A Comparison Between Two Different Speech in Noise Test Setups

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

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Abstract

Speech in noise testing (SiN) is done to demonstrate the effectiveness of personal hearing devices, the effect of noise and distance on speech discrimination and to validate the setup of wireless remote microphone systems (WRMS). Currently, there is no standard protocol for configuration of speakers used for speech in noise testing in the UK. The majority of testing is done with two speakers however this may not effectively replicate the listening experience of children and young people in busy classrooms surrounded by noise. This study investigates the difference in speech discrimination scores of CYP using WRMS systems when tested using a 2-speaker setup and a 3-speaker setup.

Empirical data was collected from participants aged 8 to 18 years old. Each participant was administered the same speech discrimination tests several months apart using a 2-speaker setup and then a 3-speaker setup. Scores for each signal to noise ratio (SNR) tested were compared between the two different speaker setups both with and without WRMS. Trends were identified and data analysed for statistical significance.

Results showed that WRMS provided benefit in every SNR for both speaker setups. The 3-speaker setup without WRMS showed lower speech discrimination scores than the 2-speaker speech discrimination scores. The 3-speaker setup showed higher speech discrimination scores when using WRMS at all SNR. A significant difference was found between the two speaker setups at -10 dB SNR with WRMS.

Taking into account how personal hearing devices and WMRS function and the need to replicate CYP immersion in noise similar to the classroom listening experience, the 3-speaker setup would appear to be the more effective setup for testing with WRMS up to a SNR of -10 dB. However, it needs a larger floor area, takes longer to set up and is more expensive to purchase.

The study was low in power due to the small sample size (N=11) so further testing is needed to validate the results and to look at a number of variables between the two test protocols. Liaison and communication need to be established between SiN test manufacturers and hearing technology companies so there is shared understanding of how technology functions and how it can be tested effectively. There is need for a

standard test protocol to be established and shared at least UK wide to ensure parity of testing and reliability of results.

Acknowledgements

I would like to thank my supervisors, Lisa Bull and Joy Rosenberg, not only for their support and encouragement throughout this undertaking but also for their invaluable advice and feedback. Thank you to Stuart Whyte and Tony Murphy who have generously given their time and expertise to answer questions and to pitch in with testing different setups.

Many thanks to Russel and Julia Jepson from SoundByte Solutions who kindly lent the equipment for the 3-speaker test setup and gave advice and made adjustments to the equipment throughout the testing procedures as needed.

Thank you to the Qualified Teachers of the Deaf that I work with and those who have taken the Educational Audiology course alongside me. You all continue to inspire and support.

Finally, thank you to my wonderful family who have believed in me all the way and have given me time and lots of cups of tea in order to get me through.

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List of Abbreviations

AAA	American Academy of Audiology
ABWL	Arthur Boothroyd Word List
ALTWG	Assistive Listening Technology Working Group
ANS	American National Standard
BATOD	British Association of Teachers of Deaf Children and Young People
BB93	Building Bulletin 93
BKB	Bamford-Kowal-Bench
CYP	Child(ren) or young person
EA	Educational Audiologist
FIST	French Intelligibility Sentence Test
FSA	French Society of Audiology
HINT	Hearing in Noise Test
ManCAD	Manchester Centre for Audiology and Deafness
MJWL	Manchester Junior Word List
NDCS	National Deaf Children's Society
PLD	Personal listening device
SiN	Speech in Noise
SPiN	Speech in Noise toolkit
ToD	Teacher(s) of the Deaf
WRMS	Wireless remote microphone system

1. Introduction

Speech in noise (SiN) testing should be an integral part of the practice of Teachers of the Deaf and Educational Audiologists (EA) and, should be a reliable, repeatable process that gives results that are trustworthy and representative of the listening experience of the child or young person (CYP). There are various validated tests that can be used, e.g. AB word list, Manchester Junior Word List, Manchester Picture Test, Bamford-Kowal-Bench (BKB) sentence test, CHEAR Consonant Confusion Test and Auditory Perception Test, Quick-SIN, Hearing In Noise Test (HINT), and Listening In Spatialised Noise (LISN-S), depending on what the professional is assessing or demonstrating and the age and stage of the CYP's development. The majority of tests were developed and standardised on hearing participants.

In the UK, recommendations for SiN testing procedures have been published by the UK Children's FM Working Group (now known as the Assistive Listening Technology Working Group (ALTWG)) and the Ewing Foundation and are hosted on the British Association of Teachers of Deaf Children and Young People (BATOD) website (BATOD, 2020 a). These were published in response to Quality Standard 10 of the National Deaf Children's Society (NDCS) publication "Quality Standards for the use of personal radio aids" (NDCS, 2017) which was written with the collaboration of the ALTWG. The British Society of Audiologists (BSA) have published practice guidance for SiN testing for adults (BSA, 2019) but have not published any specifically aimed at testing CYP.

Two commonly used SiN test kits used in the UK are the Parrot Plus, produced by Soundbyte Solutions, and the Ewing Foundation Speech in Noise (SPiN) Toolkit, sold through Connevans. Both systems use a 2-speaker setup that places a sound source in front of the listener and a noise source at 180° behind the listener (see Fig. 1).

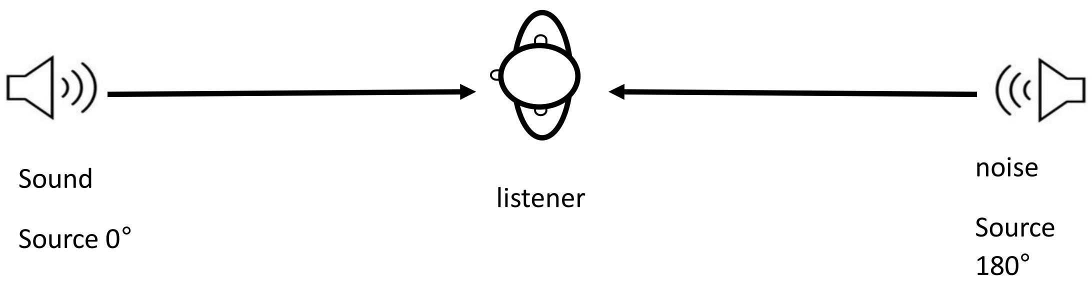


Fig. 1. Speaker and listener setup for the Parrot Plus and SPiN Toolkit systems. The sound source is in front of the CYP at 0° and the noise sources is behind the SYP at 180°. Both speakers are placed so sound intensity at the ear is 60 dBA.

The purpose of this study was to compare these existing, 2-speaker, setups to a 3-speaker setup recommended by the Audiology Expert Group which is part of the European Union of Hearing Care Professionals (Europäische Union der Hörakustiker e.V., 2017), where the sound source is again in front, but the noise producing speakers are set to the sides giving a more diffuse noise effect (see Fig. 2). This setup is based on a paper written by Husstedt et al. (2021). If a statistically significant difference is found in the results between the two different speaker setups, then consideration should be given to choosing the test setup that most closely matches what the CYP experiences in their classroom day to day.

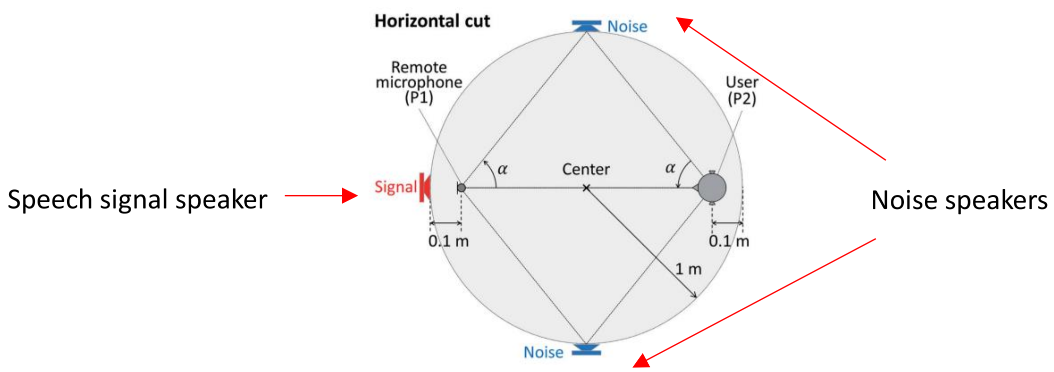
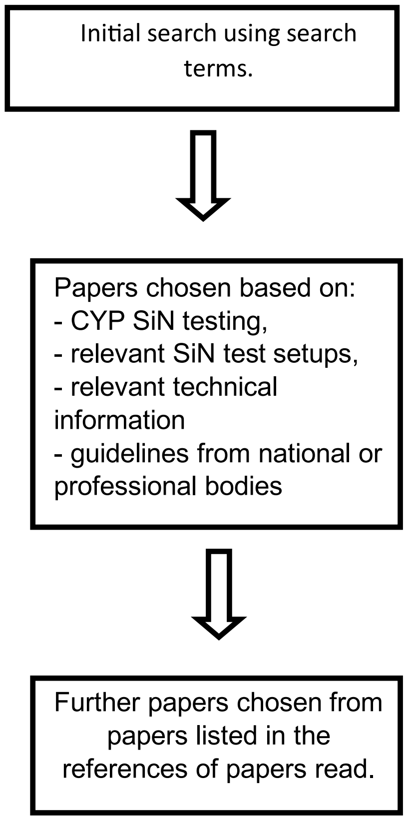


Fig. 2. Recommended setup by Europäische Union der Hörakustiker e.V., (2017). User (P2) is the CYP.

2. Literature Review

2.1 Research Methodology

The literature review was conducted using searches on the University of Hertfordshire online library for papers and books related to the topic of SiN testing.



The initial search terms included:

- Speech in noise testing
- Speech in noise testing children hearing impaired
- Listening in noise children hearing impaired
- Remote wireless microphone verification
- Remote wireless microphone validation
- Digital remote microphone system
- Classroom acoustics
- Assistive listening devices hearing impaired children
- Listening difficulty hearing impaired children

Further papers were identified through references within papers as well as guidelines published by the NDCS and ALTWG. Papers where the research was based on CYP were given priority over adult based research, although those were included if relevant.

Although there were references in many papers to specific SiN tests which have been developed and are in common use, there was relatively little information about recommended SiN speaker setup. Papers that explained or showed how speakers and WRMS were situated for testing were selected.

2.2 Listening to Speech in Noise

2.2.1 Why is listening to speech in noise a problem?

Hearing aids are set up using the audiogram derived from testing the quietest sounds a listener can hear across the frequencies 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz and 8000 Hz. These tests are carried out in a sound-proof booth in an audiology clinic. When children leave the clinic, they are plunged into a world where there is constant background noise that includes the whole range of frequencies accessible by the human ear, not just the discrete pure tones tested in a clinic. In classrooms, noise levels are considerably higher than in audiology booths. Sala and Rantala (2016) reviewed studies that measured noise levels in classrooms in Finland (preschool and elementary school) and found that occupied classroom noise levels ranged between 52 and 85 dBA. My own investigation in a preschool showed sound levels ranging from 60 to 88 dBA (See Fig. 3) over the course of an hour.

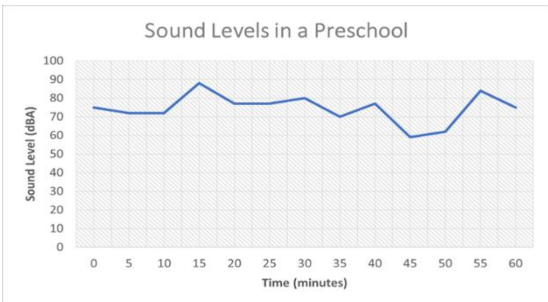


Fig. 3. Sound levels measured every 5 minutes in a preschool at the child's ear level over the course of an hour.

Beck and Flexer (2011) described hearing and listening as made up of bottom up (sensory) and top down (cognitive) systems. In order for communication to be successful both systems need to work optimally. There are several ways in which the speech signal can be degraded (Brannstrom et al., 2020):

- Bottom up:
  - At the source of sound (poorly produced signal e.g. speech disorder, accent)
  - During transmission by background noise and reverberation
  - Receiver limitations (hearing loss)
- Top Down:
  - Limitations in cognitive function or an incomplete language model

Bradley and Sato (2008) found that 6-year-olds with normal hearing needed a +20 dB signal to noise ratio (SNR) in order for speech to be intelligible and estimated that grade 6 students (11- to 12-year-olds) would need a +15 dB SNR. Schafer et al. (2013) had similar findings. When classroom background noise levels are as high as 85 dBA, this is impractical and therefore children are unable to discriminate speech.

When children have a hearing loss and are using personal listening devices (PLDs), e.g., hearing aids, cochlear implants or bone conduction hearing aids, additional difficulties are present for listening to SiN. When listening in noise, children with hearing loss have been shown to need a signal to noise ratio (SNR) that was more than 8 dB higher than that of children with normal hearing (McCreery et al., 2019). Some reasons for this include:

- Young children with hearing loss are more susceptible to distortion and masking (Inglehart, 2020).
- Poor spectral resolution capabilities of cochlear implant devices leading to poor resolution of the fine spectral structure of speech (Zaltz et al., 2020).
- Poor discrimination of the fundamental frequency in cochlear implant users (Goldsworthy and Markle, 2019).
- Reduction of spectro-temporal resolution used for ‘glimpsing’ target speech (Goldsworthy and Markle, 2019).
- Reduced ‘top down’ perceptual and cognitive processes that aid speech recognition such as working memory, attention (McGarrigle at al., 2018)

weaker phonemic category formation, poorer vocabulary and struggles in recognising language structure (Caldwell and Nittrouer, 2013) information processing speed and inference-making skills (Grant and Seitz, 2000).

In addition to this, CYP with hearing loss seem to have particular difficulty discriminating speech in fluctuating noise as opposed to steady state noise or music (Goldsworthy and Markle, 2019), which is the majority of noise encountered in a classroom.

If a child is having to commit additional brain processing to decoding and understanding a degraded speech signal, then there is less processing available for other tasks being asked of the brain e.g., storing and retrieving information (Brannstrom et al., 2020). This can lead to increased listening fatigue which in turn is a risk factor for developing mental and emotional disorders (Davis et al., 2021).

Gustafson et al. (2021) found that CYP with lower language abilities were also likely to suffer from increased listening fatigue and as CYP with hearing loss are often in danger of poorer language outcomes (Marschark et al., 2010), the effect is compounded. Other co-morbidities may also require additional listening effort, adding to increased fatigue (Davis et al., 2021).

2.2.2 Listening Environments in Schools

Once children reach school age, they spend a significant proportion of their lives in an educational setting. If a CYP are to achieve comparable outcomes to their peers, they must be able to hear their key worker, teacher, tutor or lecturer clearly. The oldest school buildings in the UK were built pre-1900, with many of the smaller village schools having high ceilings and poor acoustics. A classroom with a reverberation time of 1.2s was identified in a school attended by a student with a bilateral severe sensori-neural hearing loss on my caseload. Other classrooms with similar reverberation times are not uncommon in my experience.

In the UK, Building Bulletin 93: Acoustic Design of Schools (BB93) sets out the recommended minimum standards for the acoustics of school buildings (Department for Education, 2015). The American National Standard (ANS) (Acoustical Society of America, 2010) and Swedish standards (Knecht et al., 2002) also set out reverberation times and minimum unoccupied sound levels (see Table 1).

Country	Unoccupied Room sound level	Reverberation time
America	35 dB	0.6s
Sweden	35 dBA	0.6-0.9s
UK (hearing children)	35 dB SPL (new build) 40 dB SPL (refurbished)	≤ 0.6s (new build) ≤ 0.8s(refurbished)
UK (Children with hearing loss)	30 dB SPL (new build) 35 dB SPL (refurbished)	≤ 0.4s

Table 1. Comparison of unoccupied maximum classroom noise levels and reverberation times (Acoustical Society of America, 2010; Department for Education, 2015; Knecht et al., 2002)

The guidelines are similar for all three countries; however, only the UK specifies separate recommendations for students with hearing loss.

2.3 Speech in Noise Testing

Given the difficulties CYP with hearing loss face when listening in class, it is important that Teachers of the Deaf (ToD) and Educational Audiologists (EA) can assess speech discrimination in this environment and validate whether wireless remote microphone systems (WRMS) are providing an advantage to the listener, i.e., hearing the teacher's voice above background noise and when the teacher is positioned outside the effective range of the CYP's PLD.

It has been increasingly recognised that pure tone audiometry alone is not a good predictor of speech perception in noise (Beck and Nilson, 2013; BSA, 2019; Moore et al., 2019) therefore SiN testing is useful for a number of reasons:

1. Validation of the performance of the PLD that was set up at Audiology in a soundproof booth, giving an indication of the device functionality and the CYP's speech discrimination ability in differing levels of noise outside of the 'ideal' listening environment.
2. Validation of the setup of a WRMS which has to integrate with the CYP's hearing device, giving a listening advantage in noise without affecting the performance of the PLD.
3. Demonstration to school professionals, families and CYP the effect of noise on CYP with a hearing loss and the benefit of using a WRMS.

In this study I am focussing on point number 2.

2.3.1 Wireless Remote Microphone Systems

WRMSs are used for CYP where the speech signal is likely to be degraded by background noise, reverberation, and distance from the speech signal. Sound intensity reduces as it travels away from the source of the sound following the inverse square law. Consequently, at a 4m distance from the speaker, speech will be 12 dB quieter than it was at 1m from the source. Sound intensity is also affected by room size and reverberation properties. The WRMS transmitter is worn close to the speaker's mouth giving a sound intensity of approximately 80 dB SPL (Hussetdt et al., 2021). This gives an 'advantage' to the speaker's voice above background noise when it is transmitted to the listener's PLD.

2.3.2 Speech in Noise Tests

There are a variety of different SiN tests in use. The majority are sentence or word based (see Table. 2). They are either designed to be used with a fixed SNR or adaptive SNR.

Sentence Based	Word Based	Other
HINT QuickSIN BKB LiSN-S	AB Manchester Junior Word List Manchester Picture Test CHEAR AAP CHEAR CCT Words in Noise	FreeHear (Moore, 2019)

Table 2. A selection of SiN tests currently in use.

A fixed SNR could be used without and then with a PLD to show the difference in the CYP's performance. This is a direct comparison of scores, hopefully showing that the hearing device gives a better access to speech. Taylor (2003) points out that choosing where to fix the SNR can be difficult. If it is too easy, no advantage is shown to wearing the hearing device. If it is too hard, the CYP may become demoralised.

An adaptive SNR test has a changing SNR ratio, either due to a change in background noise level or speech signal intensity (mimicking increased distance from the sound source). This can be used to show the effect of background noise on the CYP and to assess performance of a WRMS in different background noise levels. This can be important as some WRMS are dynamic, adjusting gain levels as noise levels rise, and some have a fixed gain.

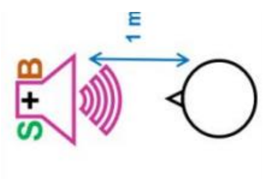
2.4 Speaker Setup

Most papers, when referring to SiN testing, do not give an indication of speaker setup, they merely refer to the test used e.g., BKB/Quick-SiN. Some recommended speaker configurations are set out by The American Academy of Audiology (2011), The French Society of Audiology (FSA) (Joly et al., 2020) and ALTWG (BATOD, 2020 a).

2.4.1 Single Speaker Setups

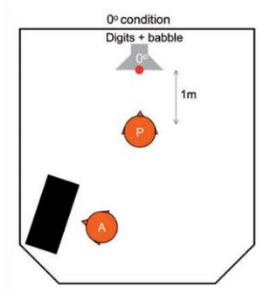
These setups have a single speaker in front of the listener (see Fig. 4). Papers specified that the speaking voice and the background noise are presented from the same speaker, usually at varying levels depending on whether the test is using fixed or adaptive SNR (Joly et al., 2020). As the signal and noise emanate from the same speaker, testing with a WRMS is not suitable due to the noise and speech emanating from the same source. Sound detection is much better when a masker and signal are in different locations (Lentz, 2020). The proximity of the speaker to the listener also makes it unsuitable for use with a WRMS as the PLD is within its optimal operating range. It would be difficult to show whether the WRMS or the PLD is detecting the speech signal.

a)



Recommended setup for the French Intelligibility Sentence Test (FIST), Framatrix, and suggested layout for the Disyllabic Lafon – Marie Haps Procedure (Joly et al., 2020). In this setup, the speech signal (S) and the background noise (B) come from the same speaker, with the listener at a distance of 1m.

b)



A suggested setup for the FreeHear test (Moore et al. 2019). A = the audiologist administering the test. P = the test subject. In this test setup, the distance from the speaker is 1m. The test signal (in this case numbers rather than words) and the babble come from the same speaker.

Fig. 4. Examples of single speaker setups for SiN testing.

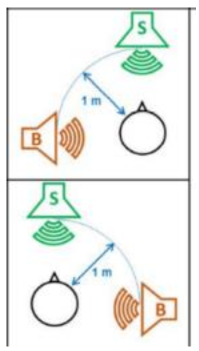
2.4.2 Two Speaker Setups

Two speaker setups seem to be a more common arrangement, with the majority placing the signal speaker at 0° and noise speaker 180° (see Fig. 5). This setup is more valid for WRMS testing as the remote microphone can be placed a short distance from the signal producing speaker and background noise levels can be raised or lowered independently so that the benefit of the WRMS being close to the speaker's mouth can be shown. Tests a) and b) e) have a 1m or less distance specified between the listener and signal speaker, which may be too close, as mentioned previously.

a)

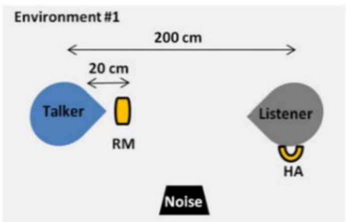
Verbo Frequency Audiometry (Joly et al., 2020). Signal speaker (S) at 0° and noise speaker (B) at 180°.

b)



Hearing in Noise Test HINT (Joly, 2020). This speaker setup tests one ear at a time, with the speech signal (S) coming from the front at 0° and the noise coming from the same side as the hearing instrument being worn at 90° or 180° (B).

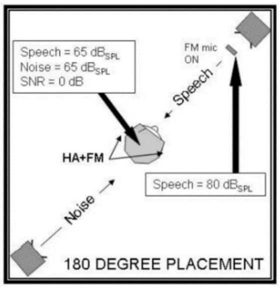
c)



This test uses two different speaker setups to represent different acoustic conditions (Salahi et al., 2018) and was designed to test and compare the performance of several different WRMS. In this setup an acoustically benign room is simulated, i.e., low reverberation levels of 0.1s. The distance between speech signal (talker) and CYP (listener) is 2m, making it possible to differentiate between the hearing aid input and the WRMS benefit. The noise is presented from one side, rather than from the front or rear. This may be because they tested only one hearing aid (HA) in conjunction with the WRMS (RM) at a time. A live subject was not used for this test.

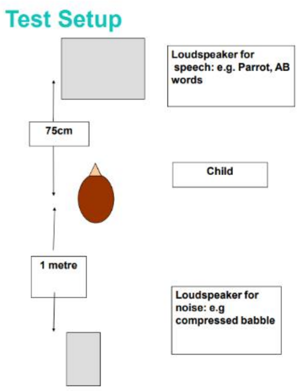
Fig. 5. Examples of two speaker setups.

d)



FM testing recommended setup (American Academy of Audiology, 2011). This speaker configuration is designed for testing the benefit of a WRMS specifically. The speakers are placed at 0° and 180°. No distance measurements are specified, however sound intensity levels at the listener's ears and at the position of the WRMS are specified.

e)



The Parrot Plus 2 speaker setup recommended by the ALTWG (Newman, no date; BATOD, 2020 a). The speech signal speaker is placed at 0° and the noise speaker at 180°. The distance between the speakers and listener is 75cm with a sound level of 60 dBA measured at the listener's ear.

Fig. 5. continued. Examples of two speaker setups.

A recent study by Manchester Centre for Audiology and Deafness (ManCAD) (Stone et al., 2022) commissioned by the NDCS also used a 2-speaker setup to test and compare WRMS. The signal speaker was positioned at 0° at 2m from the listener and the noise speaker at 180° at 1m from the listener. Similar to c) in Fig. 6., a 2m distance between the signal speaker and the listener could enable the benefit of a WRMS to be shown.

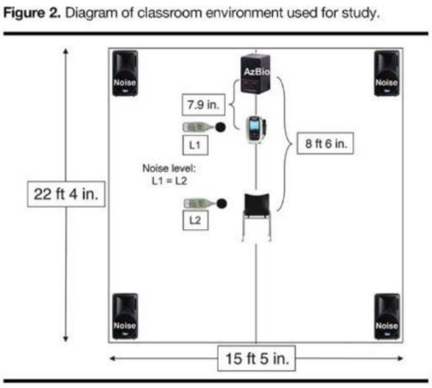
2.4.3 Multi speaker setups

Although two speaker setups are more appropriate for WRMS and are simple to set up, there is some question as to whether they model real-life situations closely enough, as classroom noise comes from all directions, not just from behind. A more accurate model involves using three or more speakers that present noise in a more diffuse way to the listener. The FSA (Joly, et al., 2020) recommend a minimum of 5 speakers to avoid acoustic interference.

These setups involve more equipment and are therefore less portable for the peripatetic ToD.

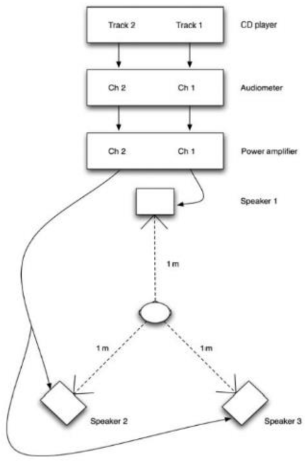
The aim of multiple speakers producing background noise is for the effect to be more diffuse. Some examples of setups can be seen in Fig. 6.

a)



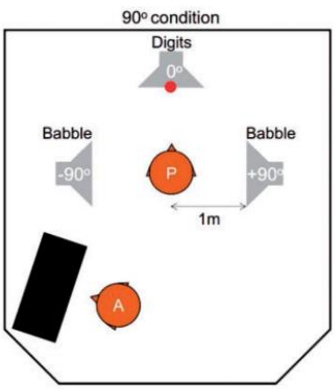
A four-speaker setup (Wolfe et al., 2015). This setup was designed to test a number of different WMRS. The speech signal comes from 0° and four speakers are placed in the corners of the room. The distance of the speech signal speaker from the listener is specified. The noise speaker distance is not specified but the sound level is adjusted to be the desired intensity at the listener's ears. A sound level meter is used at the WRMS (L1) and at the listener's position (L2).

b)



A three-speaker setup (Possami et al., 2012). This setup was used to test SiN pre and post grommet insertion. The signal speaker is from the front at 0° as usual. Noise is presented from two speakers from behind but at an unspecified angle. This distance from the listener is 1m for all speakers and no WRMS was used. The two channels control the speech (track 1) and noise (track 2) signals. This would seem to give more diffuse background noise than just one speaker at 180° but from behind.

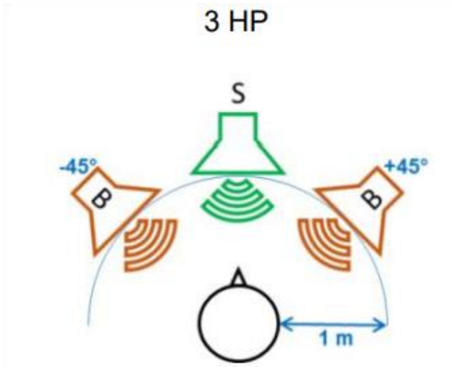
c)



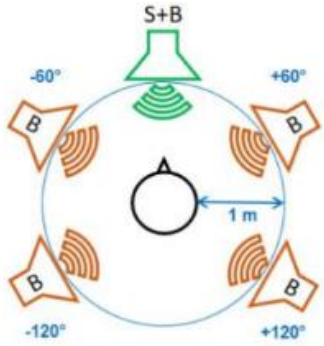
A three-speaker setup (Moore et al., 2019). A = the audiologist administering the test. P = the test subject. In this test setup, the distance from the noise speakers is 1m. It is assumed that the distance from the signal speaker is also 1m but it is not explicitly noted in the diagram. The test signal (numbers) comes from 0° while the noise comes from speakers at 90° and 270°. The 1m distance from the signal speaker is likely to be too close to test benefit of a WMRS in this setup.

Fig. 6. A variety of multi-speaker setups for SiN testing.

d)

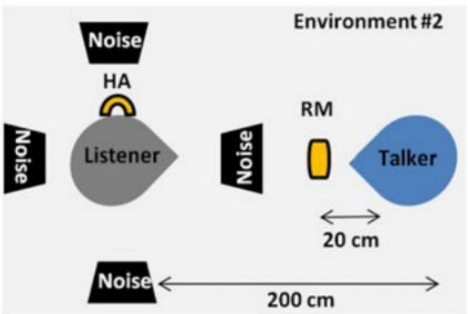


e)



Setups d) and e) both use multiple speakers and are recommended for the Disyllabic Lafon or Marie Haps Procedure and the Fast Vocal in Noise (Joly et al., 2020). Both use a 1m distance from the listener for all of the speakers (the signal speaker being at 0° for both setups). Again, because of the close proximity of the speakers to the listener, the setups may not be suitable for a WRMS test.

f)



A 4-speaker setup (Salehi et al., 2018). Interestingly, the speech signal comes from 0° as along with one of the background noise speakers. This completely surrounds the listener with noise and is meant to simulate a hostile listening environment with high reverberation levels. A WRMS is used in this testing, but only one hearing aid at a time. Binaural hearing gives an advantage when listening in noise (Lentz, 2020) due to the better ear advantage (one ear hearing better than the other) and binaural squelch (the poorer ear supporting the listening of the better ear). Testing only one hearing aid at a time cannot show how the listener will perform binaurally. The distance between the speech signal speaker and listener is 2m, more appropriate for testing WRMS benefit.

Fig. 6 continued. A variety of multi-speaker setups for SiN testing.

The majority of the speaker setups show 1m distance between the speakers and the CYP, apart from setup a) which worked within the confines of the room and adjusted the sound levels accordingly. The important point made in all of these setups, however, is not the exact distance, but the sound level measured at the ear of the listener. The volume of the speakers is then adjusted to the desired level.

Calibrating a speaker system setup so that a desired sound level is present at a set distance may enable a quick setup and works well for static speaker systems in audiology clinics. In the school environment, testing is carried out in a variety of rooms, none of which are sound proofed, and which all have differing acoustic qualities. Very reverberant rooms may increase sound intensity at the CYP's ear level. Rooms with unevenly distributed furniture may be more reverberant in one direction than another. This necessitates the use of a sound level meter and adjustment of either the speaker position or volume to ensure that the sound intensity at the listener's ear is accurate. Reliance on a measured distance in a room in which the setup was not calibrated will not give accurate results.

2.4.4 Choice and duration of background noise

The choice of noise produced to disrupt the speech signal varied in the tests. Noise types used included steady state noise e.g., white noise, broadband noise, narrow band noise and traffic noise, or fluctuating noise e.g., music, speech and multi-talker babble. Babble or multi-talker speech has been shown to be the most effective in disrupting the speech signal for listeners (Lewis et al., (1988) cited in American Academy of Audiology, 2011; Shukla et al., 2018).

The Parrot Plus system produced by Soundbyte Solutions, which is the 2-speaker system I am currently using, plays multi-talker babble, either adult or child. During the test, the multi-talker babble starts before a target word is said. The babble stops after a short time and there is a silent break before the babble is presented for the next word. No specification for noise duration has been noted in any of the papers used for this study. In discussion about the development of the International Speech Test Signal (ISTS), Holube (2015) describes the first 15 seconds being used for the 'adjustment of the hearing instrument's signal processing to the speech signal'. I have also been told anecdotally that Phonak hearing aids and WRMS (Phonak Roger devices) need 15 seconds of continuous noise to sample and then to adapt the signal. Currently there is not 15 seconds of noise before the target signal is presented using the Parrot Plus system. It is also unlikely that speech and background noise in a classroom would behave in this way so is therefore not necessarily representative of a real-life situation. Background noise is more likely to be continuous rather than short segments, suggesting that a continuous background noise signal would be a better choice.

2.5 Summary

SiN noise testing is a valuable tool in measuring the benefit and effectiveness of PLD and WRMS systems in noise and at distance from the speaker. Test setups should reflect the CYP's real listening experience as closely as possible in order to give an accurate picture of the CYP's performance.

SiN tests can be adaptive or fixed, depending on the purpose of the testing and a range of test types are available utilising sentences, words or numbers for the listener to repeat. Background noise can be fluctuating (music or speech based) or steady state (white noise, broadband, narrowband or traffic noise), although fluctuating speech/babble is the most difficult for listeners.

In terms of speaker setups for SiN testing, as can be seen from above, there are a wide variety being used internationally. Some are not suitable for testing the benefit of a WRMS due to the signal speaker proximity to the listener or noise and speech coming from the same source. Some speaker setups testing WRMS benefit used a distance from the signal speaker of at least 2m, although the Parrot Plus 2 setup suggests the shortest distance of 75cm. The American Academy of Audiology (2011) and Wolfe et al. (2015) specify sound at the listener's ear (60dBA) level rather than speaker distance.

3. Methodology

SiN testing is part of normal practice for CYP on caseload therefore ethical approval was sought to use the data from SiN testing for this study. Any concerns raised by the results of SiN testing for the participants were addressed by liaison with parents and Audiology.

In this chapter I will discuss how the equipment was set up, the SiN tests used, and the limitations of the testing carried out.

There are a variety of methodologies that can be used in research, including (but not limited to) experimental, case studies, surveys and literature reviews. An experimental investigation is designed to investigate a relationship under controlled conditions to test relationships or theories (Denscombe, 2021) and I felt that this method would give performance data that could be compared and that was objective rather than subjective. Questionnaires and surveys are designed to show how people think or feel (Hammond and Wellington, 2020) and, although I could have asked students what their experience of the SiN testing was, if felt that it would be difficult to compare these results because they are so subjective. A literature review would be very difficult as I could not find any research pertaining to the effect of speaker quantity and position on SiN testing. Case studies are more suitable for looking at a small number of students in depth but would not give the data and comparison needed to compare the two speaker setups, therefore I chose to use experimental methodology.

Data was collected from participants aged 8 to 18 years old. Each participant was administered two SiN tests several months apart. Tests were administered in the field in schools/colleges. This method was chosen for the following reasons:

- These test setups need to be used by ToDs and EA out in the field because students learn and use WRMS in classrooms. Testing should reflect functional listening capacity in educational settings.
- A variety of students with differing PLD were included. Many studies choose to limit the participants to one type of PLD; however ToDs need to know that the test gives reliable results for all PLD they may encounter.

- Testing was done on WRMS currently in production, or still supported by manufacturers, and used by the CYP on current caseload. I have found that some studies use WRMS and PLDs that are now discontinued.

These considerations ensured that the research was relevant to the CYP on caseload and was with equipment currently being issued by Audiology and the local authority. It was up to date and locally relevant. As technology is upgraded and changed, this research will need to be extended to new technology to ensure that the findings are still relevant.

Data collection in this study was in the form of a paired study. The same participants were administered SiN tests in two different speaker setups: 2-speaker and 3-speaker. The test results were then compared.

The participants chosen were aged from 5 to 18 years from my caseload. They were chosen to represent:

- A spread of ages representative of a ToD or EA caseload who are able to participate in a formal assessment.
- A range of PLDs including hearing aids and cochlear implants.
- A WRMS user as part of their day-to-day education provision.

Participants were ruled out if:

- They were not able to participate in a formal assessment (for attention, speech clarity or cognitive function reasons).
- They did not use a WRMS.
- The attended a special education setting and had additional learning needs.
- They chose not to be part of the study.

This gave a total of 18 possible participants. I chose to focus particularly on CYP who use a WRMS because SiN testing is used to validate the electroacoustic setup of the WRMS and to demonstrate to staff members, family and the CYP the benefit WRMS use. After permission was sought from parents, a total of 11 CYP were included in the study.

3.1 Constants and Variables

3.1.1 Constants

As much as possible, the following elements were the same in both speaker setups.

The Speech in Noise test administered.

Each participant was administered the same word list in both tests. List order was randomised to prevent the CYP remembering word sets. Two SiN tests were used to cover the age range included: the AB word lists (ABWL) developed by Arthur Boothroyd (Boothroyd, 1968) and the Manchester Junior Word List (MJWL). The MJWL word list was administered to CYP from the age of 5 to 11 (primary school age) as the vocabulary is easier than that used for the ABWL which was administered to CYP aged 11 to 18 (secondary and college age).

The ABWL was developed by Arthur Boothroyd, based on tests used by Professor J.J. Groen (Boothroyd, 1968) and consists of isophonemic words made up of ten vowel sounds and twenty consonant sounds arranged in consonant-vowel-consonant format. Each phoneme is scored, giving each word a possible score of 3 points. Each word list consists of 10 words.

The MJWL test uses word lists of 10 words. It was specifically designed for children with hearing loss from the age of 6 and upwards (Watson, 1957) cited in (Potts, 2014). Each whole word is scored as correct or incorrect and is scored as 10% if correct.

I chose to use single word tests rather than sentence tests for the following reasons:

- In a sentence test, un-heard or mis-heard words can be inferred from the context of the sentence. This may give a listener with a good ‘top down’ grasp of language an advantage. They can deduce the word rather than hearing it clearly.
- In the AB word test, further analysis can be done on mis-heard words to see which phonemes were misheard. Peter Keen in particular has done extensive work on plotting the frequencies of consonants so that missing phonemes can be mapped onto the consonantal speech banana as part of the Keen Profile

(Keen, 2014). This can be used to ask for adjustments in personal hearing device settings to improve access to specific frequencies.

- There are multiple word lists for each test allowing testing to be done without the need for any of the lists to be repeated.
- The tests are quick to administer Longer tests can be a particular problem with younger children who have shorter attention spans.

Noise Type

Classroom babble was used as this is the type of noise that students are exposed to in the classroom. Fluctuating noise has also been shown the be the most difficult to listen in (as discussed in 2.4.4).

Voice

The voice chosen (male or female). All tests were done with the female voice.

Setting

The participants were tested in the same room each time so that the acoustic properties of the room were the same (reverberation time and sound transfer from outside the room).

The time of day

If the participant was tested in the morning for the 2-speaker setup, they were re-tested for the 3-speaker setup in the morning again. Similarly for afternoon testing. This was to ensure that tiredness and concentration levels were similar and also that sound levels coming from lessons around the room were comparable.

Listening equipment

The participant's PLD and WRMS were the same for both tests. The participants' listening equipment was verified using an Aurical HIT testbox prior to SiN testing. Transparency was achieved for all participants. The Roger Pen is no longer in production; however, it was included as many children on caseload continue to use the device. The Roger On, its replacement was also included in the study.

3.1.2 Variables

The variables in the testing were as follows:

Participants age

As this was a paired test, the participants test scores were not compared to each other, only to themselves. Further research could be carried out to look at the influence of age on test results.

Speaker setup

The physical setup of the two tests varied in the number of speakers used and the position of the speakers in relation to the participant. This will be discussed further below (section 3.2).

Noise Presentation

One, possibly significant, difference between the tests used was way the background babble signal was presented by the two systems. The 3-speaker setup used continuous babble, while the 2-speaker setup used shorter sections of babble with a word presented in the middle of the section. See Fig. 8.

Digital hearing aids and some makes of WRMS continuously sample background noise in order to adapt their programming and the gain of the WRMS or PLD and require about 15 seconds in order to react and make changes (Staab, 2012). Background noise was allowed to run for 15 seconds before the commencement of word presentations in the 3-speaker setup.

Further testing may be needed to find out whether the shorter, intermittent presentation of background babble has a significant effect on the results as well as the speaker arrangement.

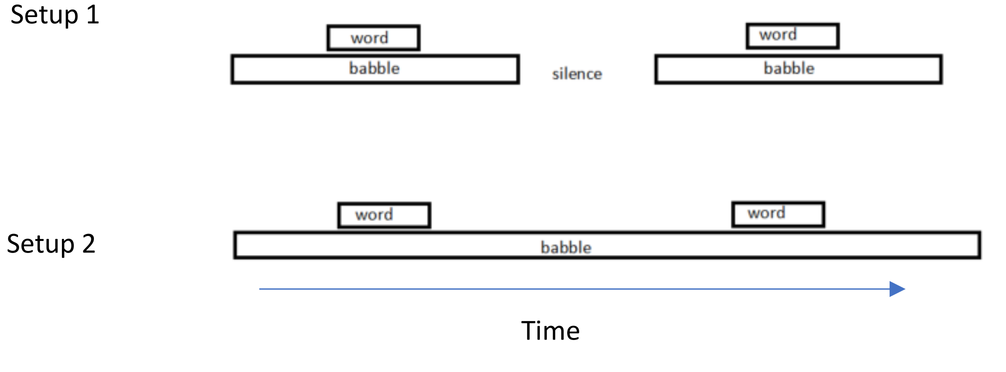


Fig. 7. Setup 1 and setup 2 word and babble presentation.

WRMS mode

In the 2-speaker setup, the WRMS was put into verification mode. In the 3-speaker setup it was left in normal functioning mode. This will be further discussed below (section 3.2.1).

WRMS position in relation to the speaker

In the 2-speaker setup the WRMS was positioned below the speaker. In the 3-speaker setup it was positioned in front of the speaker. The reasons for this will be further discussed below (section 3.2).

3.2 Speaker Setups

3.2.1 The 2-Speaker Setup

The 2-speaker setup was administered using the Parrot Plus system. This system consists of two speakers; one which delivers the speech signal at 0° and one which delivers background noise at 180° (see Fig. 8).

The CYP was situated in between the speakers, with the signal speaker at 0° and the noise speaker at 180°. The speakers were at the ear level of the child. Both speakers were placed at a distance of 0.75m from the CYP and then placement or volume was adjusted so that the calibration signals reaching the CYP's ears from both speakers separately were 60 dBA using a sound level meter situated at the CYP's ear level. In my own experience of SiN testing, the acoustics of the rooms used for testing in schools can have a varying effect on the intensity of sound reaching the CYP's ears, so speakers often need to be moved to compensate for this. Relying on a distance measurement alone is not sufficient to ensure a 60 dBA signal at the CYP's ears.

The radio aid was positioned under the speaker at a distance of 0.1m. This position was chosen to replicate the WRMS being worn around the teacher's neck, where it is positioned below their mouth. The microphone 'beam' is then pointed upwards at the mouth or speaker. This was also the WRMS position used in a recent pilot study comparing different types of WRMS for latency of signal processing and ease of use (Stone et al., 2022).

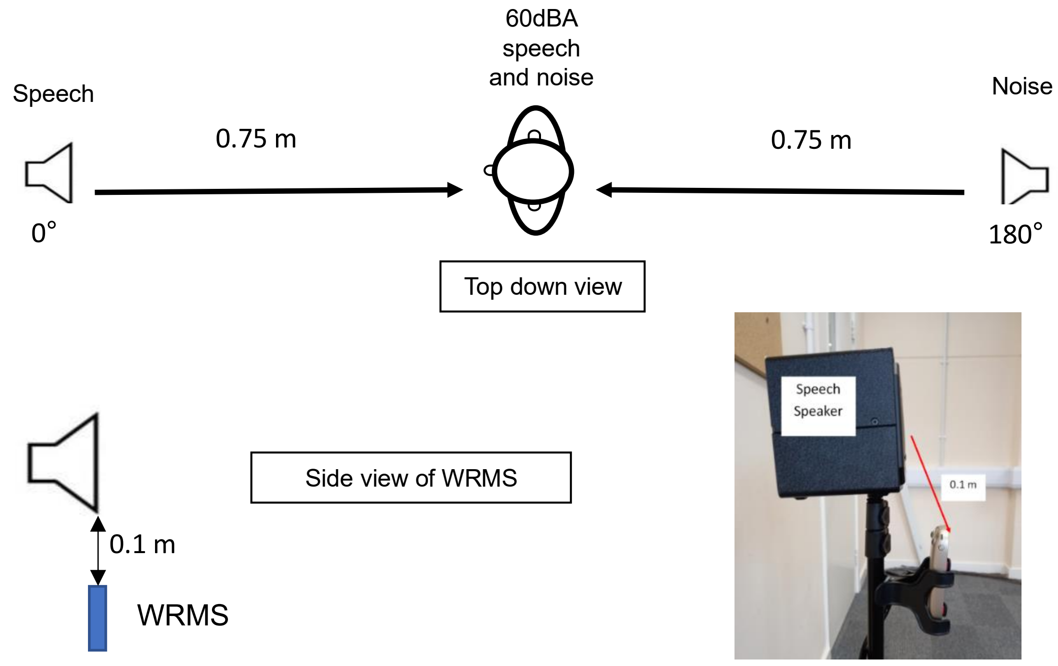


Fig. 8. Speaker and radio aid setup for the Parrot Plus 2 system.

The WRMS was put into verification mode for the duration of the testing. This was done on the recommendation of the ALTWG due to concerns about the background noise being presented in on/off cycles around the words being presented (BATOD, 2020 a). Phonak Roger transmitters and personal hearing instruments need at least 15 seconds in order to sample and adapt to background noise levels and to stabilise (Staab, 2012). Putting the radio aid into verification mode turns off the adaptive behaviour therefore negating any adaptations that the software may make in trying to respond to the short sections of noise.

3.2.2 The 3-Speaker Setup

This speaker setup was developed by Hussetedt et. al (2021). The speaker providing the speech signal was situated at 0° in front of the listener, 1.9m away. The background noise speakers were positioned at 90°and 270° to the midpoint of a 1m radius circle (See Fig. 9).

A calibration signal was used to ensure that the speech signal reaching the CYP was 60 dBA at 75cm and was therefore 58 dBA at the listener’s ear. This mimics the speech signal received by a listener standing 4m away from a speaker in an enclosed room with a 60 dB SPL speech signal (Hussetedt et al., 2021).

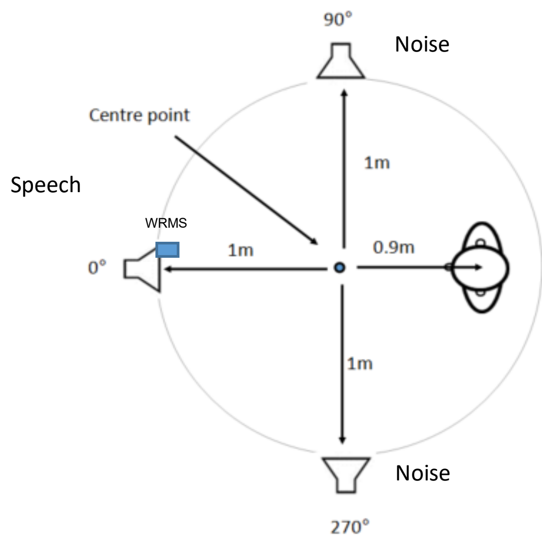


Fig.9. 3-speaker setup from Hussetedt et. al (2021).

The noise speakers were set so that, with both speakers running simultaneously, the sound level at the listener’s ear was 60 dBA. The sound intensity of the noise producing speakers could be adjusted in steps of 1 or 5 dB so they did not need to be physically moved to adjust the intensity level.

Placement of the WRMS in the 3-speaker Setup

Both Hussetdt et al. (2021) and Europäische Union der Hörakustiker e.V. (2017) state that the WRMS should be placed in front of the speaker producing the speech signal at a distance of 0.1m. Photographs in Hussedt et al. (see Fig. 10) show a Roger Pen, placed flat in line with the speaker.

a)

b)

Fig. 10. a) WRMS placement of the Roger Pen (Hussetdt et al., 2021) and b) usual placement of the Roger Pen (Phonak, no date b)

The Roger Pen, Roger Touchscreen and the newer Roger On are fitted with an accelerometer and have 3 microphone modes (Phonak, no date a; Phonak, no date b; Phonak, no date c):

- Lanyard/clip – this is designed to wear around the neck or clipped onto clothes about 20cm below the speaker's mouth.
- Interview/pointing – the WRMS is held in the hand and pointed towards the speaker at an angle.
- Conference – the WRMS is laid flat on a table and works in a 360° mode.

These first two microphone modes are designed to be highly directional and focus on the speaker. Conference mode is omni-directional, although the software focuses in on the strongest speech signal (Phonak, no date b).

As WRMS are not generally used in conference mode in the classroom (to hear the teacher) this raised concern. The main, recommended, way of using the WRMS is for the teacher/speaker to wear the device in lanyard mode. Laying the WRMS flat, so it defaults to conference mode, may not give a true representation of how the WRMS is used in class and may not be as effective at picking up the speech signal as the more directional lanyard mode. As it is a 360° microphone, it may also pick up more background noise than the focussed beam of the directional lanyard mode. There was no mention in the paper by Hussetedt et al. (2021) of putting the WRMS into verification mode.

A holder had been made for a Roger Touchscreen that could be placed 0.1m from the speaker, with the Roger Touchscreen upright (as the teacher would wear it) but facing towards the speaker (see Fig. 11). Again, I had concerns that the directional nature of the microphones would focus the 'beam' upwards, rather than towards the speaker where the speech was coming from.

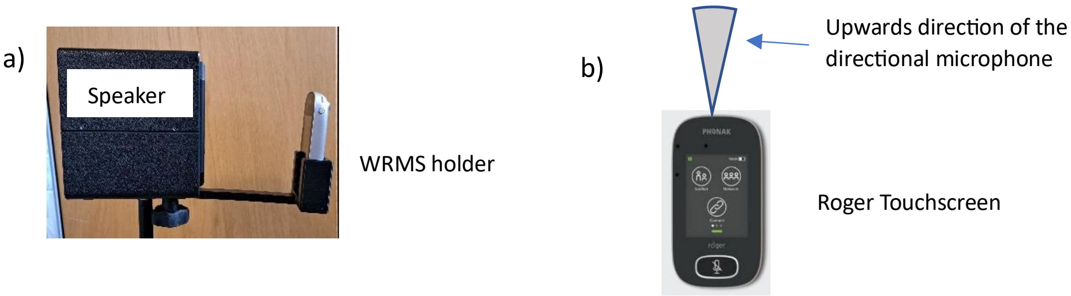


Fig.11. a) Speaker and holder for the Roger Touchscreen b) Direction of microphone beam for a Roger Touchscreen.

As the WRMS is usually worn around the neck, I hypothesised that the WRMS should be suspended below the speaker by 0.1m instead of being positioned in front to represent the way it is worn most in class (See Fig. 12). This was how I had previously been trained to position the WRMS and how it was positioned by Stone et al. (2022) in their study.

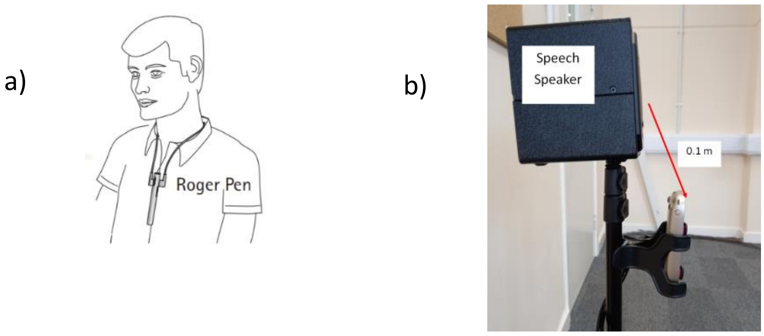


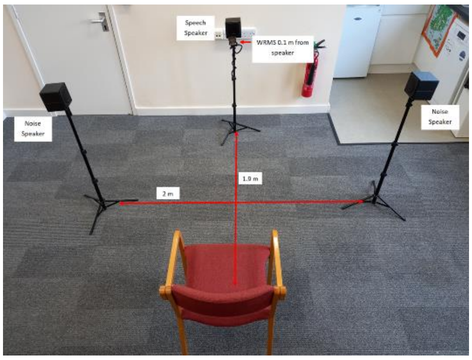
Fig. 12. a) Recommended wearing position and b) WRMS placement beneath the speech speaker.

On corresponding with a representative of Phonak (Murphy, T., 2022) (see Appendix A), there were also additional concerns:

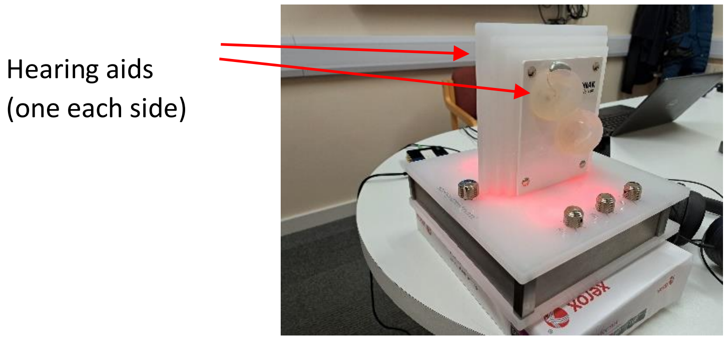
- whether recorded speech would be as effective as live voice.
- whether the WRMS should be 0.15m away.
- whether 1.9m is enough distance to ensure that the WRMS was picking up speech from the speaker and not the directional microphones on the hearing aid.

Because of these concerns, it was important that some pre-testing was done to resolve these concerns and to establish the best position for the radio aid in front of the speech signal speaker.

3.3 Pre-testing



a) The 3-speaker setup as recommended by Hussetedt et al. (2021).

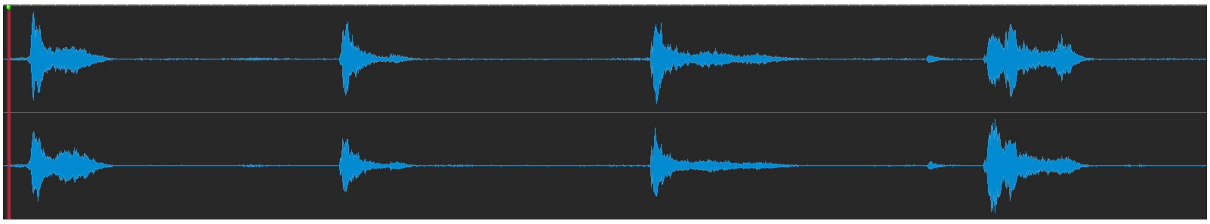


b) For recording purposes, the Klangfinder interface was placed where the listener would be sitting at 1.9 m from the speech speaker.

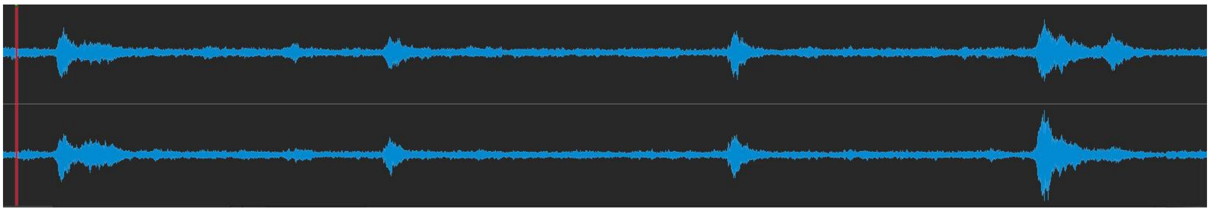
Fig. 13. a) The 3-speaker setup and b) the Klangfinder interface used to link post-aural hearing aids to a laptop.

As 9 out of the 11 personal hearing instruments and all of the WRMS devices used in the study were made by Phonak, I arranged to do some testing with a Phonak engineer. The 3-speaker setup was used in a non-soundproofed room. Two Phonak Paradise post aural hearing aids programmed with the N2 standard audiogram (Bisgaard et al., 2010) (see Appendix B) were connected to a laptop though a Klangfinder interface which mimics hearing aids being worn bilaterally on a head (see Fig. 13). ABWL 1 was played and recorded through the hearing aids.

In Figs. 14 and 15 it can be seen how background noise obscures the speech signal. The hearing aid is able to pick out the speech signal against the background noise so it can be seen/heard, but less clearly than in ambient noise levels, which were 41.7 dBA.

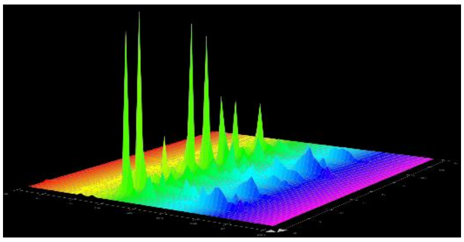


a) Hearing aids only with 60 dBA speech signal. Ambient background noise only.

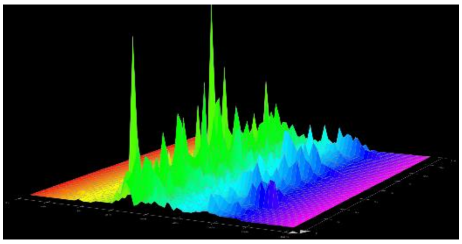


b) Hearing aids only with 60 dBA speech signal and 60 dBA background noise.

Fig. 14. Comparison of sound through hearing aids with and without background noise.



a) Hearing aid only 60 dBA with ambient noise only.

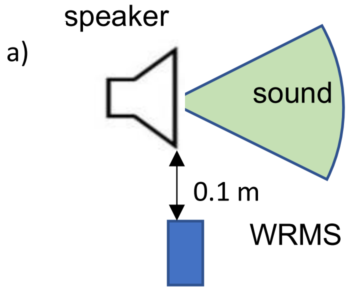


b) Hearing aid only 60 dBA with 60 dBA background noise .

Fig. 15. Spectral analysis of 60 dBA speech through a hearing aid a) in ambient noise and b) 60 dBA background noise.

3.3.1 Position in Relation to the Speaker

It was not possible to achieve a sound level of 80 dBA at the WRMS microphone when it was hanging below the speaker. Therefore, this position for the WRMS was discarded as a viable option. This is likely to be because the WRMS was not within the cone of sound coming from the speaker whereas positioning the WRMS in front of the speaker places it directly in the cone of sound (see Fig. 16).



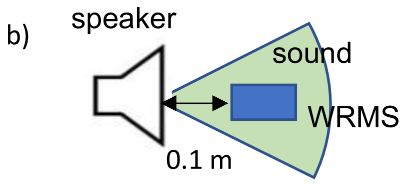
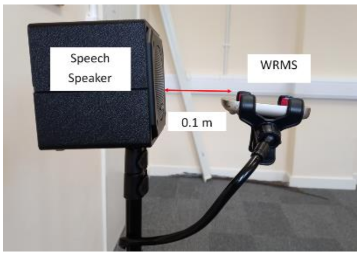
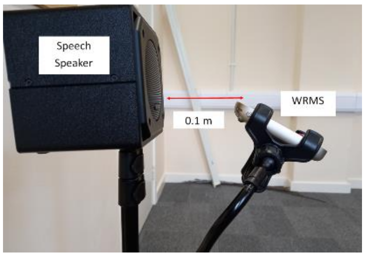


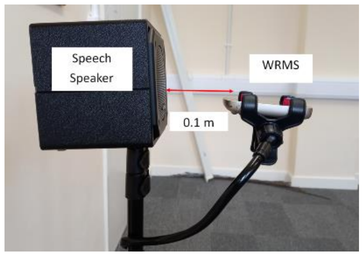
Fig. 16. WRMS placed a) beneath the speech signal speaker and b) in front of the speech signal speaker.

When placing the WRMS in front of the speaker it was possible to achieve a sound level of 80 dBA. 3 different microphone modes were manually set on the WRMS. They were then recorded with the speech signal measured at 80 dBA at the WRMS and background noise intensity 60 dBA at the hearing aids (see Fig. 17):

a) Manually put into ‘lanyard’ mode, lying flat, pointing towards the centre of the speaker. This would point the microphone ‘beam’ towards the speaker.
b) At 45° pointing at the centre of the speaker in ‘pointing’ or ‘interview’ mode. (Tipping the WRMS to 45° automatically puts the WRMS into interview mode).
c) Lying flat in front of the speaker in ‘conference’ mode. (Laying the WRMS flat automatically puts the WRMS into conference mode).







a) Lanyard Mode b) Pointing Mode c) Conference Mode

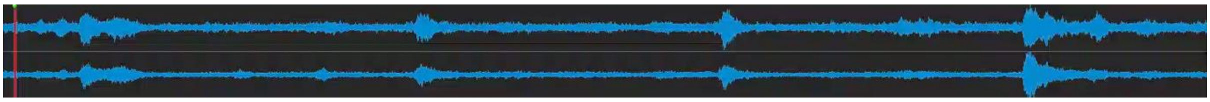
Fig. 17. Positions of the WRMS in different microphone modes.

The outputs were recorded and compared for SNR and clarity of speech (see Figs. 18 and 19).

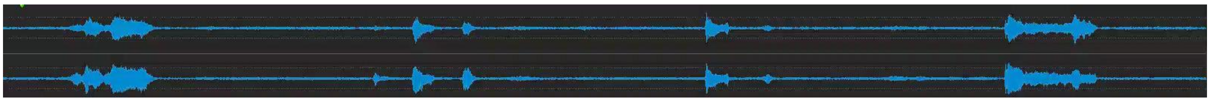
In listening to the recordings, it was obvious that the lanyard mode sounded like the speaking voice was further away and background noise was more present. Higher levels of background noise can be seen on the lanyard trace (a) in Fig. 18 compared to the other two traces. In spectral view, it can be seen that the speaking voice does not have as much energy; the frequency spikes fewer, smaller, and are less easy to pick out from the background noise (see Fig. 19, a).

There was less difference between the other two WRMS microphone settings (pointing or conference) although pointing mode seemed to have a slightly better SNR and clearer speech signal, but the difference was very small and not detectable through listening (Figs. 18 c and c and 19 b and c).

From this study, I chose to use the WRMS at a 45° angle in pointing mode in front of the speaker.



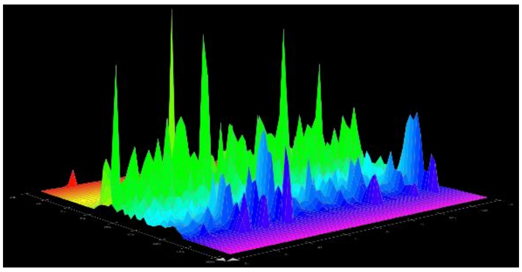
a) Lanyard mode beneath the speaker



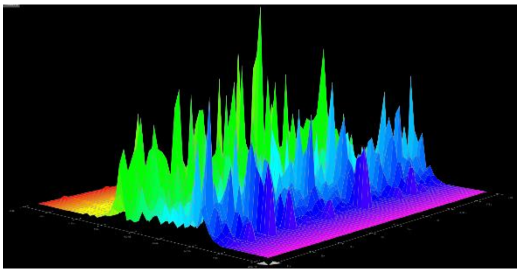
b) Lying flat conference mode

c) 45° pointing mode

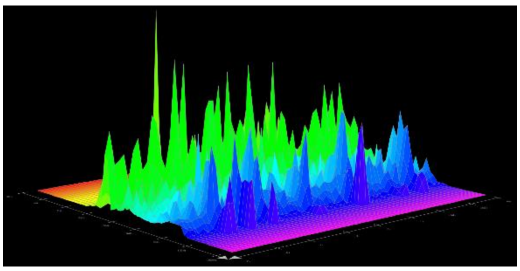
Fig. 18. Recordings of three different microphone modes through a Roger Touchscreen



a) In lanyard mode in front of the speaker.



b) Lying flat in conference mode.



c) At 45° in pointing mode.

Fig. 19. Spectral view of hearing aid output from different WRMS positions.

3.4 Summary

The 2-speaker setup was carried out as part of routine testing using the recommended setup of the manufacturer and advice from ALTWG on WRMS mode. A sound level meter was used to ensure the correct sound levels at the participant's ears but had not been used to check sound levels at the WRMS microphone.

The 3-speaker setup was carried out as recommended by Hussetedt et al. (2021) and adopted by the Audiology Expert Group (e.V., 2017) apart from the position and mode of the WRMS being altered slightly following research into the effect of microphone mode and position in relation to the speech signal speaker. This was to ensure the best SNR for the listener and the clearest speech signal.

There was no mention in either Hussetdt et al. (2021) or the Europäische Union der Hörakustiker e.V. (2017) of contact with manufacturers of WRMS to discuss how their WRMS work and the best way to use them in a test setup to get the most realistic results. This would seem to be an oversight, as different types of WRMS have different capabilities (range), programming (dynamic vs fixed gain) and directional modes of use (lanyard/interview/conference) which could potentially affect the outcome of testing and give results unrepresentative of what CYP experience in their classrooms.

4. Results

4.1 Introduction

In total 11 students took part in data collection to compare two different speaker setups. Some students' parents did not give permission for their child to be included in the study and one student was not happy with the sound quality being produced by his new hearing aids, so they were excluded.

The age of the participants ranged from 8 years to 18 years old.

The personal hearing instruments of the participants used were:

- 6 Phonak Sky M M post aural hearing aids
- 3 Phonak Sky M SP post aural hearing aids
- 1 Advanced Bionics Sky Marvel Sound Processors
- 1 Cochlear N7 Sound Processors

All were bilateral personal hearing instrument users apart from one who is severely deaf in one ear (aided) and profoundly deaf in the other ear (unaided).

All radio aids were Phonak Roger radio aids:

- 7 Roger Touchscreens
- 3 Roger Pens
- 1 Roger On

I had hoped to include a participant with Oticon Engage hearing aids and an Edumic, but permission was not given by parents.

7 Participants were tested using the MJWL and 4 participants using the ABWL.

The averages for all data were calculated using both mean and median average. The sample size was small and therefore at risk of being skewed by outlying data. Using the median value gives a more representative value than the mean (Stuart, 2016) in small sample sizes. Mean averages are used to calculate statistical significance, therefore I included both.

The mean and median average of the background noise intensity taken at each venue were very similar at 42.7 dBA and 42.6 dBA respectively. For the purposes of this study, I took this to be approximately +17 dB SNR as the speaking voice level was set at 60 dBA. Bradley and Sato (2008) estimated that the required SNR for hearing children who are 6, 8 and 11 years old respectively was +20, +18 and +15 dB respectively, so the average background noise level falls within this range. The worst ambient background noise levels were recorded in an open plan school (as would be expected) at 46 and 47.1 dBA for the two visits.

Both speaker setups showed that the WRMS gave benefit, particularly in 0 and negative SNR (see Fig. 20). Even with a positive SNR, the WRMS gave benefit to the participants, reinforcing Bradley and Sato's (2008) research that children need a higher SNR to be able to discriminate speech clearly. Merely having a positive SNR is not enough for good speech discrimination.

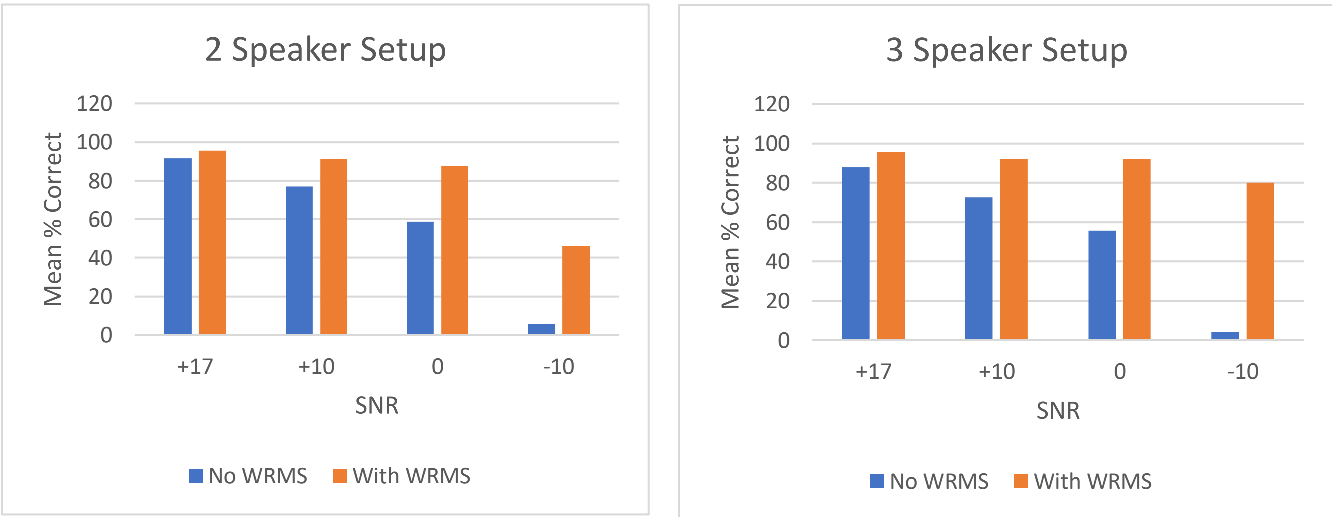


Fig. 20. Mean percentage scores with and without WRMS for both speaker setups.

Each participant completed a total of 16, 10-word lists over two visits; 8 at each visit (see Appendix C for word lists). Each word list generated a percentage score of correct words or phonemes depending on the test used. The first visit tested the 2-speaker setup. The second visit tested the 3-speaker setup. For each visit they were tested:

1. Without WRMS at:
    a. +17 dB SNR
    b. +10 dB SNR

    c. 0 dB SNR
    d. -10 dB SNR
2. With WRMS at:
    a. +17 dB SNR
    b. +10 dB SNR
    c. 0 dB SNR
    d. -10 dB SNR

The scores for each participant can be seen in Table 3.

2 Speaker Setup (first visit)																						
Participant	A	A	B	B	C	C	D	D	E	E	F	F	G	G	H	H	I	I	J	J	K	K
+17 dB SNR	100	100	90	100	80	90	93	100	80	100	80	70	100	100	97	97	97	97	100	97	90	100
+10 dB SNR	80	90	90	100	40	90	87	100	80	80	50	90	90	100	83	70	70	93	90	90	87	100
0 dB SNR	40	70	60	90	30	100	60	97	40	70	10	70	90	100	70	100	70	87	70	80	67	100
-10 dB SNR	0	10	0	40	20	10	17	57	0	60	0	10	0	60	17	67	0	47	10	50	0	97

Key
- without WRMS (green)
- with WRMS (blue)

3 Speaker Setup (second visit)																						
Participant	A	A	B	B	C	C	D	D	E	E	F	F	G	G	H	H	I	I	J	J	K	K
+17 dB SNR	100	100	90	100	90	90	90	100	70	100	70	80	90	100	90	97	97	100	90	90	90	97
+10 dB SNR	80	80	70	100	70	100	63	90	80	80	20	80	80	100	90	100	77	97	80	90	90	97
0 dB SNR	70	90	80	100	90	90	27	97	30	80	10	70	20	100	47	93	63	97	40	100	83	97
-10 dB SNR	0	80	10	90	0	60	0	97	0	60	0	60	0	60	0	100	23	93	0	80	13	100

Key
- without WRMS (yellow)
- with WRMS (orange)

Table 3. Percentage scores for each participant for 2 speaker and 3 speaker setups.

4.2 Method of Data Analysis

When considering how to analyse the results, I initially thought to use the method recommended by the ALTWG (BATOD, 2020 a):

1. Test without WRMS first, find the SNR where the baseline score is less than 100% and then continue to raise the background noise intensity until the participant records a score of less than 50% of the baseline score.
2. Repeating the procedure with the WRMS.
3. Comparing the SNRs where the participant scores less than 50% of the baseline score to show the benefit of the WRMS.

Once testing started it became clear that this method would not be possible. When the WRMS was introduced for the 3-speaker setup, the limit on the background noise intensity programmed into the speakers prevented the noise intensity being raised high enough for the participant to score less than 50% of the baseline score. This meant a comparison SNR level was not obtainable for testing with WRMS.

I therefore chose to separate out the test scores into two groups: those obtained without WRMS and those with WRMS. For the tests done without WRMS, I compared the mean and median results of the 2-speaker setup and 3-speaker setup for each SNR to see if there was a difference between the results.

For each SNR, the mean and median results were found for all the participants. See tables 4 and 5.

Without WRMS

Participant	+17 dB SNR		+10 dB SNR		0 dB SNR		-10 dB SNR	
	2 Speaker	3 Speaker	2 Speaker	3 Speaker	2 Speaker	3 Speaker	2 Speaker	3 Speaker
A	100	100	80	80	40	70	0	0
B	90	90	90	70	60	80	0	10
C	80	90	40	70	30	90	20	0
D	93	90	87	63	60	27	17	0
E	80	70	80	80	80	80	0	0
F	80	70	50	20	10	10	0	0
G	100	90	90	80	90	20	0	0
H	97	90	83	90	70	47	17	0
I	97	97	70	77	70	63	0	23
J	100	90	90	80	70	40	10	0
K	90	90	87	90	67	83	0	13
Mean	91.5	87.9	77	72.8	58.8	55.5	5.8	4.2
Median	93	90	83	80	67	63	0	0

Table 4. Mean and median percentage scores for each set of participants at each SNR **without** WRMS. Rounded to 1 decimal place.

With WRMS

Participant	+17 dB SNR		+10 dB SNR		0 dB SNR		-10 dB SNR	
	2 Speaker	3 Speaker	2 Speaker	3 Speaker	2 Speaker	3 Speaker	2 Speaker	3 Speaker
A	100	100	90	80	70	90	10	80
B	100	100	100	100	90	100	40	90
C	90	90	90	100	100	90	10	60
D	100	100	100	90	97	97	57	97
E	100	100	80	80	70	80	60	60
F	70	80	90	80	70	70	10	60
G	100	100	100	100	100	100	60	60
H	97	97	70	100	100	93	67	100
I	97	100	93	97	87	97	47	93
J	97	90	90	90	80	100	50	80
K	100	97	100	97	100	97	97	100
Mean	95.5	95.8	91.2	92.2	87.6	92.2	46.2	80
Median	100	100	90	97	90	97	50	80

Table 5. Mean and median percentage scores for each set of participants at each SNR **with** WRMS. Rounded to 1 decimal place.

4.3 Data Trends

Comparing the mean scores between the 2 and 3 speaker setups for each SNR revealed differences between the results for the two setups. As mentioned previously, both the mean and median scores were analysed to be sure that there were no outlying scores that might skew the results.

4.3.1 Without WRMS

With reference to Tables 6 and 7, and Figures 21 and 22:

Apart from the median -10 dB SNR score, which was 0% for both tests, both the mean and median averages showed:

- A trend of decreasing scores in both setups as the SNR decreased and then became negative.
- The difference between the 2 and 3 speaker setup scores was similar each time, apart from at -10 dB SNR where the scores were the most similar. This does not appear to show an increasing or decreasing trend.
- The 2-speaker setup mean and median scores were consistently higher than the 3-speaker scores.

These results would imply that the participants found the 2-speaker setup slightly easier as the average scores were higher than for the 3-speaker setup. Participant H reported about the 3-speaker setup: “it’s much harder with the noise all around me”.

Mean Average Score no WRMS			
SNR	2 Speaker Setup % Score	3 Speaker Setup % Score	Difference %
+17 dB SNR	91.5	87.9	3.5
+10 dB SNR	77	72.7	4.3
0 dB SNR	58.8	55.5	3.3
-10 dB SNR	5.8	4.2	1.6

Table 6. Mean average percentage score of each set of participants for both test setups at each SNR level without WMRS.

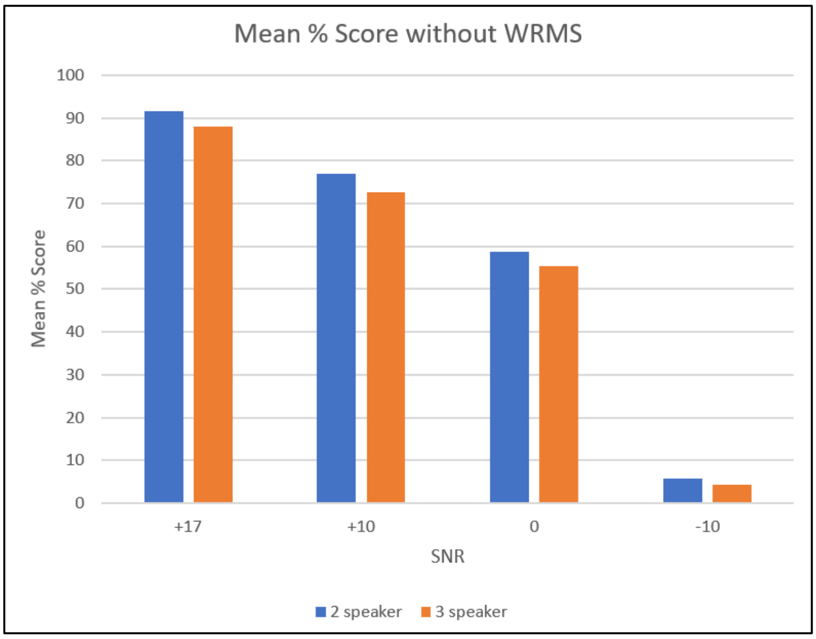


Fig. 21. Participants' mean percentage score for both tests without WRMS.

Median Average Score no WRMS			
SNR	2 Speaker Setup % Score	3 Speaker Setup % Score	Difference
+17 dB SNR	93	90	3%
+10 dB SNR	83	80	3%
0 dB SNR	67	63	4%
-10 dB SNR	0	0	0%

Table 7. Median average percentage score of each set of participants for both test setups at each SNR level without WRMS.

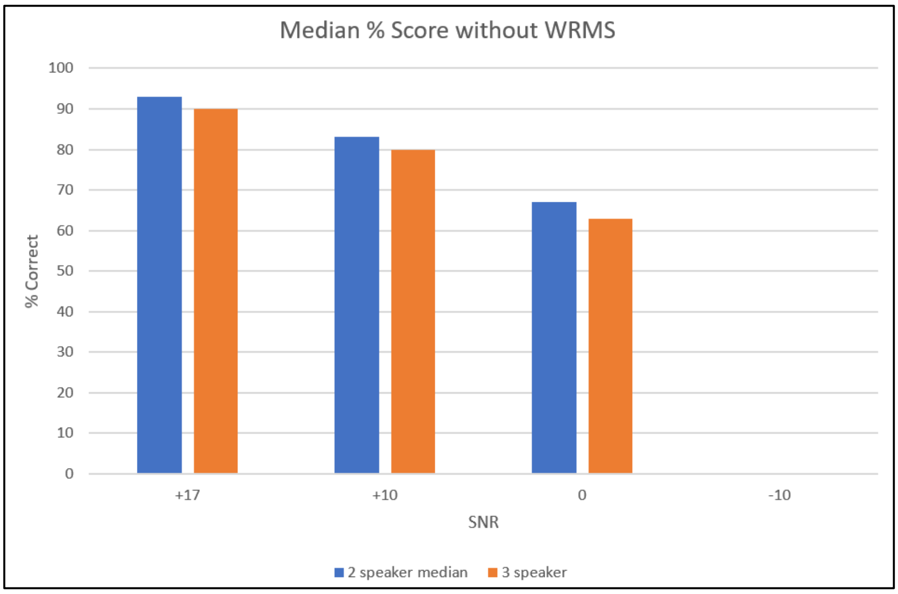


Fig. 22. Participants' median percentage score for both tests without WRMS.

4.3.2 With WRMS

With reference to Tables 8 and 9 and Figures 23 and 24:

The mean and median averages revealed that there was an increasing difference in the benefit that the WRMS was giving the participants between the two setups as the SNR decreased:

- At +17 dB SNR, the percentage scores for both tests were very similar. At this point the WRMS was not making much difference to the listener as background noise intensity was low. It may be that the participant was relying more on their personal hearing instrument than the WRMS.
- At +10 and 0 dB SNR, the 3-speaker setup showed a higher mean and median score than the 2-speaker setup. The WRMS was giving more of an advantage in the 3-speaker setup at both SNRs.
- At -10 dB SNR, there was a clear difference between the scores for the two setups. The participants gained much more benefit from their WRMS in the 3-speaker setup at the highest intensity of background noise.

Mean Average Score with WRMS			
SNR	2 Speaker Setup % Score	3 Speaker Setup % Score	Difference %
+17 dB SNR	95.5	95.8	0.3
+10 dB SNR	91.2	92.2	1.0
0 dB SNR	87.6	92.2	4.6
-10 dB SNR	46.2	80	33.8

Table 8. Mean average percentage score of each set of participants for both test setups at each SNR level **with** WRMS.

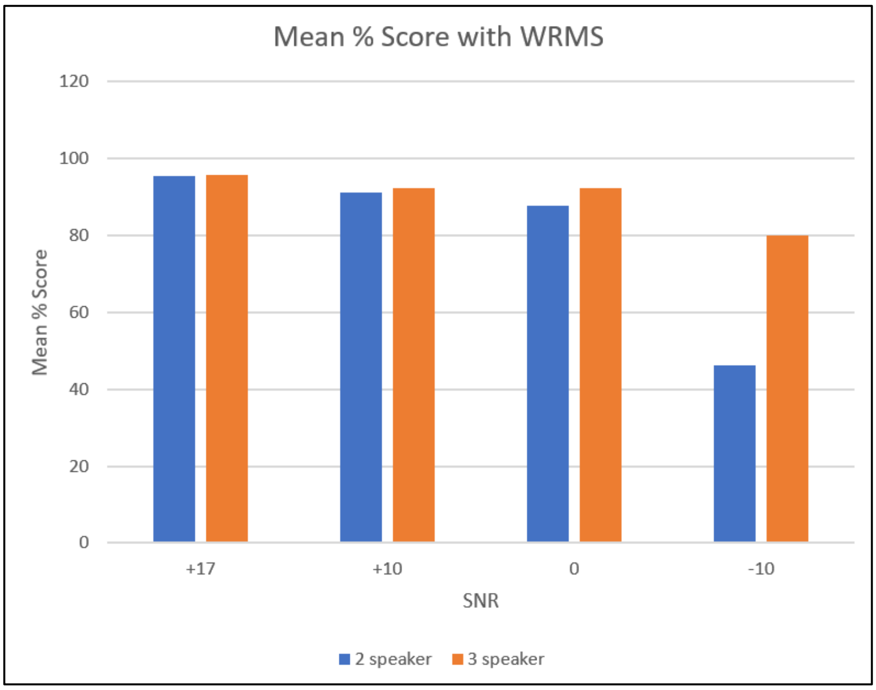


Fig. 23. Participants' mean percentage score for both tests with WRMS.

Median Average Score with WRMS			
SNR	2 Speaker Setup % Score	3 Speaker Setup % Score	Difference %
+17 dB SNR	100	100	0
+10 dB SNR	90	97	7
0 dB SNR	90	97	7
-10 dB SNR	50	80	30

Table 9. Median average percentage score of each set of participants for both test setups at each SNR level **with** WRMS.

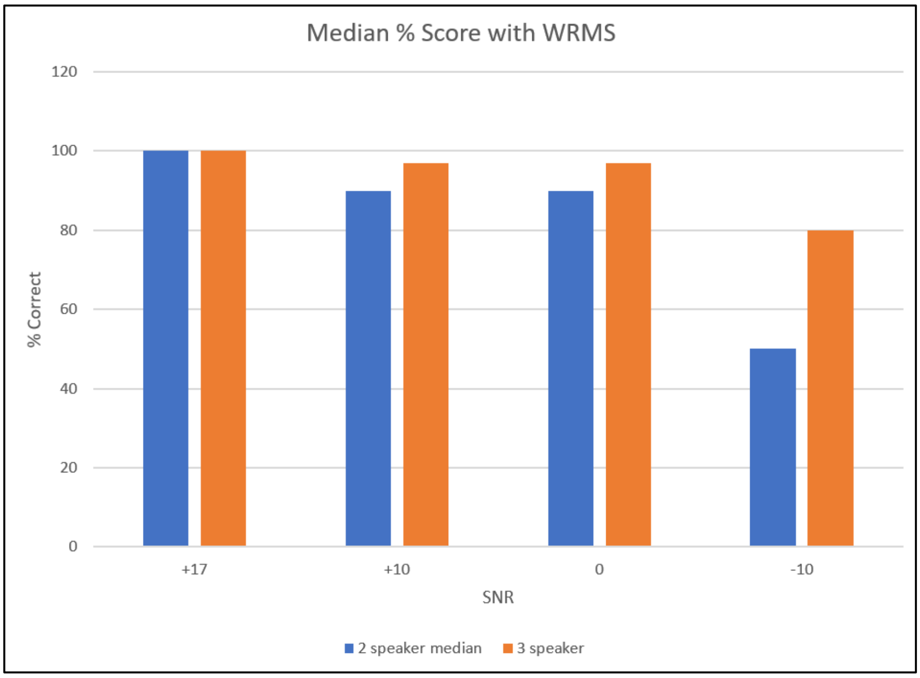


Fig. 24. Participants' median percentage score for both tests with WRMS.

4.4 Significance Testing

4.4.1 Normality Test

Data was tested for normality using the Shapiro-Wilk test. This was chosen as opposed to the Kolmogorov-Smirnov test, as the sample size is small (n<50) (Stuart, 2016). Four of the 16 data sets could be considered normally distributed using this test (see Table 10). However not exhibiting a normal distribution, non-parametric tests were chosen for further statistical analyses.

No WRMS		
	2 Speaker	3 Speaker
+17	0.27	0.001
+10	0.04	0.001
0	0.447	0.52
-10	<0.001	<0.001

With WRMS		
	2 Speaker	3 Speaker
+17	<0.001	<0.001
+10	0.028	0.007
0	0.013	0.011
-10	0.229	0.021

Table 10. Shapiro-Wilks test results for normality. Green highlighted cells show normally distributed data (Null hypothesis H_0 accepted p>0.05).

4.4.2 Data Comparisons

The Wilcoxon Signed-Rank Test was used to compare the two data sets for each SNR (2-speaker compared to 3-speaker setup). This was chosen due to small sample size and related data sets (the same students in each set of data) (Stuart, 2016). In order to compare like with like, data for all subjects without WRMS and with WRMS were analysed separately. SPSS was used for the calculations.

The null hypothesis was that there was no significant difference between the two test setups and would be rejected in favour of the alternative hypothesis if $p < 0.05$. Only the comparison for an SNR of -10 dB while using the WRMS showed significance (p<0.05) (see Table 11).

	Without WRMS	With WRMS
+17	0.114	0.854
+10	0.342	0.931
0	0.61	0.136
-10	0.671	0.007

Table 11. Wilcoxon Signed-Rank Test for statistically significant difference of the 2-speaker setup compared to the 3-speaker setup for subjects without or with WRMS. The highted cell shows statistical significance $p<0.05$.

4.5 Summary of Results

Comparison of the 2 and 3-speaker setups using analyses of the mean and median of the combined data sets (see Table 3 and Table 4) showed the following trends:

- Use of a WRMS gave benefit for participants in both speaker setups in all SNR conditions. The higher the background noise intensity, the greater the benefit gained from using the WRMS (see section 4.3)
- Speech discrimination scores using the 3-speaker setup without WRMS were consistently lower than the 2-speaker setup for all participants (see Table 3 and Table 4).
- Using a WRMS in the 3-speaker setup showed greater benefit than in the 2-speaker setup at all SNR levels and at -10 dB SNR the difference was significant ($p<0.05$).

The sample size used (n=11) was small, decreasing statistical power and so making significant differences harder to detect. Therefore, a larger sample size would be needed in order to increase statistical power and potentially identify more normally distributed data sets allowing more robust parametric tests to be applied instead (Stuart, 2016) and therefore a more powerful comparison of the two different speaker setups. In terms of statistical significance, the 3-speaker setup showed better performance at a SNR of -10 dB only, but general data trends showed better performance with WRMS than the 2-speaker setup. Therefore, it could be said that the 3-speaker setup is more fit for purpose in testing the benefit of WRMS.

5. Discussion

5.1 Literature Review

In comparing research on 2 and 3-speaker speaker setups, there seems to be little research on the effects of speaker position and number on the outcome of SiN tests. As CYP are surrounded by noise in classrooms, rather than noise coming from one point a multiple speaker setup would intuitively be more realistic.

Currently, there is no standard protocol for speaker setup in administration of SiN tests in the UK for ToDs or in Audiology clinics. Guidelines exist for administering the tests in terms of SNR (fixed or adaptive) and although the signal is always presented from 0°, there are no recommendations for how noise is presented. This lack of standard protocol means that care needs to be taken in interpreting and comparing SiN test results as different speaker setups and WRMS placements may produce significantly different results.

PLD and WRMS manufacturers do not publish any guidelines on testing for SiN with their products. Professionals carrying out SiN testing therefore need a thorough understanding of how PLD and WRMS work. Without this, devices may be used in a way that do not give the CYP optimal access to the speech test signal, therefore affecting their score.

Consideration could be given to the purpose of testing, i.e., whether testing the performance of a PLD only or a PLD with a WRMS. Different speaker setups may be suitable for different purposes but, again, there are no standard protocols in existence.

5.2 Limitations of the research

This study was carried out with a small number of participants (n=11) resulting in low statistical power. It is a useful pilot study showing that there may be differences between the results gained by different speaker setups. There remain a number of unanswered questions including:

- **WRMS position in relation to the speaker.** In the 2-speaker test the WRMS was placed below the speaker but in the 3-speaker setup it was placed in front of the speaker. Therefore, doubt is introduced as to whether the WRMS position or the speaker setup is responsible for differences in scores. Further testing of WRMS position in the 2-speaker setup is needed.

- **Noise presentation.** In the 2-speaker setup noise was presented in short 'chunks' around the target word, whereas in the 3-speaker setup it was continuous. Ideally the test should be repeated with both tests having continuous noise compared to both tests having shorter chunks of noise.
- **Room acoustics.** Although ambient noise levels were taken for each test room, time and equipment limitations meant that no reverberation measurements were taken. Room acoustics may also have an effect on test scores and should be further investigated to see whether a reverberation limit needs to be set.
- **A wider range of WRMS and PLD brands.** This study only included students using Phonak Roger WRMS and any hearing aids were also Phonak. This was due to the limited number of CYP in the study and the fitting policy of local Audiology departments. Other WRMS such as Edumic, Mini Mic 2+ and other proprietary transmitters should be included in order to be sure that the test setups are appropriate for the range of WRMS that are used in educational settings. A wider range of PLD should also be included e.g. hearing aid brands (Oticon/GN Resound), cochlear implant brands (Med EL, Advanced Bionics), and bone conduction devices (BAHA, Ponto, ADHEAR etc). Test protocol should be robust enough to be used for all combinations of WRMS and PLD that a ToD is likely to meet on their caseload.
- **Other SiN test manufacturers.** This study only used testing equipment provided by SoundByte Solutions. A comparison to the 2-speaker SPiN test produced by the Ewing Foundation is needed.
- **Recorded speech compared to live voice.** WRMS are designed to be used with live voice and may therefore produce better results than with recorded speech. Research for a protocol using live voice was recently presented at the ALTWG meeting (ALTWG, 2023).

5.3 Testing in Schools

Using the 3-speaker test setup in schools was more logistically difficult than the 2-speaker setup. Ease of setup in schools is an important consideration for ToD use. The ideal setup needs to be balanced with practicality in terms of the test being portable, simple to set up and calibrate and not too expensive, but still give a realistically representative result if these tests are to be done in the field.

The amount of floor space needed for the 3-speaker setup is larger. Finding a room with at least a 2.5m circle of clear space was challenging and needed contact with schools prior to the visit to ensure that there was a suitable room available. Often, furniture had to be moved out of the way or it had to be scheduled when a classroom or the library were free. It was easier to find rooms that could give the length needed for the 2-speaker setup than it was to find rooms with both the length and width needed for the 3-speaker setup.

Setup time for the 3-speaker arrangement was a longer due to the need for measurements for speaker position and then the calibration of the signal speaker and the noise speakers. Being able to adjust the signal and noise levels without moving the speakers was essential for the 3-speaker setup. Moving the speaker position to achieve the correct sound intensity could potentially alter the angle of speech or noise presentation and unbalance the test. Adjusting all of them would be painstaking and time consuming. Having a sound level meter and tape measure was crucial in both speaker setups.

Using speaker stands for both setups was essential to ensure that the speakers were on a level with the CYPs ears. They needed to be adjustable for an age range of 5 to 18 years. Carrying speaker stands as well as the speakers was added weight but was necessary.

In order to make sure that the WRMS was positioned correctly, a flexible phone holder was used which was wrapped around the stand and bent into position (see Fig. 25). It would be helpful if a holder or platform could be made that would put the WRMS in the correct position to remove any variability in the positioning between tests. Thought needs to be given to its design so it can be used for a variety of WRMS.

In terms of equipment to carry, the 3-speaker setup was not much more than the 2-speaker setup, apart from the extra speaker stand.

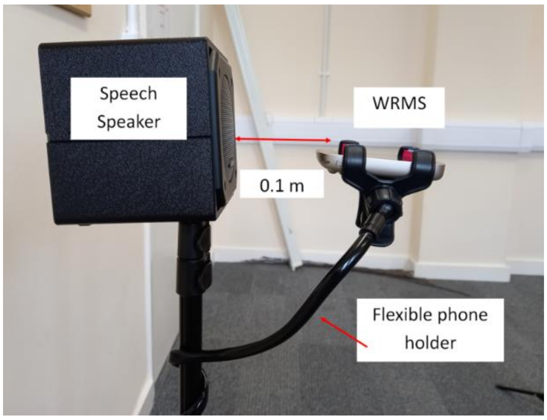


Fig. 25. Flexible phone holder used to position the WRMS.

Listening for CYP's verbal answers in 70 dBA continuous background noise was difficult. It would be easy to mis-hear a CYP, scoring them inaccurately, and it is possible that my results may be impacted because of this. In the 2-speaker setup with breaks between noise presentations the CYP's response could be heard. Sitting close enough to the CYP to hear their response and see their lip pattern was key. It may benefit the test administrator to give the participant a WRMS so the test administrator can hear their responses, using a receiver and headphones.

5.4 Reflections on learning

Liaison with the makers of SiN tests and the manufacturers of the PLD and WRMS revealed there was no collaboration to discuss how the hearing equipment works and the best way to use it in testing. In fact, when discussing the Parrot Plus setup with one of the company representatives he explained that it was never designed for testing WRMS. Over the years ToDs had begun to use it for WRMS testing without realising that it may not be fit for that purpose. In order for effective WRMS SiN testing to be carried out, the test setup designer needs to have a good understanding of how PLDs are programmed and respond to speech and noise as well as how WRMS work (microphone modes, adaptive behaviour, directional or omnidirectional microphones). Communication and co-operation between test designers and PLD/WRMS manufacturers would seem to be very important or there is a risk that test setups are not fit for purpose.

Although measuring out the distances and placements of the speakers is in the protocol, they should be a guide only. This is because the varying acoustics of the rooms affected sound levels at the participants' ears and adjustments to speaker position or sound output intensity had to be made for every setup in order to ensure parity between tests. Achieving accurate sound levels is important as Duquesnoy states:

> "A small difference in detection threshold can manifest into a large change in performance at the identification level. For example, a change of 1 dB in the speech recognition threshold can be associated with a change of 15 to 20 percentage points on a speech identification task." (Duquesnoy, 1983).

It was important to find out the best position for the WRMS in relation to the speech speaker and the best microphone mode to use. If I had been able to do this before carrying out the 2-speaker test, I may have changed the position of the WRMS before carrying out testing and may have produced different results. This highlights how important it is to question and test rather than assume how a system or protocol works.

SiN tests are attempting to replicate the noise conditions experienced by CYP in life and assess how well they can discriminate speech. The test setups should be realistic in order to reflect the listening conditions the CYP is exposed to (AAA, 2011) and repeatable in order to show possible changes in performance over time and for other practitioners to be able to reproduce and achieve consistent results. It is almost impossible to replicate a human speaking using a speaker, without expensive equipment. The speaker frequency bandwidth is limited and sound dispersal from a speaker is not the same as from a human mouth, making a completely realistic test unachievable. The advantage of a speaker is consistency of presentation levels, which is much harder to do with live voice. Because of this, some compromise is needed between realism and consistency/repeatability. The WRMS must be placed where it performs well and picks up a clear signal from the speaker, which may not completely reflect how it is worn by a real person.

5.5 Comparison of test setups

In weighing up which setup is 'better', the results of the testing need to be taken into consideration as well as cost and practicality for using in education settings.

Although the majority of the test results were not significantly different, there were trends in the data. The 3-speaker setup appeared to result in lower scores without WRMS and also showed better WRMS advantage at every SNR than the 2-speaker setup. If CYP were only exposed to a maximum SNR of 0 in classrooms, then the 2-speaker setup would probably be adequate as there was no statistical difference between the results. Unfortunately, CYP are regularly exposed to negative SNR situations (see section 2.2.1) therefore there is a need for testing in these conditions. At -10 SNR there was a statistically significant difference between the tests, with the 3-speaker setup showing much better results. At these noise levels, any dynamic WRMS should be giving a higher gain level to the speaker's voice. With Phonak Roger WRMS this was evident in the 3-speaker setup but not the 2-speaker setup. As Bradley and Sato (2008) and Schafer et al. (2013) found, the younger the child, the higher the SNR they need in order to discriminate speech well. CYP with hearing loss need an additional 8 dB more than children with normal hearing (McCreery et al., 2019), giving a potential desired SNR of up to +28 dB for 6-year-old children. This is unlikely to be achieved without very quiet rooms or the use of a WRMS.

The 3-speaker setup was more expensive, took longer to set up and needed more space, however I feel that the results that it gave are worth the extra effort, especially for testing with WRMS. It may be that a choice can be made which setup to use, depending on the reason for the test. If no WRMS is being tested, then the 2-speaker setup may be adequate.

6. Conclusion

SiN testing should be an integral part of ToD practice in order to ensure that CYP are receiving the best access to speech through the hearing equipment they use. As such, it is important that the test setups we use are reliable, repeatable and standardised but they also need to be affordable and practical to use in the field.

Currently in the UK there are some recommended protocols but no agreed on, UK wide standard setup protocols for use in the field and in paediatric Audiology. This would seem to be a gap in practice.

Technology is progressing rapidly with the move to digital transmission, the integration of receivers into PLDs, the use of Bluetooth for connection to media and streaming devices, manufacturers developing proprietary streaming technology and the development of more algorithms for processing sound and adjusting the listening experience of the user. With the introduction of Auracast Bluetooth (RNID, 2022) which can broadcast to more than one device, there is the potential for a proliferation of WMRS devices on to the market. This may be of benefit in terms of driving down prices and giving a range of choices to the user, however it is vital that ToDs and EA are able to ensure that the CYP using these devices are receiving an optimal listening experience in terms of low signal latency, wide frequency range, a reliable connection that does not drop when line of sight is lost, and at least a classroom's length range, preferably more.

Using the test box to achieve transparency will continue to be a key part of practice but it does not give a measure of how the CYP is going to be able to discriminate speech in busy classroom environments. SiN tests will continue to be an important tool in assessing how well the CYP's hearing equipment is performing, whether the settings are correct, or even whether the equipment is suitable for them in that particular environment. Having a setup, or choice of setups, that are tested, standard and agreed UK wide with hearing professionals is important in ensuring the best for CYP using PLD and WRMS. In order for this to happen, there needs to be collaboration between ToDs, EA, PLD and WRMS manufacturers and test setup manufacturers or there will continue to be a disjointed approach with little understanding of how the technology being tested interacts with the sound signal it is receiving and therefore providing unreliable results. The ALTWG includes representatives from all of the aforementioned professions and would be an ideal forum for facilitating this collaboration and sharing standardised protocols with professionals UK wide as their principal aims are about promoting the understanding and use of WRMS and influencing the quality and consistency of remote microphone provision and practice (BATOD, 2020 b).

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8. Appendices

8.1 Appendix A Emails with Phonak Engineer

Hello Tony

I wonder if I can pick your brain about a speech in noise setup that I am trialling for my MSc dissertation? I have attached some diagrams that show the speech in noise test speaker setup that I am intending to use. Essentially, the radio aid is placed 10cm from the speaker that produces the signal. In the original paper, it shows a Roger pen, horizontally placed, in line with the speaker. SoundByte Solutions have 3D printed a holder that holds a touchscreen 10cm away from the speaker, but upright and facing the speaker.

My question is:

The Pen, On and Touchscreen have the 3 different modes. If the radio aid is laid flat (as in the photograph), surely it goes into conference mode? This is not how the radio aid is usually used by the teacher, they would usually use it in lanyard mode – so would it give a different result compared to lanyard mode? If the touchscreen is upright (as in the Soundbyte solution setup) it must be in lanyard mode, but it is facing the speaker rather than being below the speaker (mouth) as it would be when worn by the teacher. Would this affect the result as I assume the microphone in lanyard mode is directional and pointing upwards?

I essence, I am trying to find the best way to position the radio aid for testing to mimic how it is used in class, which is usually lanyard mode. Would it be better place below the speaker, as it would be if worn around the neck? Would putting the radio aid into verification mode solve this?

Many thanks

Anne

Hi Anne

Yes you are correct in this, The Pen and TS should not be flat. Also I would suggest that the radio aid should be at least 3 m From the subject, as if not you are within the critical distance of the hearing aid so you are not testing the benefit of the radio aid. You would probably be testing the directionality of the aids more. Be careful also where and how you measure the noise levels as this can have a dramatic effect on the results. The noise speakers may also affect the results so theses position may also affect the directionality of the aid so it’s probably better to have them behind the subject You also need to ensure that any noise is played for 15s prior to a measurement. Recorded voice can also be tricky as the transmitter may not recognise this as speech and hence not activate it.

Suffice to say the setup is critical to the test so you need to be careful how you do this. I suggest a bit of experimentation first but certainly you need to be outside the critical distance of the aid and also understand how the aid is programmed. The mic should be below the speaker 150mm away. The speaker design may not trigger the transmitter so also be careful of this.

Let me know if you need further help

Regards

Tony

Hi Tony

I am essentially doing the same test as S but in the field with children in schools who have either hearing aids or CIs depending on the child. I am comparing the Parrot Plus 2 with essentially the Parrot plus speakers but in a different configuration.

Another thought I had - when you mentioned that the Roger system may be able to tell the difference between live voice and recorded voice and may react differently, how does that affect test box verification as that is a recording as well? I usually get good results with my Aurical HIT.

Anne

Hi Anne

Test box is OK as ISTS and the test box are specifically designed for this.

I have not used the Parrott 2 with an aid or Implant so this may affect things as the aid and probably the implant will react. I would need to see it, as I don't know if this would be an issue. I would suggest it would react at those distances. The higher the noise level the higher the affect. Maybe Ok at 55dB but anything over 60 the mic directionality would certainly start to react. Its complex but I would question if you are measuring the aid benefit or the radio aid. The aid will provide the audibility as programmed by the audiologist so it's the radio aid benefit you are trying to prove. Again, I could be wrong but you need to ensure you are doing this. Hence removing the aid outside its critical distance would seem to make sense.

We would probably need to do some testing as this is more an assumption perhaps.

Regards

Tony

8.2 Appendix B Standard Audiograms

Standard Audiograms (Bisgaard et al., 2010)

No	HL	ISO Category	250		500		1k	1,5k	2k	3k	4k	6k
N1	16	Very Mild	10	10	10	10	10	10	15	20	30	40
N2	31	Mild	20	20	20	22,5	25	30	35	40	45	50
N3	46	Moderate	35	35	35	35	40	45	50	55	60	65
N4	63	Moderate/Severe	55	55	55	55	55	60	65	70	75	80
N5	76	Severe	65	67,5	70	72,5	75	80	80	80	80	80
N6	89	Severe	75	77,5	80	82,5	85	90	90	95	100	100
N7	103	Profound	90	92,5	95	100	105	105	105	105	105	105

8.3 Appendix C Ethics Application Form

UNIVERSITY OF HERTFORDSHIRE

FORM EC1A: APPLICATION FOR ETHICS APPROVAL OF A STUDY INVOLVING HUMAN PARTICIPANTS

(Individual or Group Applications)

Please complete this form if you wish to undertake a study involving human participants.

Applicants are advised to refer to the Ethics Approval StudyNet Site and read the Guidance Notes (GN) before completing this form:
http://www.studynet2.herts.ac.uk/ptl/common/ethics.nsf/Homepage?ReadForm

Applicants are also advised to read the FAQ General Data Protection Regulation (GDPR) before completing this form.
http://www.studynet2.herts.ac.uk/ptl/common/ethics.nsf/Frequently+Asked+Questions/4AD88CD88D0F3F2D8025829800300621

Use of this form is mandatory [see UPR RE01, 'Studies Involving Human Participants', Sections 7.1-7.3]

Approval must be sought and granted before any investigation involving human participants begins [UPR RE01, S 4.4 (iii)]

Note: Supervisors should submit this form on behalf of their students.

Please submit this form and any accompanying documentation to the appropriate Ethics Committee with Delegated Authority (ECDA):

Health, Science, Engineering and Technology ECDA: hsetecda@herts.ac.uk or

Social Sciences, Arts and Humanities ECDA: ssahecda@herts.ac.uk

(If you require any further guidance, please contact either hsetecda@herts.ac.uk or ssahecda@herts.ac.uk)

THE STUDY

Q1 Please give the title of the proposed study

A Comparison Between Two Different Speech in Noise Test Setups

THE APPLICANT

Q2 Name of applicant/(principal) investigator (person undertaking this study)

Anne Bailey

Student registration number/Staff number

20016265

Email address

Anne.Bailey@hants.gov.uk

Status:

☐Undergraduate (Foundation) ☐Undergraduate (BSc, BA)

☐Postgraduate (taught) ☒Postgraduate (research)

☐Staff ☐Other

If other, please provide details here:

Click here to enter text.

School/Department:

School of Education

If application is from a student NOT based at University of Hertfordshire, please give the name of the partner institution: Mary Hare

Name of Programme (eg BSc (Hons) Computer Science): MSC Educational Audiology

Module name and module code: Research Methods and Dissertation 7FHE1108-095-2022

Name of Supervisor: Lisa Bull co-supervised by Joy Rosenberg Supervisor's email: lisa.bull@achievingforchildren.org.uk joy.rosenberg@maryhare.org.uk

Name of Module Leader if applicant is undertaking a taught programme/module:

Imran Mulla

Names and student/staff numbers for any additional investigators involved in this study (students should read GN Sections 1.5 and 2.2.1 concerning responsibilities of all members of the group)

None

Is this study being conducted in collaboration with another university or institution and/or does it involve working with colleagues from another institution?

☐Yes ☒No

If yes, provide details here:

DETAILS OF THE PROPOSED STUDY

Q3 Please give a short synopsis of your proposed study, stating its aims and highlighting where these aims relate to the use of human participants (See GN 2.2.3)

The aim is to compare two different Speech in Noise test setups to see if the results are statistically significantly different. This will involve comparing the results of two different speech in noise tests which were administered to the human participants with a short period of time between the tests. These testing is carried out as part of my day to day role as a Teacher of the Deaf. The results will then be analysed and compared.

Q4 Please give a brief explanation of the design of the study and the methods and procedures used. You should clearly state the nature of the involvement the human participants will have in your proposed study and the extent of their commitment. Ensure you provide sufficient detail for the Committee to, particularly in relation to the human participants. Refer to any Standard Operating Procedures SOPs under which you are operating here. (See GN 2.2.4).

This study accesses data/records of assessments carried out as part of the normal job of the applicant. Ethics approval and parents' consent is sought for accessing their data/records for the dissertation project. The participants in the study will be young people who are on caseload, who have a bilateral hearing loss, and who use a wireless remote microphone system. Speech in noise testing is currently part of the battery of assessments that are administered as part of normal practice to young people on the caseload to ensure that their equipment is working correctly. Speech in Noise testing uses speakers to deliver a speech signal to the listener and background noise that disrupts the speech signal. The listener is scored on the accuracy of their responses. The testing uses two different speaker configurations administering the same test a few weeks apart. The first speech in noise test is administered according to the manufacturer's instructions with a speaker in front and behind. The alternative setup uses three speakers in a different configuration. The same listening test is used for both configurations so that the results can be directly compared. The alternative configuration is recommended by the European Union of Hearing Care Professionals, and the testing is carried out to their recommended measurements and speaker placement. These assessments are carried out regularly, so I am asking ethics approval and parents'/students' consent to use data that is held as part of my normal role.

Q5 Does the study involve the administration of substances?

☐Yes ☒No

PLEASE NOTE: If you have answered yes to this question you must ensure that the study would not be considered a clinical trial of an investigational medical product. To help you, please refer to the link below from the Medicines and Healthcare Products Regulatory Agency:

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/317952/Algothrim.pdf

To help you determine whether NHS REC approval is required, you may wish to consult the Health Research Authority (HRA) decision tool: http://www.hra-decisiontools.org.uk/ethics/

If your study is considered a clinical trial and it is decided that ethical approval will be sought from the HRA, please stop completing this form and use Form EC1D, 'NHS Protocol Registration Request'; you should also seek guidance from Research Sponsorship.

I confirm that I have referred to the Medicines and Healthcare Products Regulatory Agency information and confirm that that my study is not considered a clinical trial of a medicinal product.

Please type your name here: Anne Bailey

Date: 28/09/2022

Q6.1 Please give the starting date for your recruitment and data collection: **If you decide to take part in the study the data collected during Speech in Noise Assessments will be used by the researcher. You will not have to provide any additional information.**

As soon as Ethics approval is received.

Q6.2 Please give the finishing date for your data collection: It is anticipated to complete data collection by the end of March 2022.

(For meaning of 'starting date' and 'finishing date', see GN 2.2.6)

Q7.1 Where will the study take place?

The study will take place in my office accessing data/records collected as part of my normal job role. By parents/students agreeing to take part, i.e. allowing access to

their child's or their own records for this project, the data collected during Speech in Noise tests will be analysed. There will be no need for additional visits to any setting.

Please refer to the Guidance Notes (GN 2.2.7) which set out clearly what permissions are required;

Please tick all the statements below which apply to this study

Q7.2 **Permissions**

This question is about two types of permission you may need to obtain. Depending on the study you may need more than one of each of these:

i Permission to access a particular group or groups of participants to respond to your study

ii Permission to use a particular premises or location in which you wish to conduct your study

If your study involves minors/vulnerable participants, please refer to Q18 to ensure you comply with the University's requirement regarding Disclosure and Barring Service clearance.

TICK THE APPROPRIATE BOXES IN EACH COLUMN

(i) Permission to access participants (tick)		**(ii) Permission to use premises/location** (tick)	
	I confirm that I have obtained permission to access my intended group of participants and that the permission is attached to this application		Permission has been obtained to carry out the study on University premises in areas outside the Schools and the agreement is attached to this application.
✓	I have yet to obtain permission but I understand that this will be necessary before I commence my study. For student applicants only: I understand that the original copies of the permission letters must be verified by my supervisor before data collection commences		Permission has been obtained from an off-campus location to carry out the study on their premises and the agreement is attached to this application
	This study involves working with minors/vulnerable participants. I/we have		I have yet to obtain permission but I understand that this will be necessary before I commence my

	obtained permission from the organisation (including UH/UH Partner Institutions when appropriate) in which the study is to take place and which is responsible for the minors/vulnerable participants. The permission states the DBS requirements of the organisation for this study and confirms I/we have satisfied their DBS requirements where necessary		study. For student applicants only: I understand that the original copies of the permission must be verified by my supervisor before data collection commences
	Permission is not required for my study. **Please explain why:**	√	Permission is not required for my study. **Please explain why: Testing was carried out as part of normal working practice on school sites who have not required risk assessments. The study is analysing data stored on record.**

HARMS, HAZARDS AND RISKS

Q8.1 It might be appropriate to conduct a risk assessment (in respect of the hazards/risks affecting both the participants and/or investigators). **Please use form EC5, Harms, Hazards and Risks, if the answer to any of the questions below is 'yes'.**

If you are required to complete and submit a School-specific risk assessment (in accordance with the requirements of the originating School) it is acceptable to make a cross-reference from this document to Form EC5 in order not to have to repeat the information twice.

Will this study involve any of the following?

Invasive Procedures/administration of any substance/s? ☐YES ☒NO

IF 'YES' TO THE ABOVE PLEASE COMPLETE EC1 APPENDIX 1 AS WELL AND INCLUDE IT WITH YOUR APPLICATION

Are there potential hazards to participant/investigator(s) from the proposed study? (Physical/Emotional or other non-physical harm) ☐YES ☒NO

Will or could aftercare and/or support be needed by participants? ☐YES ☒NO

Q8.2 Is the study being conducted off-campus (i.e. not at UH/UH Partner?) ☒YES ☐NO

It might be appropriate to conduct a risk assessment of the proposed location for your study (in respect of the hazards/risks affecting both the participants and/or investigators) (this might be relevant for on-campus locations as well). Please use Form EC5 and, if required, a School-specific risk assessment (See GN 2.2.8 of the Guidance Notes).

If you do not consider it necessary to submit a risk assessment, please give your reasons:

The study takes place in my office and uses data/records that have been collected as part of my normal job role.

ABOUT YOUR PARTICIPANTS

Q9 Please give a brief description of the kind of people you hope/intend to have as participants, for instance, a sample of the general population, University students, people affected by a particular medical condition, children within a given age group, employees of a particular firm, people who support a particular political party, and state whether there are any upper or lower age restrictions.

The participants, whose data I am seeking consent to use, are young people between the ages of 5 and 19 who have been referred to the Hampshire Specialist Teacher Advisory Service because they have a hearing loss and who attend a mainstream school. Consent to work with the young people has been given in writing by parents and is held on record by the service. Further consent to access the data/records for the purpose of this study will be obtained. Testing and recording of data is carried out regularly as part of day-to-day practice already.

Q10 Please state here the maximum number of participants you hope will participate in your study. Please indicate the maximum numbers of participants for ***each*** method of data collection.

The maximum number of participants whose data/records will be accessed is 25 participants.

Q11 By completing this form, you are indicating that you are reasonably sure that you will be successful in obtaining the number of participants which you hope/intend to recruit. Please outline here your recruitment (sampling) method and how you will advertise your study. (See GN 2.2.9).

Sampling will identify the data/records of children currently on my caseload who have a bilateral hearing loss, use hearing amplification devices, who use a wireless remote microphone system and who have no additional learning needs.

CONFIDENTIALITY AND CONSENT

(For guidance on issues relating to consent, see GN 2.2.10, GN 3.1 and UPR RE01, SS 2.3 and 2.4 and the Ethics Approval StudyNet Site FAQs)

Q12 How will you obtain consent from the participants? Please explain the consent process for each method of data collection identified in Q4

☐ Express/explicit consent using an EC3 Consent Form and an EC6 Participant Information Sheet (or equivalent documentation)

☐ Implied consent (participant information will be provided, for example, at the start of the questionnaire/survey etc)

☒ Consent by proxy (for example, given by parent/guardian)

Use this space to describe how consent is to be obtained and recorded for each method of data collection. The information you give must be sufficient to enable the Committee to understand exactly what it is that prospective participants are being asked to agree to.

Consent will be sought via the participant's parent/carer or guardian.

If you do not intend to obtain consent from participants please explain why it is considered unnecessary or impossible or otherwise inappropriate to seek consent.

Q13 If the participant is a minor (under 18 years of age) or is unable for any reason to give full consent on their own, state here whose consent will be obtained and how? (See especially GN 3.6 and 3.7)

Consent will be sought via the participant's parent/carer or guardian.

Q14.1 Will anyone other than yourself and the participants be present with you when conducting this study? (See GN 2.2.10)

☐YES ☒NO

If YES, please state the relationship between anyone else who is present other than the applicant and/or participants (eg health professional, parent/guardian of the participant).

Q14.2 Will the proposed study be conducted in private?

☒YES ☐NO

If 'No', what steps will be taken to ensure confidentiality of the participants' information. (See GN 2.2.10):

Q15.1 Are personal data of any sort (such as name, age, gender, occupation, contact details or images) to be obtained from or in respect of any participant? (See GN 2.2.11) (You will be required to adhere to the arrangements declared in this application concerning confidentiality of data and its storage. The Participant Information Sheet (Form EC6 or equivalent) must explain the arrangements clearly.)

☒YES ☐NO

If YES, give details of personal data to be gathered and indicate how it will be stored.

Personal data such as age, type and level of hearing loss, type of personal hearing device and speech in noise scores will be obtained. Data will be stored on a work provided laptop which is encrypted and only accessible by myself or my employer. Data used for the study will be anonymised, so the young person is not identifiable.

PLEASE NOTE: If you are processing personal information you MUST consider whether you need to complete a Data Protection Impact Assessment (DPIA). Please read the DPIA guidance available from the FAQ section of the UH Ethics Approval StudyNet site:

http://www.studynet2.herts.ac.uk/ptl/common/ethics.nsf/Frequently+Asked+Questions/935D97CDBC546E69802583A9005213A6

If you need to complete one, please find the DPIA template in the University's website here

The DPIA must be completed in consultation with the University's Data Protection Officer and submitted with your application for ethics approval.

Will you be making recordings?

☐YES ☒NO

If YES, give details of the types of recordings to be made and describe how and where they will be securely stored.

Q15.2 If you have made a YES response to any part of Q15.1, please state what steps will be taken to prevent or regulate access to personal data and/or recordings beyond the immediate investigative team, as indicated in the Participant Information Sheet.

Data will be kept on an encrypted laptop provided by my employer. No-one can access the laptop except myself and my employer. As a student of a partner programme, I do not have access to a University of Hertfordshire One Drive.

Indicate what assurances will be given to participants about the security of, and access to, personal data and/or recordings, as indicated in the Participant Information Sheet.

Data protection information is shared with parents when they are referred to the service. They give written consent to the storage of the data. It will be explained to parents and students over 16 verbally and via the Participant Information Sheet that all data for the study will be anonymised so their child, or they themselves, cannot be identified and all data will be kept on an encrypted computer.

State as far as you are able to do so how long personal data and/or recordings collected/made during the study will be retained and what arrangements have been made for its/their secure storage and destruction, as indicated in the Participant Information Sheet.

Data for the study will only be kept for the duration of the study.

Q15.3 Will data be anonymised prior to storage? ☒YES ☐NO

Q16 Is it intended (or possible) that data might be used beyond the present study? (See GN 2.2.10) ☐YES ☒NO

If YES, please indicate the kind of further use that is intended (or which may be possible).

If NO, will the data be kept for a set period and then destroyed under secure conditions? ☒YES ☐NO

If NO, please explain why not:

Q17 Consent Forms: what arrangements have been made for the storage of Consent Forms and for how long?

Consent forms will be stored in a secure, locked cupboard in my place of work. No-one else will have access to the cupboard or the forms.

Q18 If the activity/activities involve work with children and/or vulnerable adults satisfactory Disclosure and Barring Service (DBS) clearance may be required by investigators. You are required to check with the organisation (including UH/UH Partners where appropriate) responsible for the minors/vulnerable participants whether or not they require DBS clearance.

Any permission from the organisation confirming their approval for you to undertake the activities with the children/vulnerable group for which they are responsible should make specific reference to any DBS requirements they impose and their permission letter/email must be included with your application.

More information is available via the DBS website -

https://www.gov.uk/government/organisations/disclosure-and-barring-service

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REWARDS

Q19.1 Are you receiving any financial or other reward connected with this study? (See GN 2.2.14 and UPR RE01, S 2.3)

☐YES ☒NO

If YES, give details here:

Click here to enter text.

Q19.2 Are participants going to receive any financial or other reward connected with the study? (Please note that the University does not allow participants to be given a financial inducement.) (See UPR RE01,

S 2.3)

☐YES ☒NO

If YES, provide details here:

Click here to enter text.

Q19.3 Will anybody else (including any other members of the investigative team) receive any financial or other reward connected with this study?

☐YES ☒NO

If YES, provide details here:

Click here to enter text.

OTHER RELEVANT MATTERS

Q20 Enter here anything else you want to say in support of your application, or which you believe may assist the Committee in reaching its decision.

The results of this study could potentially influence how speech in noise testing is carried out within my current organisation and if shared through professional groups, could influence national practice.

DOCUMENTS TO BE ATTACHED

Please indicate below which documents are attached to this application:

☐ Permission to access groups of participants

☐ Permission to use University premises beyond areas of School

☐ Permission from off-campus location(s) to be used to conduct this study

☐ Form EC5 (Harms, Hazards and Risks: assessment and mitigation)

☒ Consent Form (See Form EC3/EC4)
☒ Form EC6 (Participant Info Sheet)
☐ Data Protection Impact Assessment (DPIA)

☐ A copy of the proposed questionnaire and/or interview schedule (if appropriate for this study). For unstructured methods, please provide details of the subject areas that will be covered and any boundaries that have been agreed with your Supervisor

☒ Any other relevant documents, such as a debrief, meeting report. Please provide details here:

Employers Permission Form

DECLARATIONS

1 DECLARATION BY APPLICANT

I undertake, to the best of my ability, to abide by UPR RE01, 'Studies Involving the Use of Human Participants', in carrying out the study.

I undertake to explain the nature of the study and all possible risks to potential participants,

Data relating to participants will be handled with great care. No data relating to named or identifiable participants will be passed on to others without the written consent of the participants concerned, unless they have already consented to such sharing of data when they agreed to take part in the study.

All participants will be informed **(a)** that they are not obliged to take part in the study, and **(b)** that they may withdraw at any time without disadvantage or having to give a reason.

(**NOTE**: Where the participant is a minor or is otherwise unable, for any reason, to give full consent on their own, references here to participants being given an explanation or information, or being asked to give their consent, are to be understood as referring to the person giving consent on their behalf. (See Q 12; also GN Pt. 3, and especially 3.6 & 3.7))

Enter your name here: Anne Bailey Date 14/10/2022

GROUP APPLICATION

(If you are making this application on behalf of a group of students/staff, please complete this section as well)

I confirm that I have agreement of the other members of the group to sign this declaration on their behalf

Enter your name here: Click here to enter text. Date Click here to enter a date.

DECLARATION BY SUPERVISOR (see GN 2.1.6)

I confirm that the proposed study has been appropriately vetted within the School in respect of its aims and methods; that I have discussed this application for Ethics Committee approval with the applicant and approve its submission; that I accept responsibility for guiding the applicant so as to ensure compliance with the terms of the protocol and with any applicable ethical code(s); and that if there are conditions of the approval, they have been met.

Enter your name here: Lisa Bull and Joy Rosenberg Date Click here to enter a date.

8.4 Appendix D Participant Information

UNIVERSITY OF HERTFORDSHIRE

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

FORM EC6: PARTICIPANT INFORMATION SHEET

1 **Title of study**

A Comparison Between Two Different Speech in Noise Test Setups

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 study that is being undertaken 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 regulation, UPR RE01, 'Studies Involving the Use of Human Participants' can be accessed via this link:

https://www.herts.ac.uk/about-us/governance/university-policies-and-regulations-uprs/uprs

(after accessing this website, scroll down to Letter S where you will find the regulation)

Thank you for reading this.

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

The purpose of this study is to compare two different speaker setups for use in Speech in Noise testing to see which one gives the closest results to students listening to noise in a classroom. Speech in Noise testing is used to give an idea of how well a student with hearing loss can hear in quiet and in different levels of noise, just like they would in a classroom. It enables us to adjust their personal hearing devices and to give advice to schools and staff in supporting the student’s listening in class.

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

It is completely up to you whether or not you decide to take part in this 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 students taking part in this study are of school age, between 5 and 18 years old.

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

The study uses data collected as part of normal assessments.

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

Scores from Speech in Noise tests will be compared to see how they differ. You will not need to do anything different for this study.

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

There should be no disadvantages to taking part in this study.

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

If, during testing, it is identified that the student is having difficulty in discriminating speech beyond what is expected the parents and the Audiology department will be informed so that the student's personal hearing device can be adjusted to an optimal level.

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

The students in the study will not be identified in any way beyond their age, hearing loss and type of personal hearing device. Their test scores will be kept on an encrypted computer that is provided by Hampshire County Council. The computer can only be accessed by the investigator.

11 **Audio-visual material**

No audio-visual material will be recorded or used.

12 **What will happen to the data collected within this study?**

- The data collected will be stored electronically, in a password-protected environment, for 4 months, after which time it will be destroyed under secure conditions;
- The data will be anonymized prior to storage.

13 **Will the data be required for use in further studies?**

- The data will not be used in any further studies.

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 <*SHE/PGR/CP/05748*>

15 **Factors that might put others at risk**

There are no factors that may 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 and, under such circumstances, you will be withdrawn from the study.

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:

Anne Bailey

Anne.bailey@hants.gov.uk

07784262854

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 at the following address:

Secretary and Registrar

University of Hertfordshire

College Lane

Hatfield

Herts

AL10 9AB

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

8.5 Appendix E Participant Consent Form

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:

A Comparison Between Two Different Speech in Noise Test Setups

(UH Protocol number …………………………………)

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 data/records from normal assessments carried out as part of the Specialist Teacher Advisor's job role will be accessed, 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 (consent to access his/her data records from normal routine assessments). 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 his/her data/records 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 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 19.10.22

Name of (principal) investigator

ANNE BAILEY