The impact of improved classroom acoustics on autistic students

Research findings and classroom applications

FINAL REPORT

Wayne Wilson
Keely Harper-Hill
Jill Ashburner
Cerys Downing
Rebecca Armstrong
Kelsey Perrykkad

September 2019

Australian Government
Department of Industry, Innovation and Science
Business Cooperative Research Centres Program

The impact of improved classroom acoustics on autistic students

Research findings and classroom applications

Wayne J. Wilson
School of Health & Rehabilitation Sciences, The University of Queensland I Autism CRC

Keely Harper-Hill
School of Cultural and Professional Learning, Queensland University of Technology I Autism CRC

Jill Ashburner
Autism Queensland I Autism CRC

Cerys Downing
School of Health & Rehabilitation Sciences, The University of Queensland

Rebecca Armstrong
School of Health & Rehabilitation Sciences, The University of Queensland I Autism CRC

Kelsey Perrykkad
School of Philosophical, Historical and International Studies, Monash University

ISBN: 978-1-922365-01-9

Citation: Wilson, W.J., Harper-Hill, K., Ashburner, J., Downing, C., Armstrong, R., & Perrykkad, K. (2019). The impact of improved classroom acoustics on autistic students. Brisbane, Australia: Cooperative Research Centre for Living with Autism.

Copies of this report can be downloaded from the Autism CRC website autismcrc.com.au.

AutismCRC

Acknowledgements

The authors acknowledge the financial support of the Cooperative Research Centre for Living with Autism (Autism CRC), established and supported under the Australian Government's Cooperative Research Centre Program. Staff and non-staff in kind were provided by Autism CRC participants –

The Cooperative Research Centre for Living with Autism (Autism CRC)

The Cooperative Research Centre for Living with Autism (Autism CRC) is the world's first national, cooperative research effort focused on autism. Taking a whole-of-life approach to autism focusing on diagnosis, education and adult life, Autism CRC researchers are working with end-users to provide evidence-based outcomes which can be translated into practical solutions for governments, service providers, education and health professionals, families and people on the autism spectrum.

autismcrc.com.au

Table of contents

AutismCRC

1. Executive Summary

This report presents the results of *Project 2.028RS The Impact of improved classroom acoustics on autistic students* from *Program 2: School Years - Enhancing Learning and Teaching* within *The Cooperative Research Centre for Living with Autism (Autism CRC)*.

Overall, the results of Project 2.028RS support the trialling sound field amplification (SFA) in classrooms for students on the autism spectrum. By making it easier for students to hear the teacher, SFA put students in a better position to learn but did not guarantee students would go on to learn in the short-term. The benefits of SFA were realised with no observed risks for students on the spectrum.

Autism Spectrum Disorders (ASD) is the collective term for a group of neurodevelopmental disorders characterised by persistent deficits in social communication and social interaction, and by repetitive patterns of behaviour and restricted interests (Whitehouse, Evans, Eapen, & Wray, 2018). Students on the autism spectrum can have difficulties with auditory, speech and language processing, although the nature of these difficulties is complex. Most primary schools in Australia include students on the spectrum (Australian Advisory Board on Autism Spectrum Disorders, 2010) with support for these students mandated by Government policies for inclusive education. One such support could be sound field amplification (SFA), which has the teacher wear a microphone so that her voice can be distributed via a loudspeaker to the whole classroom.

The first study in Project 2.028RS used a systematic review of the scientific literature to conclude that improving classroom acoustics could help improve classroom performance in students on the spectrum.

The second study in Project 2.028RS used a single group, cross-sectional analysis of the acoustics in 33 classrooms in primary schools in and around Brisbane, Australia. It concluded that the “acoustic health” of these classrooms was generally poor and these classrooms could benefit from trialling SFA.

Studies three and four in Project 2.028RS used a two-group, randomised controlled trial with crossover to determine if SFA supported students on the spectrum in primary school classrooms in Brisbane, Australia.

Study three used standardized measures to show that short-term use of SFA in classrooms could assist students on the spectrum to improve their skills in some areas of phonological

processing (blending nonwords) in quiet and noise, but not in other areas of phonological processing (nonword repetition) in quiet and noise or in areas of attention, memory, literacy or numeracy.

Study four used functional measures in the form of teacher and student questionnaires and video assessment to show that short-term SFA in classrooms supported some functional listening behaviours for students including those on the spectrum. The supported behaviours included focusing on verbal instructions, attending to directions, staying on task, answering questions, attending to verbal instruction when noise is present, and rate of comprehension. The unsupported behaviours included student self-advocacy, awareness of distracting or non-distracting sounds, self-reported ability to hear the teacher, and response time to teacher instructions and questions.

At the time of this report, the products from *Project 2.028RS* included five papers in the peer-reviewed scientific literature (two published and three submitted), 13 papers at scientific conferences (seven presented, three submitted, and three to be submitted), and four translational works (three completed and one in preparation) for Autism CRC's inclusionEd a professional development platform and community of practice for educators working with students with diverse learning needs, including autism.

2. Introduction

2.1 Background

2.1.1 Autism Spectrum Disorder

The National Guideline for the Assessment and Diagnosis of Autism Spectrum Disorders (ASD) in Australia (Whitehouse, Evans, Eapen, & Wray, 2018, p. 2) defines ASD as the collective term for a group of neurodevelopmental disorders characterised by persistent deficits in social communication and social interaction, and by repetitive patterns of behaviour and restricted interests. These guidelines note that the behavioural features that characterise ASD are often present before three years of age but may not become apparent until the school years or later in life. The developmental challenges, signs and/or symptoms can vary widely in nature amongst individuals and over time, and may include co-occurring mental and physical health conditions.

2.1.2 Primary schools and students on the autism spectrum in Australia

Drawing on data obtained from 2012 to 2015, the Australian Bureau of Statistics (2015) reported 2.8% of children aged five to nine years in primary schools in Australia were on the autism spectrum. Support for these children is mandated by Government policies for inclusive education (e.g., Every Student with Disability Succeeding [Queensland Government, 2019] and Education for All [Victoria State Government, 2019]) that seek to identify effective classroom adjustments and strategies to meet the needs of diverse learners and create environments where all learners experience a sense of value and belonging.

2.1.3 Autism Spectrum Disorder and audition

Children on the spectrum are known to have difficulties with auditory, speech and language processing, although the nature of these difficulties is complex. As predicted by the Weak Central Coherence model and the Enhanced Perceptual Functioning model of autism, systematic reviews of the research literature have reported diverse examples of atypical processing of auditory information that are more likely (and more severe) for speech versus non-speech stimuli and for complex versus simple auditory information (Haesen, Boets, & Wagemans, 2011; O'Connor, 2012; Samson et al., 2011). Other complexities such as hypo- and hyper-sensitivity to sounds, phonophobia, and over-interest in sounds (Ashburner, Ziviani, & Rodger, 2008; Tan et al., 2012) have also been reported.

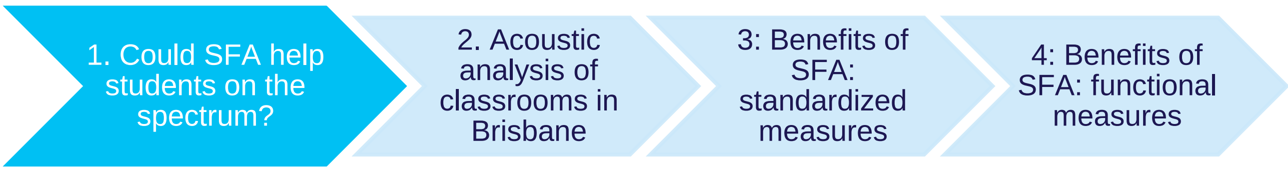
2.1.4 Sound field amplification

Sound field amplification (SFA) systems have recently attracted interest as an inclusive classroom adjustment for children on the spectrum (Rance, Chisari, Saunders, & Rault, 2017; van der Kruk et al., 2017). These systems typically consist of a microphone and transmitter worn by the teacher and a speaker or speakers placed in the classroom. When functioning optimally, SFA improves the signal-to-noise ratio (SNR) throughout most of a classroom by maintaining the teacher's voice (the signal) at a higher level than the classroom noise (the noise) (American Academy of Audiology, 2011a, 2011b; W. J. Keith & Purdy, 2014).

The potential benefits of SFA for children on the spectrum are many. As children spend 45-60% of the school day listening to their teacher and classmates (Butler, 1975; Rosenberg et al., 1999) often in poor acoustic environments (high noise levels and long reverberation times; Wilson et al., 2019), SFA could put children in a better position to learn (McArthur, Ellis, Atkinson, & Coltheart, 2008). For children on the spectrum this potential is suggested by Rance et al. (2017) who found SFA was associated with lower salivary cortisol levels in ten children on the spectrum tasked with listening in a noisy environment. Rance et al. (2017) concluded SFA could reduce classroom listening stress for these children.

The potential benefits of SFA for children on the spectrum can also be extrapolated from research into remote microphone hearing aids (RMHAs). RMHAs replace the speaker/s used in SFA with a receiver and earpiece/s worn by an individual child (American Academy of Audiology, 2011a, 2011b; W. J. Keith & Purdy, 2014). This allows the teacher's voice to be transmitted directly to the child's ear/s. Reported benefits of RMHAs for children on the spectrum include improved general listening, communication, on-task behaviours, auditory filtering, resistance to noise and reverberation, and aversiveness to sound (Rance, Saunders, Carew, Johansson, & Tan, 2014; Schafer et al., 2013; Schafer et al., 2016); but not in listening comprehension or auditory memory (Schafer et al., 2016). Mitigating these benefits is the potential for RMHAs to aggravate tactile sensitivities that may be present in some children on the spectrum (Rance et al., 2017; Rance et al., 2014).

2.2 The four studies within project 2.028RS



AutismCRC

2.2.1 Could improving classroom acoustics support children on the autistic spectrum?

A systematic review of the scientific literate was conducted to determine if improving classroom acoustics could help improve classroom performance in children on the spectrum.

2.2.2 The acoustics of classrooms in Brisbane, Australia

A single group, cross-sectional research study was conducted to determine the classroom acoustics of a large sample of primary school classrooms in and around Brisbane, Australia. These classrooms were investigated for their unoccupied sound levels, reverberation times, occupied sound levels, and speech transmission index values. These results were compared against relevant Australian and New Zealand standards (Standards Australia Limited/Standards New Zealand, 2016) and research recommendations (Mealings, 2016).

2.2.3 Does SFA support children on the autism spectrum in the classroom, part 1: Standardized measures

A two-group, randomised controlled trial with crossover was conducted to determine if SFA supported children on the spectrum in primary school classrooms in Brisbane, Australia. Part 1 of this study used standardized measures of phonological processing, attention, memory, literacy and numeracy to determine the level of support offered by SFA to children on the spectrum.

2.2.4 Does SFA support children on the autism spectrum in the classroom, part 2: Functional measures

Part 2 continued this study by using teacher and student questionnaires and video assessment of student behaviour to determine the level of support offered by SFA to children on the spectrum.

3. Could improving classroom acoustics help children on the autism spectrum?

Improving classroom acoustics could help children on the autism spectrum

3.1 Background

Reports that children on the autism spectrum experience significant difficulties with school participation and academic performance, combined with reports that these children could have difficulties processing sound (particularly processing speech in noisy environments), highlight the potential need to improve the acoustics in their classrooms (Haesen et al., 2011; O'Connor, 2012). An immediate way of achieving this is to improve the signal-to-noise ratio (SNR) in the classroom. The SNR is the ratio of the level of the signal versus the level of the noise (e.g., the teacher's voice versus the background noise in the classroom). When represented in decibels (dB), the SNR can be conveniently calculated as the difference between the signal and noise levels (Seibein, Gold, Siebein, & Ermann, 2000; Smaldino & Crandell, 2000). Young, typically-developing listeners with normal hearing have been reported to need SNRs of at least 6 dB to perform maximally in the classroom (i.e., the signal needs to be at least 6 dB higher than the noise: Crandell & Bess, 1987; Elliott, 1979, 1982; Nabelek & Robinson, 1982). The American National Standards Institute (ANSI S12.60-2002) (American National Standards Institute, 2002) and the American Speech-Language-Hearing Association (American Speech-Language-Hearing Association, 2005) recommend a much higher SNR of at least +15 dB for neurodiverse individuals.

By improving the SNR in the classroom, SFA has the potential to improve a students' classroom performance by improving speech perception and recognition (the potential for the child to better hear and understand the teacher), classroom listening behaviours (the potential for the child to better attend to the teacher), and academic performance (the potential for the child to benefit from being in a better overall position to learn).

Improving the SNR in classrooms by SFA and other means (e.g., personal sound amplification and acoustically treating classrooms) has been reported to support both typically developing children (Dockrell & Shield, 2012; Dockrell & Shield, 2006; Massie &

Dillon, 2006; Shield & Dockrell, 2003; Vickers et al., 2013; Wilson, Marinac, Pitty, & Burrows, 2011) and children with severe intellectual disabilities or specific learning disabilities (Blake, Field, Foster, Platt, & Wertz, 1991; Flexer, Millin, & Brown, 1990), Down Syndrome (Bennetts & Flynn, 2002), ADD/ADHD (Schafer et al., 2014; Updike, 2006), language disorders (Schafer et al., 2014) and auditory processing disorder (APD) (Johnston, John, Kreisman, Hall, & Crandell, 2009; Reynolds, Kuhaneck, & Pfeiffer, 2016; Schafer et al., 2014; Young, Bradle, Hickson, & Lawson, 1997). Such reports suggest children on the spectrum could also benefit from SFA and its potential to improve the SNR in classrooms.

3.1.1 Aim

The aim of this study was to systematically review of the scientific literature to answer the following question: does improving the signal-to-noise ratio (intervention) lead to improved classroom performance (outcome) in children on the spectrum (population) compared to no intervention (comparison)?

3.2 What we did

Six databases were searched for the terms acoustics, signal-to-noise ratio, classroom and ASD. To be included in this review, the selected studies had to involve school-aged children on the spectrum with or without other comorbid developmental disorders (such as ADD/ADHD) who were exposed for any duration to some form of SNR enhancement be that device (e.g., personal sound amplification or SFA) or environmental (e.g. acoustic treatment of the classroom) in nature. If the study included children with disorders other than ASD, it must have separately reported data for the children on the spectrum. The selected studies also had to have used a research design that allowed for comparison of treatment versus no treatment conditions and measured any aspect of student listening and/or classroom performance.

3.3 What we found

Five studies were found that met the inclusion criteria:

- Three studies (Rance et al., 2014; Schafer et al., 2013; Schafer et al., 2016) reported that the use of personal FM systems resulted in improvements in areas including listening (Rance et al., 2014; Schafer et al., 2016), auditory performance (Schafer et al., 2016), communication (Rance et al., 2014), speech recognition in noise (Schafer et al., 2013; Schafer et al., 2016), on-task behaviours (Schafer et al., 2013), auditory filtering (Schafer et al., 2016), effects of noise and reverberation (Rance et al., 2014; Schafer et al., 2016) and aversiveness to sound (Rance et al., 2014).

- One study (Schafer et al., 2016) reported no significant improvements in the areas of listening comprehension and auditory memory.
- One study (Rance et al., 2017) reported the use of SFA systems could reduce listening stress.
- One study (Kinnealey et al., 2012) reported that the use of sound-absorbing walls resulted in decreased inattentive behaviour.

3.4 What we think this means

The evidence is suggestive that improving the SNR (intervention) leads to improved classroom performance (outcome) in children on the spectrum (population) compared to no intervention (comparison). This conclusion was most suggestive for improved SNR achieved by using personal FM systems (three studies, total participant n = 29). Other methods of improving SNR were investigated in only a single study each by using SFA systems (participant n = 10) and sound-absorbing walls (participant n = 3).

3.5 Limitations

The conclusions of this systematic review were limited by the few studies that met the selection criteria, the lack of randomized controlled trials, the lack of explicit descriptions of how ASD was diagnosed in participating children, small sample sizes, potential participant bias in some questionnaire data, low teacher response rates, and the relatively low number of children on the autism spectrum with greater support requirements.

This systematic review was published as: Van der Kruk, Y., Wilson, W.J., Downing, C., Palghat, K., Harper-Hill, K., & Ashburner, J. (2017). Improved signal-to-noise ratio and classroom performance in children with Autism Spectrum Disorder: A systematic review. Review Journal of Autism and Developmental Disorders, 4(3), 243-253.

4. The acoustics of classrooms in Brisbane, Australia

> **The "acoustic health" of primary school classrooms in Brisbane is generally poor**

4.1 Background

Poor classroom acoustics has been widely reported to negatively affect student performance across a range of measures (Anderson, 2001). These include speech reception (Bolt & Macdonald, 1949; Crandell & Smaldino, 2000; Lochner & Burger, 1964; Nabelek & Pickett, 1974), speech perception (Crandell & Smaldino, 2000; Finitzo-Hieber & Tillman, 1978; Mealings, Buchholz, Demuth, & Dillon, 2015); reading and language comprehension (Klatte, Lachmann, & Meis, 2010; Maxwell & Evans, 2000; Ronsse & Wang, 2013); linguistic and cognitive processing (Anderson, 2001; Maxwell & Evans, 2000); and cognition, concentration, and psychoeducational and psychosocial achievement (Crandell & Smaldino, 2000; Shield, Greenland, & Dockrell, 2010). These effects can be greater in children with hearing impairment (Crandell & Smaldino, 2000), auditory processing disorders (R. W. Keith, 1999), children who are introverts (Cassidy & MacDonald, 2007); and children for whom English is a second language (Nelson, Kohnert, Sabur, & Shaw, 2005; Nelson & Soli, 2000; Shield et al., 2010). Teachers can also be affected as the need to raise their voices for extended periods can lead to vocal strain and pathological voice conditions (Gotaas & Starr, 1993; Smith, Gray, Dove, Kirchner, & Heras, 1997).

To address the effects of poor classroom acoustics on student performance, many groups around the world have offered acoustic standards and recommendations for school classrooms. These standards and recommendations typically consider a range of acoustic measures (Greenland & Shield, 2011; Mealings, 2016; Mealings et al., 2015; Standards Australia Limited/Standards New Zealand, 2016; Steeneken & Houtgast, 1980) including:

- Unoccupied sound level: the sound present when the classroom should be at or near its quietest.
- Reverberation time (RT): the time taken for a briefly played sound to decay by 60 dB.

- Occupied sound level: the sound present when children and teachers are in the classroom.
- Speech transmission index (STI): an estimate of how easily speech sounds could be heard in a room.

In Australia and New Zealand, recommendations for the acoustic measures listed above can be drawn from two sources: Australian/New Zealand Standard 2107: acoustics-recommended design sound levels and reverberation times for building interiors (AS/NZS 2107:2016) (Standards Australia Limited/Standards New Zealand, 2016), and Mealings (2016). For teaching spaces/single classrooms in primary schools, these sources recommend unoccupied sound levels of <35 dB LA_{eq}, RTs of <0.3 s to 1.2 s (depending on room size), occupied sound levels of <50 dB LA_{eq} (Berg, Blair, & Benson, 1996; Mealings, 2016), and STI values of >0.75 for classrooms containing younger primary school children and >0.60 for classrooms containing older primary school children (Greenland & Shield, 2011; Mealings, 2016).

4.1.1 Aim

The aim of this study was to examine the classroom acoustics of a large sample of primary school classrooms in and around Brisbane, Australia, to determine if their unoccupied sound levels, RTs, occupied sound levels, and STI values complied with relevant Australian and New Zealand standards (Standards Australia Limited/Standards New Zealand, 2016) and recommendations made by Mealings (2016).

4.2 What we did

The acoustic measures of unoccupied sound level and RT were obtained from 33 primary school classrooms in Brisbane, Australia. The further acoustic measures of occupied sound level and STI were obtained from 12 of these classrooms. All three education systems in the region were represented across the sampled classrooms: the public education system offered by Queensland Government’s Department of Education (3 schools, 7 classrooms), the catholic education system offered by the Archdiocese of Brisbane Catholic Education Council (5 schools, 8 classrooms), and the independent education system offered by Independent Schools Queensland (5 schools, 18 classrooms). All classrooms were chosen by the Principals of the participating schools on the basis of those classrooms being scheduled for use by year three students in 2017. All classrooms were typical for the region being single cell or dual cells separated by a concertina divider, varying in volume from 69 to 378 m^3, and made predominantly from acoustically hard materials.

The unoccupied sound level and RT measures were completed using a Brüel & Kjær Type 2250B handheld analyzer, a Class 1 sound level meter under Australian Standards/International Electrotechnical Commission Standard 61672.1, Electroacoustics – Sound level meters – Specifications (AS IEC 61672.1-2004) (Standards Australia Limited, 2004) with a type 4189, free field ½ inch microphone, BZ-7222 sound level meter software, and BZ-7227 reverberation time software. The results of these measures were compared against AS/NZS 2107:2016 (Standards Australia Limited/Standards New Zealand, 2016).

The occupied sound level and STI measures were obtained using an iPad model A1474 (iOS version 9.2) running the Listen App for Schools (version 1.07: https://itunes.apple.com/au/app/listenapp-for-schools/id981300043?mt=8). The results of these measures were compared against the recommendations made by Mealings (2016).

4.3 What we found

The unoccupied sound levels ranged from 25.7 to 50.0 dB LA_{eq} and reverberation times (RTs) from 0.34 to 1.26 s. This represented a 26% failure rate for unoccupied sound level and 79% failure rate for RTs against Australian Standards for teaching spaces in primary school classrooms. The further analysis of 12 of the classrooms showed occupied sound levels from 49.8 to 64.8 dB LA_{eq} during quiet activity, and STI values ranging from 0.35 to 0.80 (on a scale of 0 to 1). This represented a 92% failure rate for occupied sound level and STI against research recommendations for teaching spaces in primary school classrooms in Australia.

4.4 What we think this means

The “acoustic health” of the present study’s 33 primary school classrooms in Brisbane and its surrounding regions was generally poor but similar to that seen in classrooms around the world. These results were most likely due to the design and build of these classrooms, being single cells or dual cells separated by a concertina divider often of large volumes and predominantly constructed from acoustically hard materials including concrete, brick, plaster, wood and glass. These classrooms would likely benefit from routine measurement of their classroom acoustics and relatively standard methods of improving those acoustics. The trialling of SFA was also deemed to be a viable option for these classrooms.

4.5 Limitations

This study had at least five limitations. First was its sampling of classrooms from Brisbane, Australia, only. This warrants caution when generalising this study's results to classrooms outside that region. Second was the relatively simple acoustics measurements taken from the classrooms. These measures are single measures taken from the centre of each classroom on single days only. This limits generalising this study's results to all areas of those classrooms at all times during any school day. Finally, the occupied sound levels are inherently dependant on the number of students occupying the classroom and the nature of their activity at the time of assessment. Changes in these variables will change the resulting occupied sound levels in the classroom.

This study was published as: Wilson, W.J., Downing, C., Perrykkad, K., Armstrong, R., Arnott, W.L., Ashburner, J., & Harper-Hill, K. (In press). The "acoustic health" of primary school classrooms in Brisbane, Australia. Speech, Language and Hearing. doi: 10.1080/2050571X.2019.1637042.

5. Does SFA support children on the autism spectrum in the classroom, part 1: Standardized measures

> **Short-term SFA in classrooms helped children on the autism spectrum to improve their phonological processing but not their attention, memory, literacy or numeracy.**

5.1 Background

Sound field amplification (SFA) systems have recently attracted interest as an inclusive classroom adjustment for children on the autism spectrum (Rance et al., 2017; van der Kruk et al., 2017). The potential benefits of SFA are many as children spend 45-60% of the school day listening to their teacher and classmates (Butler, 1975; Rosenberg et al., 1999) in often poor acoustic environments (high noise levels and long reverberation times [Wilson et al., 2019]).

While the potential for SFA use with children on the spectrum is promising, it must be tempered against what can be reasonably expected in real world environments. It could be argued that behaviours more likely to benefit from short-term SFA use would be those more likely to immediately benefit from an improved signal-to-noise (SNR) alone. This could include auditory processing (the ability to process the frequency, intensity, timing and location of sound), phonological processing (the ability to process the different parts of speech), auditory attention (the ability attend to sound) and auditory memory (the ability to remember sound). Continuing this argument, more complex skills that develop over longer periods would be less likely to immediately benefit from short-term SFA. This could include language processing (the ability to process different parts of language) and academic performance (literacy and numeracy, performance in science, arts, etc.).

The argument offered above is consistent with previous suggestions that SFA could put children in a better position to learn by making it easier to hear, but those children must still go on to learn by deriving meaning from what they have heard (after McArthur, Ellis, Atkinson & Coltheart, 2008). This argument gains some support from reports of the use of remote microphone hearing aids (RMHAs) being more associated with short-term improvements in speech perception and recognition (hearing the teacher) and classroom-listening behaviours (attending to the teacher) than with overall academic performance (literacy, numeracy, etc) in typically-developing children (Dockrell & Shield, 2012; Dockrell & Shield, 2006; Massie & Dillon, 2006; Shield & Dockrell, 2003; Vickers et al., 2013; Wilson, Marinac, Pitty, & Burrows, 2011) and children with severe intellectual disabilities or specific learning disabilities (Blake, Field, Foster, Platt, & Wertz, 1991; Flexer, Millin, & Brown, 1990), Down Syndrome (Bennetts & Flynn, 2002), ADD/ADHD (Schafer et al., 2014; Updike, 2006), language disorders (Schafer et al., 2014), or auditory processing disorder (APD) (Johnston, John, Kreisman, Hall, & Crandell, 2009; Reynolds, Kuhaneck, & Pfeiffer, 2016; Schafer et al., 2014; Young, Bradle, Hickson, & Lawson, 1997).

Expectations of the potential benefits from SFA also require further consideration of the specific challenges facing children on the spectrum. While such children are known to have difficulties with auditory, speech and language processing, these difficulties are complex. As predicted by the Weak Central Coherence model and the Enhanced Perceptual Functioning model of autism, systematic reviews have reported diverse examples of atypical processing of auditory information that are more likely (and more severe) for speech versus non-speech stimuli and for complex versus simple auditory information (Haesen, Boets, & Wagemans, 2011; O'Connor, 2012; Samson et al., 2011). Other complexities such as hypo- and hyper-sensitivity to sounds, phonophobia, and over-interest in sounds (Ashburner, Ziviani, & Rodger, 2008; Tan et al., 2012) have also been reported.

5.1.1 Aim

The present study aimed to determine if SFA can be used to support children on the spectrum in the classroom in the areas of phonological processing in quiet and noise, attention, memory, literacy and numeracy.

5.2 What we did

A two-group, randomised controlled trial (RCT) with crossover was conducted. Thirteen children (9 males, aged 7.6 to 8.4 years) on the spectrum and 17 children not on the spectrum (7 males, aged 7.6 to 9.3 years) participated from 12 primary schools in and near to Brisbane, Australia. Seventeen of these children had an SFA system in their classrooms in semester one and 13 in semester two of their fourth year of formal schooling (Year 3).

Prior to beginning the study, all children were assessed on measures of reciprocal social behaviours associated with ASD (The Social Responsiveness Scale, 2nd edition: SRS-2), sensory processing (the Short Sensory Profile: SSP), intelligence (The Kaufman Brief Intelligence Test, 2nd edition: KBIT-2), and concepts and following directions (the concepts and following directions subtest of the Clinical Evaluation of Language Fundamentals, 4th edition, Australian Standardised Edition: CELF-4 C&FD).

During the study, all children were assessed at the beginning of semester one, between semesters one and two, and at the end of semester two on measures of phonological processing in quiet and in noise (the nonword repetition and blending nonwords subtests of the Comprehensive Test of Phonological Processing, 2nd edition: CTOPP-2, presented with and without four-speaker babble noise), attention (the auditory component of the Test of Variables of Attention: TOVA), memory (the number memory forward and number memory backward subtests of the Test of Auditory Processing Skills, 3rd edition: TAPS-3), and educational achievement (Kaufmann Test of Educational Achievement, 3rd edition: KTEA-3).

5.3 What we found

Linear mixed model analyses showed significant effects involving SFA were observed for group by treatment interactions on the CTOPP-2 blending nonwords scores in quiet ($p<0.05$), in noise ($p<0.005$) and total ($p<0.005$). For the blending nonwords scores in quiet, the coefficient for this interaction effect was 2.55 with a standard error of 1.06 and a confidence interval of 0.47 to 4.63. For the blending nonwords scores in noise, the coefficient for this interaction effect was 3.35 with a standard error of 1.16 and a confidence interval of 1.09 to 5.62. For the blending nonwords scores in total, the coefficient for this interaction effect was 5.89 with a standard error of 1.99 and a confidence interval of 1.99 to 9.78. The coefficients for these significant interaction effects showed that compared to children not on the spectrum, children on the spectrum improved their raw scores on the blending nonwords test after SFA versus after no SFA by an average 2.55 points (items) more for blending nonwords in quiet, 3.35 points (items) more for blending nonwords in noise, and 5.89 points (items) more for blending nonwords in total.

5.4 What we think this means

The short-term use of SFA in classrooms could assist children on the spectrum to improve their skills in some areas of phonological processing (blending nonwords) in quiet and noise, but not in other areas of phonological processing (nonword repetition) in quiet and noise or areas of attention, memory, literacy or numeracy.

The gains observed in children on the spectrum on the blending nonwords test suggests short-term SFA supported at least some aspects of their phonological processing in quiet and noise. The ability to blend nonwords is thought to rely on a range of phonological processing skills including speech perception, phonological encoding, phonological memory, and phonological assembly. These skills are thought to develop in a graded manner as a child gains facility with the phonemes of his or her native language (Coady & Evans, 2008). We postulate that SFA supported elements of this graded development by allowing the children on the spectrum to more clearly and consistently hear the phonemes spoken by their teachers in their classrooms over the course of a semester. By easing the task of hearing, SFA could have allowed cognitive resources to be reallocated to the more complex task of phonological processing.

The absence of gains following short-term SFA on the tests of attention, memory, literacy and numeracy suggests no benefit for children on the spectrum in these areas. Longer periods of SFA may been needed to elicit measurable gains in these areas and/or non-standardized measures may be needed to better determine any gains present in this population as they are challenging to assess.

The absence of any reports of SFA aggravating hypo- or hyper-sensitivity to sounds, phonophobia, or over-interest in sounds, and the absence of any significant losses in phonological processing, attention, memory, literacy or numeracy, suggests the potential for SFA to harm children on the spectrum in the classroom is low.

Overall, the present study's results supported the suggestion that one semester of SFA could put children on the spectrum in a better position to learn but does not guarantee those children will go on to immediately improve their learning (after McArthur et al., 2008). This was consistent with reports of similarly graded scales of benefit from SFA and remote microphone hearing aid use in both typically and non-typically developing children. It also indicated the need for realistic expectations as to the immediate benefits of SFA for children on the spectrum in the classroom.

5.5 Limitations

This study had at least five limitations. First, its children on the spectrum represented a limited subpopulation of all children on the spectrum (those who can attend mainstream schools and complete lengthy batteries of standardised tests) that limited generalising the results to other populations of children on the spectrum. Second were the small sample sizes and the lack of pairing of children on and not on the spectrum. Third was the use of standardized measures of cognition and educational performance after SFA that could have missed functional gains in these areas during SFA. Fourth was the use of SFA for a single semester only and the assessment of participating children over a single year only, both of which could have missed benefits from longer term SFA. Finally, the present study compared participant groups and not individuals, which warrants particular caution when applying the study's results to individual children on the spectrum.

This study has been submitted for publication as: Wilson, W.J., Harper-Hill, K., Armstrong, R., Downing, C., Perrykkad, K., & Ashburner, J. (nd). Soundfield amplification for primary school students on the autism spectrum: standardised measures, Journal of Autism and Developmental Disorders.

6. Does SFA support children on the autism spectrum in the classroom, part 2: Functional measures

Short-term SFA in classrooms improved some listening behaviours in children, including those on the autism spectrum

6.1 Background

Despite its potential, research into classroom soundfield amplification (SFA) for children on the autism spectrum is limited to two studies. Rance et al. (2017) found SFA was associated with lower salivary cortisol levels in ten children on the spectrum (all male, aged 13.3 to 16.8 years) tasked with listening in a noisy environment. Those authors concluded that SFA could reduce the stress of listening in the classroom for children on the spectrum. Our third study in Project 2.028RS (section 5 above) found one semester of SFA in classrooms assisted children on the spectrum to improve their skills in some areas of phonological processing (blending nonwords) in quiet and noise, but not in other areas of phonological processing (nonword repetition) in quiet and noise or in academic performance (reading, spelling and maths), attention or memory. The mixed success of SFA for children on the spectrum in these two studies warrants the setting of reasonable expectations of the benefits that can be achieved from short term SFA in the classroom.

A potential limitation of both Rance et al. (2017) and our third study in Project 2.028RS was the use of standardised measures of behaviour. Such measures could have been insensitive to the minute-to-minute benefits of SFA or invalid as measures of the target behaviours in children on the spectrum whose abilities may not be reflected in their performances on standardised assessments. This is not a new concern in ASD research, having been noted by authors such as Rance et al. (2014) and Schafer et al (2016) who recommended functional measures be included in intervention studies involving children on the spectrum.

Functional measures attempt to quantify an individual’s performance on a particular task or activity in the context of specified social and physical environments; often focusing on tasks and activities related to work or self-care (collectively known as “activities of daily living”) (Frey, 2018). Two types of functional measurements were favoured for the present study: listening questionnaires and video classroom observation.

6.1.1 Aim

The present study aimed to determine if SFA supported the functional listening abilities of children on the spectrum in the classroom.

6.2 What we did

A two-group, randomised controlled trial (RCT) with crossover was conducted. Thirteen children (9 males, aged 7.6 to 8.4 years) on the spectrum and 17 children not on the spectrum (7 males, aged 7.6 to 9.3 years) participated from 12 primary schools in and near to Brisbane, Australia. Seventeen of these children had an SFA system in their classrooms in semester one and 13 in semester two of their fourth year of formal schooling (Year 3).

Prior to beginning the study, all children were assessed on measures of reciprocal social behaviours associated with ASD (The Social Responsiveness Scale, 2nd edition: SRS-2), sensory processing (the Short Sensory Profile: SSP), intelligence (The Kaufman Brief Intelligence Test, 2nd edition: KBIT-2), and concepts and following directions (the concepts and following directions subtest of the Clinical Evaluation of Language Fundamentals, 4th edition, Australian Standardised Edition: CELF-4 C&FD).

During the study, all children were assessed near to the end of semester one and near to the end of semester two on two measures: a set of questionnaires and an analysis of video recordings of their listening behaviours during normal classroom activities.

The set of questionnaires included two questionnaires asking teachers to reflect on the listening behaviour of the participating children during that semester – the Listening Inventory For Education-Revised, Teacher Checklist: Self-Advocacy and Instructional Access (LIFE-R TCSAIA: Anderson, Smaldino & Spangler, 2011) and the Listening Inventory For Education-Revised, Teacher Appraisal of Listening Difficulty (LIFE-R TALD: Anderson, Smaldino & Spangler, 2011); and two questionnaires asking the participating children to reflect on their listening behaviour during that semester – the Annoying Noises Questionnaire (ANQ: adapted from Dockrell and Shield, 2004) and a “How well did you hear your teacher” Questionnaire (HQ: adapted from Dockrell and Shield, 2004).

The video recordings of children’s listening behaviour in the classroom were completed in real-time on the day of each recording. Cameras were positioned to record forward facing or a rear facing view of participating children in each classroom from the beginning of a day’s classroom activities until the midday break (approximately three hours for each recording).

All classroom activities proceeded as per normal and without modification for the recordings. The video recordings were analysed offline using Vosaic Connect software and tagged in time to indicate the beginning of classroom activities (whole class or individual), teacher utterances requiring a response from a participating child (instruction or question), and child responses to teacher utterances (responses could be verbal or physical as appropriate to the teacher's instruction or question). These tags were used to calculate for each participating child the time in whole class activities, time in individual student activities, number of teacher instructions, number of teacher questions, number of child responses to teacher instructions, number of child responses to teacher questions, average time each student took to respond to teacher instructions, and average time each student took to respond to teacher questions.

6.3 What we found

Mixed design ANOVA analyses and non-parametric statistical analyses of the questionnaire scores showed teachers reported that SFA benefitted listening ($p<0.01$, LIFE-R Listening) for all children including those on the spectrum. No other benefits from SFA were observed in the other measures of teacher ratings of child self-advocacy and instructional access (LIFE-R TCSAIA) or child ratings of detecting annoying noises (ANQ) and hearing the teacher (HQ). Linear mixed model analysis of the video data showing no benefits from SFA for children's average response times to teacher instructions and questions for children both on and not on the spectrum.

6.4 What we think this means

The use of SFA in the classroom supported some but not all functional listening abilities in children including those on the spectrum. The abilities supported were indicated by teachers on the LIFE-R Listening questionnaire as including focusing on/following verbal instructions, attending to and following directions and class activities, staying on task, answering questions, attending to verbal instruction and understanding when noise is present, and rate of comprehension (teacher ratings on the LIFE-R Listening questionnaire). The functional listening abilities not supported by SFA were student self-advocacy for listening in the classroom (teacher ratings on the LIFE-R Self-advocacy questionnaire), hearing and being annoyed by distracting or non-distracting sounds in the classroom (child responses on the ANQ), hearing the teacher in poorer or better listening conditions (child ratings on the HQ), and student response times to teacher instructions and questions (video analyses).

The mixed benefits of SFA for children including those on the spectrum in the present study was consistent with similar (although limited) reports in other clinical populations with Maag and Anderson (2006) reporting SFA improved the speed of compliance with task demand directions but not with high interest directions in the classroom in children with emotional and behavioural disorders, and Maag and Anderson (2007) reporting SFA improved the speed of response to four types of directions in the classroom in children with attention deficit hyperactivity disorder (ADHD). While the differences in populations sampled and measurements used is noted, combining the present study's results with those of Maag and Anderson (2006, 2007) supports a conclusion that while the potential for SFA use with children on the spectrum is promising, it must be tempered against the benefits that can reasonably be expected to be achieved in real world environments.

Overall, the present study's finding that SFA use in classrooms supported some functional listening abilities in children including those on the spectrum adds to previous reports that SFA shows sufficient potential for improving classroom performance in children on the spectrum to warrant trialling on a case-by-case basis (Rance et al., 2017; section 5 above). Realistic expectations of the benefits that can reasonably be expected from SFA in real world classroom environments is needed, however, as is the need to consider the auditory, speech and language processing difficulties of children on the spectrum and the likelihood of those difficulties benefitting from SFA alone. The absence in the present study of any overtly negative effects of SFA suggests the potential for SFA to harm children on the spectrum in the classroom is low.

6.5 Limitations

This study had at least five limitations. First, given its shared participants with the third study in Project 2.028RS, its children on the spectrum represented a limited subpopulation of all children on the spectrum (those who can attend mainstream schools and complete questionnaires) that limits generalising the study's results. Second were the small sample sizes and the lack of pairing of children on and not on the spectrum. Third was the particular questionnaires used and the video analyses being limited to child response times to teacher instructions and questions only, both of which could have missed other functional listening gains during SFA. Fourth, the series of mixed design ANOVAs used to analyse the scores on the teacher and student questionnaires did not consider the cross-over design of the study and made use of parametric tests when analysing ordinal data. Finally, the present study compared participant groups and not individuals, which warrants particular caution when applying the study's results to individual children on the spectrum.

This study has been submitted for publication as: Wilson, W.J., Harper-Hill, K., Downing, C., Armstrong, R., Perrykkad, K., & Ashburner, J. (nd). Soundfield amplification for primary school students on the autism spectrum: Functional measures. Journal of Autism and Developmental Disorders.

7. Overall conclusions

SFA shows sufficient potential for improving classroom performance in children on the autism spectrum to warrant trialling on a case-by-case basis

7.1 Summary of all findings

7.1.1 Supporting children on the autism spectrum in the classroom

The National Guideline for the Assessment and Diagnosis of Autism Spectrum Disorders (ASD) in Australia (Whitehouse et al., 2018, p. 2) defines ASD the collective term for a group of neurodevelopmental disorders characterised by persistent deficits in social communication and social interaction, and by repetitive patterns of behaviour and restricted interests. Most primary schools in Australia include children on the spectrum (Autism Advisory Board on Autism Spectrum Disorders, 2010) with the Australian Bureau of Statistics (2015) reporting a prevalence of 2.8% in children aged five to nine years age from data obtained in 2012 to 2015. Support for these children is mandated by Government policies for inclusive education (e.g., Every Student with Disability Succeeding [Queensland Government, 2019] and Education for All [Victoria State Government, 2019]) that seek to identify effective classroom adjustments and strategies to meet the needs of diverse learners and create environments where all learners experience a sense of value and belonging.

Children on the autism spectrum are known to have difficulties with auditory, speech and language processing, although the nature of these difficulties is complex. As predicted by the Weak Central Coherence model and the Enhanced Perceptual Functioning model of autism, systematic reviews of the research literature have reported diverse examples of atypical processing of auditory information that are more likely (and more severe) for speech versus non-speech stimuli and for complex versus simple auditory information (Haesen et al., 2011; O'Connor, 2012; Samson et al., 2011). Other complexities such as hypo- and hyper-sensitivity to sounds, phonophobia, and over-interest in sounds (Ashburner et al., 2008; Tan et al., 2012) have also been reported.

Sound field amplification (SFA) systems have recently attracted interest as an inclusive classroom adjustment for children on the spectrum (Rance et al., 2017; van der Kruk et al., 2017). These systems typically consist of a microphone and transmitter worn by the teacher and a speaker or speakers placed in the classroom. When functioning optimally, SFA improves the signal-to-noise ratio (SNR) throughout most of a classroom by maintaining the teacher's voice (the signal) at a higher level than the classroom noise (the noise) (American Academy of Audiology, 2011a, 2011b; W. J. Keith & Purdy, 2014).

The potential benefits of SFA for children on the spectrum are many. As children spend 45-60% of the school day listening to their teacher and classmates (Butler, 1975; Rosenberg et al., 1999) in often poor acoustic environments (high noise levels and long reverberation times; Wilson et al., 2019), SFA could put children in a better position to learn (McArthur et al., 2008). For children on the spectrum this potential is suggested by Rance et al. (2017) who found SFA was associated with lower salivary cortisol levels in ten children on the spectrum tasked with listening in a noisy environment. Rance et al. (2017) concluded SFA could reduce classroom listening stress for these children.

7.1.2 Could SFA help children on the autism spectrum in the classroom?

SFA could help children on the autism spectrum

A systematic review of the scientific literature was conducted to determine if improving classroom acoustics could help improve classroom performance in children on the spectrum. The evidence was found to be suggestive that improving the SNR (intervention) leads to improved classroom performance (outcome) in children with ASD (population) compared to no intervention (comparison).

7.1.3 The acoustics of classrooms in Brisbane, Australia

The "acoustic health" of primary school classrooms in Brisbane is generally poor

A single group, cross-sectional research study was conducted to determine the classroom acoustics of a large sample of primary school classrooms in and around Brisbane, Australia. The "acoustic health" of 33 primary school classrooms in Brisbane and its surrounding regions was found to be generally poor but similar to that seen in classrooms around the world. These results were most likely due to the design and build of these classrooms. These classrooms were deemed to be likely to benefit from routine measurement of their classroom acoustics and relatively standard methods of improving those acoustics. The trialling of SFA was also deemed to be a viable option for these classrooms.

7.1.4 Does SFA support children on the autism spectrum in the classroom, part 1: Standardised measures

Short-term SFA in classrooms helped children on the autism spectrum to improve their phonological processing but not their attention, memory, literacy or numeracy.

A two-group, randomised controlled trial with crossover was conducted to determine if SFA supported children on the autism spectrum in primary school classrooms in Brisbane, Australia. Part 1 of this study used standardized measures to show that short-term use of SFA in classrooms could assist children on the spectrum to improve their skills in some areas of phonological processing (blending nonwords) in quiet and noise, but not in other areas of phonological processing (nonword repetition) in quiet and noise or attention, memory, literacy or numeracy. These results supported the suggestion that one semester of SFA could put children on the spectrum in a better position to learn but does not guarantee those children will go on to immediately improve their learning (after McArthur et al., 2008). This was consistent with reports of similarly graded scales of benefit from SFA and remote microphone hearing aid use in both typically and non-typically developing children. It also indicated the need for realistic expectations as to the immediate benefits of SFA for children on the spectrum in the classroom.

7.1.5 Does SFA support autistic children in the classroom, part 2: Functional measures

Short-term SFA in classrooms improved some listening behaviours both in children including those on the autism spectrum

Part 2 continued the two-group, randomised controlled trial with crossover by using teacher and student questionnaires and video assessment of student behaviour to determine the level of support offered by SFA to children on the spectrum. Its results showed the use of SFA in the classroom supported some but not all functional listening abilities in children including those on the spectrum. These results were consistent with similar (although limited) reports in other clinical populations and support a conclusion that while the potential for SFA use with children on the spectrum is promising, it must be tempered against the benefits that can reasonably be expected to be achieved in real world environments.

7.2 Sound filed amplification for students on the autism spectrum in the classroom

Overall, the findings of *Project 2.028RS* findings add to previous reports that SFA shows sufficient potential for improving classroom performance in children on the spectrum to warrant trialling on a case-by-case basis (Rance et al., 2017; Wilson et al., submitted, submitted). Realistic expectations of the benefits that can reasonably be expected from SFA in real world classroom environments is needed, however, as is the need to consider the auditory, speech and language processing difficulties of children on the spectrum and the likelihood of those difficulties benefitting from SFA alone. The absence in *Project 2.028RS* of any overtly negative effects of SFA suggests the potential for SFA to harm children on the spectrum in the classroom is low.

7.3 Future research

The potential for SFA to improve classroom performance in children on the spectrum warrants future research. This research should consider several factors including:

- Longer-term use of SFA. *Project 2.028RS*'s use of SFA for a single semester (two terms) only, and its assessment of the participating children during a single year only, prevented comment on any longer term benefits arising from SFA. If SFA does put children on the spectrum in a better position to learn, then longer-term investigations into the use of SFA would allow researchers to determine the degree to any such learning takes place in the presence of ongoing SFA.

- Greater use of functional outcome measures. While partly addressed by the use of teacher and student questionnaires and classroom observation in *Project 2.028RS*, further use of a wider range of function measures is recommended. Video analyses of real-time listening abilities in classrooms with and without SFA has potential in this regard as a means of directly measuring functional listening abilities that are only indirectly measured by teacher and student questionnaires and often not measured by standardised assessments of audition, language and cognition.

- Investigation of a wider range of children on the spectrum. *Project 2.028RS* was limited to considering children on the spectrum who could attend mainstream schools and complete lengthy batteries of standardised tests, questionnaires, and video recording. The results of SFA for other populations of children on the spectrum may differ to those obtained in the present study.

- Case studies. *Project 2.028RS* compared participant groups and not individuals. Given the wide range of abilities present in children on the spectrum, future research would benefit from the inclusion of carefully designed case studies to further demonstrate the need to consider SFA on a case-by-case basis for children on the spectrum.

Independent of children on the spectrum in the classroom, future research into the acoustics of classrooms in Australia is needed both in the short and long term. In the short term, research is needed to determine why long-standing and ongoing calls to systematically improve classroom acoustics remain unanswered. In the long term, data is needed to better describe the acoustic status of a wider range of classrooms stratified by type and region across Australia. Both of these areas of research will require greater co-operation amongst all stakeholders interested in childhood education.

8. Implications for Research and Practice

8.1 Implications for research

The findings of *Project 2.028RS* support ongoing research into the potential benefits of improving classroom acoustics for children on the autism spectrum. To date, this research has focused on the use of remote microphone hearing aids (RMHAs) with initial reports suggesting RMHA (Rance et al., 2017; Rance et al., 2014; Schafer et al., 2013; Schafer et al., 2016) may be more beneficial than SFA (Rance et al., 2017; this report) for some children on the spectrum. Limitations such as the potential for RMHAs to aggravate tactile sensitivities in some children on the spectrum (Rance et al., 2017; Rance et al., 2014) supports the need for ongoing research into alternative methods of improving classroom acoustics such as SFA and classroom acoustic modification. To better determine the benefits or not of classroom SFA for children on the spectrum, future research should consider longer-term use of SFA, greater use of functional outcome measures, investigation of a wider range of children on the spectrum, and the use of case studies to expand on the small but promising body of research into the use of classroom SFA for children on the spectrum.

8.2 Implications for practice

The findings of *Project 2.028RS* show SFA has sufficient potential for improving classroom performance in children with ASD to warrant trialling in classrooms on a case-by-case basis. Realistic expectations of the potential benefits of SFA for children on the spectrum are needed with it being reasonable to expect that short-term SFA could benefit children on the spectrum in some areas of phonological processing and functional listening abilities, but not all areas phonological processing and functional listening abilities and not attention, memory, literacy or numeracy. This suggests SFA could put children on the spectrum in a better position to learn but does not guarantee those children will go on to immediately improve their learning (after McArthur et al., 2008). The absence in *Project 2.028RS* of any overtly negative effects of SFA suggests the potential for SFA to harm children on the spectrum in the classroom is low.

9. Key Recommendations

9.1 The trialling of SFA in classrooms is warranted

The trialling on a case-by-case basis of SFA in classrooms with children on the autism spectrum is warranted. Realistic expectations of the potential benefits of SFA for children on the spectrum are needed with SFA potentially putting children in a better position to learn but not guaranteeing they will go on to immediately improve their learning. SFA also offers a low risk of harm for children on the spectrum

9.2 Further research into classroom acoustics for children on the spectrum

The potential for any improvement in classroom acoustics to benefit children on the spectrum in the classroom warrants further research. Continued investigation into all means of improving classroom acoustics is recommended, including SFA, RMHAs and classroom acoustic modification.

10. Project Outputs

10.1 Completed

10.1.1 Papers published in peer reviewed scientific journals

1. Wilson, W.J., Downing, C., Perrykkad, K., Armstrong, R., Arnott, W.L., Ashburner, J., & Harper-Hill, K. (2019). The "acoustic health" of primary school classrooms in Brisbane, Australia. Speech, Language and Hearing. doi: 10.1080/2050571X.2019.1637042.

2. Van der Kruk, Y., Wilson, W.J., Downing, C., Palghat, K., Harper-Hill, K., & Ashburner, J. (2017). Improved signal-to-noise ratio and classroom performance in children with Autism Spectrum Disorder: A systematic review. Review Journal of Autism and Developmental Disorders, 4(3), 243-253.

10.1.2 Presentations at scientific conferences

1. Carrington, S., Harper-Hill, K., Whelan, M., Kerr, J., & Wilson, W.J. (2019). Supporting teachers to include all: Research to practice. A panel presentation at The Inclusive Education Summit (TIES) 2019, Oct 25-27, Auckland, New Zealand. [Note: the presentation from the work of Project 2.028RS was titled: A UDL approach to improving classroom acoustics].

2. Armstrong, R., Downing, C., Harper-Hill, K., Perrykkad, K., Ashburner, J., & Wilson, W.J. (2019). A classroom acoustics guide for speech pathologists 101. A paper presented at the Speech Pathology Australia and New Zealand Speech Therapy Association Joint Conference titled "Engaging, collaboration, Empowering", June 2-5, Brisbane, Australia.

3. Wilson, W.J., Downing, C., Perrykkad, K., Armstrong, R., Ashburner, J., & Harper-Hill, K. (2019). Measuring and improving the acoustics of your classroom. An invited paper presented at Autism Queensland's "Research to Practice: Inclusion and universal design for learning", May 10, Brisbane, Australia.

4. Wilson, W.J., Downing, C., Perrykkad, K., Armstrong, R., Ashburner, J., & Harper-Hill, K. (2019). Improving classroom acoustics. An invited webinar presented as part of the Cooperative Research Centre for Living with Autism Spectrum Disorders (Autism CRC) School Years webinar series for Autism Month. Presented on Tuesday, April 30, 2019.

5. van der Kruk, Y., Wilson, W.J., Palghat, K., Downing, C., Harper-Hill, K., & Ashburner, J. (2018). A review of SNR and classroom performance in children on the autism spectrum. A poster presented at the 23rd National Conference of Audiology Australia, May 20-23, Sydney, Australia.

6. Wilson, W.J., Downing, C., Palghat, K., Armstrong, R., van der Kruk, Y., Ashburner, J., & Harper-Hill, K. (2018). Acoustics in Brisbane classrooms. A paper presented at the 23rd National Conference of Audiology Australia, May 20-23, Sydney, Australia.

7. Wilson, W.J., Harper-Hill, K., Ashburner, J., Kerlen, Y., Palghat, K., Downing, C., & Armstrong, R. (2017). (Central) auditory processing, language & Autism Spectrum Disorder: ACRC Project 2.028 RS. An invited paper presented at Autism Queensland's "Research to Practice: Exploring and explaining current autism research. Part One: Sensory processing issues of people with ASD: What we can do to help", May 19, Brisbane, Australia.

10.1.3 Translational works

1. Wilson, W.J., Harper-Hill, K., Downing, C., Armstrong, R., Perrykkad, K., & Ashburner, J. (2019). The impact of improved classroom acoustics on autistic students. A Core Research module on the inclusionEd supporting diverse learners service of the Autism CRC.

2. Wilson, W.J., Harper-Hill, K., Downing, C., Armstrong, R., Perrykkad, K., & Ashburner, J. (2019). Improving the acoustics of your classroom. A Practice module on the inclusionEd supporting diverse learners service of the Autism CRC.

3. Wilson, W.J., Harper-Hill, K., Downing, C., Armstrong, R., Perrykkad, K., & Ashburner, J. (2019). Assessing the acoustics of your classroom. A Practice module on the inclusionEd supporting diverse learners service of the Autism CRC.

10.2 Pending

10.2.1 Papers submitted for publication in peer reviewed scientific journals

1. Wilson, W.J., Harper-Hill, K., Armstrong, R., Downing, C., Perrykkad, K., & Ashburner, J. (nd). Soundfield amplification for primary school students on the autism spectrum: standardised measures, Journal of Autism and Developmental Disorders.

2. Wilson, W.J., Harper-Hill, K., Downing, C., Armstrong, R., Perrykkad, K., & Ashburner, J. (nd). Soundfield amplification for primary school students on the autism spectrum: Functional measures. Journal of Autism and Developmental Disorders.

3. Wainman, B., Harper-Hill, K., Armstrong, R., Downing, C., Perrykkad, K., Ashburner, J., & Wilson, W.J. (nd). Soundfield amplification for primary school students on the autism spectrum: Case studies. Learning & Instruction.

10.2.2 Papers submitted for presentation at scientific conferences

1. Wilson, W.J., Harper-Hill, K., Downing, C., Perrykkad, K., Ashburner, J., & Armstrong, R. (2020). Does sound field amplification help the classroom performance of Year 3 students on the autism spectrum? An abstract paper submitted for the Speech Pathology Australia 2020 National Conference titled "Local Contexts, Global Practice", to be held in Darwin, Australia in May 2020.

2. Harper-Hill, K., Armstrong, R., Downing, C., Perrykkad, K., Ashburner, J., & Wilson, W.J., (2020). What is the impact of improved classroom acoustics on perceived ease-of-listening and instruction response times in Year 3 students on the autism

spectrum and their peers? An abstract paper submitted for the Speech Pathology Australia 2020 National Conference titled “Local Contexts, Global Practice”, to be held in Darwin, Australia in May 2020.

3. Armstrong, R., Wilson, W.J., Wainman, B., Downing, C., Perrykkad, K., Ashburner, J., & Harper-Hill, K. (2020). Case studies on sound field amplification for children on the autism spectrum in the classroom. An abstract paper submitted for the Speech Pathology Australia 2020 National Conference titled “Local Contexts, Global Practice”, to be held in Darwin, Australia in May 2020.

10.2.3 Papers to be submitted for presentation at scientific conferences

1. Wilson, W.J., Harper-Hill, K., Armstrong, R., Downing, C., Perrykkad, K., & Ashburner, J. (nd). Soundfield amplification for primary school students on the autism spectrum: standardised measures, An autism conference to be selected.

2. Wilson, W.J., Harper-Hill, K., Downing, C., Armstrong, R., Perrykkad, K., & Ashburner, J. (nd). Soundfield amplification for primary school students on the autism spectrum: Functional measures. Journal of Autism and Developmental Disorders. An autism conference to be selected.

3. Wainman, B., Harper-Hill, K., Armstrong, R., Downing, C., Perrykkad, K., Ashburner, J., & Wilson, W.J. (nd). Soundfield amplification for primary school students on the autism spectrum: Case studies. Learning & Instruction. An autism conference to be selected.

10.2.4 Translational works in preparation

1. Wilson, W.J., Harper-Hill, K., Downing, C., Armstrong, R., Perrykkad, K., & Ashburner, J. (2019). Sound field amplification for your classroom. A Practice module on the inclusionEd supporting diverse learners service of the Autism CRC.

References

American Academy of Audiology. (2011a). Clinical practice guidelines: Remote microphone hearing assistance technologies for children and youth from birth to 21 years (includes supplement A). Retrieved from https://audiology-web.s3.amazonaws.com/migrated/HAT_Guidelines_Supplement_A.pdf_53996ef7758497.54419000.pdf

American Academy of Audiology. (2011b). Clinical practice guidelines: Remote microphone hearing assistance technologies for children and youth from birth to 21 years. Supplement B: Classroom audio distribution systems - selection and verification. Retrieved from https://audiology-web.s3.amazonaws.com/migrated/HAT_Guidelines_Supplement_A.pdf_53996ef7758497.54419000.pdf

American National Standards Institute. (2002). ANSI. 2002. ANSI S12.60-2002, Acoustical performance criteria, design requirements, and guidelines for schools. In. Melville, NY: Acoustical Society of America.

American Speech-Language-Hearing Association. (2005). Acoustics in educational settings: Position statement.

Anderson, K. (2001). Kids in noisy classrooms: what does the research really say? Journal of Educational Audiology, 9, 21-33.

Ashburner, J., Ziviani, J., & Rodger, S. (2008). Sensory processing and classroom emotional, behavioral, and educational outcomes in children with autism spectrum disorder. American Journal of Occupational Therapy, 62(5), 564-573. doi:DOI 10.5014/ajot.62.5.564

Australian Advisory Board on Autism Spectrum Disorders. (2010). Education and Autism Spectrum Disorders in Australia: The provision of appropriate educational services for school-age students with Autism Spectrum Disorders in Australia. Retrieved from Forestville, Australia: http://www.saasso.asn.au/wp-content/uploads/2012/11/Education-Autism-Spectrum-Disorders-in-Australia.pdf

Australian Bureau of Statistics. (2015). 4430.0 - Disability, ageing and carers, Australia: Summary of findings, 2015 Retrieved from https://www.abs.gov.au/ausstats/abs@.nsf/Latestproducts/4430.0Main%20Features752015

Bennetts, L. K., & Flynn, M. C. (2002). Improving the classroom listening skills of children with Down syndrome by using soundfield amplification. Down's Syndrome, Research and Practice, 8, 19–24.

Blake, R., Field, B., Foster, C., Platt, F., & Wertz, P. (1991). Effect of FM auditory trainers on attending behaviors of learning-disabled children. Language, Speech, and Hearing Services in Schools, 22, 111-114.

Bolt, R. H., & Macdonald, A. D. (1949). Theory of speech masking by reverberation. Journal of the Acoustical Society of America, 21(6), 577-580. doi:Doi 10.1121/1.1906551

Butler, K. (1975). Auditory perceptual skills: Their measurement and remediation with preschool and school-age children. Paper presented at the American Speech-Language-Hearing Association Convention, Washington, D.C.

Cassidy, G., & MacDonald, R. A. R. (2007). The effect of background music and background noise on the task performance of introverts and extraverts. Psychology of Music, 35(3), 517-537. doi:10.1177/0305735607076444

Coady, J. A., & Evans, J. L. (2008). Uses and interpretations of non-word repetition tasks in children with and without specific language impairments (SLI). International Journal of Language & Communication Disorders, 43(1), 1-40. doi:10.1080/13682820601116485

Crandell, C., & Bess, F. (1987). Sound-field amplification in the classroom setting. ASHA, 29, 87.

Crandell, C., & Smaldino, J. J. (2000). Classroom acoustics for children with normal hearing and with hearing impairment. Language Speech and Hearing Services in Schools, 31(4), 362-370. doi:Doi 10.1044/0161-1461.3104.362

Dockrell, J. E., & Shield, B. (2012). The impact of sound-field systems on learning and attention in elementary school classrooms. Journal of Speech Language and Hearing Research, 55(4), 1163-1176. doi:10.1044/1092-4388(2011/11-0026)

Dockrell, J. E., & Shield, B. M. (2006). Acoustical barriers in classrooms: The impact of noise on performance in the classroom. British Educational Research Journal, 32(3), 509-525. doi:10.1080/01411920600635494

Elliott, L. L. (1979). Performance of Children Aged 9 to 17 Years on a Test of Speech-Intelligibility in Noise Using Sentence Material with Controlled Word Predictability. Journal of the Acoustical Society of America, 66(3), 651-653. doi:Doi 10.1121/1.383691

Elliott, L. L. (1982). Effects of noise on perception of speech by children and certain handicapped individuals. Sound and Vibration, 71, 9-14.

Finitzo-Hieber, T., & Tillman, T. W. (1978). Room acoustics effects on monosyllabic word discrimination ability for normal and hearing-impaired children. Journal of Speech and Hearing Research, 21(3), 440-458.

Flexer, C., Millin, J. P., & Brown, L. (1990). Children with developmental disabilities: The effect of sounds filed amplification on word identification. Language, Speech, and Hearing Services in Schools, 21, 177–182.

Frey, W. D. (2018). Functional measurement. Encyclopedia Britannica. Retrieved from https://www.britannica.com/science/functional-measurement

Gotaas, C., & Starr, C. D. (1993). Vocal fatigue among teachers. Folia Phoniatrica, 45(3), 120-129. doi:Doi 10.1159/000266237

Greenland, E. E., & Shield, B. M. (2011). A survey of acoustic conditions in semi-open plan classrooms in the United Kingdom. Journal of the Acoustical Society of America, 130(3), 1399-1410. doi:10.1121/1.3613932

Haesen, B., Boets, B., & Wagemans, J. (2011). A review of behavioural and electrophysiological studies on auditory processing and speech perception in autism spectrum disorders. Research in Autism Spectrum Disorders, 5(2), 701-714. doi:10.1016/j.rasd.2010.11.006

Johnston, K. N., John, A. B., Kreisman, N. V., Hall, J. W., & Crandell, C. C. (2009). Multiple benefits of personal FM system use by children with auditory processing disorder (APD). International Journal of Audiology, 48(6), 371-383.

Keith, R. W. (1999). Clinical issues in central auditory processing disorders. Language, Speech, and Hearing Services in Schools, 30(339-344).

Keith, W. J., & Purdy, S. C. (2014). Assistive and therapeutic effects of amplification for auditory processing disorder. Seminars in Hearing, 35(1), 27-38.

Kinnealey, M., Pfeiffer, B., Miller, J., Roan, C., Shoener, R., & Ellner, M. L. (2012). Effect of Classroom Modification on Attention and Engagement of Students With Autism or Dyspraxia. American Journal of Occupational Therapy, 66(5), 511-519. doi:10.5014/ajot.2012.004010

Klatte, M., Lachmann, T., & Meis, M. (2010). Effects of noise and reverberation on speech perception and listening comprehension of children and adults in a classroom-like setting. Noise & Health, 12(49), 270-282. doi:10.4103/1463-1741.70506

Lochner, J. P. A., & Burger, J. F. (1964). Influence of reflections on auditorium acoustics. Journal of Sound and Vibration, 1(4), 426-&. doi:Doi 10.1016/0022-460x(64)90057-4

Maag, J. W., & Anderson, J. M. (2006). Effects of sound-field amplification to increase compliance of students with emotional and behavior disorders. Behavioral Disorders, 31(4), 378-393.

Maag, J. W., & Anderson, J. M. (2007). Sound-field amplification to increase compliance to directions in students with ADHD. Behavioral Disorders, 32(4), 238-253.

Massie, R., & Dillon, H. (2006). The impact of sound-field amplification in mainstream cross-cultural classrooms: Part 1 - Educational outcomes. Australian Journal of Education, 50(1), 62-77.

Maxwell, L. E., & Evans, G. W. (2000). The effects of noise on pre-school children's pre-reading skills. Journal of Environmental Psychology, 20(1), 91-97. doi:DOI 10.1006/jevp.1999.0144

McArthur, G. M., Ellis, D., Atkinson, C. M., & Coltheart, M. (2008). Auditory processing deficits in children with reading and language impairments: Can they (and should they) be treated? Cognition, 107(3), 946-977.

Mealings, K. T. (2016, 9-11 November 2016). Classroom acoustic conditions: Understanding what is suitable through a review of national and international standards, recommendations, and live classroom measurements. Paper presented at the Acoustics 2016, Brisbane, Australia.

Mealings, K. T., Buchholz, J. M., Demuth, K., & Dillon, H. (2015). Investigating the acoustics of a sample of open plan and enclosed Kindergarten classrooms in Australia. Applied Acoustics, 100, 95-105. doi:10.1016/j.apacoust.2015.07.009

Nabelek, A. K., & Pickett, J. M. (1974). Reception of consonants in a classroom as affected by monaural and binaural listening, noise, reverberation, and hearing-aids. Journal of the Acoustical Society of America, 56(2), 628-639.

Nabelek, A. K., & Robinson, P. K. (1982). Monaural and Binaural Speech-Perception in Reverberation for Listeners of Various Ages. Journal of the Acoustical Society of America, 71(5), 1242-1248.

Nelson, P. B., Kohnert, K., Sabur, S., & Shaw, D. (2005). Classroom noise and children learning through a second language: Double Jeopardy? Language Speech and Hearing Services in Schools, 36(3), 219-229. doi:10.1044/0161-1461(2005/022)

Nelson, P. B., & Soli, S. (2000). Acoustical barriers to learning: Children at risk in every classroom. Language Speech and Hearing Services in Schools, 31(4), 356-361. doi:Doi 10.1044/0161-1461.3104.356

O'Connor, K. (2012). Auditory processing in autism spectrum disorder: A review. Neuroscience and Biobehavioral Reviews, 36(2), 836-854. doi:10.1016/j.neubiorev.2011.11.008

Queensland Government. (2019). Every student with disability succeeding. Retrieved from https://education.qld.gov.au/students/students-with-disability/succeeding-with-disability

Rance, G., Chisari, D., Saunders, K., & Rault, J. L. (2017). Reducing listening-related stress in school-aged children with autism spectrum disorder. Journal of Autism and Developmental Disorders, 47(7), 2010-2022. doi:10.1007/s10803-017-3114-4

Rance, G., Saunders, K., Carew, P., Johansson, M., & Tan, J. (2014). The use of listening devices to ameliorate auditory deficit in children with autism. Journal of Pediatrics, 164(2), 352-357. doi:10.1016/j.jpeds.2013.09.041

Reynolds, S., Kuhaneck, H. M., & Pfeiffer, B. (2016). Systematic review of the effectiveness of frequency modulation devices in improving academic outcomes in children with auditory processing difficulties. American Journal of Occupational Therapy, 70(1). doi:10.5014/ajot.2016.016832

Ronsse, L. M., & Wang, L. M. (2013). Relationships between unoccupied classroom acoustical conditions and elementary student achievement measured in eastern Nebraska. Journal of the Acoustical Society of America, 133(3), 1480-1495. doi:10.1121/1.4789356

Rosenberg, G. G., Blake-Rahter, P., Heavner, J., Allen, L., Redmond, B. M., Phillips, J., & Stigers, K. (1999). Improving classroom acoustics (ICA): A three-year FM sound field classroom amplification study. Journal of Educational Audiology, 7, 8-28., 7, 8-28.

Samson, F., Hyde, K. L., Bertone, A., Soulieres, I., Mendrek, A., Ahad, P., . . . Zeffiro, T. A. (2011). Atypical processing of auditory temporal complexity in autistics. Neuropsychologia, 49(3), 546-555. doi:10.1016/j.neuropsychologia.2010.12.033

Schafer, E. C., Mathews, L., Mehta, S., Hill, M., Munoz, A., Bishop, R., & Moloney, M. (2013). Personal FM systems for children with autism spectrum disorders (ASD) and/or attention-deficit hyperactivity disorder (ADHD): An initial investigation. Journal of Communication Disorders, 46(1), 30-52. doi:10.1016/j.jcomdis.2012.09.002

Schafer, E. C., Traber, J., Layden, P., Amin, A., Sanders, K., Bryant, D., & Baldus, N. (2014). Use of wireless technology for children with auditory processing disorders, attention-deficit hyperactivity disorder, and language disorders. Seminars in Hearing, 35(3), 193–205.

Schafer, E. C., Wright, S., Anderson, C., Jones, J., Pitts, K., Bryant, D., . . . Reed, M. P. (2016). Assistive technology evaluations: Remote-microphone technology for children with Autism Spectrum Disorder. Journal of Communication Disorders, 64, 1-17. doi:10.1016/j.jcomdis.2016.08.003

Seibein, G. W., Gold, M. A., Siebein, G. W., & Ermann, M. G. (2000). Ten ways to provide a high-quality acoustical environment in schools. Language, Speech, and Hearing Services in Schools, 31, 376–384.

Shield, B., & Dockrell, J. E. (2003). The effects of noise on children at school: a review. Building Acoustics, 2(97–116).

Shield, B., Greenland, E., & Dockrell, J. (2010). Noise in open plan classrooms in primary schools: A review. Noise & Health, 12(49), 225-234. doi:10.4103/1463-1741.70501

Smaldino, J. J., & Crandell, C. C. (2000). Classroom amplification technology: Theory and practice. Language Speech and Hearing Services in Schools, 31(4), 371-375. doi:Doi 10.1044/0161-1461.3104.371

Smith, E., Gray, S. D., Dove, H., Kirchner, L., & Heras, H. (1997). Frequency and effects of teachers' voice problems. Journal of Voice, 11(1), 81-87. doi:Doi 10.1016/S0892-1997(97)80027-6

Standards Australia Limited/Standards New Zealand. (2016). AS/NZS 2107:2016 Acoustics - Recommended design sound levels and reverberation times for building interiors. In: Standards Australia Limited and Standards New Zealand.

Steeneken, H. J. M., & Houtgast, T. (1980). Physical method for measuring speech-transmission quality. Journal of the Acoustical Society of America, 67(1), 318-326. doi:10.1121/1.384464

Tan, Y. H., Xi, C. Y., Jiang, S. P., Shi, B. X., Wang, L. B., & Wang, L. M. (2012). Auditory abnormalities in children with autism. Open Journal of Psychiatry, 2, 33–37.

Updike, C. D. (2006). The use of FM systems for children with attention deficit disorder. Journal of Educational Audiology, 13, 7-14.

van der Kruk, Y., Wilson, W. J., Palghat, K., Downing, C., Harper-Hill, K., & Ashburner, J. (2017). Improved signal-to-noise ratio and classroom performance in children with autism spectrum disorder: A systematic review. Review Journal of Autism and Developmental Disorders, 4(3), 243-253. doi:10.1007/s40489-017-0111-7

Vickers, D. A., Backus, B. C., Macdonald, N. K., Rostamzadeh, N. K., Mason, N. K., Pandya, R., . . . Mahon, M. H. (2013). Using personal response systems to assess speech perception within the classroom: An approach to determine the efficacy of sound field amplification in primary school classrooms. Ear and Hearing, 34(4), 491-502. doi:10.1097/AUD.0b013e31827ad76f

Victoria State Government. (2019). Education for all. Retrieved from https://www.education.vic.gov.au/about/programs/Pages/Education-for-all.aspx

Whitehouse, A. J. O., Evans, K., Eapen, V., & Wray, J. A. (2018). A national guideline for the assessment and diagnosis of autism spectrum disorders in Australia. Brisbane, Australia: Cooperative Research Centre for Living with Autism.

Wilson, W. J., Downing, C., Perrykkad, K., Armstrong, R., Arnott, W. L., Ashburner, J., & Harper-Hill, K. (2019). The ‘acoustic health’ of primary school classrooms in Brisbane, Australia. Speech, Language and Hearing. doi:10.1080/2050571X.2019.1637042

Wilson, W. J., Marinac, J., Pitty, K., & Burrows, C. (2011). The use of sound-field amplification devices in different types of classrooms. Language Speech and Hearing Services in Schools, 42(4), 395-407. doi:10.1044/0161-1461(2011/09-0080)

Young, D., Bradle, P., Hickson, L., & Lawson, M. (1997). Preferred FM system listening levels of children with central auditory processing disorders. Journal of the Academy of Rehabilitative Audiology, 30, 53-61.

Autism CRC
The University of Queensland
Long Pocket Precinct
Level 3, Foxtail Building
80 Meiers Road
Indooroopilly QLD 4068

T +61 7 3377 0600
E info@autismcrc.com.au
W autismcrc.com.au

@autismcrc

Australian Government
Department of Industry, Innovation and Science

Business
Cooperative Research Centres Program