manchester has insurance policies in place to cover its sponsorship of research and the research activities of both staff holding substantive appointments and of registered students who are responsible for or conduct research projects or similar activities which involve human subjects. Where the assured is severally or separately responsible for the design, management and conduct of such research, the insurance cover appropriately includes the design, management and conduct of the research.

Insurance cover is conditional upon the research receiving appropriate academic approval and ethical approval by the University of Manchester Senate Committee on the Ethics of Research on Human Beings.

Insurance is provided on the following basis:

For *negligent* harm: University of Manchester Public, Products and Employers' Liability (for students, this would cover the supervisor, who would be held responsible for his or her student). If NHS patients are involved, NHS compensation arrangements would apply provided the correct NHS honorary contracts and R&D management approvals were in place.

For *non-negligent* harm: The University has an insurance policy which offers No Fault Compensation for research led by substantive employees of the University or by students conducting the research as part of their course of study with the University.

Yours Faithfully,

pp **Dr Karen Shaw**
Head of the University of Manchester Research Office

Version 1.0 January 10th 2007

NHS

National Research Ethics Service

Sheffield Research Ethics Committee

1st Floor Vickers Corridor
Northern General Hospital
Herries Road
Sheffield
S5 7AU

Tel: 0114 2714894
Fax: 0114 256 2469

27 May 2010

Mr Imran Mulla
PhD Researcher
B2.16 Ellen Wilkinson Building
School of Psychological Sciences,
University of Manchester, Oxford Rd
M13 9PL

Dear Mr Mulla

Study title:	**Exploration of FM system use with hearing aids in the home setting by early identified deaf children**
REC reference:	**09/H1308/94**
Protocol number:	

This study was given a favourable ethical opinion by the Committee on 22 May 2009.

It is a condition of approval by the Research Ethics Committee that the Chief Investigator should submit a progress report for the study 12 months after the date on which the favourable opinion was given, and then annually thereafter. To date, the Committee has not yet received the annual progress report for the study, which was due on 21 May 2010. It would be appreciated if you could complete and submit the report by no later than 21 July 2010.

Guidance on progress reports and a copy of the standard NRES progress report form is available from the National Research Ethics Service website.

The NRES website also provides guidance on declaring the end of the study.

[Failure to submit progress reports may lead to the REC reviewing its opinion on the study.]

09/H1308/94:	**Please quote this number on all correspondence**

Yours sincerely

SRose

Mrs Sue Rose
Committee Co-ordinator

E-mail: sue.rose@sth.nhs.uk

Copy to: *Dr Karen Shaw*
[R&D Department for NHS care organisation at lead site]

MANCHESTER
1824

The University
of Manchester

Secretary to Dr. T Stibbs
Room 2.005
John Owens Building
The University of Manchester
Oxford Road
Manchester M13 9PL

www.manchester.ac.uk

ref: TPCS/CA/ethics/09084

26 June 2009

Mr Imran Mulla
B2.16 Ellen Wilkinson Building,
School of Psychological Sciences,
University of Manchester

Dear Mr Mulla,

Committee on the Ethics of Research on Human Beings

09084 Mulla, McCracken: Exploration of FM system use with hearing aids in the home setting by early identified deaf children (Sheffield 09/H1308/94)

I write to confirm that at its meeting on 25 June 2009, the Committee received the report on the above project, which had been approved by a recognised ethics committee. That approval is therefore endorsed by the University Ethics Committee.

If you have cause to inform the REC of any unusual or unexpected results that raise questions about the safety of the research, you should also forward a copy to our office. We also ask that you provide us with details of any substantial amendments approved by the REC.

I am pleased to say that we now have a facility to accept and store electronic versions of documents, particularly copies of NRES application forms. From now on, therefore, electronic documents can be emailed to me at the address below. We are happy to accept documents in hard copy. Typically LREC approval letters will be in this form and we would prefer to have the ethics insurance form as a hard copy with a signature.

Yours sincerely

Eliza Pimlott
Secretary to Dr T P C Stibbs

Timothy Stibbs
Compliance and Risk Management
0161 275 2206
0161 275 5697
Timothy.stibbs@manchester.ac.uk

GM PC ReGrouP — Greater Manchester Primary Care Research Governance Partnership NHS

NHS SalfoR+D
Acute & Primary Care Research

Acting NHS SalfoR+D Director: Dr Stephen Waldek
NHS SalfoR+D Associate Director: Dr Lloyd Gregory
ReGrouP Manager: Mrs. Linda Dack

Enquiries: Email: Salford-Regroup-RD@manchester.ac.uk
Tele: 0161 206 8343 - 7650 - 7032 / 4272
Fax: 0161 206 4205

SalfoR+D web address: http://www.nhssalfordrd.org.uk/
ReGrouP web address: http://www.gmregroup.nhs.uk/index.html

10th July 2009

Mr Imran Mulla
University of Manchester
HCD division
Humanities Building (Devas)
Oxford Road
Manchester
M13 9PL

Dear Imran,

Study Title: Exploration of FM system use with hearing aids in the home setting by early identified deaf children
REC Reference No: 09/H1308/94

Thank you for forwarding all the required documentation for your study as above. I am pleased to inform you that your study has been registered with NHS SalfoR+D / ReGrouP and has gained NHS R&D approval from the following NHS Trusts:

- NHS Bolton (PCT)
- NHS Oldham (PCT)

All clinical research must comply with the Health and Safety at Work Act, www.hse.gov.uk and the Data Protection Act. http://www.hmso.gov.uk/acts

It is a legal requirement for Principal Investigators involved in Clinical Trials to have completed accredited ICH GCP training within the last 2 years. Please ensure that you provide the R&D Department with evidence of this (certificate for completing the course). A list of GCP training courses can be obtained from the R&D Office.

All researchers who do not hold a substantive contract with the Trust must hold an honorary research contract before commencing any study activities related to this approval. The 'Research Passport Application Form'.

This can be obtained from web addresses: http://www.gmregroup.nhs.uk/researchers/passports.html and http://www.hope-academic.org.uk/academic/salfordrd/Research%20Passports.html This form should be completed and returned, with a summary C.V and recent (within 6 months) CRB to the address shown above.

Research & Development
Clinical Sciences Building, SRFT, Stott Lane, Salford, Manchester, M6 8HD final version

GM PC ReGrouP — Greater Manchester Primary Care Research Governance Partnership — NHS

NHS SalfoR+D — Acute & Primary Care Research

Acting NHS SalfoR+D Director: Dr Stephen Waldek
NHS SalfoR+D Associate Director: Dr Lloyd Gregory
ReGrouP Manager: Mrs. Linda Dack

Enquiries: Email: Salford-Regroup-RD@manchester.ac.uk
Tele: 0161 206 8343
Fax: 0161 206 4205

SalfoR+D web address: http://www.nhssalfordrd.org.uk/
ReGrouP web address: http://www.gmregroup.nhs.uk/index.html

10th December 2009

Mr Imran Mulla
University of Manchester
HCD division
Humanities Building (Devas)
Oxford Road
Manchester
M13 9PL

Dear Imran,

Study Title: Exploration of FM system use with hearing aids in the home setting by early identified deaf children
REC Reference No: 09/H1308/94
R&D Reference: RMG 09 087

Thank you for forwarding all the required documentation for your study as above. I am pleased to inform you that your study has been registered with NHS SalfoR+D / ReGrouP and has gained NHS R&D approval from the following NHS Trusts:

- NHS Trafford PCT
- NHS Salford PCT

All clinical research must comply with the Health and Safety at Work Act, www.hse.gov.uk and the Data Protection Act. http://www.hmso.gov.uk/acts

It is a legal requirement for Principal Investigators involved in Clinical Trials to have completed accredited ICH GCP training within the last 2 years. Please ensure that you provide the R&D Department with evidence of this (certificate for completing the course). A list of GCP training courses can be obtained from the R&D Office.

All researchers who do not hold a substantive contract with the Trust must hold an honorary research contract before commencing any study activities related to this approval. The 'Research Passport Application Form'.

This can be obtained from web addresses: http://www.gmregroup.nhs.uk/researchers/passports.html and http://www.hope-academic.org.uk/academic/salfordrd/Research%20Passports.html This form should be completed and returned, with a summary C.V and recent (within 6 months) CRB to the address shown above.

Research & Development
Clinical Sciences Building, SRFT, Stott Lane, Salford, Manchester, M6 8HD final version

Appendix B: Parent FM Diary

MANCHESTER 1824

The University of Manchester

My FM Diary

Important contact details:

PhD Researcher:

Imran Mulla MRes, BSc Audiology
University of Manchester
Room B2.16
Ellen Wilkinson Building
Oxford Road
imran.mulla@postgrad.manchester.ac.uk
0161 275 3380

Supervisors:

1. Wendy McCracken
wendy.mccracken@manchester.ac.uk
0161 275 3384

2. Graham Sutton
graham.sutton@manchester.ac.uk
0161 306 1697

Local Audiology Department

Contact Name: ______________________

Phone Number: ______________________

Address: ______________________

____

Participant Id number: ________

2

Date:______________________

Total use: __________(hrs:mins)

Hours of use:
1. From: _________ To: _________

Where:___________ Useful: Yes/No/Not sure

2. From: _________ To: _________

Where:___________ Useful: Yes/No/Not sure

3. From: _________ To: _________

Where:___________ Useful: Yes/No/Not sure

4. From: _________ To: _________

Where:___________ Useful: Yes/No/Not sure

5. From: _________ To: _________

Where:___________ Useful: Yes/No/Not sure

Use the pictures on the next page for ideas.

Please tick the boxes yes (Y) or no (N) below the picture for the places you felt the hearing aid/FM system was useful (Y) or not (N) or leave blank if not used in that given situation.

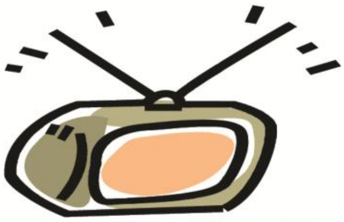
Playground: Y ☐ N ☐

In car: Y ☐ N ☐

Outdoors: Y ☐ N ☐

Meals: Y ☐ N ☐

Shopping: Y ☐ N ☐



Television: Y ☐ N ☐

Indoor Play: Y ☐ N ☐

Pram: Y ☐ N ☐

1. Where did you feel the FM system worked best?

____

____

____

____

____

2. Where did you feel the FM system was of little use?

____

____

____

____

____

3. Can you see any differences in your child's communication?

____

____

____

____

____

4. How did you child show they were listening to you or other sounds?

____

____

____

____

____

5. Were there any changes in your child's behaviour when using the FM   system?

____
____
____
____
____

6. Were there any difficulties/problems in using the FM system?

____
____
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____

7. Is there any other information you would like to share? (this would be very useful)

____
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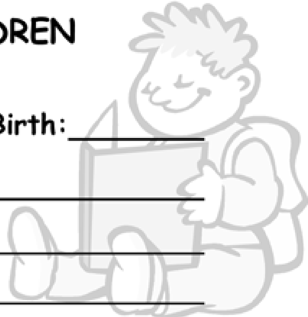
Appendix C: FMLEC

FM LISTENING EVALUATION FOR CHILDREN



Name:____Date of Birth:________

Completed by:____________________________________Date:_______________

__parent __audiologist __teacher other-specify____________________________

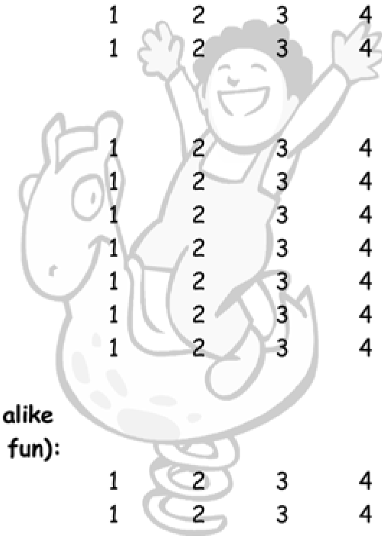
Length of hearing aid usage:____________ HA brand/model:_______________________

Length of FM usage:__________________ FM brand/model:_______________________

___FM used daily Number of hours per day used ______

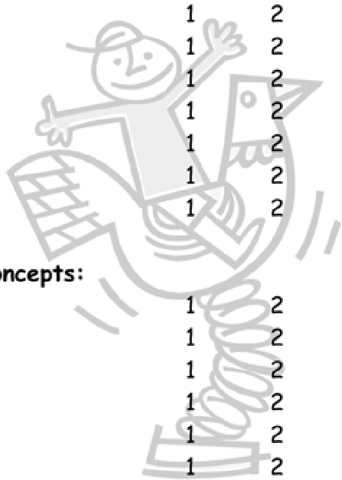
___FM used occasionally Number of hours per week used ______

Please rate the following skills based on the child's behavior or performance on typical days.
Indicate if performance was obtained ☐ with FM or ☐ without FM (baseline).
To score, subtract any NA (not applicable) items from the total, then determine percent for total performance and for each situation.



	SELDOM		SOMETIMES		USUALLY	
1. Child responds to his/her name when spoken to:						
a. In a quiet room, within 3 feet	1	2	3	4	5	NA
b. In a quiet room, at 10 feet	1	2	3	4	5	NA
c. In a noisy room, within 3 feet	1	2	3	4	5	NA
d. In a noisy room, at 10 feet	1	2	3	4	5	NA
e. Without visual cues	1	2	3	4	5	NA
f. From another room	1	2	3	4	5	NA
g. Outside/in the community	1	2	3	4	5	NA
2. Child attends to person speaking:						
a. In a quiet room, within 3 feet	1	2	3	4	5	NA
b. In a quiet room, at 10 feet	1	2	3	4	5	NA
c. In a noisy room, within 3 feet	1	2	3	4	5	NA
d. In a noisy room, at 10 feet	1	2	3	4	5	NA
e. Without visual cues	1	2	3	4	5	NA
f. From another room	1	2	3	4	5	NA
g. Outside/in the community	1	2	3	4	5	NA
3. Child distinguishes between words that sound alike (e.g., bay for day, sink for think, or sun for fun):						
a. In a quiet room, within 3 feet	1	2	3	4	5	NA
b. In a quiet room, at 10 feet	1	2	3	4	5	NA
c. In a noisy room, within 3 feet	1	2	3	4	5	NA
d. In a noisy room, at 10 feet	1	2	3	4	5	NA
e. Without visual cues	1	2	3	4	5	NA
f. From another room	1	2	3	4	5	NA
g. Outside/in the community	1	2	3	4	5	NA

	SELDOM		SOMETIMES		USUALLY	
4. Child responds accurately to spoken directions and/or questions:						
a. In a quiet room, within 3 feet	1	2	3	4	5	NA
b. In a quiet room, at 10 feet	1	2	3	4	5	NA
c. In a noisy room, within 3 feet	1	2	3	4	5	NA
d. In a noisy room, at 10 feet	1	2	3	4	5	NA
e. Without visual cues	1	2	3	4	5	NA
f. From another room	1	2	3	4	5	NA
g. Outside/in the community	1	2	3	4	5	NA
5. Child comprehends oral instruction & concepts:						
a. In a quiet room, within 3 feet	1	2	3	4	5	NA
b. In a quiet room, at 10 feet	1	2	3	4	5	NA
c. In a noisy room, within 3 feet	1	2	3	4	5	NA
d. In a noisy room, at 10 feet	1	2	3	4	5	NA
e. Without visual cues	1	2	3	4	5	NA
f. From another room	1	2	3	4	5	NA
g. Outside/in the community	1	2	3	4	5	NA



TOTAL SCORE: _____/(175) = [ ] % __with FM __without FM

Situational Analysis: Quiet (a,b) ____/(50) = [ ] % **Noise (c,d,g) ____/(75) = [ ] %**

Auditory only (e) ____/(25) = [ ] % **Distance (b,d,f) ____/(75) = [ ] %**

Information on FM Use:

HA/FM system is easy to operate:	1	2	3	4	5	NA
HA/FM system has remained in good working order:	1	2	3	4	5	NA
HA/FM system is comfortable for child to use:	1	2	3	4	5	NA
Child tries to turn HA/FM system off:	1	2	3	4	5	NA
Feedback (whistling noise) is present with HA/FM:	1	2	3	4	5	NA

Indicate types of activities the FM is used for?

__ snacks __ play __ story-time/reading __ playground __ walks

__ listening/language/speech therapy __ shopping __ car

other (describe) ____

For which of the above activities do you think the FM was most beneficial?

What do you think is the greatest benefit(s) of the FM system?

What do you think is the greatest challenge(s) with the FM system?

Appendix D: LENA Developmental Snapshot

1.	When you talk to your child, does he/she look in the direction of your voice? For example: Does your child turn his/her head and/or move his/her eyes to look for you?	Yes ☐	Not Yet ☐
2.	Does your child vocalize or make sounds in response to your smile or voice?	Yes ☐	Not Yet ☐
3.	Does your child have different cries to indicate different needs? For example: Does your child's "hungry cry" sound different from the cry he/she makes when tired?	Yes ☐	Not Yet ☐
4.	Does your child express pleasure or displeasure by using sounds other than crying or laughing? For example: Does your child make "happy" sounds or sounds of frustration?	Yes ☐	Not Yet ☐
5.	Does your child bring toys or objects to his/her mouth? For example: Does your child mouth objects or place objects in his/her mouth?	Yes ☐	Not Yet ☐
6.	Does your child laugh?	Yes ☐	Not Yet ☐
7.	Does your child engage in "vocal play" by producing a wide variety of sounds? For example: Does your child produce sounds that range from very high pitch (squeals) to very low pitch (growls) and does he/she produce "raspberries" by putting lips tightly together and blowing air to produce a vibrating play-like sound?	Yes ☐	Not Yet ☐
8.	Does your child produce two or more vowel sounds, such as /ah/ or /ooh/ ?	Yes ☐	Not Yet ☐
9.	Does your child recognize his/her name (or nickname)? For example: When you say your child's name (or nickname) does it interrupt his/her activity such that he/she stops and looks toward you?	Yes ☐	Not Yet ☐
10.	Does your child shout or use vocalizations/make sounds to get your attention?	Yes ☐	Not Yet ☐
11.	Does your child imitate sounds you or others make?	Yes ☐	Not Yet ☐
12.	Does your child repeat two similar sounds together (not necessarily referring to a specific object or person)? For example: Does your child say things like "bababa" or "dadada"?	Yes ☐	Not Yet ☐
13.	When you say things to your child such as "want up?" or "bye-bye" does your child respond by lifting his/her arms or waving?	Yes ☐	Not Yet ☐
14.	Does your child put different sounds together? For example: Does your child say things such as "bah-dah", "ah-bee-tah" or "ah-mee-ga"?	Yes ☐	Not Yet ☐
15.	Does your child vocalize while gesturing to let you know what he/she wants? For example: Does your child point or motion toward a desired object while vocalizing?	Yes ☐	Not Yet ☐
16.	Does your child say any word besides "mama" or "dada"? For example: A "word" can be an attempt at a real word such as "ba" for "ball" or "wawa" for "water".	Yes ☐	Not Yet ☐
17.	Does your child give you an object when you ask for it? For example: If you say "Give me your shoes " or "Give me the ball", does your child respond correctly?	Yes ☐	Not Yet ☐
18.	Does your child follow simple 1-step directions? For example: If you say "Go get your shoes" or "Put your toy on the bed", will your child respond correctly?	Yes ☐	Not Yet ☐
19.	When you name different objects, does your child point to them? For example: If you say "Where is the ball?" or "See the truck?", will your child point to the correct object?	Yes ☐	Not Yet ☐

20.	Can you tell by the way your child's voice sounds that he/she is asking a question? For example: When your child is babbling but you can't make out the words, can you still tell that he/she is trying to ask a question by a rise in pitch at the end of the babbles?	Yes ☐ Not Yet ☐
21.	Does your child identify basic body parts on himself/herself? For example: Can your child point to his/her nose, eyes, mouth, toes, and hair?	Yes ☐ Not Yet ☐
22.	Does your child say at least 10 meaningful words that you consistently recognize? The words don't necessarily have to be pronounced perfectly. For example: If your child consistently uses "ba" for "bottle", this counts as a word.	Yes ☐ Not Yet ☐
23.	Does your child point to objects named in books? For example: If you say something like "Show me the cat", does your child point to the correct picture?	Yes ☐ Not Yet ☐
24.	Does your child spontaneously repeat words that he/she has heard in conversation?	Yes ☐ Not Yet ☐
25.	Does your child follow 2-step directions? For example: If you say something like "Go get your shoes and put them on the table" or "Go get your coat and give it to your grandma", will he/she respond correctly?	Yes ☐ Not Yet ☐
26.	Does your child understand the meaning of at least four action words without the use of gestures? For example: If you say "jump" or "throw" without demonstrating the action, will he/she respond correctly?	Yes ☐ Not Yet ☐
27.	Does your child understand "what", "where", and "who" questions?	Yes ☐ Not Yet ☐
28.	Does your child name familiar objects in a room?	Yes ☐ Not Yet ☐
29.	When you point to pictures in a book, does your child name them?	Yes ☐ Not Yet ☐
30.	Does your child understand "location" words such as "in", "on", and "out"?	Yes ☐ Not Yet ☐
31.	Does your child combine two or more words together to form simple phrases? For example: Does your child say things like "want ball" or "mommy sit"?	Yes ☐ Not Yet ☐
32.	Does your child have at least a 50 word spoken vocabulary?	Yes ☐ Not Yet ☐
33.	Does your child understand the concept of "one"? For example: If you point to a group of blocks and ask your child to hand you "one", will your child respond correctly?	Yes ☐ Not Yet ☐
34.	Does your child follow 3-step directions without getting distracted? For example: If you say something like "Go to your room, get your bear and bring it to me", will your child respond correctly?	Yes ☐ Not Yet ☐
35.	Does your child say "I", "me", and "you"?	Yes ☐ Not Yet ☐
36.	Does your child understand color words? For example: If you say something like "Point to the red one", will he/she correctly identify the object?	Yes ☐ Not Yet ☐
37.	Is your child starting to use size concepts? For example: Does your child say things like "big" and "little"?	Yes ☐ Not Yet ☐
38.	Is your child using sentences that are four words in length?	Yes ☐ Not Yet ☐
39.	Is your child adding "-s" to words to indicate "more than one"? For example: Does your child say "cats" for more than one cat, or "spoons" for more than one spoon?	Yes ☐ Not Yet ☐
40.	Can your child tell you what to do with simple objects? For example: If you say something like "Here is a toothbrush, what do we do with a toothbrush?", will he/she tell you what it is used for?	Yes ☐ Not Yet ☐

41. Is your child adding "-ing" to the end of verbs to indicate ongoing action? For example: Does your child use words like "eating", "jumping", and "running"?	Yes ☐	Not Yet ☐
42. Does your child use the words "a", "an", and "the"? For example: Does your child say things like "a bed", "an apple", and "the ball"?	Yes ☐	Not Yet ☐
43. Can your child name common shapes such as circle, triangle, square, and star?	Yes ☐	Not Yet ☐
44. Does your child understand concepts like "least", "most", and "first"?	Yes ☐	Not Yet ☐
45. Does your child understand concepts like "tall", "short", and "long"?	Yes ☐	Not Yet ☐
46. Does your child use the plural pronouns "we", "they", "them", and "us"?	Yes ☐	Not Yet ☐
47. Is your child adding "-ed" to the end of verbs to indicate an action that happened in the past? For example: Does your child say things like "jumped" or "played"?	Yes ☐	Not Yet ☐
48. Does your child spontaneously produce sentences that are 10 or more words in length?	Yes ☐	Not Yet ☐
49. Can your child name items that belong to a common category? For example: If you say something like "Tell me three fruits you like" or "Tell me the names of three animals", will your child respond correctly?	Yes ☐	Not Yet ☐
50. Can your child retell a story or event with a beginning, middle, and end without using pictures? For example: Does your child tell a complete story (beginning, middle and end) so you understand the story and what your child is expressing/explaining?	Yes ☐	Not Yet ☐
51. If you name an object, can your child describe two things about the object? For example: If you say "Tell me two things about a bike.", will your child respond correctly?	Yes ☐	Not Yet ☐
52. Does your child ask you about the meanings of words and then use the word in a sentence?	Yes ☐	Not Yet ☐

Appendix E: Interview Schedule

1. Introduction
2. How was your experience of using an FM system with your child?
3. What were the main challenges of using the FM system?
4. Were there any times or environments where you found the FM particularly useful?
5. Were there any drivers that prompted you to make more use of the FM system?
6. Were the any barriers that stopped you from using the FM system?
    a. In any specific environment?
    b. At any specific times?
7. How did you feel your child perceived the use of the FM system
    a. Reactions?
8. Did you perceive any differences when using the FM compared to when using the hearing aid alone?
    a. Car, pram, mealtimes etc.
9. What was your experience of physically using an FM?
    a. Wearing the FM?
    b. Suggestions/comments?
10. How confident were you with the technology?
    a. Did you explore/interact with the menu?
    b. Make use of any functions?
    c. Look on internet for tips etc.
11. What basic daily management was implemented for the FM system?
12. Looking back, was there any information you would have liked to have prior to being given the FM systems?
13. Overall did you find the FM system useful?
14. Do you feel you will make use of the FM system in the future with your child?
    a. Main environments?
15. Do you have any advice or suggestions for parents who may be thinking of using an FM system with their hearing aided child?
16. How was the participation in the study?
    a. Diary keeping? Always able to keep up with actual use
    b. Number of questionnaires, etc.

Appendix F: Audiology department recruitment

Site	Site Name	No of participants ID'd	Number Recruited	Reason for Non-recruitment
1	Bolton	3	3	
2	Manchester South (Trafford)	3	3	
3	Heywood, Middleton and Rochdale	3 / 4	0	Department cancelled participation because of waiting lists
4	Salford	1	1	
5	Oldham	1	0	Child was selected for CI's
6	Manchester Central	1	0	Father of infant was wheelchair user and felt study participation too intensive
7	Bury	0	0	No response
8	Manchester North	0	0	No response
9	Stockport	0	0	No response
10	Tameside and Glossop	0	0	No response

Appendix G: Audiological data for each participant

P1:

	.250 kHz	.500 kHz	1 kHz	2 kHz	4 kHz	8 kHz
Right	65	65	90	85	95	95
Left	55	55	80	80	75	75

P2:

	.250 kHz	.500 kHz	1 kHz	2 kHz	4 kHz	8 kHz
Right		90	90	85	80	
Left		95	95	95	90	

P3:

	.250 kHz	.500 kHz	1 kHz	2 kHz	4 kHz	8 kHz
Right		55	70	70	75	
Left		55	65	60	75	

P4:

	.250 kHz	.500 kHz	1 kHz	2 kHz	4 kHz	8 kHz
Right		100	95	100	100	
Left		75	85	90	100	

P5:

	.250 kHz	.500 kHz	1 kHz	2 kHz	4 kHz	8 kHz
Right		70	80	80	70	
Left		60	80	75	65	

P6:

	.250 kHz	.500 kHz	1 kHz	2 kHz	4 kHz	8 kHz
Right		90	85	80	90	
Left		95	85	85	105	

P7:

	.250 kHz	.500 kHz	1 kHz	2 kHz	4 kHz	8 kHz
Right		50	55	50	65	
Left		65	70	60	60	