Exploring the impact of classroom acoustic measurements, and follow-up adaptations, on learners and staff in the classroom

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Karen Wright

BA (Hons), PG Dip

Mary Hare, Newbury;

Partnered with the University of Hertfordshire, Hatfield

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Abbreviations

ALD	Assistive Listening Device
ADHD	Attention Deficit Hyperactivity Disorder
APD	Auditory Processing Difficulty
ASD	Autistic Spectrum Disorder
BAEA	British Association of Educational Audiologists
BB93	Building Bulletin 93
CYP	Children and young people
DCYP	Deaf children and young people
IOA	Institute of Acoustics
LA	Local Authority
NDCS	National Deaf Children's Society
PCHL	Permanent Childhood Hearing Loss
QToD	Qualified Teacher of the Deaf
SEN	Special Educational Needs
SNR	Signal-to-Noise Ratio
T_{mf}	Average mid-frequency reverberation time
UK	United Kingdom
VI	Visual Impairment

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Abstract

Aims: With the majority of deaf learners in the UK educated in mainstream schools, optimal listening conditions are needed in mainstream classrooms. BB93 states the requirements for classroom acoustics, including specific guidance for learning spaces for pupils with significant hearing or communication needs. The installation of sound absorbing acoustic panels can improve sub-optimal classroom acoustics. This study explored the impact of an acoustic adaptation programme of works, which aimed to reduce the T^{mf} to ≤0.4 seconds in ten mainstream primary classrooms where a deaf pupil was taught, by installing acoustic panels.

Method: Classroom reverberation times, before and after the acoustic modifications, were compared. Deaf pupils' perceptions of listening ability, before and after panel installation, were reviewed by retrospectively interrogating L.I.F.E.-R questionnaires. Semi-structured interviews were used to collect the before and after perceptions class teachers.

Results: The installation of acoustic panels successfully reduced the T^{mf} in each classroom to ≤0.4 seconds. Deaf primary pupils indicated that the reduction in reverberation time improved the ability to listen and understand in the classroom. However, even in optimal acoustic conditions, with access to an assistive listening device and well-fitted optimally programmed hearing devices, deaf pupils still reported challenges in listening to their peers demonstrating the consideration still required for challenges faced by deaf students even when reasonable adjustments have been made.

Class teachers reported an improvement in listening conditions for all classroom users, an increase in peer learning interactions, positive changes in behaviour for noise-sensitive pupils and an improvement in access to learning for deaf students. Teachers also benefitted from reduced vocal effort.

This acoustic adaptation study showed benefits for all learners and staff in the classroom and the positive contribution of the Educational Audiologist to the acoustic programme of works.

1. Introduction

The benefits of good physical classroom environments, with optimal acoustics, have been widely researched and documented for over fifty years (Niemoeller, 1968, p.1041).

In the United Kingdom (UK), directed acoustic measurement guidelines for learning spaces where children are taught include recommended ambient noise levels, sound insulation and reverberation times (BB93, 2015) for different learning spaces within nursery, primary and secondary schools. Recommended guidelines are given for both new build classroom buildings and refurbishments.

Despite previous research demonstrating the benefits for academic and social achievement, some children and young people are being taught in learning spaces with poor listening conditions on a daily basis.

A key part of the training of an Educational Audiologist is developing knowledge of speech acoustics and room acoustics in order to advise on optimal listening conditions for learning and wellbeing of all children and their teachers (BAEA, 2019) but especially those pupils with a hearing loss. However, the role of the Educational Audiologist varies throughout the UK (Ash, 2020) and schools in some Local Authorities may not have access to advice from an Educational Audiologist.

The Educational Audiologist role has been longstanding in the Local Authority (LA) in which I work. A key aspect of that role has been to advise on classroom acoustics by providing classroom acoustic measurement reports, with recommendations for improvements if required, for classrooms where deaf children with significant hearing and communication needs will be taught. For several years, where acoustic adaptations have subsequently been completed by the LA, ad hoc comments have been collected from teachers, teaching in the modified classroom. Comments have often suggested positive benefits for users of the classroom in addition to those with a hearing loss.

This provides the background on which this study is based; Exploring the impact of classroom acoustic measurement assessments, and follow-up adaptations, on learners and staff in the classroom.

2. Literature Review

2.1. Literature search

There is a plethora of research on classroom acoustics. Searches for relevant literature were first undertaken using the library database SCOPUS. An initial search of article titles, abstracts and keywords using the terms, “classroom” + “acoustic” revealed 1,267 results and were further filtered by adding an additional search term “reverberation” or “noise” or “speech intelligibility” or “well-being”. Furthermore, in order to elicit results relating to teachers, a further search was made including the terms “poor acoustics” + “adult” + “speech intelligibility” + “noise” + “reverberation”.

Abstracts were used to identify research with the strongest significance and applicability to the study, before analysing articles relating to key themes identified; speech intelligibility; room acoustics - ambient noise, reverberation and signal-to-noise ratio (SNR); assistive listening technology; inclusion; well-being; academic achievement.

The first section of this review will consider the ability of different cohorts to discriminate speech in a suboptimal acoustic environment; adults, adolescents, young children and children with special hearing and communication needs due to auditory processing difficulties. Degraded speech, due to teacher’s vocal strain, will be considered in relation to pupil’s speech intelligibility. Furthermore, the correlation between poor acoustics and negative impact on well-being and academic achievement will be discussed. In the second section, assistive listening devices, such as radio aids and soundfield systems, which aim to provide users with clearer access to speech for learning, will be deliberated in the context of their use in a poorer acoustic environment. International and national guidelines will be outlined in section three, together with school responsibilities for inclusion.

The section will conclude with justification for this study.

2.1.1. Speech Intelligibility

Everyday individual experiences encompass complex acoustic environments (Leibold, 2017, p.3001) with various contradicting sounds in which encoding,

committing to memory and semantic and syntactic processing all need to happen (Klatte *et al,* 2013) in order to comprehend what is being said (Prodi *et al,* 2021).

Age, health, developmental stage, hearing status or other significant communication need and native language affect the ability to hear and understand speech in the environment.

2.1.2. Adults

Alqattan and Turner (2021) propose that there are several influences that hinder the ability to understand speech including: ambient noise, reverberation and SNR; prior knowledge of the subject matter; hearing status; central auditory processing difficulties: speech clarity including speed, accent, native vs non-native listener and language and vocabulary experience.

Signal-to-noise ratio (SNR) is expressed as the difference between the signal that needs to be listened to (e.g., speech) and competing background noise. Larger differences give a clearer signal and, therefore, greater speech clarity. SNR is influenced by both direct and reverberated sound. Reverberation time is defined as the length of time (seconds) it takes for a sound to decay 60dB from when the source of the sound has stopped. Rooms with hard surfaces have longer reverberation times. Sound continues to travel around the room when there is little or no absorptive material, arriving at the ear at different times. This leads to conflicting auditory information, part of which is sound travelling directly to the ear mixed with the reflected sounds (Klatte *et al,* 2010), causing diminished speech perception (Kwak *et al,* 2018) and longer response times (Gustafson *et al*, 2019). Conversely, early reflections aid speech clarity by intensifying the target signal.

The critical distance in a room is the point at which the sound pressure level of sound directly from the source equals the sound pressure level of reverberated sound. Different frequencies have different critical distances (Crandell and Smaldino, 2000). A reverberant room has a shorter critical distance and therefore, the listener will need to be closer to the sound source to hear more clearly. A room with more sound absorbent surfaces will have a critical distance which is further from the sound source. Crandell and Smaldino, (2000) also point out that inverse square law means that the intensity of the speech signal diminishes the further away the sound source

is from the listener. Sound levels decrease 6dB each time the distance from the sound source is doubled. Therefore, beyond the critical distance, speech will directly arrive at the listener's ears but will be followed by reverberated sounds. Reverberated sounds start as the original soundwaves but reflect off harder surfaces and may have intensity, frequency and temporal differences to the original soundwaves depending on the absorbent properties within the room making it more difficult for speech discrimination.

When listening to speech, listeners gather phonetic and phonemic information from the speech signal, then analyse and blend together and try to match with known lexicon. However, if the signal is corrupted, the listener relies on context and prior experience of language to fill in the gaps (Alqattan and Turner, 2021). Adults have a bank of knowledge to call upon and are, therefore, better able to fill in the gaps of an incomplete signal.

However, as people get much older, age-related hearing loss increases the impact of poor acoustics (Kwak *et al,* 2018). Intensity of the speech signal reduces as hearing deteriorates which extends the auditory processing time required.

Additionally, Alqattan and Turner (2021) found that, although listening in background noise diminishes functional listening capabilities for all, those listening in a language other than their first language, are significantly affected. Excessive background noise and greater reverberation times negatively impact speech comprehension and listening effort for non-native language users leading to increased fatigue and poorer ability to perform several tasks at once (Borghini and Hazan, 2018). Non-native listening demands greater SNR (Borghini and Hazan, 2018, MacCutcheon *et al*, 2018) attributable to a higher cognitive effort. This is caused by the call on working memory due to incomplete lexical and semantic language knowledge in the second language (Borghini and Hazan, 2018). Peng and Wang (2016) suggest that the accent of the speaker, together with a poorer acoustic environment, compound difficulties experienced suggesting that it is easier to understand non-native speech when the speaker has the same first language as the listener.

2.1.3. Teacher's well-being / Vocal Strain

Adults who work as teachers are susceptible to the effects of poor acoustics owing to the nature of oral communication in their role (Durup *et al,* 2013). Early Years teachers are particularly vulnerable due to the immature language and reading skills of pupils requiring more oral interactions with teachers than compared with older students (Munier *et al,* 2018, p.259, Martins *et al,* 2014).

As background noise rises, teachers modify their voice pitch (Durup *et al*, 2013), raise voice intensity, as predicted by the Lombard effect (Bradley and Sato, 2008, Brill and Wang, 2021), and report having to repeat information regularly (Klatte, 2010) which disrupts the flow of teaching. This is a particular challenge noted in open plan classrooms, where more than one class share a flexible learning space (Robinson and Bellert, 2019, p.5).

The changes teachers make to their voice can lead to increased vocal effort (Durup *et al,* 2013) which in turn can lead to voice strain (Durup *et al,* 2015). This is due to the limited time the vocal folds have to recover after a prolonged period of considerable effort (Munier *et al,* 2008 p.74). Subsequently, this may lead to stress (Tiesler and Oberdörster, 2008, p.256). In 2018, research by Munier *et al* (p.259) concurred with findings of Kristiansen *et al* (2011), noting higher reverberation times and perceived noise exposure as adversely influencing job satisfaction for teachers. However, this is not a new phenomenon. In 2004, Roy *et al,*(p.542) cited research back to 1967 and, in their own study, found that, when compared with other occupations, teachers were significantly more likely to have been affected by a variety of voice conditions including dysphonia (hoarseness), discomfort, vocal fatigue, voice projection difficulties and loss of vocal range (p.546). Teachers reported that vocal strain had, at some time, reduced the number of interactions and activities they were able to perform in the classroom (p.549). Martins' *et al* (2014) review reported that between 20% and 50% of teachers had been affected by dysphonia, with Durup *et al* (2013) suggesting that teachers represent 12% of those who attend voice clinics in the UK with the cost of teacher absences amounting to £15m annually.

Gheller *et al,* (2020, p.47) note that acoustics should be such that teachers do not need to utilise excessive vocal effort.

2.1.4. Children with typical hearing

Speaking and listening are principal methods for communicating in the classroom for the majority of students and their teachers (Prodi *et al,* 2021). The majority of time is spent engaged in speaking and listening activities (Gheller et al, 2020, p.47; Prodi *et al,* 2021) with Robinson and Bellert (2019, p.1) suggesting that this can range from 60% and 80% of the day. Therefore, it is vitally important that speech is intelligible to the listener (Acoustic Engineering, 2021). Children's knowledge of language is still developing. Therefore, their range of experience does not cover the same extent as adults.

However, the acoustic properties of the classroom environment, together with ambient background noise reducing SNR and teachers' degraded voice quality, affect the intelligibility of speech (Schiller *et al,* 2020, p.2121). The detection of consonants is particularly affected in poorer acoustic environments as consonants have less spectral energy than vowels (Crandell and Smaldino, 2000, p.364) but provide most information.

Children's ability to listen and learn is impacted by *'energetic'* and *'informational'* masking (Klatte *et al,* 2013, Prodi *et al,* 2021). Noise, especially classroom babble with the "*same spectrum and temporal envelope of speech"* (Prodi *et al,* 2019, p.1, Schiller *et al,* 2020, p.2126), hampers speech perception, as both required speech and unwanted babble are detected, making it challenging to separate one from the other.

Moreover, Robinson and Bellert, (2019, p.3) point out the need for children to learn with their peers and factors such as group work and talk partners exacerbates matters by adding children's speech to existing environmental sounds of heaters, ventilation, other classrooms, electronic equipment, corridors and/or traffic.

Furthermore, detection alone is insufficient for pupils to comprehend meaning. Poor acoustics deleteriously influence listening effort. Demands on attention, cognitive capacity and development, and working memory (Prodi, 2021, Klatte *et al,* 2013) trigger challenges in auditory processing, causing an increase in cognitive effort (Gheller *et al,* 2020, p.47, Prodi *et al,* 2021).

Chronic or consistent poor acoustics correlate to poorer academic achievements (Peng *et al,* 2020) particularly tasks that require a higher executive function (Shield

and Dockrell, 2008, p.143), reading (Connolly *et al*, 2019, Puglisi *et al,* 2018) and maths (Brill and Wang, 2021). Caviola *et al,* (2021) concluded that maths achievement is detrimentally affected by poor listening conditions when complexity of the task and the age of the student is considered.

Prodi *et al,* (2019) and Neuman and Hochberg (1983) also determined that age plays a significant part in speech perception. Younger children are more susceptible to noise, with Klatte *et al,* (2013) finding that children are more likely to disengage from a task than adults. Neuroplasticity means that cognitive functions are still maturing, resulting in immature auditory processing capabilities for younger children. Consequently, children are more vulnerable to distraction.

2.1.5. Children in the Early Years

As children mature, the ability to discriminate speech in competing stimuli, known as the 'cocktail effect', continues to develop, until levels achieved by adults are reached during teenage years (Klatte *et al,* 2010, 2013). Until then, younger children need a higher SNR than adolescents or adults (Bradley and Sato, 2008) and find listening in noise demanding and strenuous especially if the quality of their teacher's voice is degraded (Schiller *et al,* 2020).

Long-term access to a quieter environment is essential (Bradley and Sato, 2008, Schiller *et al,* 2020, p.2115) for the development of auditory-verbal skills (Elliott, 1979, Klatte, 2010) especially as Anthony and Francis (2005, p.256) point out that the trajectory of phonological awareness continues to develop during pre-school and into the first few years at school. Unwanted noise causes additional challenges in recognising phonemes (Gheller *et al,* 2020, p.47).

Bradley (1986) suggest that children need a SNR of at least +15dB although +20dB SNR is recommended for very young children (Bradley and Sato, 2008, Mealings, 2016).

In addition, Astolfi *et al,* (2019) maintain that adverse listening conditions also impact on young learner's well-being suggesting that increased reverberation time impacts self-esteem and perception of enjoyment at school. Klatte *et al* (2010) report a correlation between higher reverberation times and increased noise annoyance

described by pupils, suggested to be induced by students' activities in a poor acoustic environment. This may be due to the listening effort being expended (Prodi *et al*, 2021).

2.1.6. Children with a hearing Loss

Children with special educational needs (SEN) and those listening to language which is different to their home language are more vulnerable to the effects of noise in the classroom (Shield and Dockrell, 2003, Dockrell and Shield, 2006, p.522). Research has shown that deaf children and young people (DCYP) are at greater risk from noise and reverberation than their hearing peers (McCreery *et al*, 2019, Picard and Bradley, 2001). This includes all levels of hearing loss; mild, moderate, severe, profound; unilateral or bilateral.

Challenges with speech perception due to more effortful attention and concentration (Gustafson *et al,* 2018), language development and poorer working memory are associated with poor acoustics even when DCYP receive suitable, and well-programmed, amplification (McCreery *et al*, 2019).

Aided speech intelligibility assessments in audiology clinic sound booths which are '*near-anechoic'* are not representative of children's speech perception in the classroom (Iglehart, 2020). Therefore, they may not represent a DCYPs' functional listening ability in everyday learning environments which are also influenced by individual development and capabilities and distance from the speech signal.

It has been recognised that DCYP, and those with other significant communication needs, require a greater SNR than children with typical hearing (Iglehart, 2020). However, DCYP often find learning in an oral environment stressful, frustrating (Zaidman and Dotan, 2017) and more tiring than hearing peers (Gustafson *et al*, 2018) even though that is the typical way of learning for the majority (CRIDE, 2021). Noisy and reverberant classrooms make speech perception challenging and additionally, peers, who speak quietly or too fast, hinder DCYPs' ability to actively participate in discussions and follow learning. In addition, DCYP report times when they have felt isolated because they were unable to hear jokes or other funny utterances said quietly in the classroom and have, therefore, felt excluded (Gustafson *et al*, 2018).

Furthermore, in addition to the one-to-two children per thousand who have a permanent childhood hearing loss (PCHL) identified following Newborn Hearing Screening (NHS, 2021), and those who are subsequently diagnosed with an acquired hearing loss, on average eight out of ten children experience an episode of otitis media (glue ear) before they are ten years old (NDCS, 2022). During the winter months, up to 30% of children experience otitis media with effusion causing a hearing loss of 12dB (Gheller *et al,* 2020), with one in five pre-school children having glue ear at any one time (NDCS, 2022). These children will also experience difficulties in listening in poor listening conditions.

2.1.7. Children with other SEN

There is a scarcity of research relating to the impact of acoustics on speech perception of children and young people (CYP) with communication needs other than hearing. Yet, Greenland and Shield, (2019) report, that when all needs are combined, 6% of CYP in mainstream education have a special hearing and communication need; Only 0.3% of these children have a hearing loss.

Kanakri *et al,* (2017) observed that CYP with neurodevelopmental and neurodivergent conditions find processing speech, in the presence of noise, challenging due to noise sensitivity and the inability to distinguish speech from noise.

Moreover, Schönweiller *et al,* (2020) state that between 0.5% and 1% of children present with functional hearing difficulties which are not representative of their hearing thresholds, described as Auditory Processing Difficulties (APD); Iglehart (2009) demonstrating that shorter reverberation times, within recommended guidelines, significantly benefit students with typical hearing levels and APD.

Furthermore, sounds with specific frequencies or intensity, may be particularly annoying and distracting to students with Autistic Spectrum Disorder (ASD), with some CYP becoming overwhelmed and physiologically stressed (Kanakri *et al,* 2017) due to acute acoustic sensitivity which severely hinders sensory processing and correlates to repetitive and/or distressing behaviours (Ueno *et al,* 2019, Kanakri *et al,* 2017). Van der Kruk *et al* (2017) claim that improving SNR for students with ASD improves their ability to learn in the classroom.

There is a distinct lack of research relating to classroom acoustics for children with a visual impairment (VI). However, the Institute of Acoustics and Association of Noise Consultants (IOA) acknowledge that pupils with speech, language and communication difficulties, VI, attention deficit hyperactivity disorders (ADHD), ASD or APD will benefit from *"favourable acoustic conditions"* (ioa, 2015, p.63).

2.2. Technology

Technology, such as a soundfield system or personal assistive listening device (ALD), is often offered as an aid to improve speech intelligibility. However, the acoustic environment in which technology is to be used should always be considered.

A soundfield system is designed to amplify the teacher's voice and deliver the speech signal consistently around the classroom regardless of where a pupil is seated (Trinite & Astolfi, 2021); Therefore, overcoming reduced signal intensity over distance and assisting teachers to reduce vocal effort. However, several studies have established that most improvement is demonstrated in better acoustic conditions (Wilson *et al,* 2011). Trinite & Astolfi (2021) maintain that a soundfield system should not be contemplated before '*establishing classrooms' acoustic parameters'.* This is particularly important for DCYP using hearing aids or cochlear implant speech processors.

Personal assistive listening devices (ALDs) also aim to improve the SNR by reducing the impact of distance, reverberation and background noise. The speech signal is transmitted directly to a receiver at the child's ear to reduce listening effort (Duarte da Cruz *et al,* 2020) for CYP with hearing and communication difficulties. However, for DCYP using hearing aids, both the transmitter microphone and the hearing aid microphones are in use. Therefore, Norrix *et al* (2016) maintain the importance of managing noise in the environment to gain maximum benefit; Furthermore, noting that ALDs often do not overcome the difficulties of speech perception during group work without the ability to use a complexity of features of the ALD.

2.3. Acoustic guidelines

The importance of beneficial classroom acoustics has been acknowledged around the world with international and national standards formulated for learning spaces. Building Bulletin 93 (2015) states the guidance for new build school buildings and classroom refurbishments in the UK, whilst in the United States, school buildings need to comply with the criteria set by the American National Standards Institute (ANSI, 2010). Other countries have used these documents as a basis for their own criteria e.g., Australia, Italy, the Netherlands and Germany.

The number of designated provisions or resource bases for deaf learners in the UK has decreased in recent years (CRIDE, 2012, 2019, 2021), with more deaf learners being educated in mainstream classrooms following the drive towards inclusive schooling. BB93 (2015) recommends lower unoccupied background noise levels and more favourable reverberation times in classrooms where DCYP, or pupils with other significant language and communication needs will be taught, for optimal speech intelligibility (Durup, 2015). Furthermore, the Institute of Acoustics and Association of Noise Consultants (IOA) recognise, that due to the number of children this could represent in a mainstream classroom, it would be reasonable to consider *"every teaching and learning space as being one where there are pupils who have special hearing requirements"* (ioa, 2015, p.63).

However, different criteria, for different types of classroom, could possibly lead to new build classrooms being built to the lesser criteria stated for a primary or secondary classroom, which subsequently do not meet the listening needs of learners with language and communication challenges.

2.3.1. Classroom Acoustic Environments in New Buildings

New schools are being built as a result of house building or the Government school rebuilding programme (Johnson, 2020). BB93 states that school senior leaders *"should anticipate the needs of deaf and other disabled children as current and future users of the school"*, thus, futureproofing school buildings for learners with SEN (2015, p.14).

Campbell *et al,* (2015, p.685) noted a push towards Thermally Activated Building Systems (TABS) for new schools, which help to reduce energy consumption by steadying the temperature in the building whilst providing thermal environmental comfort (Machner, 2015, p.2881). However, in order for this to be achieved the thermal mass of the structure is left open. BB93 guidelines were developed based on classrooms with full ceilings and before TABS were considered. Therefore, the challenge to balance acoustics, the thermal environment, air quality and lighting (Leccese *et al,* 2021) has increased. Campbell *et al,* (2015) state that acoustic considerations are vital for TABS new builds due to the potential for low frequency reverberation where a full ceiling is not being used for sound absorption. They even go as far as to say that suggested recommendations listed in BB93, which use the average values across the mid-frequencies, may not be suitable for TABS school buildings; Thus leaving some new TABS classrooms unsuitable for everyday speaking and listening activities (p.689) and severely impacting cognitive function and well-being of both staff and students (Machner, 2015, p.2881).

2.3.2. Accessibility

In the UK, the Equality Act 2010 states that schools are responsible for making '*reasonable adjustments*' to ensure that CYP are not disadvantaged by long-term disabilities. In relation to the listening environment, Robinson and Bellert (2019) remarked that although the majority of staff, in their Australian study, considered that enhanced acoustics would constructively improve pupil's ability to learn, they were unsure about how the acoustic environment could be improved. Anecdotal comments from mainstream teachers, Teachers of the Deaf and Educational Audiologists in the UK would appear to agree with this statement.

Despite many studies demonstrating the effectiveness of acoustic adaptations to classrooms with poor acoustics, there are still many children who are learning in a poor acoustic environment and report being troubled by noise in the classroom (Massonnié *et al,* 2020). Juneja (2016) suggests that this may be due to the benefits of acoustic adaptations being unforeseeable against the calculable cost of acoustic treatments, although, Klatte *et al*, (2010) note that a "*relatively small financial*

investment" may substantially affect the foundations for academic achievement and teacher and pupil well-being, resulting in long-term gains.

2.3.3. Effect of Acoustic Adaptations on Existing Classroom Environments

Several studies have demonstrated a positive impact of adapting existing acoustic environments on CYPs listening capabilities. Neuman and Hochberg (1983) experimented by adding and removing acoustic materials to a sound controlled room to measure the impact of reverberation on speech-intelligibility for a sample of twenty-five hearing children. This was not a working classroom. They concluded that reducing the reverberation time resulted in an increase in phoneme discrimination.

Peng *et al,* (2015) compared primary pupils' speech intelligibility scores before and after a classroom ceiling was lowered, with the addition of acoustic materials, together with pupil's perceptions of enhanced listening conditions; Whilst, Peng *et al,* (2020) reported on the reduction in reverberation time, an improvement in *"early-to-late sound ratio and the speech transmission index"* and an improvement in speech intelligibility following the addition of acoustic materials to the ceiling of two Chinese primary classrooms.

The Essex study (Canning *et al,* 2012) experimented with the addition of acoustic panels to refurbished secondary classrooms over a six month period. The school had a hearing resource unit and participants included seventeen students with a hearing loss. The study showed a positive impact on both staff and students in one school when classroom reverberation time was reduced.

Iglehart (2020) looked at the effect of different reverberation times on the ability of deaf pupils to perceive speech, in an experiment created by adding varying amounts of acoustic panels to a test classroom's walls, arriving at the conclusion that a reverberation time of 0.3 seconds was beneficial to deaf students.

2.4. Justification

Many classroom acoustic investigations have explored the impact of acoustic adaptations on speech intelligibility, often in controlled conditions using a test room (Neuman and Hochberg,1983) and with CYP with typical hearing. Although Peng *et*

al (2015, 2020) completed their studies in real-working classrooms, the students were from a selected age range. In the 2020 study (Peng *et al*), sixteen grade 6 pupils completed the speech intelligibility assessment element of the study before and after the acoustic adaptations. Furthermore, eighty-seven grade 3 pupils completed a questionnaire to gauge their perception of the difference in listening conditions in their classroom within two weeks of the installation of the acoustic materials. Whilst the age of the pupils was discussed, hearing status and cognitive ability was not mentioned.

Iglehart's research (2009; 2020) included deaf learners and discussed the impact of shorter reverberation times on their ability to discriminate speech but did not ask the students for their perception of the listening conditions of the classroom in the different test variables.

The Essex study included students with a hearing loss and asked staff and students to complete questionnaires in a blind study. The experiment took place in a secondary school with a hearing resource unit.

There is little research on the effect of acoustic works to mainstream primary classrooms where a child with a hearing loss is taught. Therefore, this study aims to explore the impact of acoustic adaptations on staff and deaf pupils in mainstream primary schools and add to the existing battery of information.

3. Methodology

A mixed-methods research approach was selected to explore the perception of staff and deaf pupils in mainstream primary school classrooms in one LA, before and after classrooms were adapted by fitting acoustic panels.

3.1. Design

A case study design frame was chosen since a case study aims to analyse a subject of particular interest to the researcher (Blichfeldt and Andersen, 2006) so that a greater insight into a particular issue is gained and a subject narrative provided (Thomas, 2017). For this study, the subject was acoustic measurement work undertaken and was only possible because of the continuous role of the Educational Audiologist in the LA and an established annual programme of required acoustic adaptations.

The study was completed in the context of a *"critical realist / contextualist"* ontological framework which Terry *et al* (2017, p.21) argue gathers an account of participants' lived encounters, influenced by both the participants and the researcher, so producing a "*socio-cultural*" version of experiences.

Combining methods for a case study is often needed to allow different facets of research to be answered, thoroughly investigating different questions which require different '*methodological responses'* (Thomas, 2017, p.189). Thus, this approach allows a researcher to gain rich understanding (Walliman, 2017, p.168) by using the strengths of each method to "*complement"* the limitations of another (Regnault *et al,* 2018, p.1) and counts on the inclusion of knowledge and perceptions shared by participants as "*sources of evidence*" (Blichfeldt and Andersen, 2006, p.4).

Each year, for at least the last ten years in this LA, maintained school classroom acoustic measurements have been taken by an Educational Audiologist following a request from the pupil's peripatetic QToD, as an element of support for children with a significant permanent hearing need identified as requiring regular support (NatSip, 2022). Where necessary, recommendations for adaptations to enhance listening conditions in a classroom have been made. If acoustic panels were suggested in

order to improve the acoustics of the classroom, recommendations were considered by the LA and a programme of classroom acoustic adaptations scheduled.

Under typical circumstances, adaptations were completed during the summer holidays in preparation for the children to be taught in the affected classrooms. Often, it was also before the class teacher had taught in that particular classroom.

3.2. Ethics

The initial stage of the study did not require ethical approval as it did not engage with human participants (Walliman, 2017, University of Hertfordshire, 2017). Past reports relating to classroom acoustic measurements were interrogated, with employer's permission, to establish which schools and individual classrooms had been assessed during the academic year 2020-21 in the LA and which classrooms were due to receive acoustic interventions.

Secondly, for schools included in the acoustic programme of works, the school accessibility plan, available in the public domain, was reviewed to ascertain if acoustics had been previously considered for improving access to the curriculum.

Subsequently, employer's permission was sought to retrospectively review data relating to individual deaf pupils being taught in those classrooms, which is typically accessed as part of my role as an Educational Audiologist.

Following BERA guidelines (2018), an application for ethical approval was made to the University of Hertfordshire for aspects of the study which encompassed the views of interviewees (Appendix I).

Ethics approval required contributors to interviews to give explicit consent to both participate in interviews and for information shared to be used in data collection for the study. Participant information document (EC6, Appendix II) and consent form (EC3, Appendix III) were used for this purpose. Details of the schools where teachers were employed were known due to the completion of acoustic works. However, data was anonymised.

Moreover, ethics approval stipulated that a time limit should be set for interview recordings to be deleted. This was confirmed in the participant sheet EC6.

3.3. Data collection – quantitative data

3.3.1. Reverberation time data collection

Retrospective interrogation of existing records revealed that acoustic adaptations were recommended for ten classrooms from eight different schools in 2021 with the aim of lowering the reverberation time to the average T_{mf} of 0.4 seconds recommended by BB93 (2015, p.34) for refurbished classrooms.

A Norsonic Nor-118 class 1 sound level meter was used for all measurements reported. Reverberation time was measured by 'exciting' the sound within the room by 'popping' a balloon. Bursting balloons is a traditional method used in room acoustic testing due to portability, low cost and light weight (Gomez-Agustina and Barnard, 2019, p.7082). Balloon 'pops' created a loud stimulus with *"sufficient energy at each relevant frequency"* in order to measure the time taken for the sound to decay by 60dB from when the balloon burst at each specific frequency. Within each room three measures were taken. The three reverberation time measurements were averaged to calculate the T^{mf} for each classroom.

In two schools, two classrooms had been identified in order to plan ahead for pupils transitioning through the Key Stages of learning.

3.3.2. Classroom acoustic adaptations

2021 presented a unique set of circumstances for the acoustic adaptation schedule of works. A combination of events; the impact of the ongoing COVID-19 pandemic; export/import regulation changes following BREXIT; infrastructure needs for HS2 and the Commonwealth games, led to a lack of materials so acoustic works were delayed. Therefore, unique to the acoustic programme in 2021, both children and teachers experienced listening conditions in the classrooms pre- and post-adaptations compared to mainly post-acoustic works in previous years.

Acoustic panels were installed to the ceiling, or wall and ceiling, in each room individually as represented in **Table 1**, dependent on the classroom design and reverberation times measured.

Table 1 Acoustic adaptations made to a selection of mainstream primary classrooms

Classroom	Acoustic wall panels	Adhered acoustic ceiling panels	Suspended acoustic ceiling panels
1	✓		✓
2	✓		✓
3	✓	✓	✓
4	✓	✓	✓
5		✓	
6		✓	
7	✓	✓	
8	✓	✓	
9	✓	✓	
10	✓	✓	

The non-parametric Wilcoxon Signed-Rank Test was chosen to analyse quantitative data collected for classroom reverberation times due to the small sample size and matched pair samples (Cohen *et al,* 2017).

3.3.3. Demographics and audiological data

A review of acoustic measurement reports and access requests showed that eight deaf pupils were being taught in the 2021 primary classrooms identified, all with a bilateral hearing loss. Demographics and audiological data are presented in **Table 2**.

Table 2 Demographics of eight students taught in acoustically adapted classrooms in 2021 in one Local Authority. Level of Hearing Loss as described by the British Society of Audiology (2018)

Demographic variable	Number (n)	%
Key Stage (n = 8)		
Reception	1	12.5%
Key Stage 1 (Year 1 and 2)	0	0%
Lower Key Stage 2 (Years 3 and 4)	3	37.5%
Upper Key Stage 2 (Years 5 and 6)	4	50%
Level of Hearing Loss (n = 8)		
Mild loss 20-40 dB	0	0%
Moderate loss 41-70 dB	2	25%
Severe loss 71-95 dB	0	0%
Profound loss >95 dB	5	62.5%
High Frequency hearing loss	1	12.5%
Hearing Equipment (n = 8, all bilateral)		
Hearing aids	2	25%
Cochlear Implant Speech Processors	5	62.5%
Bone Anchored Hearing Device	1	12.5%
Assistive Listening Device (Phonak Roger radio aid system or Oticon Edumic)	8	100%

3.3.4. L.I.F.E.-R questionnaires

The advantage of a case study is that it is accepted that reflection during each stage of the research may lead to questions being modified in order to explore new avenues of investigation that arise during the inquiry (Diefenbach, 2008).

Due to the delayed completion of the acoustic programme of works, a decision was made to retrospectively review the Listening Inventories for Education - Revised (L.I.F.E.-R) questionnaires for the eight deaf pupils completed as part of the ongoing support from their QToD to gain the perspective of the pupils.

The L.I.F.E. resource was originally developed in 1998 (Anderson and Smaldino, 1998) and is widely used by QToDs to gain individual student's perceptions of their ability to listen in different scenarios at school. The original questionnaire was used as a basis for a UK version to better reflect the learning environment for pupil's in the UK. LIFE-UK was found to be a reliable tool for identifying challenging listening

conditions and measuring the impact of specific interventions aimed at improving the listening environment including classroom acoustic modifications (Canning, 1998).

In 2012, the L.I.F.E. tool was revised to acknowledge changes in the learning environment. L.I.F.E.-R (Anderson *et al,* 2012) benefits from photographs of generalised scenarios and can be completed either online or using a paper-based version. The questionnaire is easy and quick to administer and also serves as a prompt for further discussion and a foundation for coaching pupils and teachers.

Haigh (2014) and Nelson *et al,* (2020) found that the L.I.F.E.-R is a reliable tool for gathering pupils' views of functional hearing.

L.I.F.E.-R questionnaires are routinely used by QToDs in this peripatetic service. L.I.F.E.-R questionnaires had been completed with the deaf children and their class teacher in the first half of the Autumn term before the acoustic boards were installed. Each pupil had individually completed a L.I.F.E.-R questionnaire, with a QToD or Educational Audiologist familiar to them, as part of the usual support, to assess pupil perception on how well they could hear and understand following transition to a new year group and a different classroom in September 2021.

As illustrated in Table 1, all pupils had access to an ALD from the beginning of the academic year which consisted of either a Phonak Roger transmitter and receivers or an Oticon Edumic, dependent on the make and model of hearing aids. Checks confirmed that no changes were made to any of the pupil's hearing equipment during the period of the study.

The L.I.F.E.-R questionnaire has a total of 15 questions. Questions 1-10 relate to classroom listening situations whilst 11-15 relate to listening in more social situations such as group work, assembly, P.E, talking with friends on the way to the classroom or in the dining room at lunchtime. For this study scenarios 11-15 were not relevant and therefore, only data from questions 1-10 was examined.

The Likert scale point values 0, 2, 5, 7 and 10 were used to rate how well each pupil felt they could listen and understand in different listening scenarios within the classroom; 0 representing always difficult, 2 – mostly difficult, 5 – sometimes difficult, 7 - mostly easy and 10 signifying that it was always easy to hear and understand in a particular situation. A Likert scale is often used where a person's opinion or

viewpoint is being measured (Thomas, 2017) and therefore, is relevant to a questionnaire relating to an individual's opinion of listening capability.

Scenarios 1-10 epitomise ten general classroom listening situations; Scenario 1) listening when the classroom is quiet and the teacher is standing at the front, 2) the teacher has turned away, 3) the teacher is moving around whilst talking, 4) Peers respond to a question, 5) Listening to instructions for a task, 6) other pupils are making a noise inside the classroom, 7) there is noise outside the classroom, 8) listening to multimedia, 9) noise from equipment e.g. heater, fan, projector inside the classroom and 10) two teachers simultaneously talking, one with the main group of students and another with a small group.

A second L.I.F.E.-R questionnaire was completed after each classroom was acoustically adapted, allowing sufficient time for pupils to forget what it was like to listen in the classroom before the works so that they answered the questionnaire with the perception of listening in the modified classroom. The questionnaires were completed during a visit from the pupil's usual QToD. This meant that multiple QToDs were involved in the completion of the L.I.F.E.-R questionnaires adding to the validity of the data.

Again, the non-parametric Wilcoxon Signed-Rank Test was considered to analyse quantitative data from L.I.F.E.-R questionnaires due to the small sample size and matched pair samples. However, the smaller L.I.F.E.-R sample size was insufficient for the Wilcoxon Signed-Rank test distribution of the Wilcoxon *W* statistic to form a normal distribution. Therefore, it was not possible to calculate an accurate *p*-value or a critical value for *W* for the L.I.F.E.-R data collected.

3.4. Data collection - Qualitative data

In order to add breadth and depth to the information gathered from the questionnaires, semi-structured interviews with class teachers were scheduled. Interviews fitted with the time allowance for this study as interviews are usually short in nature and not longitudinal.

A benefit of semi-structured interviews is that key themes can be focused upon using pre-determined questions but the interviewer is also free to scaffold the discussion

by probing (Thomas, 2017; Tracey, 2019); encouraging the interviewee to provide further information, opinions and thoughts linked to a particular response or focus, or by asking additional questions.

In addition, responses provided the opportunity to corroborate similarities identified from the interviewee perspective with 1) those of deaf pupils from the L.I.F.E.-R questionnaires and 2) changes in classroom reverberation times following acoustic adaptations, triangulating data (Tracey, 2019) to improve the reliability of results (Bowen, 2009).

3.4.1. Interview participants and recruitment

All participants approached were teachers with experience of teaching in the identified classrooms pre and post acoustic adaptations. No minors were asked to participate in interviews. The participant sample was a non-probability *"convenience sample"* (Jager *et al,* 2017, p.13, Thomas, 2017) due to their link with the classrooms modified in 2021. Limited generalisation is noted as a trade-off for accessibility to the participants.

3.4.2. Semi-structured interviews

Due to the ongoing COVID-19 pandemic and the fluctuating nature of the guidelines for face-to-face visits to schools, a remote interview schedule was proposed. As the number of participants was relatively small, a focus group was considered. However, Hensen *et al* (2021), point out that it is difficult to maintain anonymity online. Furthermore, Thomas (2017, p.212) suggests that respondents often act differently in a group. Responses may be affected by the dominance of one or two parties (Thomas, 2017; Atkins & Wallace, 2012) and, therefore, results may be skewed. Moreover, Thomas (2017, p.212) identified that "*risky shift phenomenon"* may lead to bolder responses being given in a group situation when compared to responses given when informants are interviewed individually. Focus groups may be more suited to research where group responses to a situation are sought (Tracey, 2019) whereas individual opinions were required for this study.

Subsequently, telephone vs online meeting was considered. Telephone interviews were dismissed as the absence of face-to-face interaction may negatively impact rapport building between interviewee and interviewer making the meeting impersonal which could result in data with less depth. In addition, evidence from subtle changes in body language and facial expressions can be lost as well as the potential for the spoken data to be distorted and information missed or misinterpreted (Irvine *et al,* 2012; Thomas, 2017, Hensen *et al,* 2021).

Therefore, one-to-one synchronous (real-time) online interviews were scheduled (Janghorban *et al,* 2014).

During the COVID-19 pandemic, teachers have become used to using online platforms for both formal and informal purposes, therefore, alleviating concerns relating to digital literacy and knowledge of online communication (Janghorban *et al*, 2014). One-to-one virtual meetings assisted rapport building as the participant could see the interviewer and it was possible to put the interviewee at ease by responding to them and their surroundings and presenting as a fellow teacher (Thomas, 2017) although camera angle obscured observations of full body language (Janghorban *et al*, 2014).

As a 'before' and 'after' interview were completed, the established rapport from the first meeting assisted the experience of the second interview as the participant had already met the researcher and a relationship had previously developed. This helped to put participants at ease. The purpose of the meeting was reiterated at the start of the second consultation.

Furthermore, a convenient time (Janghorban *et al*, 2014) could be agreed with the participant almost assuring a response (Thomas, 2017, p.202). Some participants chose before school, some after school and some during the school day during non-contact time. In addition, where technology allowed, the participant also had the opportunity to join the meeting from their own home although no requests of this nature were made.

MS Teams was used as a platform. It was possible to record the meetings with the permission of both parties. Advantages for recording the interview included time-efficiency as limited notes needed to be made which also assisted the flow of the

interview. In addition, a feature of MS Teams meant that recorded interviews were transcribed automatically.

Post adaption interviews were completed after at least six weeks following completion. This timing meant that teachers remembered what it was like to teach in the classroom before the work was completed but allowed sufficient time to observe and compare children's behaviours after acoustic changes.

Pre-determined questions were drawn up for both the pre-acoustic work interview schedule (Appendix IV) and the post-acoustic work interview schedule (Appendix V) based initially on ad hoc comments noted in existing records following previous years' acoustic programme of works.

If time had allowed, observations could have added an extra layer of data. An observer would have had the advantage of having the sole purpose of observing behaviours in the classroom pre and post works whereas the teacher's focus included the lesson objectives. However, the disadvantage for an observer would have been short observation times whereas a teacher is focusing on pupils for the majority of the day and also has the advantage of having built a relationship with children over time.

3.5. Data Analysis

3.5.1. Quantitative Data Analysis

Classroom acoustic measurement reports were interrogated to identify the initial average mid-frequency reverberation times (T_{mf}) measured in each classroom and then compared with T_{mf} measurements taken following installation of acoustic panels (Table 1). The difference the acoustic panels had made to the average mid-frequency reverberation time in each classroom was established.

Pupils overall response scores to scenarios 1-10 of the L.I.F.E.-R questionnaires before the classrooms were modified were compared with the overall response scores after installation of the acoustic boards. The data was then further compared by analysing data from each of the ten scenarios independently.

3.5.2. Qualitative Data Analysis

The transcript of each interview provided on MS Teams was checked for accuracy and corrected where necessary. Identifying data was anonymised.

Thematic analysis using the constant comparative method was used to identify emerging key themes embedded in data (Fram, 2013) from both sets of interviews, 'pre' and 'post' acoustic adaptations. Initial codes used were linked to the themes identified from previous ad hoc comments. Each interview transcription was read and key points assigned a code. The transcripts were repeatedly read and data compared (Boeije, 2002) by testing, summarising and applying coding to identify common themes (Fereday & Muir-Cochrane, 2006). Mapping was used to interpret how themes were interrelated using '*theme mapping'* (Thomas, 2017, p.246).

Auld *et al,* (2007) found that smaller data sets are often more efficiently analysed by hand. Therefore, coding and mapping were completed by hand rather than using software such as NVivo. Study limitations of time and cost meant that only one researcher decided on the relevance of data and coding weight and therefore, interpretation is subjective to the researcher.

3.6. Reflexivity

A weakness to research is the researcher's influence on the study design, methodological approach and data collection, analysis and interpretation (Diefenbach, 2008). Qualitative research involving a subject of interest to the researcher is particularly vulnerable to bias (Diefenbach, 2008). Therefore, I acknowledge that due to my role as Educational Audiologist, and my interest in classroom acoustics and CYPs' access to good listening conditions, this study may have been unwittingly subject to an unconscious bias.

4. Results

This study sought to explore the effect of classroom acoustics on learners and teaching staff. It considered the impact of classroom acoustic measurement reports, recommendations made and the completion of subsequent classroom acoustic adaptations which aimed to improve the acoustic environment for all classroom users.

Accessibility plans, for the eight schools identified from the 2021 acoustic adaptation programme of works, revealed that one school had specifically considered classroom acoustics when planning for pupil's access to the curriculum. One further school had recorded that acoustic panels had been fitted to four classrooms, however, further consideration to classroom acoustics in other areas of the school had not been documented. Three accessibility plans mentioned the availability of a 'Reasonable Adjustments' checklist for teachers to use within the classroom and one school stated that 'reasonable' changes to the school environment would be made to enable access to the curriculum. Nevertheless, classroom acoustics were not specifically acknowledged in six Accessibility plans.

4.1. Classroom Reverberation

Figure 1 summarises the reverberation time recorded in 2021 in the ten mainstream primary classrooms before and after acoustic panels were fitted to the classroom ceiling, or walls and ceiling as required .

Before the acoustic adaptations, all of the classrooms recorded T_{mf} which was longer than the 0.4 second recommendation in BB93 (2015, p.34) for a refurbished learning space where children with a significant hearing or communication need is taught.

Following the addition of the acoustic materials the average T_{mf} measured in each classroom was ≤0.4 seconds, demonstrating compliance with BB93 and the effectiveness of the acoustic panels.

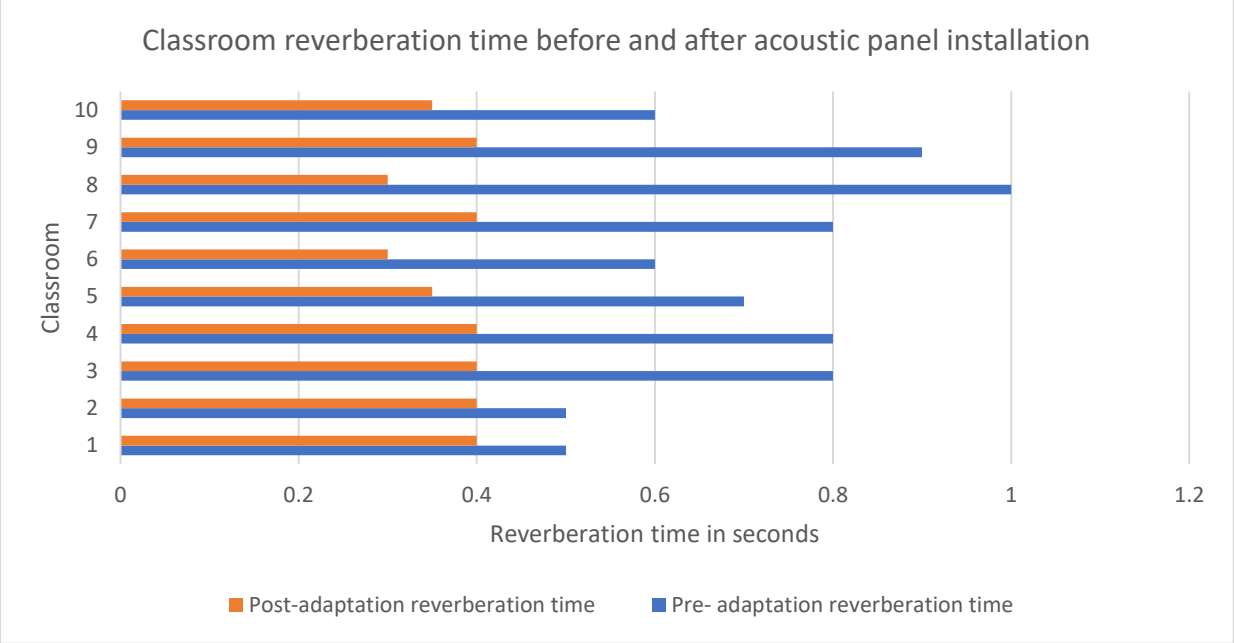

Figure 1 The average T_{mf} reverberation times recorded in ten classrooms before and after acoustic panels were installed to the ceiling, or walls and ceiling.

Results of the Wilcoxon Signed-Rank Test comparing the T_{mf} before and after the acoustic panels were installed showed the test statistic *W* is 0. The critical value for *W* at N=10 (p<.05) is 8. The null hypothesis is rejected because 0<8. Therefore, the result is significant at p<.05 demonstrating that the installation of acoustic panels had a significant impact on the reduction of classroom reverberation times.

4.2. L.I.F.E.-R Questionnaire - pupils

By interrogating records, results from L.I.F.E.-R questionnaires completed by five pupils, before and after installation of acoustic panels, were analysed. Pupils in Key Stage 2 and above are suggested (Anderson *et al,* 2012) to have the potential capacity to competently provide reliable answers regarding their own personal perceptions and, therefore, a L.I.F.E.-R self-report of listening ability had not been completed with one younger child. Furthermore, another pupil had been unable to complete the questionnaire due to COVID related guidelines affecting school visits and one L.I.F.E.-R questionnaire was discounted as the radio aid had not been used consistently in the first half of the Autumn term. Continuous use of the radio aid post-acoustic works meant an additional variable, raising the possibility that data specifically looking at the impact of the installation of the acoustic panels could be

distorted. Data from five pupil's L.I.F.E.-R questionnaires completed before the adaptations and five completed afterwards remained for analysis.

Using a ten-point Likert scale, the L.I.F.E.-R mean total classroom listening score did show a correlation between the acoustic adaptations and pupils self-reported perception of ease of listening in the classrooms. The mean classroom listening score before the acoustic works took place was 62.8 compared to 74.4 after the acoustic works; the higher value showing that deaf pupils perceived that it was easier to hear and understand what was being said after the acoustic panels were installed.

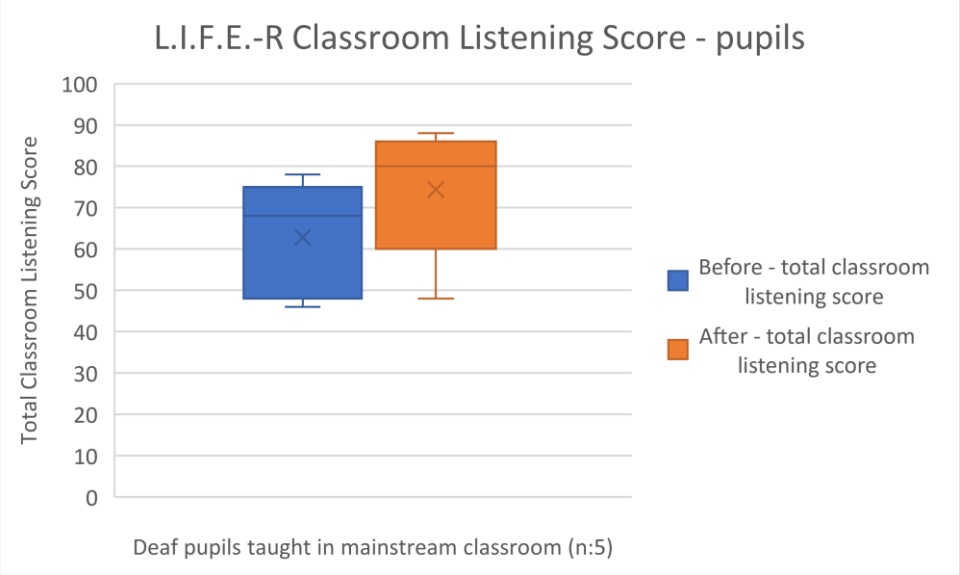

Figure 2 Total L.I.F.E.-R classroom listening scores from five deaf pupils taught in a mainstream classroom before and after acoustic panels were installed. X marks the mean total score and the coloured boxes show the second and third quartiles. The lower and upper stem designates the minimum and maximum values.

The mean score for functional listening in a classroom environment, based on the ten presented scenarios (Sc1 – Sc10) and a ten-point Likert scale, before acoustic adaptations was 6.28. This is consistent with the findings of Nelson *et al,* (2020) who reported an average of 6.0 although, considerable differences when comparing studies must be noted such as the much larger sample size in the Nelson *et al* study, a greater participant age range, and information relating to classroom acoustic measurements being unavailable.

The data relating to the ten classroom listening scenarios was then interrogated to establish how well children sensed that they could hear and understand in different

situations in sub-optimal listening conditions compared with the improved listening conditions in the modified classrooms.

Figure 3 shows pupil's responses given for each of the ten classroom listening conditions before and after the acoustic panels were added.

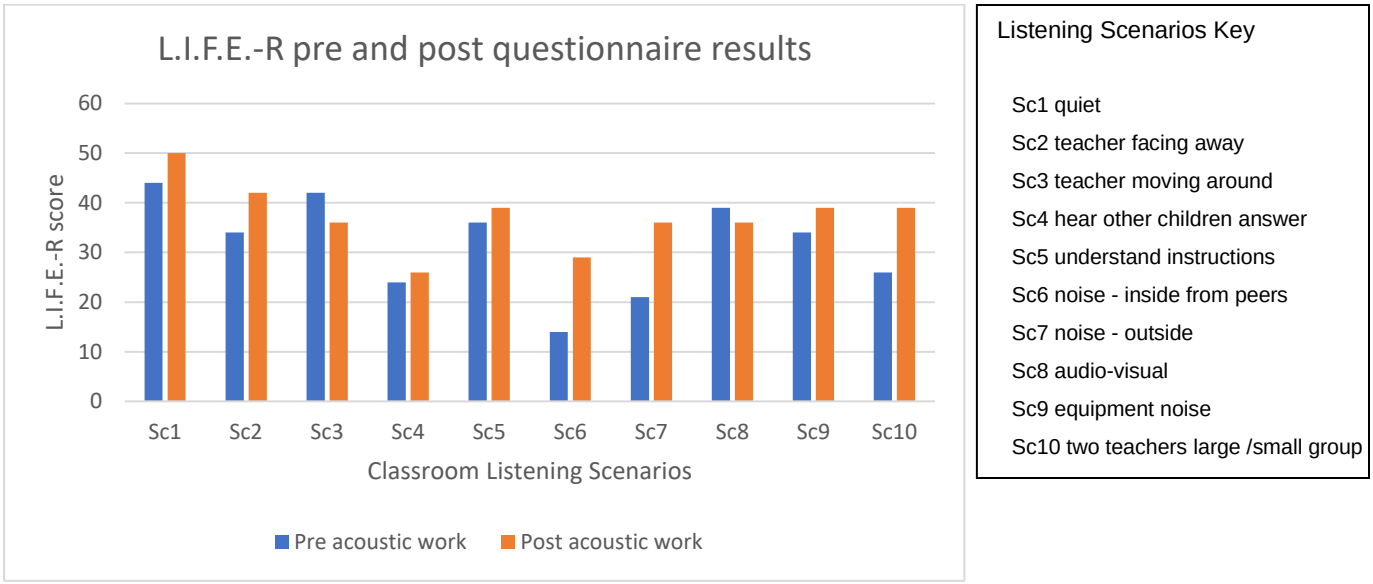

Figure 3 L.I.F.E.-R scores for ten classroom listening scenarios from five deaf pupils before and after classroom acoustic adaptations

Consequently, the data was ordered, starting with the situation in which pupils reported it was easiest to hear and comprehend in the classroom down to the situation which presented the most challenging listening conditions.

Figure 4 shows the ten scenarios in order of how well the hearing impaired pupils perceived ease of listening before the acoustic panels were fitted. Scenario 1, SC1 – listening to the teacher when the classroom was quiet and all students were listening to the teacher talking from the front of the classroom, was perceived to be the easiest condition in which to listen while scenario 6, SC6 - listening to the teacher in the classroom when other pupils were whispering, talking or making a noise with equipment or their feet, was perceived to be the most difficult environment in which to hear and understand the teacher.

Figure 5 shows the pupil's responses to questions relating to the ten different listening situations after the acoustic panels had been fitted in order of how well the pupils perceived they could hear and understand.

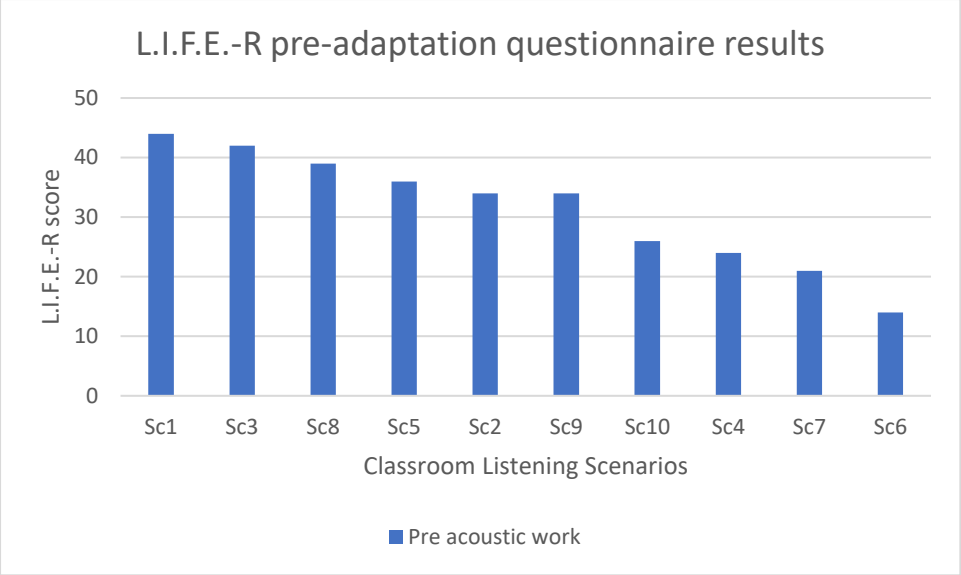

Figure 4 Total L.I.F.E.-R score for 5 pupils in ten different listening conditions in order of ease of listening pre-acoustic classroom adaptation

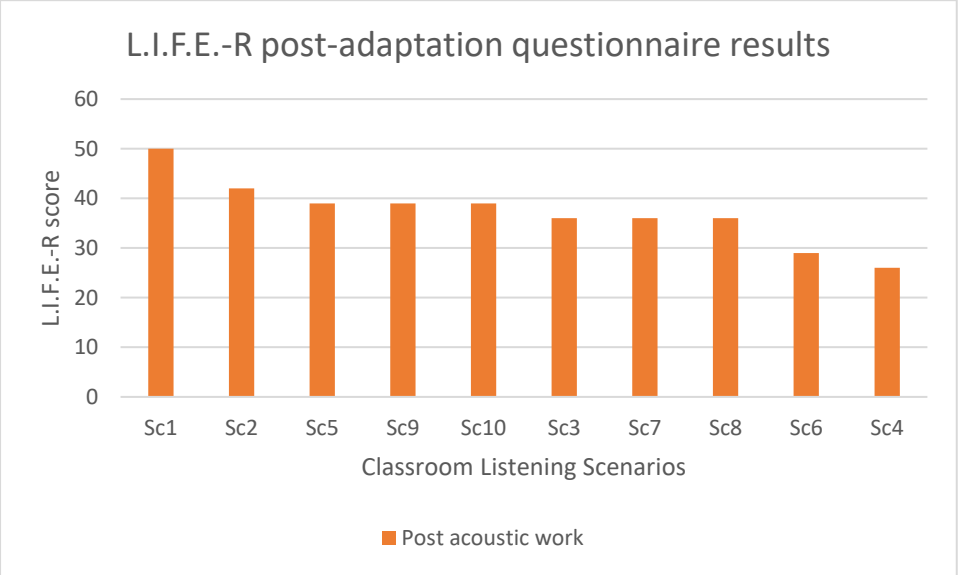

Figure 5 Total L.I.F.E.-R score for 5 pupils in ten different listening conditions in order of ease of listening post-acoustic classroom adaptation

The pupils reported that the best situation in which to listen and understand their teacher was when the classroom was quiet (Sc1), both before and after the acoustic panels were installed.

In sub-optimal acoustic conditions, responses revealed that deaf pupils perceived that it was much more difficult to listen and understand when there was noise; noise inside the classroom made by other children talking quietly, shuffling their feet or moving objects (Sc6), noise outside the classroom in the corridor, on the playground

or field or traffic (Sc7) or noise because two teachers were talking simultaneously e.g., the teacher talking to a large group and a teaching assistant to a small group (Sc10).

However, these scenarios also presented the greatest perceived improvement once the acoustic panels were fitted as shown in Figure 3. The responses given when noise was being generated by peers inside the classroom, before the acoustic work, gave a total combined score of 15 whereas after the acoustic panels were fitted the total combined score for this situation increased to 29. Answers for listening when there was noise outside the classroom moved from a total combined score for this group of pupils of 21 to 36, whilst the ease of being able to hear the teacher well and understand what was being said when another adult was also directing children in the classroom shifted from a total combined response score of 26 to 39.

Although the ability to hear other pupil's responses (Sc4) improved slightly once the reverberation time improved, from an overall score of 24 to 26, this was a small shift and pupils still reported that it was difficult to hear their peers across the classroom.

4.3. Participants' perceptions of the pre-acoustic work classroom environment

Participants were asked for their opinions about the classroom listening environment during semi-structured interviews recorded before and after their classroom's acoustic refurbishment. Thematic analysis of participants' responses presented commonalities and coding revealed key themes.

Pre-acoustic work interview themes identified were:

- **Theme 1** - Factors affecting the ability to hear in the classroom
- **Theme 2** - Managing the impact of the acoustic environment
- **Theme 3** - The effect of current classroom acoustics on pupils and staff in the classroom
- **Theme 4** - Knowledge of classroom acoustics

4.3.1. Theme 1 - Factors affecting the ability to hear in the classroom

One overarching point participants mentioned was that every classroom, year group, cohort and individual pupil is different and, therefore, as a professional educator, participants monitor the ability to hear in each classroom and manage variables.

Factors affecting the ability to hear in the classroom included the classroom construction and design, location of the classroom and proximity and type of outside noise, including increased noise from outside the classroom due to changes linked to COVID-19 guidelines, and teacher's own hearing thresholds.

4.3.1.1. Classroom buildings

The building design was thought to be significant when talking about the classroom acoustics. The age of the school buildings was discussed in both positive and negative terms in relation to the sound climate of a classroom and the shape and height of the ceiling and equipment inside the room was noted to affect the acoustics.

Table 3 Participants' quotes taken from semi-structured interviews pre-acoustic modifications relating to the construction of classroom buildings

Participant	Comment
Participant 6	*"That's the part of the problem you've got. The age of the building, the construction of the building, and it's got to be knocking on 70 years old…..Then there are a couple of inspection covers along that corridor and the one nearest to me does make a clunk as you go over it, it seems to rock"* *"The ceiling is high, it's got to be, I would guess, getting on 3 metres"*
Participant 9	*"It's got a high ceiling, almost like an apex ceiling, …. With a couple of Velux kind of windows, so it does feel nice and spacious, but I suppose it's not particularly good for sound, like, the acoustics are great if you wanted to sing and things like that, but probably….the sound might actually be bad"*
Participant 5	*"it's quite a new building ….they already had slots in for the acoustics from when they built it and the only thing that we've got that's a bit of an issue with noise is we've got these massive vents in the ceiling and then there's two at the side as well and we have to keep the vents open because of COVID, and so, if there's anything going on outside you get that noise coming in and similarly the one that's on the roof we don't have much control of"*
Participant 4	(Noise inside the classroom) *"when the heating system's on there would be noise from the radiator. It's an air blowing one and there is some element of white noise. I would suggest* (noise) *from the strip lighting and from the projector. There is definitely noise from that and the speakers, when you're plugging in the plug-in speakers in and out of the port."*

4.3.1.2. Outside noise and the impact of COVID-19

Noise from outside was noted to affect both children's and adults ability to listen and attend in the classroom.

Table 4 Participants' quotes taken from semi-structured interviews pre-acoustic modifications considering outside noise disturbance

Participant	**Comment**
Participant 3	*"every Wednesday we have the grass cut, so I know that's a big one... That's a good hour and a half where I know the volume is quite loud from outside. I know that can have an impact on the overall concentration and what people can hear"*
Participant 6	*"we do hear traffic noise … and particularly if we've got some ambulances and whatnot going by, as the (road) is the direct route to A&E."*
Participant 9	*"so one half of our classroom opens out onto the field so at times there will be children walking past to the playground or playing on the field 'cause we also have split break times…. So there's sometimes some outside noise and PE"*
Participant 8	(noise from outside) *"Yeah, another class. Yes, I'll try and make sure that the windows on that side of the building are closed so that it's less noisy inside the classroom."*
Participant 4	*"the to-ing and fro-ing of people going passed outside, I do quite often close the classroom door just to block out the distraction of that noise"*
Participant 7	*"I think we all get used to the fact that the road is quite close …."*

Unique to the current pandemic, the effect of outside noise on the ability to hear in a classroom environment, for both staff and pupils, had been exacerbated by guidelines required to reduce the spread of COVID-19 through classroom ventilation.

Table 5 Participants' quotes taken from semi-structured interviews pre-acoustic modifications noting the increase of outside noise nuisance following guidelines aimed at to reducing the spread of COVID

Participant	Comment
Participant 7	*"There is more noise ..than there normally would, because obviously we've got to keep the windows open all the time because of COVID."*
Participant 3	*"If, for example, we've run over at all at breaktime and lunchtime and we just need to stay in a bit, an extra 2 minutes or something, no chance really, because the windows are open, people screaming, there's shouting so yeah, it's a bit of a tricky one"*
Participant 9	*"we are supposed to keep the doors open at the moment because of keeping the air circulating, but outside are the toilets, and they have hand dryers and they are a pain in the neck for all of us"*
Participant 4	(Noise generated from other classes outside on the playground or Astroturf) *"which is not helped by the fact we're having staggered break times at the moment* (because of COVID guidelines)

4.3.1.3. Hearing status

Several participants proposed that their own hearing might affect how well they could hear the children's responses when teaching in their classroom, both positively and negatively.

Table 6 Participants' quotes taken from pre-acoustic modification semi-structured interviews considering teacher's own hearing thresholds

Participant	Comment
Participant 4	*"it's those ones who were just very softly spoken who would talk like this (whisper) and then you have to encourage them to speak up.. I do ask them to repeat it and use a louder voice or say because I'm getting older, my hearing's going"*
Participant 6	*"I've found it difficult over the last couple of years to hear everything that children are saying... That could be a combination of the fact that the children have got a quiet and quite high pitched voice….also I think I might need to get hearing check myself."*
Participant 8	*"Well, I probably do find that quite difficult, and as I get older I do know that that is going to be more difficult for me. I think my …'s got a hearing loss and has had for many years and I yeah I think I do lip read more than I necessarily did, you know. I think masks highlighted this"*
Participant 5	*"I'm quite blessed in that my hearing is very good, so I don't struggle so much. But I have had times whenever children have been really quiet and they've been at the back, it's been like, sorry, just say that again for me"*
Participant 3	*"if everyone else is silent, it's easier* (to hear)*, but if there's a little bit of a murmuring, then it can be a little bit trickier"*

4.3.2. Theme 2 – Managing the impact of the acoustic environment

As all the participants were classroom teachers, responses mentioned how participants adapt their teaching style and practice to the environment and to the cohort of the children being taught whilst also taking the curriculum into consideration.

4.3.2.1. Classroom management

Some teachers noted consciously reflecting on their own classroom practice and adapting their classroom management according to the design of the classroom and the pupils within it.

Table 7 Participants' quotes taken from semi-structured interviews pre-acoustic modifications discussing teacher's classroom management practice

Participant	Comment
Participant 7	*"I think as a teacher you just get used to working in different rooms. You know some have got higher ceilings than others and it's not normally a problem, it's just thinking about occasionally where you place yourself next to the children and that's more the case….. so that you know where to position yourself and how to alter the children's tables for when they're working ….I think you just naturally adapt so you work how you have to so the children can hear you"*
Participant 3	*"I would say most of the time it's relatively quiet and I think there's times where it does get louder. But then I suppose it's managing that and making sure everyone's being aware about being considerate to other people that are around them"*

4.3.2.2. Classroom activities

Participants also noted that they were aware that the curriculum, and certain types of activities in which the pupils were engaged in, affected the noise levels in the classroom and they described how they might adapt the environment in order to control the volume.

Table 8 Participants' quotes taken from pre-acoustic modifications semi-structured interview transcripts describing how listening ability in the classroom is affected by the activities in the classroom

Participant	Comment
Participant 8 (Reception)	*"it can be quite noisy when we are accessing our continuous provision, we try and use our outdoor space quite a lot so that we get some children outside, which makes inside much quieter…"* (When teaching a small group) *"Yeah, it's quite challenging. In an ideal world, we go and use a different room or take them into the corridor or somewhere"*
Participant 7 (Lower KS2)	*"yesterday, we were doing DT and they were all engaged in, you know, cutting and making and putting things together. Yeah, noisy, you expect it because they're all eager and keen, whereas, if we're doing something like, you know, some writing and they've got to focus, then I expect it much quieter"*
Participant 4 (Lower KS2)	*"there's always times when you do have to remind them to come back down to being quiet ….. probably the time where you most have to remind them to bring the level of noise down is when they get out the base 10 equipment in maths because of the clattering of the 10s rods and things like that. So from that point of view, yeah, the noise would creep up and they're obviously compensating for the fact that they're using it by bringing the level of their voices up"*
Participant 3 (Upper KS2)	*"if it's getting a little bit too noisy and there's a few children that like to have a bit quieter when they're writing, so we let them have a go outside* (desks in a separate area) *and have a bit more peace and quiet"*

4.3.2.3. Voice pitch, projection and articulation

In addition, participants described how pupils are encouraged to talk clearly and confidently and at level and clarity that both their peers and their teachers can hear and understand.

Table 9 Quotes taken from pre-acoustic modification semi-structured interviews discussing how participants encourage pupils to use a clear and articulate voice when speaking so that others can hear clearly in the classroom

Participant	Comment
Participant 4	*"If children are giving answers to things, I'm repeating them….. to make sure that everybody has understood it and heard it because some of the children do tend to mutter and it's always, could you please enunciate to the back row"*
Participant 9	*"They do have to be encouraged to project a little bit, but they don't have to speak particularly loudly for me to be able to hear them."*
Participant 6	*"I don't think some of them speak very clearly. I don't think they intonate very well"*

4.3.3. Theme 3 – The effect of current classroom acoustics on pupils and staff in the classroom

Participants were asked to think about children and staff working in the listening conditions of the classroom suggesting that differences in the cohorts of pupils and individual pupil's SEN played a part.

4.3.3.1. Cohort

Variances in different cohorts of children was suggested to affect children's perceptions of listening conditions in the classroom and to how their behaviour might change accordingly. The behaviour of the cohort and the knock-on effect on the listening environment was then suggested to impact on teaching staff.

Table 10 Quotes taken from pre-acoustic modification semi-structured interviews relating to how different pupils react differently to the listening environment

Participant	Comment
Participant 7	*"I think that's very individual, isn't it because some children cope with noise and you know they're used to a noisy environment at home and others you know have a very quiet home. Then the noise of 30 children their classroom has more impact on them."*
Participant 9	*"I think because the nature of this particular class, there isn't a negative impact, but I could well imagine that if you did have, and I have been in other classrooms in school with other children, that it could be unpleasant. It could interfere."*
Participant 8	*"there are some classes that are noisier than others. I know my colleague would have come in with my last cohort and said, Oh my word they're noisy and they've gone up to year one now and they still say, Oh my word, they're noisy!"*
Participant 4	*"of all classes I've had in that room, these are the quietest children and so actually stress or tiredness from them making too much noise isn't really an issue…. whereas last year I would have said the complete opposite"*

Several participants also reflected that the listening conditions might impact on different pupils in different ways depending on their individual needs.

Table 11 Quotes taken from pre-acoustic modification semi-structured interviews discussing how participants take into consideration the individualities of different cohorts as well as pupil's individual needs

Participant	Comment
Participant 6	*"So I think people are used to it being a bit bouncy and echoey in here, and it's just how it is … The ones who are sensitive, who struggle to maintain calm during ordinary working atmosphere.. we've got a couple of boys in this class who have ear defenders, so when it gets too much.. I think sometimes, one of them uses his ear defenders more than the other, uses it for his own peace and quiet for concentrating rather than because it's too noisy, I think he's recognized himself that he works better."*
Participant 5	(In my first class) "*she had a series of having like grommets and stuff in her ears and all that and she had a 1:1 so it was a little bit different. She had somebody to like relay the information and stuff but I've also had like people like autistic children who if it gets too noisy might have found it difficult and I think I've only ever had like one instance where I've had to remove somebody"*
Participant 9	*"we've found that the boy who is sensitive to sound, even when it is a very low mumble, he can put his hands over his ears"*

4.3.4. Theme 4 - Knowledge of classroom acoustics

Several of the participants said they did not know much about classroom acoustics. However, through discussion, comments were made that demonstrated that they were aware of classroom management practice techniques employed to keep background noise to a minimum, as discussed in 4.4.2, and small changes that could be made to improve sound adsorption in the classroom.

At least one participant had prior knowledge of classroom refurbishment that had positively affected the listening environment of the classroom.

Table 12 Quotes taken from pre-acoustic modification semi-structured interviews discussing participants' knowledge of classroom acoustics

Participant	Comment
Participant 7	"*We've got double glazing* (relating to traffic noise)…*the reception room years ago used to have really high ceilings and.. your noise level was always much higher from the children… and it sort of vibrated around and .. the children did struggle to hear.. there was a difference when we altered the ceiling height.. for the children's learning and the noise level that they created..so that just tells you that acoustics are really important and how they can influence"*
Participant 4	"*don't know a huge amount, but my understanding would be that somebody like (deaf pupil) or people with harder hearing would need to be closer to me, obviously to hear me more clearly… I'd be quite interested actually to see if I notice any changes …I've been in sound deadened rooms before.. I did a music degree and practice rooms are obviously sound deadened so you couldn't hear other people and so I'll be interested to see how it (acoustic modifications) impacts on us and what's being done."*
Participant 6	*"certainly the general bounciness in the room doesn't help. I mean I'm sitting here and there's only me in it and again in actual fact bodies absorb, don't they ,so me on my own, it is loud to me. I find the classroom echoey. There are a lot of hard surfaces. We've got… blackout blinds .. they're plastic roller blinds"*
Participant 5	*"people, they might miss information, might not fully hear what there's been ..might just hear parts of it and equally.., if they are working in a group and they can't hear one another or it's like noises bouncing off X,Y and Z and echoing .. it's difficult for them to maybe concentrate as well …. in terms of being comfortable"*

4.4. Participants' perceptions of the post-acoustic work classroom environment

Participants agreed to meet again for a further semi-structured interview after their classrooms had been modified, by the installation of acoustic panels, in order to discuss any differences they noticed. Thematic analysis of post-acoustic work transcriptions identified the following themes:

- **Post-modification Theme 1 –** Changes to the classroom environment
- **Post-modification Theme 2 –** Changes in children's behaviours in the classroom
- **Post-modification Theme 3 –** Changes to teacher's behaviours in the classroom

4.4.1. Post Theme 1 - Changes to classroom listening environment

Following the installation of the acoustic panels, participants discussed their thoughts and opinions about perceived changes in the classroom listening environment. Some teachers had noticed a significant difference in the way the classroom sounded and also how the feel of the classroom had changed.

Table 13 Participants quotes taken from post-acoustic adaptation semi-structured interviews considering changes to the classroom listening environment

Participant	Comment
Participant 8	*"it's amazing the difference…When we walked in, the first time, it just was very different acoustically..It's really interesting …because the noise levels have changed…sometimes they are quieter. Sometimes you can walk in and think, Wow, it's really calm and quiet in here, whereas before it probably wasn't ever calm.*"
Participant 7	*"The whole room feels….it sounds silly, but when you walked in that first day … it was like a feeling…. It seems to have lost the high pitchiness of the children when they're talking….I know the children are not talking any differently. It's just the fact that obviously the sounds aren't echoing around the room"*
Participant 6	*"It's certainly dampened everything down and I think it makes you feel like the children are less noisy…..I'm constantly turning the volume down… the noise doesn't seem to bounce around so much… We're definitely not as tinny….other people have commented how it's easier to get your message across, to hear the message coming back, to hear messages that shouldn't be heard in the general hubbub, particularly when you've got everybody tidying up at the same time so you've got a lot of plastic clattering and so on, that's better"*
Participant 2	*"so when I came in that first week, I was like hang on a minute I'm not echoing… It's a lot calmer..I like to have a calm environment but with the obvious bouncing, then the children's* (voices) *bouncing as well..it just made me seem like I was trying to raise my voice but I wasn't …. My class is calm, like I want it to be now."*
Participant 4	*"you've lost that slight echo.., it's dampening down the sound in the classroom …. it's definitely blocking out those additional sounds that were there before"*
Participant 1	*"I think the main difference I noticed was the dampening difference ..when I walked into the classroom for the first time, I could immediately feel the change in the acoustics without even speaking…footfall, pen drop, any noise has suddenly become much more muted so there's little or no echo"*

However, other participants had not noticed much change themselves especially when pupils were in the classroom but noted that there may have been changes in pupils' behaviours in the classroom after the acoustic panels were installed.

Table 14 Participants quotes taken from post-acoustic adaptation semi-structured interviews considering changes to the classroom listening environment

Participant	Comment
Participant 3	*"I wouldn't say it's made a noticeable difference… when I go into another classroom … there's no-one in there, I could hear the echo a bit more. Whereas if I'm in my own classroom, I can't hear that echo if I'm on my own. But then when there's children in there, I can't really tell too much of a difference.."*
Participant 5	*"I haven't noticed a massive difference ….but (pupil) said she'd noticed a difference …The thing I have noticed, because I mentioned the rain last time and we had a day when it (?* heavy rain) *it down and I don't know, it just didn't seem as loud"*

4.4.2. Post Theme 2 - Changes in children's behaviours in the classroom

Changes in behaviours were noted for children with typical hearing thresholds in the classroom, for children with SEN and for pupils with a hearing loss.

4.4.2.1. Changes in hearing children's classroom behaviours

Table 15 Participants quotes taken from semi-structured interviews reviewing changes in all pupil's behaviours post-acoustic classroom adaptations

Participant	Comment
Participant 8	"*I think they can hear each other better. I think that means that there's probably more talk. It might be at this point in the year as well, but there's more interaction actually, rather than noise. I think that it's supported children with being able to communicate with each other ….*
Participant 2	*"they tend to focus a lot more with it"* (acoustic panels)
Participant 6	*"You get volume, people talk over it, over it, over it, over it. So* (after acoustic panels were fitted) *we're not getting that.. base level of mutter is much lower."*
Participant 1	*"The children will mostly hear an instruction a little more readily than before so I perhaps don't have to repeat myself as much"*
Participant 4	*"they are quicker to respond on things and I think in some ways.. if my voice has to go up they suddenly notice it a bit more than they would have done before"*
Participant 7	*"it definitely has sort of dulled their volume down, which obviously then impacts on the teaching and learning, and that they're not fighting against their own voices when they're working"*

4.4.2.2. Changes in classroom behaviours for pupils with SEN

Table 16 Participants quotes taken from semi-structured interviews reviewing behaviour changes in pupils with SEN post-acoustic classroom adaptations

Participant	Comment
Participant 8	(noise sensitive pupils) *"puts her shoulders up if she thinks that it's too loud.. I don't think she's doing that at all anymore….we've got some noise sensitive children. I don't think they're having as much problem, and I think that it is helping them."*
Participant 6	(noise sensitive pupil) "*has used his ear defenders less"*
Participant 2	*"I've got one child, he was very sensitive to the noise. He's not deaf, but he was sensitive and he'd get distracted by the children when they were talking at the back. He'd be constantly turning around, but now he's not doing that as much and he's more focused because that noise isn't bouncing all around him"*
Participant 7	*(noise sensitive pupil) "has not really complained about it* (sounds) *as much late lately"*
Participant 5	*"I mentioned last time about one of the other children who sometimes got overwhelmed by noise and he seems to have responded really well to the change…There have been sometimes when it has been quite loud in the classroom but he doesn't seem to be affected so that's a good thing for him"*

4.4.2.3. Changes in classroom behaviours for pupils with a hearing loss

Participants noted that after the acoustic panels were installed, the deaf pupil in the classroom could hear more easily, including hearing their peers, which made it easier for them to interact with children and adults. In addition, two participants suggested that the improved acoustic environment may have enabled a deaf pupil to access the curriculum in the classroom when hearing equipment failed. Although they did not have an event to compare with, the participants thought that the deaf pupil would not have been able to continue to work in the classroom environment if the equipment had failed before the acoustic adaptations.

Table 17 Participants quotes taken from semi-structured interviews relating to deaf pupils' access to the curriculum post-acoustic classroom adaptations

Participant	Comment
Participant 8	*"I think (the deaf child) struggled to interact with the children because (the deaf child) struggled to hear them (after the acoustic works) (the deaf child) was able to hear (pupil) and they actually had proper dialogue and made proper plans of what they were building …. and how it was going to be. And I think that is probably the first time I've seen that (for that child)….."*
Participant 2	*"the deaf child in my class is a lot more focused, and she's slightly further away from me than she was…if she was further away before it had been fitted, she wouldn't be able to hear me"*
Participant 6	*"In spite of the fact that she* (TA) *wasn't right next door to him and she didn't have the mic he'd heard that* (the dinner choices)
Participant 4	*"his batteries went …. still one of them wasn't working… you could see he was really trying hard….And actually, I think if it had been prior to the sound deadening material being fitted, I think that he'd really have lost concentration. But he was really focused on what was going on"*
Participant 3	*"he didn't have his device (radio aid) and he was coping really well with it and it makes me think that if we didn't have the acoustic panels would it have been harder time for him … he could still listen to me and listen to other the children"*

4.4.3. Post Theme 3 - Changes to teacher's behaviours in the classroom

In addition, participants reflected on how changes in their ability to hear in the classroom had resulted in changes in their own behaviour.

Table 18 Participants quotes taken from semi-structured interviews discussing how participant's behaviours in the classroom had changed post-acoustic classroom adaptations

Participant	**Comment**
Participant 7	*"I'm able to, sort of, home in on* (conversations across the room) *a little bit more and sort of, you know, stop a few conversations that shouldn't take place and obviously enhance the ones that are taking place in the right direction"*
Participant 8	*"I think being able to hear the children more has certainly helped me as an adult…. when we're doing work on the carpet we have time where they talk to each other and I think that you can tune into children that are possibly further away from you than you normally would have been able to, that's really helpful obviously.. to be able to hear a bit further away rather than just the sort of five children around you."*
Participant 2	*"They* (the pupils) *were a bit more relaxed because I'm not shouting at the children and they don't have to shout their answers back.. it's not bouncing as much…* *with the other children.. sometimes you can hear them whispering and you know instantly who it is because it's not bouncing around. ..when I used to try and figure out who it was that was talking, I couldn't pinpoint who it was."*
Participant 1	*"I don't feel I need to increase my volume as much for them to be able to hear me when I give an instruction…Even just sitting here talking to you I know that if the dampening wasn't there, there would definitely be an echo so I would be straining just a little bit more than I am now to hear what you're saying"*
Participant 4	*"I can hear everything that they're saying…from the point of view that I think they're now talking over each other… but maybe I'm hearing them talking over each other more clearly, so I'm noticing them more because maybe it was just floating off a bit more into the ether."*
Participant 6	*"Yeah,(you notice) the general low level interference… And also if somebody does murmur I've got a better idea of where they've come from…"*

5. Discussion

To summarise, this study set out to explore the impact of acoustic adaptations, to a selection of mainstream primary classrooms, on teaching staff and pupils which included a deaf learner. The study aimed to build on previous research findings regarding changes in listening conditions and speech intelligibility following acoustic modifications to rooms made by fitting acoustic panels to ceilings and walls; Previous studies including those incorporating CYP with typical hearing (Neuman and Hochberg,1983; Peng, 2015, 2020) and DCYP (Canning, 1998; Iglehart, 2009; 2020).

5.1. The impact of the acoustic adaptations

Installing sound absorbing acoustic panels to the classroom ceilings, or wall and ceilings, conclusively reduced the T_{mf} in each classroom to comply with BB93 recommendations for a classroom where a pupil with a hearing loss or other significant communication need is taught; Thus demonstrating the effectiveness of the acoustic panel adaptations.

Although this programme of works was established specifically to improve the listening conditions for deaf learners, in line with the conclusions put forward by Tiesler and Oberdörster (2008, p.249), the results point to all learners benefitting from a calmer environment.

There was a noticeable effect noted for several pupils who were sensitive to noise which agrees with the findings of Ueno *et al,* (2019); Kanakri *et al,* (2017); van der Kruk *et* al, (2017). These findings also concur with Kinealey *et al,* (2012) who found that sensory-based adaptations, including the addition of sound-absorptive materials to walls, aided attention and reduced anxiety in the classroom for learners with ASD or dyspraxia. The findings of this study demonstrate that the acoustic panel installation had a positive impact on well-being for pupils and suggests a reduction in noise-induced stress for those pupils with hyper-sensitivity to noise.

In addition, participants noted that they were no longer needing to increase the intensity of their voices for pupils to be able to hear them, implying a positive impact on well-being for teachers by decreasing vocal effort and, therefore, reducing the potential for vocal strain.

Results from the perspective of adult participants collected during semi-structured interviews and from the perspective of deaf learners from the L.I.F.E.-R questionnaires, appear to reiterate the findings of numerous studies which observed that a reduction in classroom reverberation time aided speech intelligibility and reduced cognitive load by reducing listening effort (Prodi, 2021; Gheller *et al,* 2020; Klatte *et al,* 2013). However, in addition to improving the listening capacity for the deaf learner in the classroom in this cohort, the acoustic adaptations completed in 2021 will benefit all learners and teaching staff in that classroom in future years. This demonstrates a benefit to learning and well-being which appears relative to the cost. Cost-effectiveness is outside the remit of this study and could provide the topic for future research.

This study only considered existing data relating to $T_{mf.}$ Peng ***et al's*** (2020) study showed that although pupils' perceptions noted, as in this instance, that it was easier to listen after acoustic works were completed, one classroom was preferred over another. Peng *et al,* (2020) found that although the acoustic measurements in the mid-frequencies were similar in both classrooms, the least preferred classroom had more low frequency reverberation, which may have led to masking of the speech signal, making speech less intelligible. Therefore, supplementary studies could also consider low frequency reverberation.

5.2. Teacher perceptions of acoustic adaptations

Quotations gathered during semi-structured interviews revealed unexpected gains for participants following the installation of the acoustic panels, such as being able to localise better and hear more low-level discussions than they had before, so enabling the possibility of enhancing learning by scaffolding conversations linked to learning or to stop inappropriate or irrelevant conversations.

Furthermore, participants noticed that pupils were talking more about their learning, with an increase in peer to peer interaction, which again suggests the potential for enhanced learning opportunities. However, consideration should also be given that this result may have been due to participants being more able to recognise discussions taking place rather than more interactions taking place.

Participants who did not immediately notice a significant change in listening ability in the classroom following acoustic modifications, were in classrooms which had one of the shorter reverberation times pre acoustic works (0.5 seconds or 0.6 seconds) when compared with the other classrooms that were acoustically adapted in this programme of works. This meant that there was a smaller shift required to reduce the reverberation times in order to comply with BB93 for learners with a hearing loss.

However, through the completion of the L.I.F.E.-R questionnaires, the deaf pupil in each of these classrooms revealed that they perceived that it was easier to listen and understand in most classroom listening situations after the acoustic adaptations were completed.

Furthermore, following discussion in the semi-structured interviews, the participants identified events that suggested that the acoustic environment had been improved even though the teachers had not consciously noted the change. Differences included events such as recalling a comment made by a typically hearing child stating that listening was easier in the acoustically adapted classroom; noticing less of an echo when the classroom was empty; a pupil with a hearing loss being able to access learning when the assistive listening device developed a fault which may not have been possible previously and reduced noise interference from heavy rain in a classroom built using TABS.

Moreover, responses noted from the pre-adaptation L.I.F.E.-R questionnaires showed that deaf pupils found it more challenging to listen and understand in the classroom even when the acoustic measurements were only marginally outside those recommended by BB93.

The findings suggest that adult participants were able to detect and comprehend speech in a marginally poor acoustic environment which their pupils may have found more difficult, due to their age, stage of development or SEN, consistent with the conclusions of Bradley and Sato (2008). This was confirmed by the deaf pupils, in

their responses to the L.I.F.E.-R questionnaires, and to the positive changes in behaviour noted for children who were sensitive to noise once the acoustic environment was improved.

5.3. Deaf pupil's perceptions of acoustic adaptations

On completion of the second L.I.F.E.-R. questionnaire, the pupils with a hearing loss in this study were being taught in a classroom with good acoustics, had access to an assistive listening device and regular support from a QToD. Their answers revealed that they perceived that is was easier to listen and understand in the modified classroom than it had been before the acoustic panels were fitted, affirming the findings of Canning (2012) and Peng (2015; 2020).

However, even with well-fitting, individually programmed digital hearing aids or speech processors, an assistive listening device checked for transparency and optimal classroom acoustics, deaf pupils still perceived that there were circumstances in which it was difficult to listen and understand. One particular situation arose when trying to listen to peers seated away from them, either in response to a teacher's question or in more social situations and classroom banter, as in research by Gustafson *et al* (2018).

The results illustrate the considerable challenges pupils with any hearing loss face every day in the classroom even with access to more favourable listening conditions. Findings demonstrate the importance of considering classroom acoustics as a reasonable adjustment in order to give deaf students better access to learning and to enable inclusion. They also point to the importance of not only measuring the acoustics in mainstream classrooms where DCYP will be taught and considering what acoustic adaptations could be made to provide a more accessible learning environment, but also considering which classroom might provide the least noise distractions from either inside or outside of the learning environment if there is a choice to be made.

A further benefit noted by participants, for younger deaf children, was the improved ability to hear peers when accessing child-choice continuous provision allowing greater interaction and the possibility of learning with other pupils.

5.4. The role of the Educational Audiologist in managing classroom acoustics

This study was only possible because of the consistent role of the Educational Audiologist in the LA, with classroom acoustic measurements being recorded due to the special educational needs of a deaf learner. However, as previously noted, the role of the Educational Audiologist varies throughout the UK with some areas having no access to an Educational Audiologist (Ash, 2020). Therefore, this raises the question about how many deaf children are attending their local mainstream school and continue to be taught in challenging sub-optimal listening environments. Additionally, how many of their peers who also experience a drain on cognitive capacity due to listening effort affected by age, significant communication or language need or listening in a non-native language could benefit from improved classroom acoustics following advice and recommendations of an Educational Audiologist.

Findings from this study suggest that teachers adapt to sub-optimal listening conditions, changing their practice according to how well they can hear in the classroom and how well they perceive pupils can hear. Classroom management techniques are widely taught on teacher training courses which can lead to reduced background noise in a classroom. However, in addition to classroom management, good acoustics with good reverberation are needed too (ioa, 2015, p.63).

In agreement with Robinson and Bellert's study (2019), results suggest that consideration is less widely given to how acoustics may be improved in order to improve the listening conditions which cannot be controlled by good classroom management practice.

Hence, the results of this small scale study and the limited mention of acoustics in published accessibility plans may imply that the effect of classroom acoustics are being underestimated when considering universal access to learning by unconsciously contemplating adult perceptions of listening ability in classrooms over the perceptions of learners.

Furthermore, Leccese *et al,* (2021) even suggests that newbuild classroom construction using TABS may lead to an "*overestimation of the importance of thermal and underestimation of acoustics"*.

From the accessibility plans reviewed, it is theorised that acoustics are less likely to be considered as part of a school's accessibility plan than adaptations for physical disability needs or needs with higher incidence than hearing loss, even though good acoustics benefit all staff and learners.

An Acoustics – hearing, listening and learning MESHGuide (Underwood *et al, 2022*) is available online to provide information and links to research. In addition, the National Deaf Children's Society (NDCS) provide information leaflets and videos on their website explaining why a good acoustic environment is important, audits for self-review of listening conditions and suggestions for creating a good listening environment. Teachers, SENCos and school senior leadership teams are signposted to NDCS materials and/or MESHGuide by QToDs and Educational Audiologists when a pupil with a hearing loss is to be taught in the school.

Furthermore, an accessibility toolkit is available online from PDNet to support schools to develop an accessibility plan considering the needs of learners with physical disabilities. The accessibility toolkit acknowledges that other organisations have guidance relating to sensory needs. However, if there is no deaf child in the classroom and no professional to signpost to the MESHGuides and NDCS resources, acoustics may not be routinely considered for accessibility. Accessibility plans have not been fully explored as part of this study and may be a further area for future research considering how it might be possible to raise the profile of acoustics further for access to learning and inclusion. Therefore, aiming for good acoustics for quality universal provision for all learners.

5.5. Strengths and limitations

The methods used to measure acoustics in the classrooms are used by other sensory support services in the UK and are repeatable. The L.I.F.E.-R questionnaire is also well used by QToDs and Education Audiologists and has been tested in previous studies for reliability. The L.I.F.E.-R questionnaire has also been used with children with other auditory processing difficulties. Triangulation, using mixed methods, helped to strengthen the reliability of the data.

However, a limitation of the study was the short timescale, which did not allow time for the perceptions of other learners in the classroom, both with typical hearing and

those with SEN including noise sensitivity, to be collected using the L.I.F.E.-R questionnaire. Therefore, only adult participant perceptions on the impact of acoustic adaptations on all learners were recorded, linked to pupil's comments or changes in observed behaviour. A retrospective review of those questionnaires already completed by deaf pupils was possible. Therefore, limiting the views from a pupil perspective to those pupils with a hearing loss.

Fitting the acoustic panels definitely improved the reverberation times in these ten classrooms and the pupils with a hearing loss reported an improvement in being able to listen and understand in the classroom following their installation. However, a few additional points should be noted; In order that there was a sufficient time-gap between the first and the second L.I.F.E.-R questionnaires so that the children did not remember what listening conditions were like before installation, it may be possible that the pupils had settled into classroom routines more which may have influenced their perceptions. Moreover, COVID ventilation guidelines were also still in place during this study which may also have influenced perceived listening conditions in the classrooms as discussed by de la Hoz-Torres *et al,* (2021).

5.6. Implications for future studies

As discussed above, several points have been suggested for future studies including: the cost-effectiveness of classroom acoustic modifications when compared to the long-term benefits to well-being and academic achievement; the impact of low frequency reverberation on perceptions of ease of listening in the classroom.

In addition, the role of the Educational Audiologist in supporting schools with an acoustic accessibility toolkit could be investigated.

6. Conclusion

In conclusion, installation of acoustic panels was conclusively successful in reducing the T^{mf} in each classroom to the BB93 (2015, p.34) requirement of 0.4 seconds or below for a teaching space intended for students with hearing or communication needs.

L.I.F.E.-R questionnaires completed by deaf primary pupils indicated that the reduction in reverberation time improved the ability to listen and understand in the classroom. The questionnaire was reliable in providing an account of the impact of an intervention to improve listening conditions which agreed with the reduction in classroom reverberation

However, even in optimal acoustic conditions, access to an assistive listening device and well-fitted optimally programmed hearing aids, deaf pupils still reported challenges in listening to their peers in the classroom. The use of the L.I.F.E.-R questionnaire was an excellent self-advocacy tool to provide an awareness of the everyday listening challenges that students face and to demonstrate the effect of an intervention.

In addition to the improvement in the listening conditions and '*feel'* of the classroom, participants noted an increase in peer interactions leading to a potential to enhance learning opportunities, positive changes in behaviour for children sensitive to noise and an improvement in accessibility for students with a hearing loss due to an improvement in ease of listening. Participants also suggested a positive impact on their own well-being from reduced vocal effort.

The overriding conclusion of this study is that improving the acoustic climate of a classroom to meet the requirements of BB93 benefits all - pupils and staff.

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Appendices

Appendix I Ethics Approval

University of Hertfordshire UH

SOCIAL SCIENCES, ARTS AND HUMANITIES ECDA

ETHICS APPROVAL NOTIFICATION

TO	**Karen Wright**
CC	**Imran Mulla**
FROM	**Dr Ian Willcock, Social Sciences, Arts and Humanities ECDA Chairman**
DATE	**11/01/2022**

Protocol number:	cEDU/PGR/CP/05312
Title of study:	Exploring the impact of classroom acoustic measurements, and follow-up adaptations, on learners and staff in the classroom

Your application for ethics approval has been accepted and approved with the following conditions by the ECDA for your School and includes work undertaken for this study by the named additional workers below:

No additional workers named

Conditions of approval specific to your study:

Ethics approval has been granted subject to the following points to be checked by the supervisor:

- Implied consent is not acceptable for the structured interviews. Explicit consent to participate and for this data to be used in the study must be collected using an EC3 form.
- There needs to be a limit on the time the recordings are going to be stored for – I'd suggest until the exam board has met to confirm final grades.

General conditions of approval:

Ethics approval has been granted subject to the standard conditions below:

Permissions: Any necessary permissions for the use of premises/location and accessing participants for your study must be obtained in writing prior to any data collection commencing. Failure to obtain adequate permissions may be considered a breach of this protocol.

1

External communications: Ensure you quote the UH protocol number and the name of the approving Committee on all paperwork, including recruitment advertisements/online requests, for this study.

Invasive procedures: If your research involves invasive procedures you are required to complete and submit an EC7 Protocol Monitoring Form, and copies of your completed consent paperwork to this ECDA once your study is complete.

Submission: Students must include this Approval Notification with their submission.

Validity:

This approval is valid:

From: 11/01/2022

To: 01/06/2022

Please note:

Failure to comply with the conditions of approval will be considered a breach of protocol and may result in disciplinary action which could include academic penalties.
Additional documentation requested as a condition of this approval protocol may be submitted via your supervisor to the Ethics Clerks as it becomes available. All documentation relating to this study, including the information/documents noted in the conditions above, must be available for your supervisor at the time of submitting your work so that they are able to confirm that you have complied with this protocol.

Should you amend any aspect of your research or wish to apply for an extension to your study you will need your supervisor's approval (if you are a student) and must complete and submit form EC2.
Approval applies specifically to the research study/methodology and timings as detailed in your Form EC1A. In cases where the amendments to the original study are deemed to be substantial, a new Form EC1A may need to be completed prior to the study being undertaken.

Failure to report adverse circumstance/s may be considered misconduct.
Should adverse circumstances arise during this study such as physical reaction/harm, mental/emotional harm, intrusion of privacy or breach of confidentiality this must be reported to the approving Committee immediately.

Appendix II – Participant Information Document EC6

University of Hertfordshire UH Ethics Committee

UNIVERSITY OF HERTFORDSHIRE

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

FORM EC6: PARTICIPANT INFORMATION SHEET

1 Title of study

Exploring the impact of classroom acoustic measurements, and follow-up adaptations, on learners and staff in the classroom

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?

Recommended guidance states that children with a hearing loss or significant communication needs have a good signal-to-noise ratio in order to access speech in the classroom. Background noise and reverberation can impede signal-to-noise ratio and lead to poorer listening conditions which can be improved with acoustic adaptations.

As part of my role as an Educational Audiologist, I complete measurements when considering listening conditions for children with significant hearing needs. However, I am also aware of the difference that good listening conditions can make for learners with auditory processing needs, autism and other significant communication needs.

Therefore, I would like to explore the experience and knowledge of school colleagues with regards to acoustics pre and post acoustic adaptations.

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.

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

Participants asked will all have experience of a classroom pre and post acoustic adaptations and will be teachers, SENCos or Senior Leaders. No minors will be asked to participate.

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

If you decide to take part in this study, you will be asked to participate in one interview pre acoustic works and one interview post acoustic works in the academic year 2021-22. With your consent, the anonymised data collected in the interview will be used as part of the study.

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

The first thing to happen will be contact to agree a convenient time to meet remotely by Microsoft Teams. The interview will take approximately half an hour.

During the interview, you will be asked questions regarding your experience of a classroom that has received acoustic adaptations and your awareness of the acoustic environment of schools prior to acoustic measurements being taken.

Responses will be recorded, analysed and reported as part of the study exploring the acoustics properties of school buildings.

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

There are no known risks in participating in this study.

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

The responses you give will be included in the study which will add to the existing literature on the subject of classroom acoustics. Any change in practice resulting from this study could be a benefit for children's and young people's listening and learning experiences in the future.

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

All data will be anonymised before being used in the dissertation. All data and consent forms will be password protected and saved electronically on a secure encrypted laptop which is maintained in accordance with the Local Authority's IT policy.

11 **Audio-visual material**

Consent will be sought, from you, to record the interview on Microsoft Teams for the purpose of aiding the analysis the data. A copy will be available to you within 21 days if requested. Only the principal investigator will access the recording or make it available to you.

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

All data will be anonymised prior to storage and being used in the dissertation. All data and consent forms will be uploaded to a secure encrypted laptop, maintained in accordance with the Local Authority's IT Policy and saved with a password. Video recordings will only be accessed by the principal investigator. A copy will be available if requested within 21 days. Recordings will only be made for the purpose of reviewing and analysing responses given. The data collected and recordings made will be stored electronically and password protected in accordance with the Local Authority's data handling and storage policies after which time it will be destroyed under secure conditions. Recordings will be deleted at the end of the study and by 30th June 2022.

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 **cEDU/PGR/CP/05312**

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

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

Researcher: Karen Wright
Educational Audiologist and Qualified Teacher of the Deaf
Integrated Disability Service – Hearing Team
Fifth Floor Kings House
King Street
Bedworth
CV12 8LL

Tel: 07468716280
Email: karenwright@warwickshire.gov.uk

Supervisor: Dr Imran Mulla

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

Appendix III – Participant Consent Form EC3

University of Hertfordshire UH Ethics Committee

UNIVERSITY OF HERTFORDSHIRE

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

FORM EC3
CONSENT FORM FOR STUDIES INVOLVING HUMAN PARTICIPANTS

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

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

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

Exploring the impact of classroom acoustic measurements, and follow-up adaptations, on learners and staff in the classroom

(UH Protocol number **cEDU/PGR/CP/05312**)

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

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

3 In giving my consent to participate in this study, I understand that voice, video or photo-recording will take place and I have been informed of how/whether this recording will be transmitted/displayed.

4 I have been told how information relating to me (data obtained in the course of the study, and data provided by me about myself) will be handled: how it will be kept secure, who will have access to it, and how it will or may be used, including the possibility of anonymised data being deposited in a repository with open access (freely available).

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

Signature of participant……..…Date……

Signature of (principal) investigator……Date……

Name of (principal) investigator *[in BLOCK CAPITALS please]*

KAREN WRIGHT

Appendix IV Pre-Acoustic Works Semi-Structured Interview Schedule

Thank you for taking the time to talk to me today. I am interested in finding out more about the acoustics in your classroom.

Tell me about your classroom

What do you know about classroom acoustics and any potential to impact any aspects of pupil development?

What noises do you hear when you are in your classroom?

Fan noise?

Noise from heating systems within your classroom?

Noise from computers within your classroom?

Noise from overhead projectors?

Noise from nearby bathrooms / hand dryers?

Noise from pupils outside of your classroom?

Noise from clock / lights?

Other noises from outside of your classroom? What noises?

Other noise?

When you are teaching, how well can you hear what pupils are saying?

Consider:

Instructing the whole class?

Working with a small group?

Reading with a group?

When the class are engaged in learning?

How do you feel about the general noise in your classroom?

What impact, if any, do you feel that the noise in your classroom has on your health and wellbeing?

What impact, if any, do you feel that the noise has on the health and wellbeing of other adults in your classroom?

What impact, if any, do you feel that noise has on the health and wellbeing of pupils in your classroom?

Tell me about any times when you have needed to adapt how you are talking in order for pupils to hear you in your classroom

What do other staff say about teaching in your classroom?

Thank you for your time.

Appendix V Post-Acoustic Works Semi-Structured Interview Schedule

Thank you for taking the time to talk to me today. I am interested in finding out more about the acoustics and adaptations that have been made in your school to improve the listening conditions for all children.

How do you think the acoustic adaptations have impacted on all children's learning?

How do you think the acoustic adaptations have impacted on the learning of children with SEN?

How do you think the acoustic adaptations have impacted on the child/children specifically with a hearing loss in your classroom?

What changes in behaviour have you noticed since the acoustic works have been completed?

Since the acoustic adaptations have been made, how well can you hear what pupils are saying when you are teaching?

Consider:

Instructing the whole class?

Working with a small group?

Reading with a group?

When the class are engaged in learning?

How do you feel about the general noise in your classroom?

Tell me about differences (if any) you have noticed when teaching in the classroom, since the acoustic adaptations were completed?

What comments, if any, have other staff members made about the acoustics in the classroom following the adaptations?

What do you know about other ways in which acoustics can be improved in learning spaces?

What consideration, if any, has been given to acoustics in the school accessibility plan?

Are there any other thoughts or comments you would like to make about acoustic properties of school learning environments?

Thank you for your time.