Soundfield systems and Radio Aids: exploring the effects of rebroadcasting.

A study submitted in partial fulfilment of the requirements for the degree of Master of Science of the University of Hertfordshire

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Abbreviations

AAA	American Academy of Audiology
ADS	Audio Distribution system
ALD	Assistive Listening Device
ANSI	American National Standards Institute
ASA	Acoustical Society of America
AWC	Adult Word Count
BSA	British Society of Audiology
CADS	Classroom Audio Distribution system
CI	Cochlear Implant
CYP	Children and Young people
CYP(HI)	Children and Young people with a hearing impairment
DWO	Digi-Speech Weighted Output
FM	Frequency Modulation
GCSE	General Certificate of Secondary Education
HA	Hearing Aid
LENA™	Language Environment Analysis
MJWL	Manchester Junior Word lists
NAD	National Association of the Deaf
NDCS	National Deaf Children's Society
P	Participant e.g. P4 = Participant 4
PARROT	PARROTplus Speech Discrimination tester
REC	Research Ethics Committee
RAS	Radio Aid System (transmitter/receiver)
RT	Reverberation time
SFS	Soundfield system
SLM	Sound Level meter
SNR	Signal to Noise Ratio
UKCFMWG	United Kingdom Childrens FM Working Group

Abstract

Assistive listening devices play an important part in the education of children and young people with a hearing loss. Both Soundfield systems (SFS) and Radio Aid systems (RAS) are used to support effective access to learning in the classroom. There is currently little research into the impact that rebroadcasting a SFS through the RAS has on children and young people with a hearing impairment's ability to discriminate speech.

This study considers the impact that rebroadcasting has both on transparency and the ability to discriminate speech. The research adds to the body of evidence around the benefit of using Soundfield systems in the classroom. A mixed methods approach was used with four studies involving five participants with a hearing loss, of primary and secondary age.

Results using the LENA™ system showed that there was increased access to meaningful speech when a Soundfield system was used. Electro-acoustic testing demonstrated a loss of transparency when rebroadcasting, with under-amplification across all frequencies; more pronounced in the higher frequencies. The ability to discriminate speech was also negatively impacted by the process of unverified rebroadcasting. A proposed electro-acoustic balance of the rebroadcast systems appears to be of benefit, providing transparency and impacting positively on speech discrimination scores.

The research concludes that Soundfield systems support the provision of a good acoustic environment within the classroom. It also finds that the process of rebroadcasting a Soundfield system through a Radio Aid system requires careful management. The research supports the need to develop guidance on the use of electro-acoustic balance and speech discrimination testing when rebroadcasting. The verification process should also include due consideration of the individual user's preferences to support the most effective use of Assistive Listening devices.

1. Introduction

1.1. Background

Listening is a complex task that goes much beyond the ability to hear (Beck & Flexer, 2011). Carroll et al., (2016) state that the perception of speech is dependent on a range of interacting variables including acoustic-perceptual, cognitive and linguistic factors. This review will consider the impact that acoustic-perceptual factors, namely signal-to-noise ratio (SNR) interplaying with pure tone threshold, have on both children's and adults' perception of speech. It will also review the impact that the use of assistive listening devices (ALD's) has on the listener's access to speech.

ALD's is a collective term used to describe technology that supports access to audition using a microphone to capture the signal, which is then broadcast wirelessly to the listener (NAD, 2017).

1.2. Outline of chapters

This study concerns the impact signal to noise ratio has on the ability to access speech and the effective use of technology to support this access. Chapter 2 will review the literature relevant to this area of research. It will focus in particular on studies considering the benefit provided by Assistive Listening devices and review the research on, and processes to support, verification when using such devices. Chapter 3 will outline the methodology used and will include recruitment, ethics, equipment and procedure. It will also describe the quantitative and qualitative methods of data collection and analysis. Chapter 4 will collate and evaluate the results obtained though data collection. The fifth chapter will discuss the findings of this research and the study will conclude with a chapter summarising the main findings; including the strengths and weaknesses of the study and recommendations for future research.

2. Literature Review

The review will comprise seven sections. Section 1 will review the impact that altering the signal to noise ratio (SNR) has on adults' ability to discriminate speech. Section 2 and 3 will consider the impact a reduced SNR has on speech discrimination for children and young people, and more specifically for those with a hearing impairment. Assistive listening devices, namely the Radio Aid system (RAS) and the Soundfield system (SFS), used in educational settings to support access to speech, will be reviewed in Sections 4 and 5. To ensure optimal working of these devices there needs to be transparency of signal with the users' personal hearing instruments. Section 6 will consider transparency with an RAS and Section 7 will reflect on the impact rebroadcasting a RAS through a SFS has on transparency. The chapter will conclude with a section outlining the aims of this study.

2.1. Impact of Signal-to-Noise ratio (SNR) on adult listeners' perception of speech

Noise relates to any sound that interferes with the signal that the listener wishes to hear and in the context of this study that signal is speech. Distance from the speaker, reverberation time and background noise level all interact to impede the clarity of the speech signal being received by the listener. Ross et al. (2011) indicated that SNR was potentially the key factor facilitating the perception of speech. Whitmer et al. (2016: p.447) concurred, stating that the most important parameter affecting, 'the ability to hear and understand speech in the presence of background noise is the signal-to-noise ratio (SNR).'

Most young adults with hearing within normal levels are able to detect speech in poor listening conditions with a neutral or even negative SNR (Pichora-Fuller et al., 1995; Neuman et al., 2010). Klatte et al. (2010) however argued that these laboratory based findings did not relate to listening conditions in the real world. In a study of 94 adults with a mean age of 23 years they found that even with favourable reverberation times (RT = 0.47seconds), when the SNR was increased from 3dB to 15dB, speech perception scores dropped by 2%. The research indicated that when unfavourable reverberation times were introduced (RT = 1.1 seconds) scores fell by a further 30%. Furthermore Heinrich et al.

(2008) in a study of 99 adults aged 18 to 25 years found that speech noise (creating a SNR of <2dB) had an adverse effect on capability in short-term memory tasks, with an average drop of 15% in accuracy from tests performed in quiet; the speech perception scores at the same SNR were at ≥90% accuracy. Reverberant conditions coupled with a poor signal to noise ratio can have an adverse impact on a normally hearing adult's ability to both discriminate and make sense of speech.

2.2. Impact of Signal-to-Noise ratio on children's perception of speech

Studies indicate adults with normal hearing do not require as advantageous a signal to noise ratio as children with normal hearing in order to discriminate speech. The negative impact that background noise, distance from the speaker and high reverberation levels have on children's ability to discriminate speech has been well documented for over thirty years (Elliott, 1982; Ross, 1992; Eisenberg et al., 2000; da Cruz, 2016). Children do not have the advantage provided by top-down processing; a consequence of adults having a more developed linguistic register to support their discrimination.

Bradley & Sato (2008) noted significantly decreased speech intelligibility for children aged six years when noise was present, even with a SNR of +15dB. Neuman et al. (2010) in a study involving 63 children found SNR's needed to be ≥10 dB (at a low reverberation time (RT) of 0.3 seconds) in a virtual classroom to achieve 95% accuracy. In reverberant and noisy listening conditions children benefit from an enhanced signal to noise ratio to support access to speech.

2.3. Impact of Signal-to-Noise ratio on children with hearing impairment's perception of speech

Children and young people with a hearing impairment (CYP(HI)) have additional challenges in terms of access to the speech signal; a consequence of reduced access to audition, dynamic range, frequency resolution and temporal resolution (Dillon, 2012). Studies over a wide time-frame have considered the impact reducing the SNR has on speech perception (Finitzo-Hieber & Tillman, 1978; Neuman et al., 2012).

Crandell (1993) compared speech recognition capacity in noise between children with normal hearing and those with a minimal hearing loss. He found that children with a minimal hearing loss scored at 25 percentage points below their hearing peers in speech tests when the SNR was -6dB. Davies et al. (2001) in a study of 14 cochlear implanted CYP aged between 7 and 14 years, found that an increase in noise level of just 3dB impacted negatively on their speech perception. There have however been significant changes in both age at implantation and advances in personal hearing instrument technology since this research was carried out, thereby necessitating the need to consider more recent research. Iglehart (2016) considered the impact that raising the reverberation time alongside noise levels had on children in a classroom situation. The study of 23 cochlear implanted children and 23 hearing children (aged 5.8 - 16 years) found that those with a hearing loss required a higher SNR than their hearing counterparts in order to access speech at RT levels of both 0.6 seconds and 0.9 seconds. The SNR required by the CYP(HI) children to achieve 50% accuracy in speech tests ranged from +18dB to +27dB. For the hearing cohort the levels required ranged from -3dB to 18dB. Iglehart concluded that both SNR and RT are significant and interplaying variables impacting on the accessibility of speech for CYP(HI).

Equally Yang et al. (2012) in a study of 34 CYP with severe to profound hearing losses noted that a reduction in the SNR from 10dB to 0dB impacted on the average score in speech discrimination tests, with a decrease in accuracy of 17% noted. They also investigated the impact that providing contextual cues had on scores in speech discrimination tests. Yang et al. reported that with a constant SNR of 10dB, the children's accuracy level dropped by an average of 16% when the sentences contained information that had low predictability as opposed to high predictability. When the SNR was reduced to 0dB the level of predictability of the test material again impacted on overall test scores; the difference between the high and low predictability results was however only 10%. Yang et al.'s inclusion criteria indicated that the CYP had to be 10 years and above and using an auditory device for at least one year. There is no indication of age at diagnosis or indeed if they had a progressive loss which

may have affected scores in the predictability section of the experiment. Nevertheless, in classrooms where children are accessing new and unfamiliar language, a lack of predictability of language used will compound the issues that CYP(HI) have in discriminating speech in an unfavourable SNR.

There will also be other interplaying variables impacting on individual CYP(HI)'s ability to discriminate speech such as the participant's age, level of education, loss type and level and the hearing instrument used.

Whilst hearing aid technology is continuously improving and thereby offering programmes and algorithms to support listening in noise, many children still require additional assistive listening devices (ALD) to support access through the enhancement of the signal to noise ratio.

2.4. Radio Aid systems: Impact on children with a hearing impairment's perception of speech

The majority of children and young people with a hearing impairment (CYP(HI)) are educated in mainstream classrooms. In these classrooms they have to contend with the signal to noise ratio being reduced as a result of distance from the signal, raised background noise levels and in some instances less than ideal acoustic conditions. These CYP(HI) spend a significant proportion of the school day accessing learning by listening to the teacher or their peers. The use of Radio Aid systems (RAS) to support access to speech in these settings, through sufficient enhancement of the signal, is well documented (Boothroyd & Iglehart, 1998; Crandell et al., 2005; Thibodeau, 2010; Wolfe et al., 2015).

A Radio Aid system in this study is a transmitter that transmits sound wirelessly to a receiver attached to a hearing aid or cochlear implant. With the reduced speaker to microphone distance the device helps to overcome the, 'adverse impact of noise, reverberation and distance on the transmission of a speech signal' (AAA, 2011a: p.3).

Ross & Giolas (1971) in a study involving CYP(HI) using hearing aids, found that word discrimination scores in a 'typical classroom' doubled or tripled when

using a RAS. Schafer & Kleineck (2009) carried out a meta-analytic review of research into the use of ALD's involving 77 CYP(HI) using cochlear implants and non-dynamic RAS's. They found that on average they experienced an increase of 38% in speech perception scores when they used a RAS, as opposed to their scores when listening with just their personal hearing instruments.

2.5. Soundfield systems: Impact on children with a hearing impairment's perception of speech

A Soundfield system (SFS) differs from a RAS in that it wirelessly connects a transmitting microphone to one or more sound speakers which then distribute the signal around the room. This enhances the listening environment as a consistent positive signal to noise ratio is maintained throughout the room (ASA/ANSI, 2012).

By providing a consistent and positive SNR, a classroom environment more conducive to accessible learning is created. The benefits for children of using SFS's in classrooms have been studied and validated over time. Some of these studies isolate the positive impact that use of a SFS can have on academic progress. In a study by Sarff et al. (1981) 110 children with hearing ranging from normal to a mild hearing loss were assigned randomly to one of three groups. The children stayed in the original classroom, had additional teaching in a resource room or worked within a classroom accessing learning via a SFS. It was found that the children who accessed first teaching in the room with the SFS, had the most gain in progress across a range of tests measuring academic progress. This research did not however consider the impact that the specific teachers working in each room may have had on the overall results. Rosenberg et al. (1999) carried out a three year study, with 2054 participants in elementary schools in Florida. They found a significant improvement for students educated in rooms with SFS, in terms of both listening and learning behaviours and academic progress.

Larsen & Blair (2008) considered the impact a SFS can have on the acoustic environment. They took acoustical measurements in nine places in four classrooms to ascertain an average SNR for each classroom. They found that on average the children heard the teacher's voice at 13dB above the background noise level when the SFS was employed; when no SFS was used the signal to noise gain averaged 2dB.

In an unpublished case study assessing the benefit of a SFS using Language ENvironmental Analysis (LENA™), Ostergren (2013 & 2016) used the LENA™ Digital Language Processor to record the Adult Word Count (AWC). He measured the AWC in a classroom over an eight day period with a SFS utilised on alternate days. Results showed an AWC of 10,343 words when the SFS was not used which increased to 15,424 words when it was used; a percentage increase of 49%. The research was however limited to one classroom and it is unclear if there was any consideration of other variables which could influence the AWC, for example the input delivery style or variation in staff to pupil ratio as a result of specific interventions in place within the classroom. Ostergren (2016) indicated that there was a need for further research in this area.

For CYP(HI) research directly comparing the use of either a SFS or a RAS conclude that a RAS provides a better system of amplification (Iglehart, 2004; Anderson et al., 2005). Schafer & Kleinek (2009) found that the SFS provided only a 3.8% increase in speech discrimination test results over scores obtained when using just their personal hearing instruments. The RAS takes the signal directly to the CYP(HI)'s personal aids whilst the SFS transmits the signal through the air. The signal will therefore be impacted by a reduction of signal level over distance and the conclusion reached by these studies is not therefore unexpected. John & Kreisman, in Smaldino and Flexer (2012) reviewed studies involving CYP(HI) using either a RAS or a SFS between 2003 and 2011. They concluded, based on the existing data, that the use of SFS's for CYP(HI) may not be of benefit. They do not however consider the use of the two systems together and make this judgement based purely on the use by CYP(HI) of a SFS alone compared with use of a RAS alone.

2.5.1. Rebroadcasting

Some CYP(HI) use both a Soundfield system and a Radio Aid system together to support access in the classroom. For these users the signal from the SFS transmitter is sent directly to their personal hearing aids via the RAS. When the systems are connected together via an audio output lead the process is called rebroadcasting (UKCFMWG, 2008b).

There are very limited studies available comparing speech discrimination ability when accessing through the RAS alone, compared to when a SFS and RAS are used in conjunction. This interaction was investigated by Wolfe et al. (2013) in a study of fifteen CYP(HI) with a mean age of nine years and five months. The participants had sensori-neural hearing losses ranging from mild to severe and were bilaterally aided. They carried out speech testing using a range of ALD options; SFS only, RAS only and SFS rebroadcast via the RAS (using systems from both the same and different manufacturers). They demonstrated that rebroadcasting had a negative impact on the ability to discriminate speech when an RAS and a SFS from different manufacturers were used together. Wolfe et al. (2013: p.77) concluded that use of a SFS, 'negated some of the benefit provided by the personal FM system (RAS)'. There is a need for further research in this particular area to ascertain if combining these systems is an intrinsic issue or if the verification process when rebroadcasting needs to be further considered.

2.6. Transparency when using a Radio Aid system with hearing aids.

When using a RAS it is important to ensure that it is correctly balanced to the user's personal hearing instruments through objective testing to ensure transparency (AAAa, 2011; UKCFMWG, 2017). Transparency is when equal inputs to the RAS and hearing aid microphones produce equal outputs from the hearing aid (AAA, 2011a). It is important to ensure that the use of a RAS does not alter the frequency response characteristics of the wearer's hearing aid, which has been set up for optimal frequency response.

Research established the need for such testing prior to national guidance being drawn up. Schafer et al. (2007) found need for transparency and electro-acoustic testing of hearing aids; this was incorporated into national guidance (UKCFMWG, 2008a & 2017).

Transparency is achieved through an initial listening check, then electro-acoustic balance verified with speech discrimination testing. The practical process of achieving transparency is listed in Table 2.1.

Table 2.1. Process for achieving transparency between hearing aids and RAS's.

Standards	Input	Process
UKCFMWG (2008b and 2017)	Input of 65dBDWO to the RAS and hearing aid microphones.	• Find difference between hearing aid and RAS curves at: 500Hz, 1000Hz, 2000Hz and 4000Hz. • Calculate a 4-frequency average of the differences. • If the average difference is +/-2dB, transparency has been achieved. • A listening check should also be carried out and a procedure for speech-in-noise evaluation is suggested.
AAA (2011a)	Inputs of 65dBSPL to the RAS and hearing aid microphones.	• Find difference between hearing aid and RAS curves at: 750Hz, 1000Hz and 2000Hz. • Calculate a 3-frequency average of the differences. • If the average difference is ≤+2 dB transparency has been achieved. • Perform a listening check with simultaneous inputs to RAS and hearing aid to judge overall signal quality and the relationship of the RAS level to the hearing aid microphone.

2.7. Transparency when using a Soundfield system

AAA (2011a: p.9) guidance indicates that when fitting a Soundfield system in isolation to a classroom:

> For clarity of speech, (a listening check) should be performed while the teacher is speaking in an unoccupied classroom with typical vocal effort. Adjustments of equalizers may be performed to accomplish optimum signal clarity as judged by an adult with normal hearing.

> The AAA (2011a: p.10) recommends a formal behavioural evaluation of the CYP's responses when listening with an Audio Distribution System (ADS) i.e. a Soundfield system. They suggest:
>
> Age-appropriate speech perception materials, preferably sentences, should be presented in the typical listening arrangement in the occupied classroom, without visual cues with and without the classroom ADS…Percent correct results with and without the classroom ADS may be compared to determine benefit.

There is however a discrepancy between UKCFMWG advice and that provided by the AAA in terms of how to transmit speech where an RAS and a SFS are being used together.

AAA (2011a: p.10) state that dual transmitters should be worn. This is:

> Because of potential undesirable variation when interfacing a classroom ADS and personal FM system (RAS), the connection of the personal FM transmitter to the audio output of the ADS is not recommended (sequential signal processing).

However Good Practice Guidelines (UKCFMWG, 2008b: p.41) suggest that, 'it would be cumbersome, and in some cases impractical, for the teacher to wear two microphone transmitters'. They suggest rebroadcasting by, 'feed(ing) the audio content of the soundfield ….to a personal FM transmitter, which would be placed near the base unit and connected via a suitable lead' (UKCFMWG, 2008b: p.43).

Johnson (2015) indicates that the AAA (2011b) guidance is a core statement and that procedures are technology dependent and therefore there will be variation in practice dependent on the type of system used. Three current SFS manufacturers' guidance on connecting and ensuring transparency with RAS's are given below in Table 2.2. It is clear that there is indeed no uniform guidance available around verification.

Table 2.2. Manufacturers' guidance on connecting and ensuring transparency.

Product	Guidance for connecting	Guidance for balancing
Front Row (2013: pp. 4-5)	'Total Auditory Integration (or "Patching"). The classroom amplification receiver's Audio Output is connected via a cord to the PFM* transmitter's Audio Input jack. The PFM transmitter then sends all audio to the PFM receiver'.	They also list levels to set the audio output level at when setting up a SFS with a RAS. These levels have a caveat of, 'or as desired by student' & 'adjust as needed for student preference.'
Redcat (Lightspeed, 2016b: p.1)	Turn the volume control on the Redcat media side panel all the way down. Determine the appropriate jack and use a 3.5 patch cable. Connect the patch cable from the RAS microphone jack/Aux input to the 3.5mm audio jack labelled "ALD OUT.	'With the Redcat and ALD turned on, speak into the Redmike and slowly adjust the ALD volume control (audio output dial) until the appropriate audio level is attained in the ALD's (RAS) receiver headphones.' 'It may be necessary to adjust the volume on the Personal FM receiver to achieve appropriate volume level.'
Roger DigiMaster 5000 (Phonak, 2017)	Pair with the Inspiro Roger transmitter. This system cannot be directly linked with other manufacturers' RAS systems.	As the CYP(HI)'s RAS transmitter is used there is no issue raised with transparency; which will be checked as per guidance in Table 2.1. to ensure transparency between the hearing aids and the RAS.

* PFM (Personal FM) equates to RAS in this study.

The UKCFMWG (2008b: p. 44) state that:

> Assessing the quality and level of the final re-broadcast sound to the deaf child is, at present, likely to be subjective. Where any incompatibility in use is experienced it is vital that this is addressed at the earliest opportunity with manufacturers or a technician familiar with the system.

Both AAA (2011b) and UKCFMWG (2017) indicate that a listening check should be carried out to verify the appropriate levels.

John & Kreisman, in Smaldino & Flexer (2012) indicate the lack of research into the potential interaction of personal RAS's and SFS's. Unpublished research reported in an article by Peake (2013) isolated a lack of transparency as a result of poor verification when systems were rebroadcast. The Auditory Implant team at the University of Southampton designed an in–house process for achieving transparency (Peake, 2014). This process covered cochlear implants and did not define the type of SFS used.

The review highlights the significant improvements Radio Aid and Soundfield systems provide for users of hearing technologies and the importance of ensuring the systems are verified to achieve transparency. In the case of rebroadcasting however, there is limited guidance available around verification and transparency when connecting a SFS to a RAS. There is no national guidance on electro-acoustic balance of these systems when used in conjunction with each other. Equally there is no research yet available about the impact achieving transparency has on speech discrimination when rebroadcasting.

2.8. Conclusions of the Literature Review & Aims of this research

Children and in particular children with a hearing impairment require an advantageous signal to noise ratio to support access to speech in the classroom. Assistive listening devices have been shown to support access to orally delivered learning. Whilst there is research isolating the benefits of a SFS for CYP in general, there is very limited research into the benefits of using a SFS in a classroom where a CYP(HI) is also using an RAS. Ostergren (2016) indicated a need for further research into the impact that using a SFS had on levels of accessible language within the classroom.

Where a RAS is being used there is national guidance around the need for on-going management and verification to ensure transparency with the CYP(HI)'s individual hearing aids. Guidance around management and verification processes when a SFS is used in conjunction with a RAS is however limited to seeking advice from individual manufacturers and carrying out subjective

listening checks. There is currently no national guidance on how to achieve transparency of signal received when the SFS is rebroadcast through the RAS.

Evaluating the potential value of electro-acoustic verification of rebroadcast systems to ascertain transparency needs to be considered. Furthermore there is a need for functional speech discrimination testing to be carried out to access the benefit of any electro-acoustic testing process.

3. Methodology

3.1. Design

Denscombe (2014) indicates that when planning a piece of research the methodology selected needs to be considered for its suitability, feasibility and consideration of ethics. It is important therefore to consider the design frame of this research study to ensure that the findings will be valid, reliable and generalizable (Field & Hole, 2003). A discussion of the underpinning principles of the approaches selected to address the purpose of the study is important in understanding the chosen design framework.

The initial purpose of this research study is to consider whether access to a Soundfield system (SFS) in a classroom impacts positively on the listening environment and clarity of speech signal reaching the user.

Secondly in relation to CYP(HI) utilising both a Radio Aid system (RAS) and a SFS, the following hypothesis was isolated: The process of rebroadcasting needs to be managed carefully to prevent it impacting on the transparency of signal, thereby affecting discrimination of the speech signal by the listener.

Thomas (2013) advises creating a design frame which meets the inquiry rather than working within a specific methodological approach. It is important however to cite this study within the context of approaches to inquiry.

The approach to be used in this study could best be defined as action research, which was originally defined by Lewin (1946) as research leading to social action with a series of steps, 'each of which is composed of a circle of planning, action and fact-finding about the result of the action' (Lewin, 1946, in Bargal, 2006: p.373). Bell (2014) describes it as applied research carried out by practitioners who have identified a need for change or improvement. Action research is a cyclical process that seeks to make recommendations for good practice and resolve a problem, or facilitate improvements, by establishing 'changes to the rules and procedures within which they operate' (Denscombe, 2010: p.12).

Within the framework of action research the approach used to explore the hypothesis is multiple case study research. This approach seeks to 'illuminate the general by looking at the particular'; studying in detail the impact of action on a small number of cases and using isolating information that could potentially have a wider impact (Denscombe, 2010: p. 54). A particular strength of the case study approach is that it allows for a detailed and systemic analysis through the use of a variety of types of data (Thomas, 2013). Wieviorka (1992) indicates that case study participants must be selected as a 'characteristic unit' and be referred to within the context of an analytical category or theory. The analytical frame for the case studies in this research will be the impact achieving transparency has on speech discrimination. The participants will not be seen as a survey sample (Yin, 2009) but the conclusions from the case studies will collectively form a starting point for further research. The conclusions will support the development of a theory and be a part of the formative cycle of action research (Denscombe, 2014).

Much of the data being considered is quantitative in nature, seeking to use numerical data to produce quantified conclusions (Bell, 2014). Quantitative research also tends to have a structured, pre-determined question with a conceptual framework and design. Punch (2014) states that quantitative research uses statistical analysis to examine the quantitative data generated and, having assessed the quality of findings in terms of reliability and validity, reports and make conclusions to test and expand on current theories whilst also providing insight for future theories.

Qualitative data was collected to ensure that the participants' personal views were captured. In this research the interview formed part of a mixed methods approach informing the quantitative analysis. A short, semi-structured interview process with simple open-ended questions and follow-up probes was used to ensure easily coded information was elicited (Thomas, 2013). As the researcher was in a position of authority, care needed to be taken to avoid 'interviewer effect' whereby participants do not share their own views through fear of retribution (Thomas, 2013). The interviewer must take care not to unconsciously

encourage bias in the participants', leading them to respond to 'demand characteristics' rather than with their own views (Orne, 1962 in Field and Hole, 2003). There is also a need to avoid bias when interpreting the responses, as it is not easy to ensure validity of data in interviews (Bell 2014).

Triangulation reduces the risk of bias, using more than one method of data collection to cross check findings (Bell, 2014). A multi-method approach should, with criticality, make for a more robust approach to the investigation by confirming or challenging, 'the findings of one method with those of another' (Laws et al., 2013). This will be achieved in this research by using a questionnaire to consider the impact ascertaining electro-acoustic transparency has on access to a clear speech signal. This was a repeated measures design in that all the participants partook in all the rebroadcasting sections of the experiment. It is hoped that the procedure used will enable interrater reliability through a detailed description of process and that a test-retest approach would produce similar findings over time (Thomas, 2013).

The sample selected for the multiple case study approach must be adequate to meet the research aims and objectives. For the purposes of this study non-probability convenience sampling was used, with all participants drawn from within the researcher's geographical area of work due to limitations of time. Non-probability sampling is widely used in behavioural research but may restrict generalisations being made from the data due to the small and specific sample size (Banerjee & Chaudhury, 2010). It was considered relevant to this action research approach to use participants typical of the population for which clarity on the processes and implications of rebroadcasting would be beneficial.

3.2. Recruitment and Participants

The participant inclusion criteria for the study were as follows:

- They had a hearing loss (BSA, 2011) and were bilaterally aided.
- They were of school age.
- They used a Radio Aid system, with additional access to a Soundfield system for at least some of their lessons.

- They had no defined additional learning need.
- They used spoken English as their primary mode of communication.

Cochlear-implanted CYP were excluded from the study as there is currently no nationally agreed protocol for measuring transparency of signal between a RAS and an implant.

Five participants of primary and secondary age were selected with ages ranging (at the start of data collection) from 7 years 7 months to 15 years 11 months, with an average age of 11 years 6 months. Selection on gender was random with three females and two males participating. The average loss level of the participants is included in Figure 3.1. with Table 3.1. containing detail relating to individual participants.

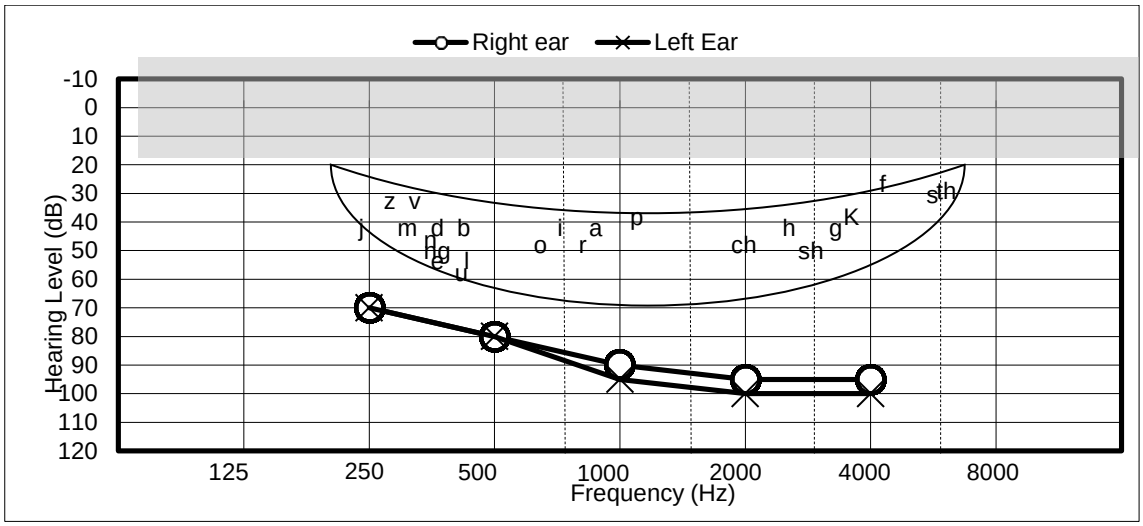

Figure 3.1. Audiogram showing average hearing loss of participant.

Table 3.1. Details of participants' level of education and hearing loss category.

Participant	Stage of education	Level of loss
P1	Secondary	Severe to profound
P2	Secondary	Severe to profound
P3	Primary	Severe to profound
P4	Primary	Moderate to severe
P5	Primary	Severe to profound

(The specific hearing loss and year grouping of each participant was not listed in order to maintain anonymity in a low incidence population).

3.3. Ethics

The data was collected as part of the researcher's routine work as the Audiology Lead in the county, to ensure validation of effective use of the equipment. Consent was sought from parents and participants to use this data to form the main body of this research paper. Ethics approval for this process was sought from the Research Ethics Committee, University of Hertfordshire and copies of the approved documentation are included in Appendix 1.

3.4. Equipment

3.4.1. Language ENvironmental Analysis (LENA™)

The LENA™ Language Environment Analysis system was designed to estimate adult and key child interactions using an automated audio recording system (LENA™ Research Foundation, 2016). This research will consider two of the functions of the system.

The LENA™ software v3.4.0 will analyse and segment the audio data to produce a report on the Adult Word Count (AWC) i.e. the number of adult words spoken to or near to the participant. It will also analyse the recorded audio environment near the participant and categorise the environment into five audio components; Meaningful Speech, Distant & Overlapping Speech, TV & Electronic Sound, Noise and Silence & Background noise.

3.4.2. The Radio Aid system (RAS)

All the participants in this trial were using a Phonak Zoomlink+ Radio Aid system (Phonak, 2016) which comprised a Dynamic FM transmitter with two universal Dynamic FM MLxi receivers. These are attached to the participants' post-aural hearing aids via the audio input shoes recommended for their specific post-aural hearing aids.

3.4.3. The Soundfield system (SFS)

The SFS used by the participants in this study was a Lightspeed REDCAT® All-in-one Classroom Audio System. This comprises an all-in-one unit with integrated infra-red receiver with infra-red sensors, amplifier and flat sound

panel speaker with exciter technology. There is also a ‘Classroom microphone’ provided to transmit the teacher’s voice with an optional ‘Share handheld microphone’ for use by others contributing within the classroom (Lightspeed, 2016a).

For the CYP(HI) utilising these systems together via the process of rebroadcasting, the Zoomlink+ transmitter is linked to the Redcat SFS using an audio lead. This lead runs from the audio socket on the Zoomlink interfacing block to the audio output socket on the Redcat SFS; see Figure 3.2.

Figure 3.2. Image of a Lightspeed REDCAT® SFS and Phonak Zoomlink+ RAS connected to enable rebroadcasting of the SFS signal.

The teacher wears the SFS transmitter and the handheld microphone can also be passed around for use by individuals contributing to the lesson. When either microphone is switched on, the user’s voice is heard at a consistent level across the room by all the class, with the signal also being rebroadcast directly via the RAS to the participant’s hearing aids.

3.4.4. The PARROTplus Speech Discrimination Tester (PARROT)

This system was used to administer the speech discrimination tests. It is a portable digital speech screening system comprising a loudspeaker and a handset which enables the user to choose both the test item and the presentation level (Soundbyte, 2016). A range of speech discrimination tests can be uploaded to the tester.

3.4.4.1. Manchester Junior Word short list (MJWL)

This open set word test was selected from the battery of tests. It was originally developed by T.J. Watson in 1957 (Sounding Board, 2009) for use with hearing-impaired children aged 6 years and above. It consists of eight word lists containing ten words each.

List 1	List 2	List 3	List 4	List 3	List 6	List 7	List 8
Red	Some	Dog	Bus	Knock	Cold	Gate	Spoon
Snow	Not	Head	Side	Spin	Tent	Nice	Queen
Wood	Tin	Sit	Ring	Front	Run	Stick	That
Lid	Hat	Plant	Dress	Room	Sky	Man	Milk
Cat	Gold	Smoke	Green	Drive	Thing	Cot	Road
Sweet	This	Good	Lost	Hole	End	His	Net
Dig	Sail	Feet	Can	Start	Hill	Set	Salt
Night	Bed	Dish	Brick	Meat	Tap	Nose	Name
Pond	Moon	Sun	Coat	Fell	Mouse	Done	Pin
Push	Knife	Time	Pain	Hit	Same	Blue	Ride

Figure 3.3. Manchester Junior Word Lists (Source: Soundbyte, 2016).

3.4.4.2. Norsonic Environmental Noise Meter Nor139

The PARROT was calibrated and the ambient noise levels within the test situation were measured using this integrating sound level meter which is designed to meet IEC 61672 Class 1 standards (Norsonic, 2016).

3.4.5. The Fonix *FP35* Analyser Test-box

The FP35 test box (Frye, 2016) provides electro-acoustic information. In this instance this is in the form of coupler multi-curves, used to assess how a

hearing instrument is performing in terms of amplification across frequencies. This process is known as measuring FM Advantage (or transparency) (UKCFMWG, 2008b; AAA, 2011a). Evans (2004: p.5) indicated that ensuring FM Advantage means that the RAS, 'has an advantage over the general noise picked up by the hearing aid (instrument) and that the overall system functions as intended.'

3.5. Procedure

The participants were all familiar with the routine collection of test-box data to ensure that equipment provided to support their hearing needs was working effectively. They also regularly completed speech discrimination tests to measure benefit provided by equipment and inform advice given to both CYP(HI) and staff in settings. Participants were also aware that it was usual practice to have an on-going dialogue with them around the use of SFS in conjunction with a RAS, and that information would be collated to inform this study.

The participants and their families gave their permission prior to the research study for use of the collected data. Following the collection of the speech discrimination data they also completed a questionnaire around the listening conditions in each of the three test situations. Once the quantitative data had been collected they also shared their views on which combination of their current equipment (RAS and SFS) they found most effective within the classroom situation.

Data on the benefit of the use of a SFS within the classroom was collected using quantitative methods through LENA™ recordings and qualitatively by asking participants a number of open questions to ascertain views on equipment.

Data on the transparency of the rebroadcast signal was collected using quantitative methods; namely output curves from electro-acoustic testing. Data on the impact of electro-acoustic balance was collected by quantitative methods

using speech discrimination test scores. The questionnaire completed by the participants supplemented the quantitative data.

3.6. Quantitative data collection

3.6.1. Study 1: Language ENvironmental Analysis (LENA™)

The initial strand of the research involved the collection of LENA™ data on the Adult Word Count and Audio Environment. In an initial pilot, the LENA™ data recorder was worn by one of the participants in a primary setting for two days. On the first day the SFS was utilised, whilst on the second day it was not used. It was found that there were too many variables at play across the two days in terms of timings, the numbers of adults working in the room and the teaching styles employed, to make the data collected meaningful.

For the final research, the LENA™ data recorder was used within the settings of three of the participants over a period of one or two days to record lessons both with and without the SFS being utilised. The process of collecting data was refined by noting in detail throughout the testing period the style of teaching delivery against five minute time blocks. This was used to support analysis of the collected data.

The remaining research involved assessing the impact on the signal of the process of rebroadcasting the RAS through the SFS.

3.6.2. Study 2: Transparency testing

Balance curves for the participants' hearing aids and RAS were obtained using the Fonix FP35 test box analyser. An input level of 65dBDWO was used following the guidance and procedure issued by the UKCFMWG (2008b) with transparency achieved and recorded; Curve1 for the hearing aid and Curve 2 for the RAS.

The SFS microphone was then placed in the open test-box chamber with the RAS transmitter plugged in for rebroadcasting. The output curves for the rebroadcast SFS were then fixed twice; for this particular SFS at a level of

65dBDWO. The first curve (Curve 3) recorded the original SFS output audio level; set by a listening check only when the SFS was initially set up for use in the field. The second curve (Curve 4) was achieved by starting with a live Curve 3. The audio output dial was then adjusted to achieve transparency with the RAS reference curve before being fixed. Full details of the electro-acoustic verification process are included in Appendix 2.

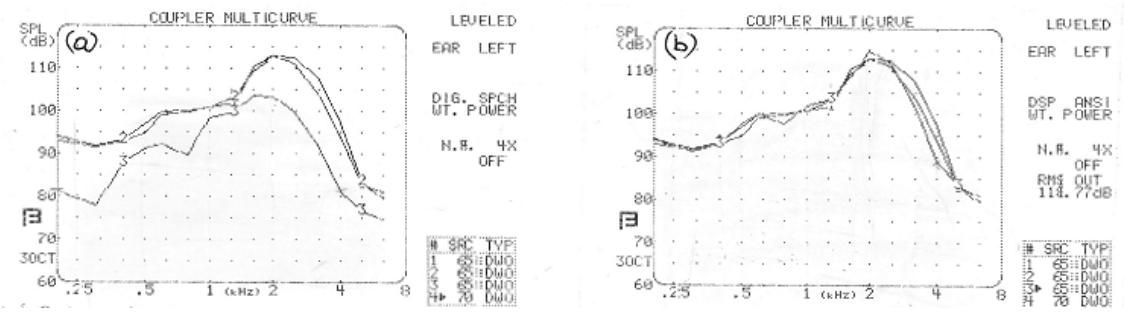

Figure 3.4. Test-box print-out for a participant showing (a) pre-balance curves 1, 2 & 3 and (b) post-balance Curves 1, 2 & 4.

The test-box data for each participant was collected within their own classroom. Whilst the room dimensions and outline varied in each setting, the same room was used by each participant for all of the electro-acoustic testing. The same equipment was also used to ensure reliability of data and all testing was carried out at the end of the school day when pupils were off-site. The timings enabled easy access to teaching rooms and ensured optimal listening conditions in terms of ambient noise levels.

The next step was to investigate if Speech Discrimination test results were impacted by any variation in transparency pre and post balancing of the rebroadcast systems.

3.6.3. Study 3: Speech Discrimination tests and Questionnaire

3.6.3.1. Speech Discrimination tests

The speech discrimination testing was again carried out in a quiet room at the end of the school day. All tests were administered at 65dBSPL in quiet with sound level meter readings taken of average ambient noise level. The average noise level and the range of variation were noted for each participant across the testing period.

The tests were all carried out with the PARROT speaker at a height of 1.2 metres to simulate an average height of a seated teacher. The microphones of the transmitters were always placed at a distance of fifteen centimetres (cms) from the PARROT tester speaker. This is the recommended distance the transmitter microphone should be from the speakers' mouth (Phonak, 2016). The participant was seated at a distance of three metres from the Parrot speaker. The microphone volume on the SFS was turned to zero for both Tests 2 and 3 so that only the rebroadcast signal was heard.

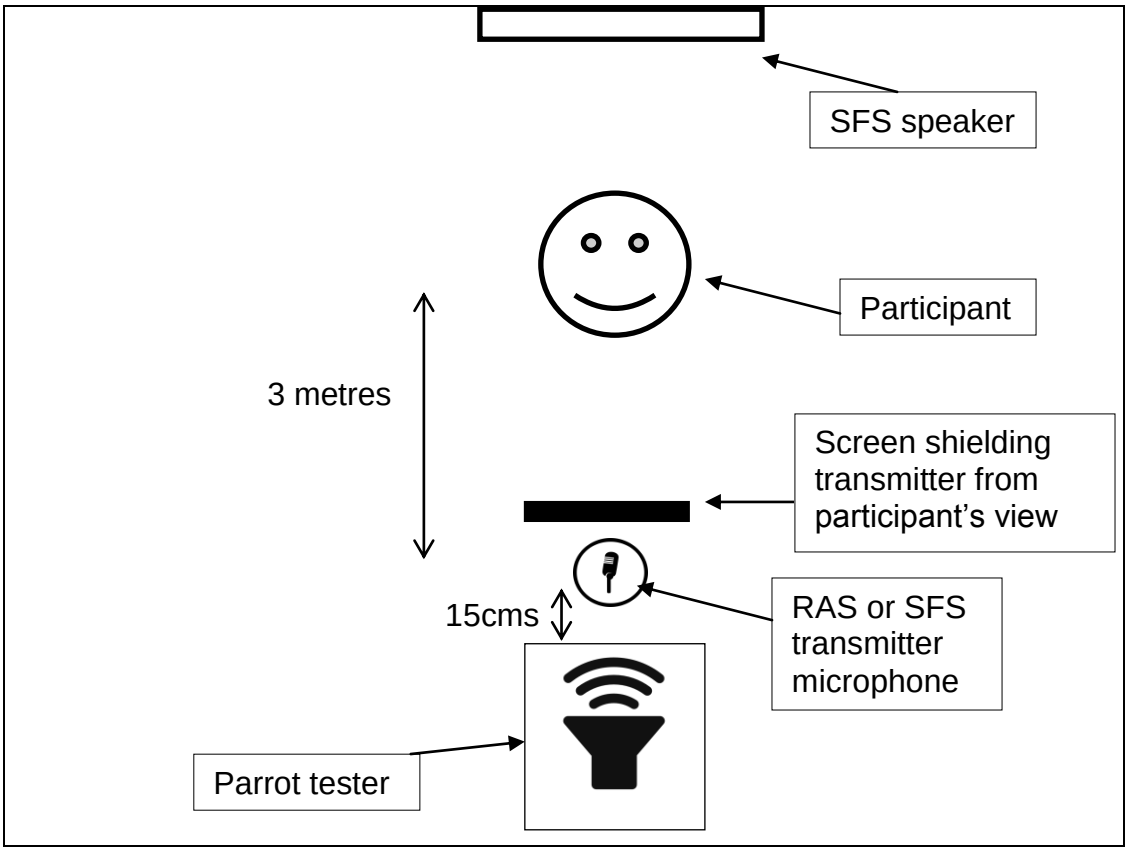

Figure 3.5. Diagram of room set up for Test 3: Speech Discrimination testing

Each participant was tested three times with two lists of words delivered in each test situation (see Table 3.2.). In all three situations the participants were given the same script prior to the presentation of the word lists. This reminded them to repeat exactly what they heard, even if it did not make sense or if it appeared to be only part of the word. They were advised that they would get a score for the beginning, middle and end of each word presented. The participant could not see which transmitter was being used during the testing to prevent bias when completing the questionnaire.

Table 3.2. Table isolating Manchester Junior Word lists used in each test situation.

Test situation	MJWL used
RAS only	1 & 2
SFS/RAS pre-balance using SFS audio dial	3 & 4
SFS/RAS post-balance using SFS audio dial	5 & 6

The participants' responses to each presentation were noted and scored using the process outlined in Table 3.3. The total for each word list was then recorded as a percentage, with the average percentage score recorded for each of the three test situations.

Table 3.3. Scoring process for Manchester Junior Word Lists.

Number of phonemes identified in each word	Number of points given	Percentage equivalent (%)
3	3	10
2	2	7
1	1	3
0	0	0

3.6.3.2. Questionnaire

At the end of each test the participants were asked, using a common script, to score the ease of listening experience and their perception of the sound quality, on a visual questionnaire with numerical coding, (see Appendix 3).

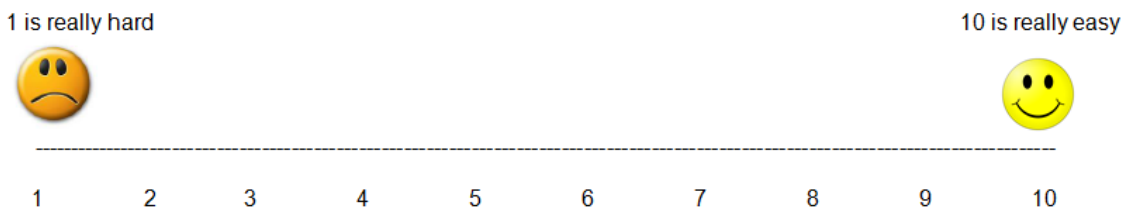

Figure 3.6. Extract from the questionnaire showing the scale used.

3.7. Qualitative data collection

3.7.1. Study 4: Participants' Views

The participants were asked between two and four semi-structured questions, with the option of follow-up questions and probes if required. The exact wording of the questions was dependent on the individual participant's language ability. The aim was to extract their reasoned preferences around use of their ALD's. Care was taken to put the participants at ease and to ensure they felt the researcher was interested in their opinions and that there was no right or wrong answer.

Initial and follow-up questions:

'Which equipment do you like using?' 'Why is that?'

'If you could choose to use the RAS only or the RAS/SFS, which would you choose?' 'Why?'

'Do they sound the same or different?' 'Can you explain this in more detail?'

'Is there anything else you want to tell me about the systems?'

Probes: 'Tell me more' and 'And'.

3.8. Quantitative data analysis

3.8.1. Study 1: Language ENvironmental Analysis (LENA™)

Five minute blocks were isolated for inclusion in the study using the detailed notes taken of lesson delivery style. The blocks were chosen to provide paired blocks, comparable in terms of the teaching style and oral input. The blocks were selected prior to data extraction from the LENA™ to prevent any potential researcher bias had the word counts been known at the time of selection. Data on the Adult Word Count and the Audio Environment was then extracted using automatic analysis by the LENA™ software.

The researcher then listened to recordings of the isolated paired time blocks to ensure they were well matched in terms of actual oral delivery style. This was to confirm that selection based on information from the notes was valid; any blocks that did not match in terms of actual delivery style at this stage were then removed. The AWC data for the remaining paired blocks was then tabulated and analysed for variance in results when a SFS was utilised. The distant and

meaningful speech components were extracted from the overall breakdown of the audio environment data and converted to percentage scores for comparison.

3.8.2. Study 2: Transparency Testing

The transparency curves were printed off from the test-box for each participant and then converted to tables isolating the output SPL(dB) against the following frequencies; 250Hz, 500Hz, 1kHz, 2kHz and 4kHz.

Table 3.4. Key to the curves referred to within the results

Curve	What the output curve on test-box was measuring
1	Hearing aid
2	RAS (balanced)
3	RAS plugged into SFS to rebroadcast and SFS mic placed in test box
4	Same as Curve 3 but live so the audio output dial could be adjusted to achieve transparency.

The differences between Curves 2 and 4 and between Curves 3 and 4 at each of these frequencies were also tabulated. The differences noted for each participant at each frequency were scrutinised with trends isolated by converting the data to graphical form.

3.8.3. Study 3: Speech Discrimination tests & Questionnaire

3.8.3.1. Speech Discrimination tests

The participants' results for speech discrimination tests in three situations were recorded as noted in Table 3.2. The scores for each test situations were presented in table form as both raw data and as percentage differences for each participant. These differences were reviewed and trends noted both for each participant. The scores for the five participants were totalled and averaged for each test situation to extrapolate variance across results.

3.8.3.2. Questionnaire

The grading given by the participants were compared with the actual results obtained in speech testing. Each participant's results were converted to

percentage scores and compared with percentages achieved in the speech testing.

3.9. Qualitative Data Analysis

3.9.1. Study 4: Participants' views

The participants were asked a number of open questions about the assistive listening devices used in the classroom. This was to elicit their views on the quality of access to speech given by each system. Their views were then analysed and compared with the objective responses obtained through speech discrimination testing and the completed questionnaires.

Whilst collating quantitative data through the questionnaire, qualitative data in the form of commentary made by the participants was also obtained. This qualitative data added a layer of additional detail to the evidence on participant perception.

4. Results

4.1. Study 1: LENA™

Teaching staff in three of the settings agreed to the use of the LENA™ by participants in their classrooms. The participant wore the device throughout the period of recording in a pouch attached to a neck harness.

A pilot study in Participant 5's primary setting indicated a higher Adult Word count (AWC) at 12,195 words on the day the SFS was used, with 10,175 words isolated when the SFS was not used. The AWC was higher when the SFS was used despite there being only one adult in the room that day, as opposed to four when the SFS was not used. Nevertheless as there was significant variation in the style of teaching across these two days the results did not form part of the main body of data.

The AWC for sixteen isolated blocks of comparable teaching style (T1- T16) were collected from the recorded material, with 4 blocks isolated from Participants 1 and 2's data and 8 blocks from Participant 5's data. The AWC's for these blocks were then totalled for each participant in Table 4.1.

Table 4.1. Total AWC for each participant for selected periods of time with and without use of the SFS and with percentage increases in AWC when SFS in use.

Participant	Total AWC with:		Increase in AWC when SFS on (number of words)	Percentage increase in AWC when SFS on (%)
	SFS off (number of words)	SFS on (number of words)		
P1	1866	2472	606	32.5%
P2	1434	1659	225	15.7%
P5	1574	2415	841	53.4%
Total P1, P2 & P5	**4874**	**6546**	**1672**	**34.3%**

Participants 1 and 2 had one five minute slot each (T3 & T8), when the AWC was higher without the SFS in use; both T3 and T8 were recorded in secondary classrooms.

The total AWC for each participant increased when the SFS was in use during periods of comparable teaching delivery style. Participant 1 had an average of

30.3 words more per minute when the SFS was used, Participant 2 averaged 11.3 words more and Participant 5 averaged 21 words more with the SFS utilised.

There was a total word per minute increase of 20.9 words a minute when the SFS was used. This is an average percentage increase of 34.3% for all three participants. Figure 4.1. shows the individual percentage differences in AWC when the Soundfield was used.

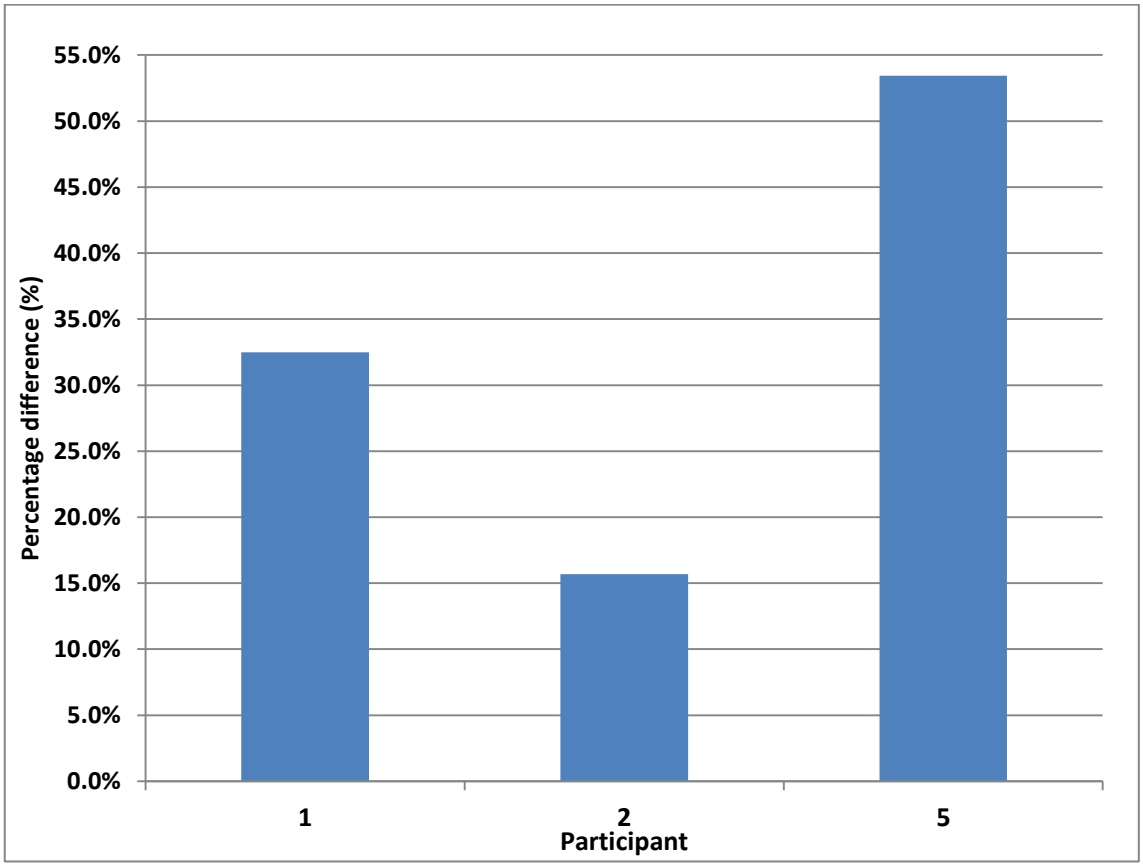

Figure 4.1. Percentage difference in Adult Word Count (AWC) for participants when the SFS was switched on.

The percentage increase in AWC was highest for Participant 5 at 53.4%. This participant is accessing learning in a primary school classroom where there were higher levels of 'working noise' during the lessons. Participant Two's percentage increase in AWC was 15.7%. This was significantly lower than that of Participant One's which was 32.5%.

The audio environment percentages for distant and meaningful speech were also isolated for the same time intervals (T1-16).

Table 4.2. Converting distant and meaningful speech scores from a percentage of the audio environment to a percentage of speech within the audio environment for P1.

Participant P1						
Time Interval	SFS Off		SFS On		% Difference in Speech when SFS is ON	
	% of Speech within Audio Environment					
	Distant	Meaningful	Distant	Meaningful	Distant	Meaningful
T1	45	55	67	33	49%	-40%
T2	29	71	45	55	54%	-22%
T3	28	72	14	86	-52%	20%
T4	72	28	69	31	-5%	13%
T1-4	**44**	**56**	**49**	**51**	**11%**	**-9%**

Table 4.3. Converting distant and meaningful speech scores from a percentage of the audio environment to a percentage of speech within the audio environment for P2.

Participant P2						
Time Interval	SFS Off		SFS On		% Difference in Speech when SFS is ON	
	% of Speech within Audio Environment					
	Distant	Meaningful	Distant	Meaningful	Distant	Meaningful
T5	40	60	16	84	-59%	40%
T6	50	50	18	82	-63%	63%
T7	72	28	66	34	-9%	22%
T8	79	21	68	33	-15%	55%
T5-8	**60**	**40**	**42**	**58**	**-30%**	**46%**

Table 4.4. Converting distant and meaningful speech scores from a percentage of the audio environment to a percentage of speech within the audio environment for P5.

Participant P5						
Time Interval	SFS Off		SFS On		% Difference in Speech when SFS is ON	
	% of Speech within Audio Environment					
	Distant	Meaningful	Distant	Meaningful	Distant	Meaningful
T9	55	45	47	53	-15%	18%
T10	59	41	52	48	-12%	18%
T11	74	26	71	29	-4%	12%
T12	65	35	66	34	3%	-5%
T13	66	34	61	39	-7%	15%
T14	80	20	74	26	-7%	31%
T15	44	56	30	70	-33%	26%
T16	75	25	34	66	-55%	165%
T9-16	**65**	**35**	**54**	**46**	**-16%**	**30%**

Table 4.5. Average distant and meaningful speech scores from a percentage of the audio environment to a percentage of speech within the audio environment for P1 - P5.

Average Results for Participants P1, P2, P5						
Time Interval	SFS Off		SFS On		% Difference in Speech when SFS is ON	
	% of Speech within Audio Environment					
	Distant	Meaningful	Distant	Meaningful	Distant	Meaningful
T1-16	**58**	**42**	**50**	**50**	**-15%**	**21%**

There was an overall increase of 21% in the number of meaningful words isolated when the SFS was utilised across blocks of comparable teaching style.

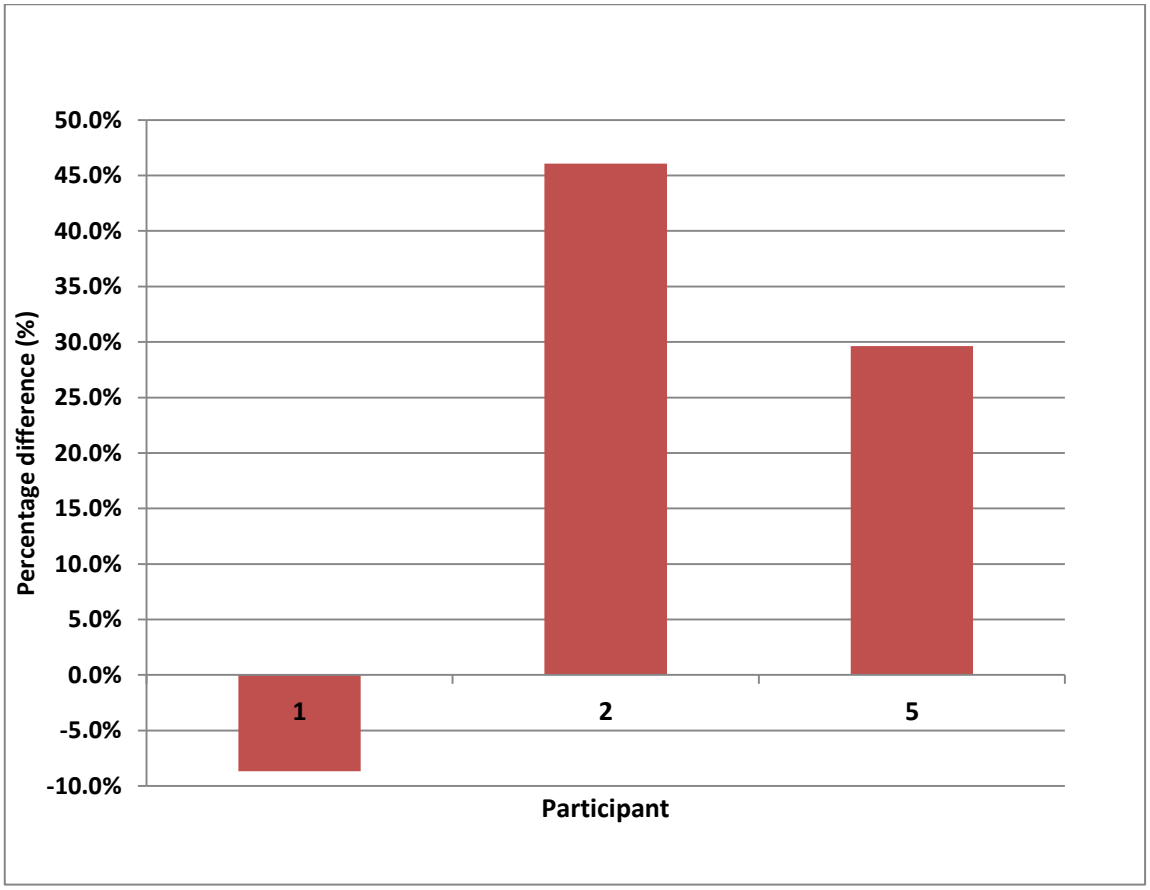

Figure 4.2. Percentage difference in meaningful speech for participants when the SFS was switched on

For P2 there was a percentage increase in meaningful speech of 46% and 30% for P5. For these participants there is an indication of improved access to input, from either the teacher or the handheld microphone, when the SFS was used. P1 conversely had a decrease in the overall amount of meaningful speech accessed; this participant was in top-set streamed GCSE classes, where the students were on task and focused. In addition the roving shared handheld

microphone was not used in P1's class. For P1 this may have been a contributing factor in the lack of improvement in access to overall meaningful speech percentage when the SFS was in use. Without use of the handheld roving shared microphone, oral contributions of P1's peers may not have been identified as meaningful speech.

There was a 15% reduction in the percentage of distant noise recorded averaged across all three participants in paired listening conditions when the SFS was utilised. If P1, in the focused GCSE class is removed, the percentage reduction was 23%. Both teachers of this participant indicated anecdotally and unsolicited, that they found the SFS to be of more benefit with younger and less focused year groupings where noise levels tended to be higher. This overall reduction appears to indicate that the pupils in the lessons spent less time in 'chatter' (distant speech) when they can more easily access the teacher and their peers' oral contributions with the SFS in use.

4.2. Study 2: Transparency testing

Test-box data, collated in Table 4.6. showed that the process of rebroadcasting through a SFS using only a listening check had a negative impact on the transparency curves for all five participants. Individual participant's results are attached in graph form in Appendix 4. Under-amplification was noted across all frequencies with the average difference for all participants being -13.6dB pre-balance as noted in Figure 4.3. The average under-amplification ranged from 9.6db at 500Hz to 18dB at 2kHz. Individual differences were noted in output of between 10dB and 25dB at 2kHz and 4kHz.

Table 4.6. Results from Transparency testing showing difference between pre and post electro-acoustic balancing of the rebroadcast systems.

	Curve 1	Curve 2	Curve 3	Curve 4	Difference between Curves 2 & 3	Difference between Curves 2 & 4	Difference between Curves 2 & 3 and 2 & 4
Frequency	**HA Curve**	**RAS Curve**	**SFS pre balance**	**SFS post balance**	**RAS/SFS pre-balance**	**RAS/SFS post-balance**	**RAS/SFS pre-balance**
Hz	**dB**	**dB**	**dB**	**dB**	**dB**	**dB**	**dB**
Participant P1							
250	108	110	90	110	-20	0	**-20**
500	105	105	91	107	-14	2	**-16**
1000	110	109	94	110	-15	1	**-16**
2000	118	115	93	115	-22	0	**-22**
4000	84	84	65	84	-19	0	**-19**
			Average Difference		**-18**	**0.6**	**-18.6**
Participant P2							
250	92	92	80	92	-12	0	**-12**
500	92	93	91	95	-2	2	**-4**
1000	100	100	93	100	-7	0	**-7**
2000	113	113	103	113	-10	0	**-10**
4000	94	95	82	90	-13	-5	**-8**
			Average Difference		**-8.8**	**-0.6**	**-8.2**
Participant P3							
250	107	103	97	103	-6	0	**-6**
500	105	103	97	102	-6	-1	**-5**
1000	95	95	85	95	-10	0	**-10**
2000	105	105	80	105	-25	0	**-25**
4000	75	75	65	76	-10	1	**-11**
			Average Difference		**-11.4**	**0**	**-11.4**
Participant P4							
250	90	91	82	93	-9	2	**-11**
500	101	101	89	104	-12	3	**-15**
1000	102	103	81	103	-22	0	**-22**
2000	110	108	90	108	-18	0	**-18**
4000	100	100	75	101	-25	1	**-26**
			Average Difference		**-17.2**	**1.2**	**-18.4**
Participant P5							
250	66	65	50	63	-15	-2	**-13**
500	73	73	67	75	-6	2	**-8**
1000	89	90	79	89	-11	-1	**-10**
2000	100	100	85	100	-15	0	**-15**
4000	83	83	67	83	-16	0	**-16**
			Average Difference		**-12.6**	**-0.2**	**-12.4**
Average of Participants P1 to P5							
250	92.6	92.2	79.8	92.2	**-12.4**	**0**	**-12.4**
500	95.2	95	87	96.6	**-8**	**1.6**	**-9.6**
1000	99.2	99.4	86.4	99.4	**-13**	**0**	**-13**
2000	109.2	108.2	90.2	108.2	**-18**	**0**	**-18**
4000	87.2	87.4	70.8	86.8	**-16.6**	**-0.6**	**-16**
			Average Difference		**-13.6**	**0.2**	**-13.8**

The recorded outputs across all frequencies fell well below the recommended levels of +/-2dB cited for achieving transparency with a RAS (UKCFMWG, 2008b).

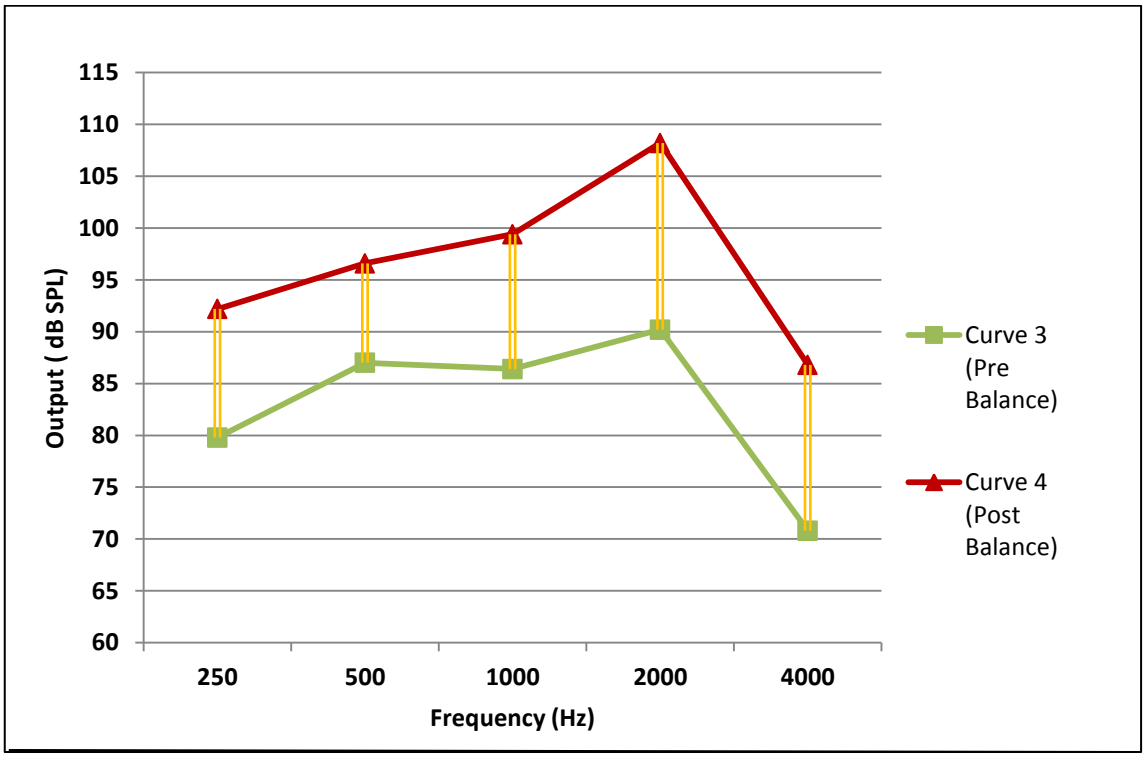

Figure 4.3. A graph showing average outputs pre and post electro-acoustic balance for participants using SFS/RAS at each frequency.

Post electro-acoustic balance, the average difference between the RAS transparency curve and the rebroadcast curve was reduced to a 0.2dB difference with a neutral variable at three frequencies. This falls well within the desired maximum variation of +/-2dB cited in the UK standards for transparency (UKCFMWG, 2008b).

4.3. Study 3: Speech Discrimination tests & Questionnaire

4.3.1. Speech Discrimination test

Speech discrimination test results, in each of the three listening conditions (RAS only, SFS/RAS pre-balance and SFS/RAS post-balance) were collated in Table 4.7. and Figure 4.4.

Table 4.7. Percentage score achieved in each word list against the listening condition..

Participant identifier	Percentage score (%) achieved per MJW list by each participant and listening condition					
	List1 RAS	List2 RAS	List3 SFS pre	List4 SFS pre	List5 SFS post	List6 SFS post
P1	73.0	87.0	67.0	60.0	67.0	73.0
P2	77.0	70.0	63.0	57.0	73.0	70.0
P3	50.0	80.0	51.0	70.0	87.0	67.0
P4	73.0	67.0	67.0	73.0	83.0	77.0
P5	83.0	93.0	70.0	83.0	90.0	80.0

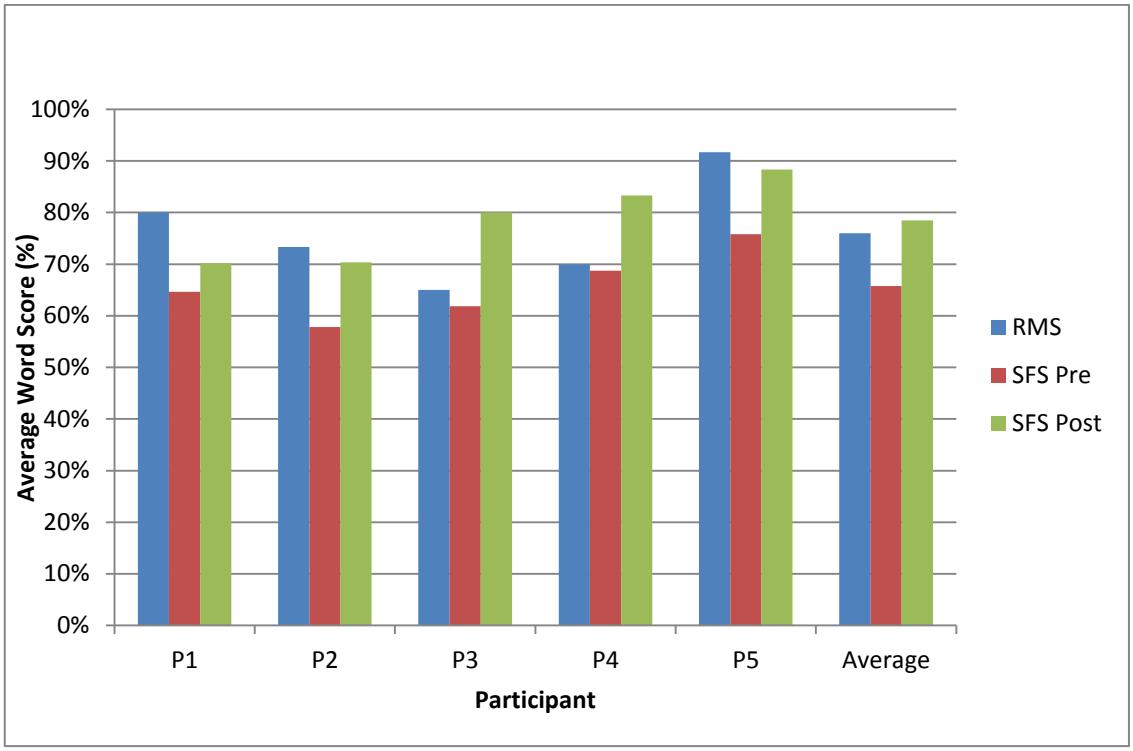

Figure 4.4. Bar chart of average scores in Speech Discrimination tests for Participants 1-5 in each listening condition.

In terms of accessibility to speech it was found that for three participants (P1, P2 and P5) the highest score post-balance was with the RAS only. For P2 and P5 the RAS had marginal benefit with 2.7% and 3.4% percentage increases respectively in test scores when compared with the rebroadcast RAS/SFS post balance. P1 had a more notable difference in scores with the RAS only achieving the best result by 10%. For the other participants (P3 & P4) it was the rebroadcast SFS post-balance which provided the best access to speech. P3

had an 18% increase and P4 a 14% increase in their speech discrimination test scores when using the balanced SFS/RAS compared to the RAS only.

It is clear that the process of balancing the SFS curve has an impact on speech discrimination scores. All participants recorded their lowest percentage scores in the pre-balance rebroadcast SFS listening condition. The average speech discrimination test score pre-balance was 65.8% accuracy with individual scores ranging from 57.8% to 75.8% accuracy.

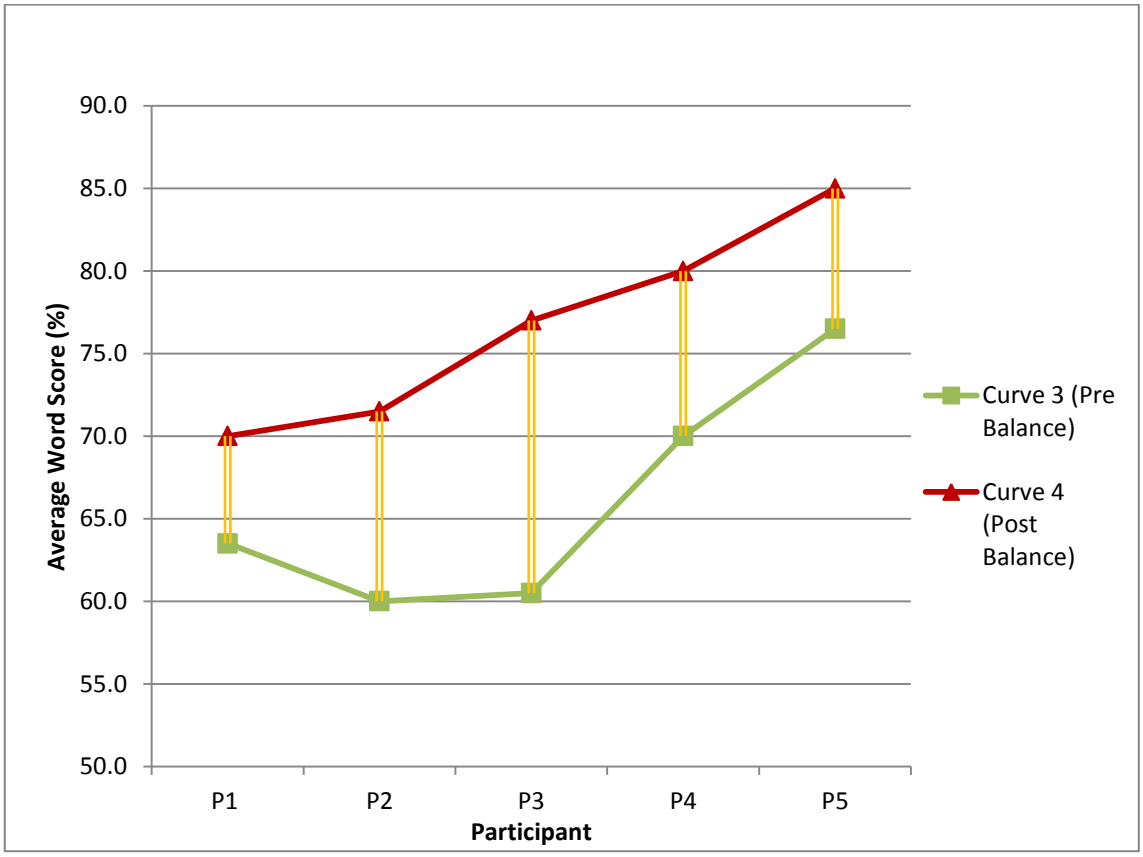

Figure 4.5. Comparison of average word score in Speech Discrimination tests pre and post balancing of the rebroadcast systems.

Figure 4.5. demonstrates the impact rebroadcasting, without appropriate verification, has on speech discrimination test scores. The average percentage increase in speech discrimination scores when the systems were balanced was 10.7%. The difference ranged from a 6% increase for P1 to 17% for P3.

4.3.2. Questionnaire

Table 4.8. Responses to the questionnaire completed by each participant during the speech discrimination testing to capture their perspective on the ease of access in each test situation.

Participant	Questionnaire rated responses (1 is really hard, 10 is really easy)		
	RAS only	SFS Pre-balance	SFS Post-balance
P1	10	8	6
P2	10	5	7
P3	10	10	10
P4	7	7	8
P5	10	8	10

Table 4.8. demonstrates that four participants felt the RAS only provided optimal access; P3 however perceived all listening conditions as equal and P5 felt the SFS post-balance to be equitable to the RAS only. P4 could not distinguish between the RAS only and the SFS pre-balance. Only P1 and P2 felt there was a variance in ease of listening across all three listening conditions.

Whilst completing the questionnaire all the participants clarified their choices and their commentary is noted in Table 4.9. Comments on the pre-balance signal stated it was, 'not as clear' and was, 'fuzzy and quiet.' Post-balance comments perceived the sound to be 'louder' and 'clearer,' although P1 perceived it to be echoic.

Table 4.9. Participant comments regarding ease of access in the three test situations.

Participant	Comments which participants volunteered when completing their Questionnaires.		
	RAS only	SFS Pre-balance	SFS Post-balance
P1	That was clear The mic (RAS) doesn't move around in the test and it does in the classroom*	That was a tiny bit louder than first one	That was harder. It sounded 'echoey' and some of the syllables were lost in the echo**.
P2	Easy , it was the clearest and loudest	I had to concentrate harder on that one, not as clear	That was better than last one, it was louder and a bit clearer
P3	Easy	Easy	Easy
P4	Okay	Same	Same
P5	That was good	That wasn't so easy, it sounded a bit like fuzzy and quiet	That was better; I didn't have to concentrate so hard.

*Comment made after the questionnaire was completed.
** Room was not acoustically treated. No carpets and single glazing.

The participants' scores were tabulated to compare their actual scores in speech tests with their perception of ease of access to speech in Table 4.10. The scores were based on the questionnaire responses and the speech discrimination test scores. All participants correctly anticipated their best listening condition with P1, P2 and P5 isolating RAS only and P3 and P4 recognising that the SFS post-balance produced their best listening condition. The participants' subjective views matched their objective test results 60% of the time. Only P2 and P4 had speech test scores that matched their perception scores for all three listening conditions.

Table 4.10. Speech test scores compared with participants' views on the questionnaire.

Participant	RAS only		SFS Pre-Balance		SFS Post-Balance	
	Actual (%)	Perceived (%)	Actual (%)	Perceived (%)	Actual (%)	Perceived (%)
P1	80	100	64	80	70	60
P2	74	100	60	50	72	70
P3	65	100	61	100	77	100
P4	70	70	70	70	80	80
P5	88	100	77	80	85	100
Average	**75**	**94**	**66**	**76**	**77**	**82**

Only P2 recognised that the SFS pre-balance was the worst listening condition. P1 and P3 however perceived their worst listening condition, the pre-balance SFS, to be their best listening condition. This is of significance for professionals who use the 'voice of the child' when verifying equipment.

4.4. Study 4: Participants' views

Views were also sought from the participants about which Assistive Listening Device they preferred to use within the classroom, as opposed to the Questionnaire which focused solely on the test situations. Participants' views on preferred use of systems in the classroom did not always match with their responses and commentary on the Questionnaire.

Table 4.11. Participants' preferences and views on use of ALD's for accessing oral learning

Participant	Views on RAS and SFS in the classroom situation. responses to open questions
P1	The loudness and sound quality are similar. I would probably choose the SFS because it doesn't have the same amount of clothes rub on the mic and the neck loop is better. I like being able to switch the receivers on and off if the teacher forgets to switch the mic off. My friends can see how annoying it is when the teacher forgets to switch off the SFS mic and they're not talking to the whole class. It does depend on the lesson though and sometimes I don't use it 'cos it's not great having to go to plug it in, especially if I'm one of last into the room as it takes time.
P2	I'd basically rather not have to use either mic but I know that's not an option. I don't like having to walk to the back of the room to plug in my transmitter to the SFS. It's annoying if the teachers accidentally put the SFS mic on the wrong way round so it doesn't work (infra-red). Then they turn it round and it takes ages and is embarrassing. Other students take the leads from the SFS as they work with their laptops so sometimes I can't plug it in. Sometimes other students turn the dial way up so that when the teacher puts it on it makes too much noise and then I have to get up to sort it out. The sound quality is the same with RAS and SFS or with just the RAS, but the RAS transmitter is a bit louder. If they use the handheld mic I can mostly hear the others but if not I just have to wait for the teacher to repeat it or I don't hear it. I don't really like using it though.
P3	I prefer RAS mic only in classroom, It bit loud. Like handheld mic.
P4	I really don't like having to go and plug in my RAS mic. I use the RAS mic a lot outside to hear my friends. I can't hear the other children unless we use the handheld mic and that is really good. They sound the same the mic's in the class.
P5	I think it is better with the SFS and the RAS that is what we always do. The handheld mic (SFS) means I can hear them (children) when they talk. I can't hear without it. It was a bit noisier today (no SFS day). If I could choose I would just have the RAS mic as it's easiest to hear with.

P1 noted a difference between the test situation and the classroom. He stated that the microphones were fixed in the test situation whereas they could move around the teacher's neck in the classroom. P1 therefore indicated a preference within the classroom for the SFS due to the microphone style. P3 and P5 indicated a preference for the RAS only in the classroom setting; for P3 however the RAS did not provide the best listening condition in the speech testing situation. Four participants mentioned the benefit of using the handheld microphone to support their access to peers. Three commented on the practical issues regarding rebroadcasting saying they found it socially difficult. P1 and P2 who are in secondary settings noted management issues with the systems with P2 stating he would prefer to use no assistive listening device.

5. Discussion

The research was designed to quantitatively and qualitatively explore the value and impact that using a Radio Aid system (RAS) and a Soundfield (SFS), within the classroom setting, had on access to audition for school-aged CYP(HI).

This research is significant as national quality standards for use of resources and provision for CYP(HI) (NDSC 2011: p.15).indicate that:

> Deaf children and young people (should) have access to up to date technology that is appropriately managed to improve their ability to access spoken language, the curriculum, the auditory environment and support development of their language skills.

Furthermore current quality standards on the use of RAS (UKCFMWG, 2017: p.23), refer to the need to ensure that:

> Where Soundfield systems are used in conjunction with personal radio aids, equipment must be selected and set up to ensure that the performance of the personal radio aid system is not compromised

Study 1 used quantitative data obtained from the language environment analysis (LENA™) system to analyse the role of a SFS in supporting access to speech in the classroom. This study provided information about potential benefits for all CYP. Study 2 considered the impact rebroadcasting a SFS through a RAS had on transparency of signal using quantitative data obtained from an electro-acoustic balancing procedure. The third study also used quantitative data to investigate the discrimination of speech using different assistive technology. It considers access through a RAS and through a SFS rebroadcast via the RAS, both before and after the balancing process. The fourth and final study used both quantitative and qualitative measures to support reflection on the CYP(HI)'s voice, through the use of a questionnaire and interview.

The findings are amalgamated and discussed under three sections. The first section focuses on the perceived benefit of using a SFS within the classroom. It also considers implications for the use of a SFS alongside a RAS. Secondly there is discussion of the impact rebroadcasting a SFS through a RAS has on the transparency of electro-acoustic output curves and discrimination of speech by CYP(HI). The third section considers the role of the voice of the child in decision-making around provision and best use of assistive listening devices. The chapter concludes with a review of the strengths and limitations of this research, alongside its implications for practice in the field and scope for future research.

5.1. Perceived benefit for CYP(HI) using a SFS within the classroom

It is widely accepted that SFS's provide positive benefits to the learning environment in classroom settings for CYP; through enhanced signal to noise ratio and by enabling better learning and social behaviour leading to improved educational outcomes (Rosenberg, 2005; John & Kreisman, 2012). Research has indicated the need for an enhanced SNR for CYP(HI) (Neuman et al., 2012). SFS's have been shown to lead to quieter working classrooms (Dillon & Massie, 2006; Larsen & Blair, 2008), providing an improved SNR when used of up to 11dB. Data from the LENA™ study collected in working classrooms indicated an increased AWC reaching the participants when the SFS was used; this is in agreement with research. Equally a reduction in distant speech was noted when the SFS was used. This could be a consequence of participants accessing more meaningful speech and therefore less distant speech. It could also be an indication that CYP heard more of the teacher input with increased engagement resulting in a reduction in background 'pupil chatter.'

This study also isolated the use of the SFS roving handheld microphone, to capture oral input from peers' in the classroom, as another benefit of using the SFS. This is of particular importance in the modern classroom where student participation often forms a significant part of the overall learning process. Rekkedal (2015) in a study of students' listening perception in the classroom concluded that handheld microphones were positively associated with the ability

of CYP(HI) to hear what their peers' said in the classroom. Responses in the Study of Participant Views concurred with this research. The use of the handheld microphone with the SFS was perceived as an additional benefit, even by those participants who preferred listening through the RAS. In the analysis of percentages of meaningful speech the participants using the roving handheld had significantly higher scores, in terms of access to meaningful speech, than the participant who did not use it. Use of a separate handheld microphone in addition to the SFS teacher transmitter enables access to peers' contributions in a more easily managed way than using just the RAS transmitter.

When collectively evidenced there is an advantage provided in accessing oral learning within the classroom through a SFS signal rebroadcast via a RAS. The results from the LENA™ study suggest the use of a SFS within a classroom was beneficial though increased access to meaningful speech and reduction in background speech levels. There was also an overall increase the Adult Word Count when the SFS was utilised, thereby providing better access to the teacher delivering the oral input. These benefits provide a better listening environment for all children, but especially for children with a hearing loss who require an advantageous SNR (Neuman et al., 2012).

5.2. Impact of rebroadcasting on transparency and speech discrimination

Research studies comparing the benefits for CYP(HI) of using either a SFS or a RAS concluded that a RAS provided a better system to support access to speech (Anderson & Goldstein, 2004; Iglehart, 2004; Anderson et al, 2005). This research does not however take account of the benefits for classroom acoustics and the listening environment provided through use of a SFS. John & Kreisman, in Smaldino & Flexer (2012: p.62) indicated that there is limited research evaluating, 'the potential interaction of FM (RAS) and Classroom Assistive Devices (SFS) used in the same space'. This is particularly pertinent as results from this study indicate the potential issues that arise for CYP(HI) using these systems together when the process of rebroadcasting has not been

verified. It is not the ‘interaction’ of the systems in itself that is an issue, but that the interaction needs to be effectively verified.

There is long-standing research and national guidance around the need for electro-acoustic testing of transparency when using a RAS (UKCFMWG, 2008a; AAA, 2011a; UKCFMWG, 2017). This is to ensure that the signal received through the CYP(HI)’s hearing aids provides an advantageous signal to noise ratio, when the RAS is used to transmit the signal. There is no such national guidance for ensuring transparency is maintained when rebroadcasting the signal through a SFS. The UKCFMWG (2017: p.23) states that rebroadcasting must be, ‘set up to ensure that the performance of the personal radio aid system is not compromised’ but current advice from UKCFMWG (2008b: p.44) indicates that the process of ensuring the quality and level of the final rebroadcast sound is ‘likely to be subjective’.

A listening balance when setting up the system, where the professional or student selects the appropriate level at which to set the audio dial, is recommended in manufacturer guidance (Front Row, 2013; Lightspeed, 2016b). It is clear from the output curves in the Transparency testing study that the process of rebroadcasting impacts on the transparency of signal when the SFS audio output dial is not set accurately. For all five participants there was an under-amplification noted prior to balance, with the most significant differences noted at the higher frequencies (Figure 4.9.). The recommendation to set the level based on student perception must also be questioned given that only one of the participants in this study recognised that the rebroadcast system pre-balance gave the weakest scores. This research used a process (see Appendix 2) to electro-acoustically balance a rebroadcast SFS. For the Lightspeed Redcat SFS and Phonak Zoomlink+ RAS combination this process enabled transparency of signal to be achieved. It ensured that the performance of the radio aid system was not compromised when rebroadcast, with all five rebroadcast systems producing output curves within the four frequency average difference of +/-2dB recommended for transparency with RAS’s (UKCFMWG, 2008b & 2017).

Wolfe et al. (2013) demonstrated that rebroadcasting had a negative impact on the ability to discriminate speech when an RAS and a SFS from different manufacturers were used together. They found that in noisy conditions rebroadcasting through two different systems resulted in speech discrimination test scores that were significantly lower than listening through a RAS only. Wolfe et al. (2013: p. 76) retrospectively concluded from their findings that the educational audiologist needed to, 'administer validation measures of the child's performance when the RAS is used with a SFS to, 'prevent negative impact' to the RAS signal. It would appear from Wolfe's study, which refers to a lack of gain control on the SFS used, that validation had not been carried out prior to speech testing using the rebroadcasted systems. The results in Wolfe et al.'s study more closely match those obtained in this research when the RAS and SFS were not electro-acoustically balanced. It could be argued that with appropriate electro-acoustic testing used to achieve transparency, systems from different manufacturers can be used together effectively.

Verification through speech testing when Soundfield systems are used is an important requirement recommended by AAA (2011). It is clear from this research that this process is indeed supportive to the process of assuring optimal access to the speech signal. Data from the Speech Discrimination testing in this study demonstrated that when the rebroadcast systems are not balanced and verified the transmitted signal is compromised; this then impacts on CYP(HI)'s ability to discriminate speech. All five participants recorded their lowest scores when the rebroadcast system had not been verified, with an average score of 65.8% recorded in Speech Discrimination testing. In comparison the SFS/RAS rebroadcast with transparency provided listening conditions comparable to, or exceeding, those recorded when using just the RAS. All participants scored with between 70% and 88% accuracy on speech discrimination tests when listening to the rebroadcast signal post electro-acoustic balance. Indeed for three of the participants this proved to be their optimal listening condition. This study demonstrates that when verification is considered rebroadcasting can ensure optimal access to the speech signal.

5.3. The role of the voice of the child in use of audiological equipment decision making

Assistive listening devices can be seen by the CYP(HI) as a tool to enable independence but also as a visible sign of disability (Rekkedal, 2012). Engaging with the user is vital to optimise the chances for the ongoing use of this equipment. It is also recommended as good practice to collate the user's subjective views on the benefit of, and barriers to use of, the devices (UKCFMWG, 2017).

The participants' views within the research isolated many pertinent points with regard to the advantages and disadvantages of their systems and their preferences. The participants could all isolate, and give reasons, for their preferred mode of signal delivery in the classroom. It should be noted however that they were not always able to isolate the best listening conditions in the speech test situation. Only two participants recognised that the pre-balance RAS/SFS delivery was the most difficult listening condition. Professionals in the field need to be mindful that CYP(HI) may not always be able to isolate the best equipment to provide optimal access to the signal.

Johnston (2015) references the impact that the student's knowledge about their equipment has on their ultimate acceptance or rejection of equipment in teenage years. She recommends students are involved in the process of identifying benefit and usage of their systems so that they can be familiar with and define the benefits provided by equipment. This research showed clearly that participants could articulate both their preferences regarding assistive listening devices and isolate potential barriers to effective use of the equipment. P1 noted that he did not like the microphones of the RAS, yet he has previously rejected other RAS's after trialling them because they lack an on/off option on the receivers which he perceived as a loss of user control. Manufacturers need to canvass the views of CYP(HI) as well as professionals when designing technology if best use is to be made of devices.

Even when the optimum listening device has been isolated for an individual, there needs to be continuing dialogue and a need for the professionals to work

within the CYP(HI)'s own perceptions. Franks (2008) in her study of rejection of RAS systems found social reasons were cited as the main cause of rejection of assistive devices in over half of her test population. In this research one participant stated that he would rather not use the equipment at all and more than half the participants referred to issues with the logistics of managing the rebroadcast system in the classroom. Whilst effective use of a rebroadcast and balanced SFS/RAS may be the optimal form of audition for some users, it may not always work for those CYP(HI) socially. Professionals need to be able to discuss results of speech testing validation whilst considering the CYP(HI)'s views. This should support both the best choice of equipment for that individual and continued use in the field of some form of additional assistive listening device.

The results of the LENA™ testing also have potential to be used to support the dialogue between professionals and users of the assistive listening devices. Mulla (2011) stated that LENA™, 'provides very useful acoustic information related to children's environment and can be used as a positive counselling tool'. The data from the LENA™ device can be used to review the acoustic environment that CYP(HI) are working within and to counsel students who are reluctant to use equipment, believing they can 'hear fine' without using it. It can also be used to inform classroom management training for professionals and deaf awareness training for peers. The aim of this training would be positive management of classroom noise and enabling effective access to oral learning.

Scherer et al. (2005) stated that when fiscal resources are limited it is important to effectively match the assistive technology with the user in order that best use is made of available resources. This is particularly salient in today's climate of increasing financial restraint. Where possible authorities should seek to provide the SFS and RAS combination that works most effectively, both in terms of objective test results and the CYP(HI)'s individual preferences. This research shows that there is not just one option that works best for all CYP(HI). Providing choice and options in partnership with CYP(HI) should be part of the local offer.

6. Conclusion

This research provides an important contribution to the existing literature on the use of ALD's within the learning environment. The LENA™ study which used the LENA™ device to capture adult word count and room acoustics highlighted the benefits of using such technology. The data captured by the LENA™ device provided clear and accessible information that can be used to counsel teachers and professionals on the benefits of an improved SNR, as well as isolating the benefits of using a SFS in the classroom. The Transparency and Speech Discrimination testing studies both indicated the potential issues with rebroadcasting. The data clearly demonstrated that without effective verification of the rebroadcasting process, the signal was significantly under-amplified resulting in reduced access to the speech signal. The process of electro-acoustic balance ensures that rebroadcast systems provide optimal benefit for CYP(HI) as the quality of the received signal is not compromised. The Participants' Views study elicited pertinent information to support further review of training to settings and support for the individual CYP(HI) to ensure effective use of the systems to support access to learning. The data collected in the interview process clearly demonstrate the value that can be added by listening to the voice of the CYP and working within their individual circumstances.

Key findings from this research are that:

- The use of a SFS within a classroom had an impact in terms both of the amount of meaningful speech heard and a reduction in background speech levels.
- Rebroadcasting speech from a SFS through the RAS had an impact on the transparency curves resulting in an under-amplification of speech across all frequencies. This was most marked at the higher frequencies.
- The process of rebalancing the SFS resulted in a high level of transparency with output curves for the rebroadcast SFS/RAS within the acceptable levels for achieving transparency as defined for the RAS (UKCFMWG, 2017).
- Rebroadcasting without balance had a negative impact on speech discrimination scores.

- The use of an RAS did not provide better listening condition over the use of a SFS rebroadcast through a RAS for all participants.
- CYP(HI) are not always able to identify the best equipment to support their listening in either the real life situation or within a test situation. They were however able to give pertinent and useful information about both benefit and barriers to use that could be used to inform interventions supporting better management of their devices.

Access to a Soundfield system (SFS) in a classroom impacts positively both on the listening environment and the clarity of speech signal reaching the user.

The process of rebroadcasting a signal received by a SFS, through a RAS must be managed carefully to prevent it impacting on the transparency of signal thereby affecting discrimination of speech signal by the listener.

6.1. Strengths and limitations

This mixed methods research adds value to the very small number of current studies looking at the interfacing of RAS and SFS's. It has addressed a critical gap in knowledge as there is currently no published research into the impact achieving transparency has on speech discrimination scores when rebroadcasting. It has also highlighted the implications for practice in the field and provided a replicable process to ameliorate the issue.

Access to data from LENA™ enabled a more detailed analysis of the acoustic and linguistic environment of a working classroom than time would have permitted had manual measurement and coding of language been required. This provided useful evidence on both the acoustic environment and the amount of useful speech reaching the participants within the working classroom.

The number of participants in this study would invite caution when extrapolating any findings around the views of the CYP.

The study was carried out at the end of the school day to ensure an empty classroom and low background noise levels; this may have impacted speech test results. The three test situations were carried out in the same order for each participant. It could be argued that fatigue over the period of speech testing may have impacted on results.

The background noise levels averaged within 5dB in all the speech testing situations. Procedurally there was no option when using the PARROT tester to manipulate the signal level to ensure the SNR was exactly equitable for all participants.

When considering the electro-acoustic balance process with cochlear implants caution would be advised as there is currently no national guidance on the process of achieving transparency with cochlear implants.

For three of the students the RAS only gave the best outcome on speech discrimination testing. For these CYP it would be beneficial to continue the action research cycle to ascertain if further adjustment of the audio output dial would improve outcomes for speech testing when rebroadcasting.

This research would benefit from replication by others with a range of RAS and SFS combinations. There would need to be further checks made with individual manufacturers of SFS's to establish protocol with other systems. An assessment of what process of validation is currently in place within individual authorities across the country when rebroadcasting occurs would help build a national picture of processes.

6.2. Implications for the future

This research supports the advantage provided by SFS within the classroom for CYP(HI)'s access to audition though the increased access to the speech signal. It clearly demonstrates the advantage that CYP(HI) perceive the handheld microphone provides them in terms of access to the oral contributions of their peers. The roving handheld microphone is provided as an optional extra with

many Soundfield systems yet this study demonstrates its integral value to the overall access to learning within the classroom.

This study evidences the negative impact on the rebroadcast signal when verification of the rebroadcast signal is not considered. It highlights the need to roll out the process of achieving transparency of signal when rebroadcasting to professionals working in the field. It must equally become standard practice to carry out speech discrimination testing to verify that the rebroadcast signal is indeed providing benefit.

CYP's views must be taken into account when assigning additional assistive listening devices particularly where there is little objective difference noted between systems. An on-going dialogue with the users of the equipment is essential to ensure not only the best use of available resources but most importantly the effective use of equipment to support access to learning within the classroom.

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Appendices

Appendix 1: Ethics Approval Information

1.1. Email indicating approval

SOCIAL SCIENCES, ARTS AND HUMANITIES ECDA
ETHICS APPROVAL NOTIFICATION
TO: Mary Atkin
CC: Dr Imran Atkin
FROM Dr Tim Parke, Social Sciences, Arts and Humanities ECDA Chairman
DATE: 20/9/16

Protocol number: **EDU/PGT/CP/02651**
Title of study: What effect does re-broadcasting of a remote microphone (RM) system through a Soundfield system have on transparency and on the Children or Young Person's (CYP) access to speech?
Your application for ethics approval has been accepted and approved by the ECDA for your School.
This approval is valid:
From: 20/9/16
To: 1/5/17
Please note:
Approval applies specifically to the research study/methodology and timings as detailed in your Form EC1. Should you amend any aspect of your research, or wish to apply for an extension to your study, you will need your supervisor's approval and must complete and submit form EC2. In cases where the amendments to the original study are deemed to be substantial, a new Form EC1 may need to be completed prior to the study being undertaken.
Should adverse circumstances arise during this study such as physical reaction/harm, mental/emotional harm, intrusion of privacy or breach of confidentiality this must be reported to the approving Committee immediately. Failure to report adverse circumstance/s would be considered misconduct.
Ensure you quote the UH protocol number and the name of the approving Committee on all paperwork, including recruitment advertisements/online requests, for this study.
Students must include this Approval Notification with their submission.

1.2. EC3: Consent Form for Studies Involving Human Participants

UNIVERSITY OF HERTFORDSHIRE
ETHICS COMMITTEE FOR STUDIES INVOLVING THE USE OF HUMAN PARTICIPANTS (‘ETHICS COMMITTEE’)

FORM EC3
CONSENT FORM FOR STUDIES INVOLVING HUMAN PARTICIPANTS

I, the undersigned *[please give your name here*, *in BLOCK CAPITALS]*

…….
of *[please give contact details here, sufficient to enable the investigator to get in touch with you, such as a postal or email address]*

…..……
hereby freely agree to take part in the study entitled:

What effect does re-broadcasting of an Radio Aid system through a Soundfield system have on transparency and on the Child or young Person’s access to speech?

(UH Protocol number EDU/PGT/CP/02651)

1 I confirm that I have been given a Participant Information Sheet (a copy of which is attached to this form) giving particulars of the study, including its aim(s), methods and design, the names and contact details of key people and, as appropriate, the risks and potential benefits, how the information collected will be stored and for how long, and any plans for follow-up studies that might involve further approaches to participants. I have also been informed of how my personal information on this form will be stored and for how long. I have been given details of my involvement in the study. I have been told that in the event of any significant change to the aim(s) or design of the study I will be informed, and asked to renew my consent to participate in it.

2 I have been assured that I may withdraw from the study at any time without disadvantage or having to give a reason.

3 I have been told how information relating to me (data obtained in the course of the study, and data provided by me about myself) will be handled: how it will be kept secure, who will have access to it, and how it will or may be used.

4 I understand that if there is any revelation of unlawful activity or any indication of non-medical circumstances that would or has put others at risk, the University may refer the matter to the appropriate authorities.

5 I have been told that I may at some time in the future be contacted again in connection with this or another study.

Signature of participant……..…Date……

Signature of (principal) investigator……Date……

Name of (principal) investigator

MARY E ATKIN

1.3. EC4: Consent Form for Studies Involving Human Participants

UNIVERSITY OF HERTFORDSHIRE

ETHICS COMMITTEE FOR STUDIES INVOLVING THE USE OF HUMAN PARTICIPANTS ('ETHICS COMMITTEE')

FORM EC4
CONSENT FORM FOR STUDIES INVOLVING HUMAN PARTICIPANTS
FOR USE WHERE THE PROPOSED PARTICIPANTS ARE MINORS, OR ARE OTHERWISE UNABLE TO GIVE INFORMED CONSENT ON THEIR OWN BEHALF

I, the undersigned *[please give your name here, in BLOCK CAPITALS]*
……
of *[please give contact details here, sufficient to enable the investigator to get in touch with you, such as a postal or email address]*
……
hereby freely give approval for *[please give name of participant here, in BLOCK CAPITALS]*
.....
to take part in the study entitled:

What effect does re-broadcasting of an Remote Microphone (RM) system through a Soundfield system have on transparency and on the Child or Young Person's (CYP) access to speech?
(UH Protocol number EDU/PGT/CP/02651)

1 I confirm that I have been given a Participant Information Sheet (a copy of which is attached to this form) giving particulars of the study, including its aim(s), methods and design, the names and contact details of key people and, as appropriate, the risks and potential benefits, how the information collected will be stored and for how long, and any plans for follow-up studies that might involve further approaches to participants. I have also been informed of how my personal information on this form will be stored and for how long. I have been given details of his/her involvement in the study. I have been told that in the event of any significant change to the aim(s) or design of the study I will be informed, and asked to renew my consent for him/her to participate in it.

2 I have been assured that he/she may withdraw from the study, and that I may withdraw my permission for him/her to continue to be involved in the study, at any time without disadvantage to him/her or to myself, or having to give a reason.

3 I have been told how information relating to him/her (data obtained in the course of the study, and data provided by me, or by him/her, about him/herself) will be handled: how it will be kept secure, who will have access to it, and how it will or may be used.

4 I understand that if there is any revelation of unlawful activity or any indication of non-medical circumstances that would or has put others at risk, the University may refer the matter to the appropriate authorities.

5 I have been told that I may at some time in the future be contacted again in connection with this or another study.

6 I declare that I am an appropriate person to give consent on his/her behalf, and that I am aware of my responsibility for protecting his/her interests.

Signature of person giving consent

……Date……
Relationship to participant
.....
Signature of (principal) investigator

.....Date……..

Name of (principal) investigator MARY E ATKIN

1.4. EC6: Participant Information Sheet

UNIVERSITY OF HERTFORDSHIRE

ETHICS COMMITTEE FOR STUDIES INVOLVING THE USE OF HUMAN PARTICIPANTS
('ETHICS COMMITTEE')

FORM EC6: PARTICIPANT INFORMATION SHEET

1 **Title of study: Rebroadcasting an Remote Microphone (RM) system through a Soundfield system**

2 **Introduction**

You are being invited to take part in a study. Before you decide whether to do so, it is important that you understand the research that is being done and what your involvement will include. Please take the time to read the following information carefully and discuss it with others if you wish. Do not hesitate to ask us anything that is not clear or for any further information you would like to help you make your decision. Please do take your time to decide whether or not you wish to take part. The University's regulations governing the conduct of studies involving human participants can be accessed via this link:
http://sitem.herts.ac.uk/secreg/upr/RE01.htm

Thank you for reading this.

3 **What is the purpose of this study?**

It is recommended that children with a hearing loss need a good signal to noise ratio in order to best support their access to language within the classroom. A Remote Microphone (RM) system and a soundfield system (SFS) can support this, and your child currently uses both of these systems linked together so that the teacher's voice is rebroadcasted to their hearing aids or cochlear implants..

As part of my job as a Teacher of the Deaf in Oxfordshire and lead in Audiology I routinely monitor and collect data on the function of these systems to ensure that they are providing maximum benefit for the children using them.

I would like your consent to allow me to use this data to form the main body of my dissertation with the University of Hertfordshire.

4 **Do I have to take part?**

It is completely up to you whether or not you decide to let me use this data, around the function of your child's RM system and Soundfield system, as part of my study. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. Agreeing to join the study does not mean that you have to complete it. You are free to withdraw at any stage without giving a reason. A decision to withdraw at any time, or a decision not to take part at all, will not affect any treatment/care that you may receive (should this be relevant).

5 **Are there any age or other restrictions that may prevent me from participating?**

The candidates selected will be children and young people, aged between 7 years and 18 years, who have a severe to profound hearing loss, and use an RM system rebroadcast through a Soundfield system.

6 **How long will my part in the study take?**

If you decide to take part in this study, your child's data will continue to be collected as part of our routine work. Some has already been collected and is held on case files. There will be some more collected over the period between now and Christmas 2016 as would be usual practice. Consent is required to use this data for the purposes of the dissertation as well as informing our best practice.

You may be asked for permission in the future to use the data to complement further research.

7 **What will happen to me if I take part?**

The first thing to happen will be that the data will continue to be collected as routine practice for your child to make sure their systems are working well. This will include;

- Electro-acoustic testing of your child's equipment.
- Your child will also continue to do some speech discrimination tests and complete a short questionnaire about their equipment.
- Some children will be using a system called a LENA™ to collect more information about the amount of speech is accessible to them in the classroom.

Should you require any further information on any of this please do not hesitate to contact me.

This data is used to inform our practice and make sure that we effective use of the Soundfield system with the RM system

If you take part in the study your child's data will be anonymised, analysed and reported on in order to support sharing of information on the effective use of the soundfield system with the RM system.

8 **What are the possible disadvantages, risks or side effects of taking part?**

There are no known risks to participating in this study.

9 **What are the possible benefits of taking part?**

I will share my findings with you. I will also liaise with your child's setting so that the equipment is used to best effect. Any changes to practice following this research will be of benefit to other CYP within the authority as this study will inform practice across the county.

10 **How will my taking part in this study be kept confidential?**

All data will be anonymised before being used in the dissertation. All data and consent forms will be kept in a secure and locked cupboard either in my office or home until they can be uploaded to a secure encrypted laptop which is maintained in compliance with Oxfordshire's ICT policy

11 **Audio-visual material**

No audio-visual material will be collected or used within this study. .

12 **What will happen to the data collected within this study?**
The data collected will be stored electronically, in a password-protected environment, in accordance with Oxfordshire's data storage and handling policies, after which time it will be destroyed under secure conditions;

The data collected will be stored in hard copy by me will be held in a locked cupboard for less than one month, after which time it will be destroyed under secure conditions;

The data will be fully anonymised prior to storage.

13 **Will the data be required for use in further studies?**
You are consenting to the re-use or further analysis of the data collected in a future ethically-approved study;

The data collected will be stored electronically, in a password-protected environment, in accordance with Oxfordshire's data storage and handling policies, after which time it will be destroyed under secure conditions;

The data collected will be stored in hard copy by me in a locked cupboard for less than one month, after which time it will be destroyed under secure conditions.

14 **Who has reviewed this study?**
This study has been reviewed by the University of Hertfordshire Social Sciences, Arts and Humanities Ethics Committee with Delegated Authority

The UH protocol number is EDU/PGT/CP/02651

15 **Factors that might put others at risk**
Please note that if, during the study, any medical conditions or non-medical circumstances such as unlawful activity become apparent that might or had put others at risk, the University may refer the matter to the appropriate authorities.

16 **Who can I contact if I have any questions?**
If you would like further information or would like to discuss any details personally, please get in touch with me, in writing, by phone or by email:

Researcher: Mary Atkin
Teacher of the Deaf and SENSS(HI) Area Team Manager
Samuelson House
Tramway Road
Banbury
Oxon OX16 5AU
Telephone: 07584 581204
Email: mary.atkin@oxfordshire.gov.uk

Supervisor: Dr Imran Mulla

Although we hope it is not the case, if you have any complaints or concerns about any aspect of the way you have been approached or treated during the course of this study, please write to the University's Secretary and Registrar.

Thank you very much for reading this information and giving consideration to taking part in this study.

Appendix 2: Process for electro-acoustic balance of the SFS when rebroadcast through the RAS

Soundfield and Radio Aid Systems

Rebroadcasting and balancing with Redcat and Zoomlink

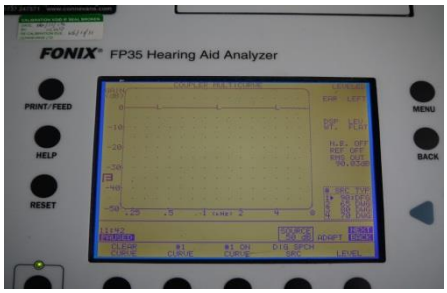
THE PROCESS

Always do a listening check through RAS and then through RAS/SFS and check if it sounds similar in terms of the quality and volume.

This test outlined below must be done when first setting up the SFS system in a setting. It must be repeated every time the system is moved to a new location or a new hearing aid/RAS is introduced.

GETTING STARTED

Plug in testbox + switch on.
Press 'F3' Coupler/Multicurve**.**



LEVELLING

Leave lid open (with mic on target).
Press F5.
Press Start.
Obtain level graph.

Check test box 'Menu' is set to→

Press 'Exit' to exit the menu.

Ear – choose left or right Display – 3rd Oct SPL Data/ Graph – Graph Aid group – Adaptive Distortion – Total Noise Red (Comp) – 4X Noise Red (Tone) - Off

CURVE 1 (Hearing Instrument frequency response)

- Select 'digi-spch SRC' (using F4) by scrolling through options.
- Select output level of 65DWO It is best to start off at 40-45output and come up to indicated level.
- Always put a fresh battery in the hearing aid or check power level.

Attach the hearing aid to 2cc coupler with mic inside the coupler.

Place hearing aid with mic on target.

Press ‘Start’ to obtain curve.

Fix by pressing ‘F2’.

CURVE 2 (RAS frequency response)

Repeat to obtain FR curve for RAS (again with lid up).

It is best to test on omni-directional setting for all Zoomlink systems, and essential for the Zoomlink + (dynamic system).

Put the hearing aid in a soundproof box to block off the microphones; do not use blue-tac as it can block filters.

Check output is set to correct level for instrument using the frequencies listed in table below. Also check that you are using a ‘digi-spch SRC’ signal.

It is best to start with a low output (40-45DWO) and work up to 65DWO to avoid risk of putting system into compression.

Press Start to get curve.
Press F2 to fix the curve.

Hopefully the curves will balance.

If not balanced, you can use Successware to balance.

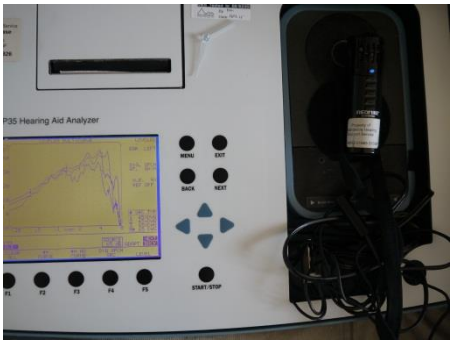
HOWEVER before doing so:

- Make sure the MLXi is on, if it is an enabled one.
- It’s always worth starting again to check for human error.
- Please check that it is not a compression issue causing curve mismatch.
- If in doubt check with a colleague/Ed Aud.

CURVE 3 (SFS/RAS frequency response)

Plug the connecting lead into the ‘audio’ socket on the connecting block.

Plug RAS transmitter into the SFS (switched on!) via the port under the audio output.



Place SFS transmitter in the test box with mic (switched on!) on target.
On the Redcat SFS turn the volume to zero on Channels A and B.

The lid should be open.

There should be no barrier to infra-red waves passing between the SFS speaker and the SFS mic. Ensure testbox is facing towards Redcat and that you are not blocking waves.

Obtain frequency response curve(digi-spch SRC) starting at 40/45 and working up to 65DWO.

To start the curve press Start.

The aim now is to get the curves to match but you cannot alter individual frequencies so you are looking for line of best fit.

Use the ‘audio out’ dial on the SFS to adjust the live curve to best fit.

Fix curve using F2.

Do not adjust SFS output curve to exceed output curves for hearing aid /RAS system.

Print the results and check with CYP that they are happy with the sound. Do a repeat listening check to confirm you are happy that neither the volume not quality is impacted when rebroadcasting. Verify with speech discrimination tests.

Appendix 3: Questionnaire

Questionnaire Participant Number: Protocol number:

Example

1 is really hard 10 is really easy


---

1 2 3 4 5 6 7 8 9 10

How did you find listening to the word lists?

Position 1

1 is really hard 10 is really easy


---

1 2 3 4 5 6 7 8 9 10

How did you find listening to the word lists?

Position 2

1 is really hard 10 is really easy


---

1 2 3 4 5 6 7 8 9 10

How did you find listening to the word lists?

Position 3

1 is really hard 10 is really easy


---

1 2 3 4 5 6 7 8 9 10

Appendix 4: Test-box results in graph form for Participants

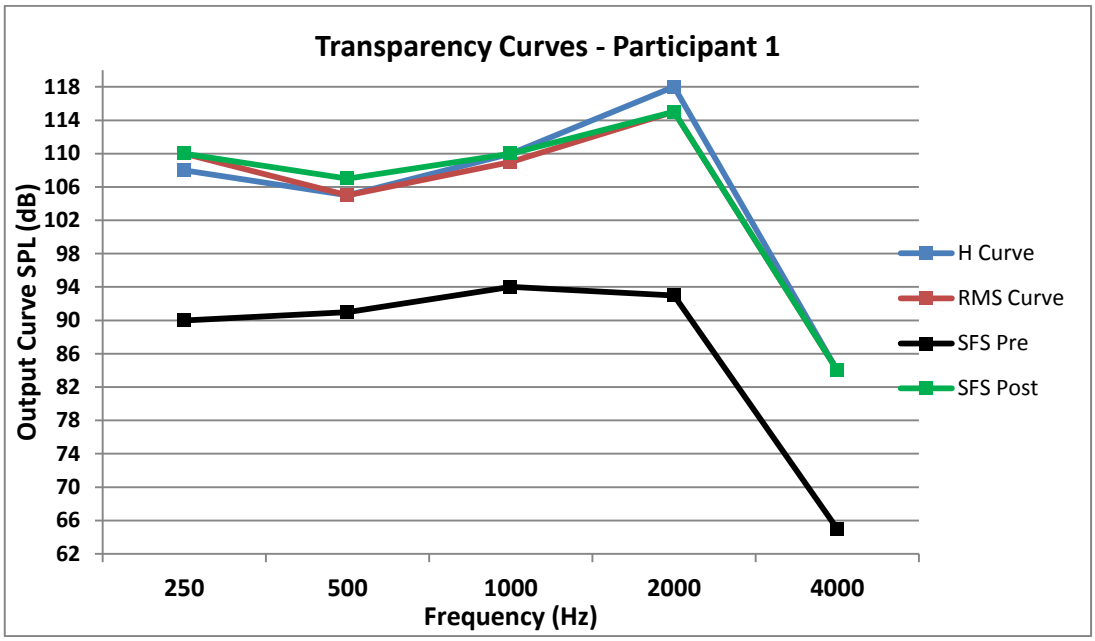


Figure 8.1. Transparency curves for Participant 1 showing output curves for hearing aids, RAS and the SFS pre and post balancing.

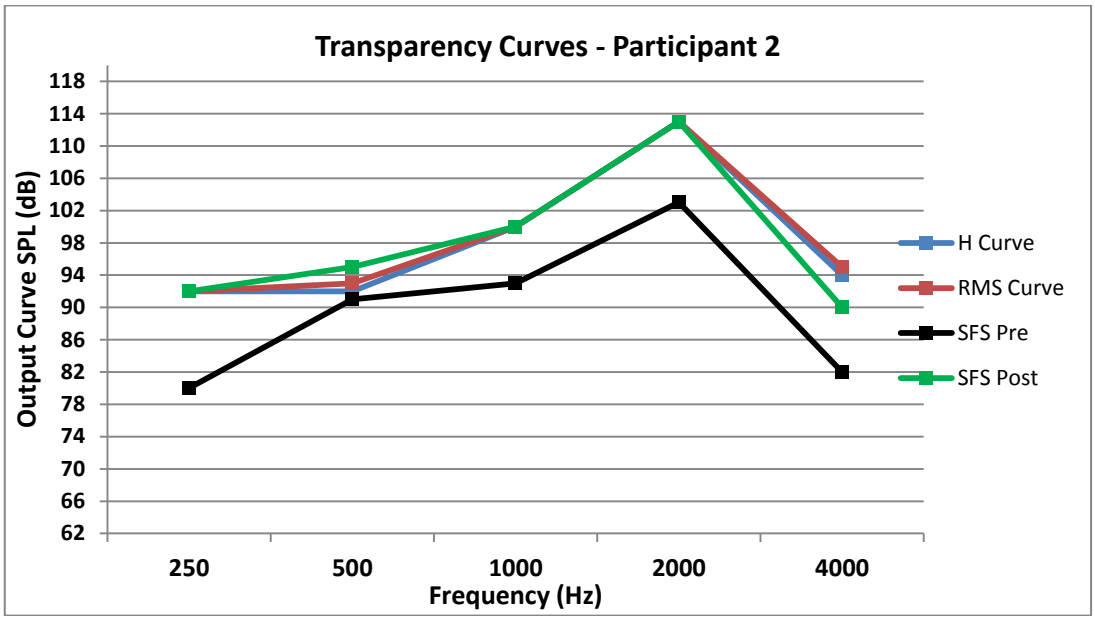


Figure 8.2. Transparency curves for Participant 2 showing output curves for hearing aids, RAS and the SFS pre and post balancing.

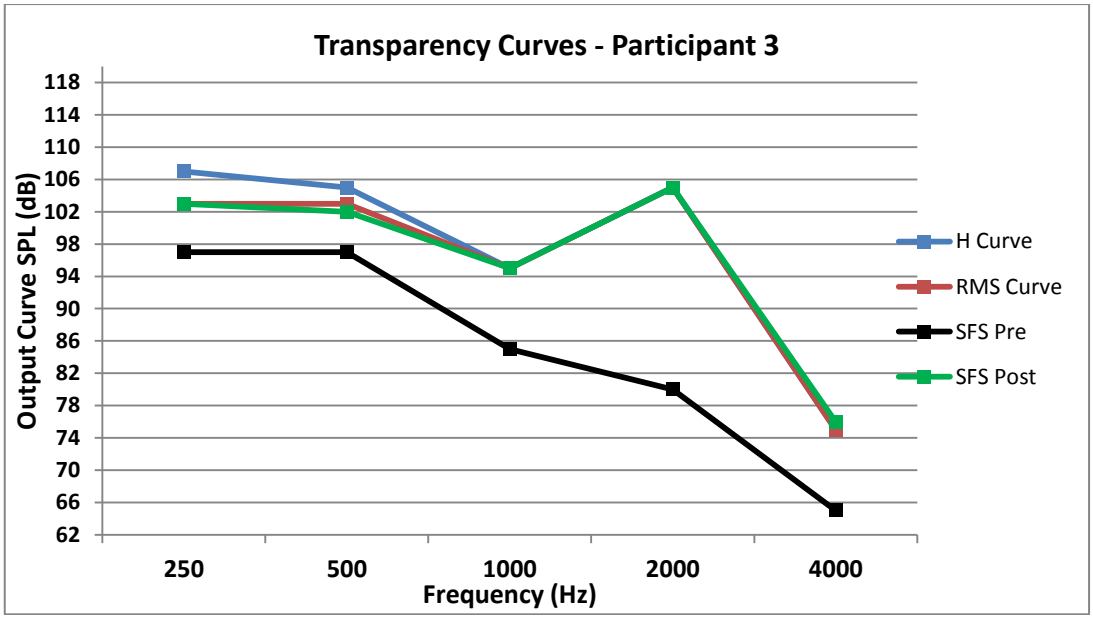


Figure 8.3. Transparency curves for Participant 3 showing output curves for hearing aids, RAS and the SFS pre and post balancing.

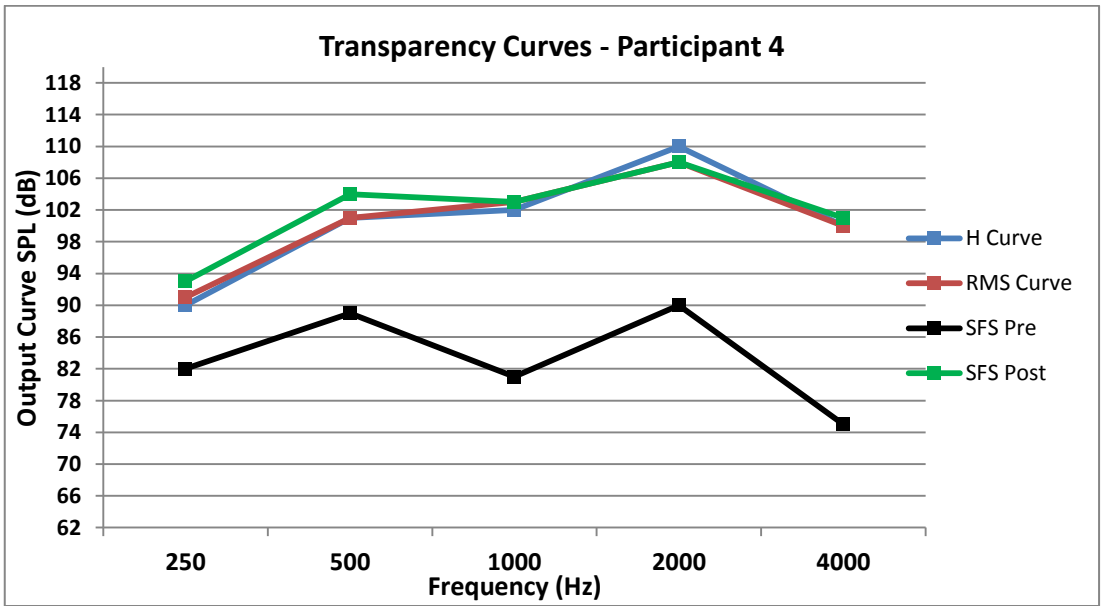


Figure 8.4. Transparency curves for Participant 4 showing output curves for hearing aids, RAS and the SFS pre and post balancing.

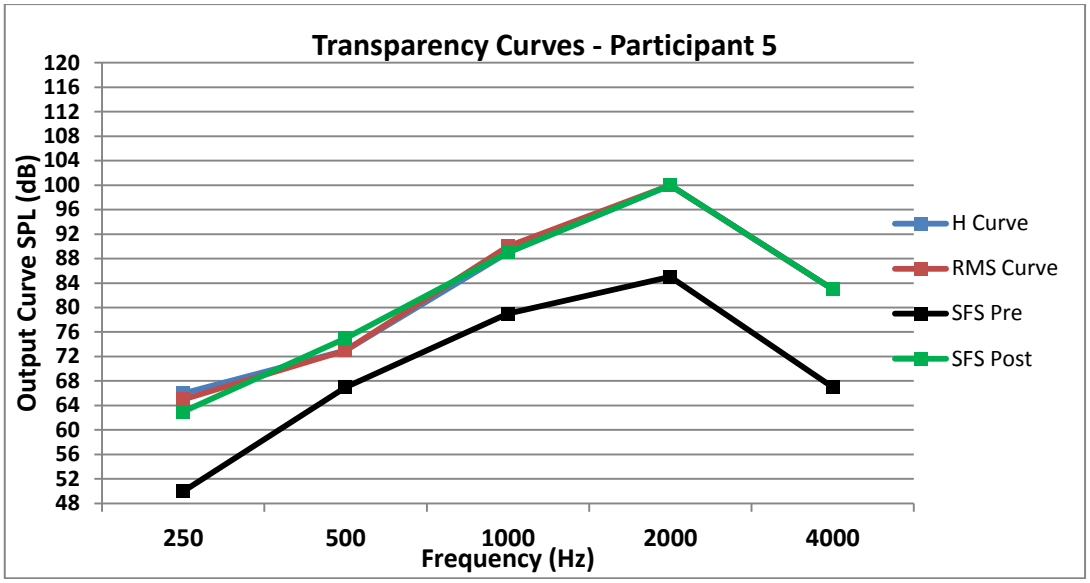


Figure 8.5. Transparency curves for Participant 5 showing output curves for hearing aids, RAS and the SFS pre and post balancing.

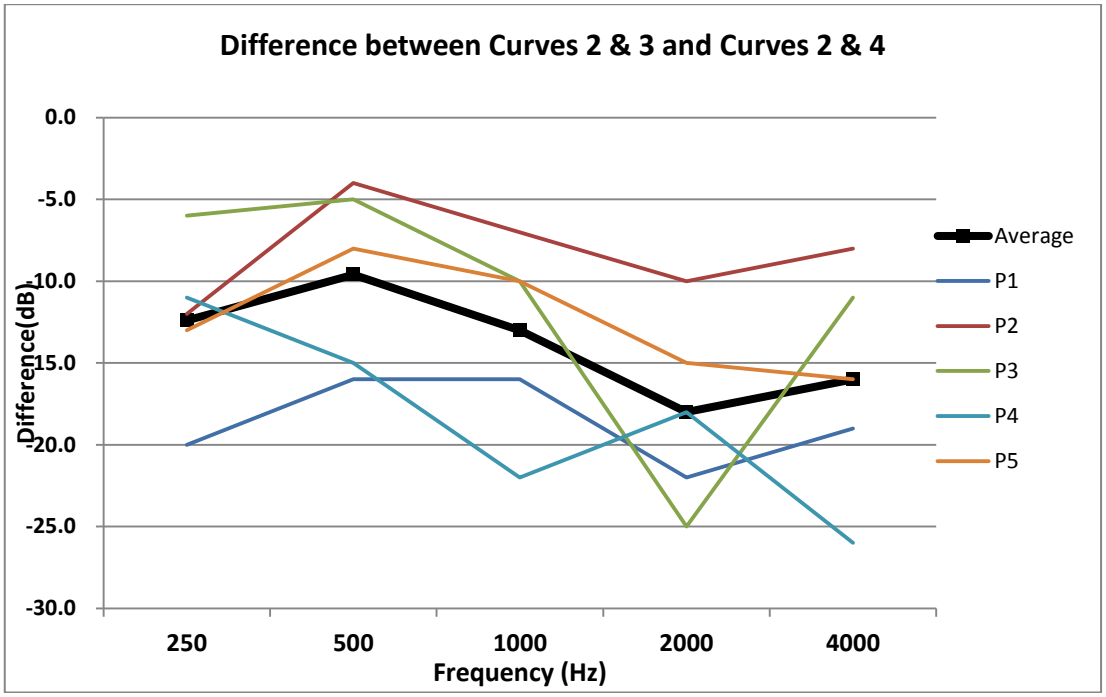


Figure 8.6. Differences between pre and post balance curves for participants at each frequency.