AN INVESTIGATION INTO HOW THE ACOUSTICS OF OPEN PLAN AND ENCLOSED CLASSROOMS AFFECT SPEECH PERCEPTION FOR KINDERGARTEN CHILDREN

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Declaration

The research presented in this thesis is my original work and it has not been submitted for a higher degree in any other institution. In addition, I certify that all information sources and literature used are indicated in the thesis. The research presented in this thesis has gained ethics from Macquarie University (5201300038).

Some of the material in this thesis has already been submitted/accepted for publication. Chapter 2 is based on the publication (1). Chapter 3 is based on the publication (2). Chapter 4 is based on the publication (3). Chapter 5 is based on the publication (4). Chapter 6 is based on the publication (5).

- 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
- (2) Mealings, K. T., Demuth, K., Buchholz, J. M., & Dillon, H. (2015). The development of the Mealings, Demuth, Dillon, and Buchholz Classroom Speech Perception Test. *Journal* of Speech, Language, and Hearing Research, 58, 1350-1362. doi:10.1044/2015_JSLHR-H-14-0332
- (3) Mealings, K. T., Demuth, K., Buchholz, J. M., & Dillon, H. (2015). The effect of different open plan and enclosed classroom acoustic conditions on speech perception in Kindergarten children. *Journal of the Acoustical Society of America*.
- (4) Mealings, K. T., Dillon, H., Buchholz, J. M., & Demuth, K. (in press). An assessment of open plan and enclosed classroom listening environments for young children: Part 1 – Children's questionnaires. *Journal of Educational, Pediatric & (Re)Habilitative Audiology.*
- (5) Mealings, K. T., Demuth, K., Buchholz, J. M., & Dillon, H. (under review). An assessment of open plan and enclosed classroom listening environments for young children: Part 2 – Teachers' questionnaires. *Journal of Educational, Pediatric & (Re)Habilitative Audiology.*

I additionally certify that I was the first author of all the chapters of this thesis, and all data collection and writing of the papers was completed by me.

Signed: KMealings

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Thesis Summary

Open plan classrooms, where several class bases share the same space, have recently reemerged in Australian primary schools. This is due to a more child-centred teaching philosophy which focuses on group work, sharing resources, and the social development of the child. They also promote team-teaching and joint collaboration which is thought to facilitate a more cooperative and supportive teaching and learning atmosphere. However, because of the large number of children engaging in different activities and the lack of barriers between classes, these spaces are subject to high noise levels. Therefore, it is timely to conduct research in these classrooms to assess their appropriateness for 5-6-year-old Kindergarten children.

This thesis by publication is comprised of five studies that aim to comprehensively compare the listening environments of four different types of classrooms: an enclosed classroom with 25 children, a double classroom with 44 children, an untreated linear fully open plan triple classroom with 91 children, and a purpose-built semi-open plan Kindergarten-to-Year-6 classroom with 205 children. Chapter 1 provides an introduction to the studies. Chapter 2 describes the first objective study which calculated and compared the noise levels, signal-to-noise ratios, speech transmission index scores, and reverberation times across classrooms. Chapter 3 describes the development of a new classroom speech perception task that can be conducted live and efficiently in real classroom listening environments. This speech perception task was used in the third study (Chapter 4) to objectively assess how the acoustics of the classrooms measured in the first study affect children's speech perception accuracy and speed. Chapters 5 and 6 describe the subjective studies of this thesis which examined the children's and teachers' perceptions of their classroom listening environment via a questionnaire. Finally, Chapter 7 discusses the impact of these findings for each classroom, draws conclusions, and suggests future research directions.

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CHAPTER 1: INTRODUCTION

Kindergarten is children's first experience of formal primary school education in Australia. Throughout this year at school, children are introduced to the basic literacy and numeracy concepts which will be the building blocks for the rest of their education. As the principal modes of communication in the educational setting are speaking and listening, it is important that the acoustic learning environment is conducive from these early stages to enhance future opportunities for these children. The most common classroom type over the past 30-40 years has been a traditional enclosed classroom with four walls and 20-30 children and their teacher occupying the space. Recently, however, open plan classrooms (often renamed as '21st century learning spaces') have been re-emerging in countries such as Australia, New Zealand, the United Kingdom, the United States of America, Canada, Norway, Sweden, Portugal, Denmark, and Japan, after first being popular in the 1960's and 1970's. In these classrooms classes are still divided into class bases of 20-30 children with their own teacher, but there are multiple class bases in the one room without walls separating them. Open plan classrooms in Sydney vary in size from double classrooms with 40-50 children up to classrooms containing a whole primary school of 200 children. Therefore, it is timely to assess the suitability of these different sized classrooms as listening environments for young children. In particular, we need to determine whether the modern designs and advanced acoustic treatments installed in some of these newer classrooms have made these spaces more usable than the original open plan classrooms of the 1960's and 1970's.

Open Plan Classrooms

Open plan classroom styles were first popular during the educational reform of the 1960's and 1970's due to both post-war economic restraints and educational reasons (Bennett, Andrae, Hegarty, & Wade, 1980). During the educational reform, there was a shift from traditional didactic teaching to a more 'child-centered' approach (Brogden, 1983; see also Shield, Greenland, & Dockrell, 2010). As a result, open plan classroom styles were increasingly adopted for their less authoritarian, more 'home-like' atmosphere that allowed for a range of activities to be carried out (Brogden, 1983; Maclure, 1984). Additionally, they were thought to

better facilitate group work, the children's social development, and make children take more responsibility for their work (Brogden, 1983; Hickey & Forbes, 2011). Open plan classrooms were also seen to benefit teachers as they promoted the sharing of skills, ideas, and experiences, allowed for team-teaching, joint planning and organisation, and provided access to a wide range of resources and equipment (Brogden, 1983). They also allowed teachers to share children, thereby avoiding child-teacher personality clashes (Brogden, 1983). Overall, these benefits were thought to facilitate a more cooperative and supportive teaching and learning atmosphere (Brogden, 1983; Hickey & Forbes, 2011). However, because of noise and visual distraction due to large numbers of children sharing the area and being engaged in a range of activities, many of these open plan spaces were converted back to enclosed classrooms in the 1980's (Shield et al., 2010). Nonetheless, the 21st century has seen a return to the child-centered educational philosophy, hence open plan classrooms have become popular once again, particularly in the United Kingdom and more recently in Australia (Greenland, 2009; Stevenson, 2011).

Noise in Classrooms

It is estimated that children spend around 45-60% of their time at school engaged in listening (see Rosenberg et al., 1999). Therefore, is essential that they can discriminate and comprehend their teacher's and classmates' speech despite there being many other interfering noises present in the classroom environment (Rosenberg et al., 1999). These interfering noises include external noises such as traffic and construction work, intruding noises from children in adjacent rooms and corridors, and internal noises from children, air-conditioning units, appliances, and equipment within the room. Of these many sounds, noise generated by the children in the classroom is the generally the loudest noise source (Shield & Dockrell, 2004). High noise levels are problematic as they result in poor signal-to-noise ratios (SNRs; a direct measurement of the intensity of the signal [e.g. the teacher's voice] compared to the background noise level) which reduces children's ability to perceive speech clearly (Crandell & Smaldino, 1995). In addition, the use of sound-reflecting building materials creates long reverberation times for both the background noise and the speech signal. The synergistic combination of noise and reverberation results in masking and distortion of speech, further reducing its intelligibility (Crandell & Smaldino, 2000; Finitzo-Hieber & Tillman, 1978).

Several American studies have shown that traditional enclosed classroom acoustic environments rarely achieve favorable listening conditions (American Speech-Language-Hearing Association, 2005; Knecht, Nelson, Whitelaw, & Feth, 2002). It is generally recommended that unoccupied ambient noise levels should not exceed 35 dBA and unoccupied reverberation times should be less than 0.4 s (American National Standards Institute, 2002; Australia/New Zealand Standard, 2000; Crandell & Smaldino, 2000; MacKenzie & Airey, 1999; Shield et al., 2010; Wilson, 2002). However, many studies have shown that unoccupied ambient noise levels reach 60 dBA and unoccupied reverberation times range from 0.4 to 1.2 s (American Speech-Language-Hearing Association, 2005; Crandell & Smaldino, 2000; Finitzo, 1988). In occupied classrooms, student generated noise can create noise levels measuring between 50-70 dBA (Crandell & Smaldino, 2000; Wilson, 2002). While it is recommended that SNRs should be greater than +15 dB (Crandell & Smaldino, 2000), these high noise levels can result in SNRs between -7 to +5 dB (American Speech-Language-Hearing Association, 2005). Additionally, it is recommended that Speech Transmission Index (STI) scores (which take into account both noise and reverberation times to provide a guide of the quality of the speech transmitted, with 0 indicating that no speech would be understood and 1 indicating that all speech would be understood) should be above 0.75 for 6-year-old children (Greenland & Shield, 2011), but this too is rarely achieved (Airey, 1998; Greenland & Shield, 2011; MacKenzie & Airey, 1999).

Effects of Classrooms Noise on Children and Teachers

High noise levels have been shown to adversely affect children's speech perception (Crandell & Smaldino, 2000; Finitzo-Hieber & Tillman, 1978), reading and language comprehension (Klatte, Lachmann, & Meis, 2010; Maxwell & Evans, 2000; Ronsse & Wang, 2013), cognition, concentration, and children's psychoeducational and psychosocial achievement (see the American Speech-Language-Hearing Association, 2005; Crandell & Smaldino, 2000; and Shield et al., 2010, for a review). For this reason, the American National Standards Institute (2002) strongly discourages the use of open plan classrooms for young children stating that the high levels of background noise negatively impact on children's learning processes which defeats any advantages in the teaching methods. Additionally, the lack of acoustic (as well as visual) privacy is particularly distracting for children with behavioral, intellectual, and physical disabilities (see Shield et al., 2010).

Furthermore, it is not only the children who suffer from poor classroom acoustics. Teachers in any classroom are susceptible to experiencing vocal strain as they are required to speak for extended periods of time (Gotaas & Starr, 1993). While only 5% of the general population experiences vocal fatigue, it is experienced by 80% of teachers which puts them at high risk of vocal abuse and developing pathological voice conditions from constantly needing to raise their voice above a comfortable level to be heard (Gotaas & Starr, 1993; Smith, Gray, Dove, Kirchner, & Heras, 1997). We would therefore expect vocal health problems to be a major issue for teachers in poorly designed open plan classrooms. Many other studies have shown that high noise levels can raise blood pressure, increase stress levels, cause headaches, and result in fatigue (e.g. Airey, MacKenzie, & Craik, 1998; Anderson, 2001; Evans & Lepore, 1993; Shield et al., 2010). As a result, teachers in classrooms with poor acoustics are more likely to have sick days off work and believe their job contributes to voice and throat problems (MacKenzie & Airey, 1999). Self-reports from teachers in open plan classrooms have shown that they can find them chaotic and feel more anxious teaching in these spaces compared to when they teach in enclosed classrooms (Hickey & Forbes, 2011).

Motivation for Thesis

Despite evidence from the 1970's that high noise levels are a common problem in classrooms with open plan designs (see Shield et al., 2010), many schools in Australia and other countries are still currently converting to new open plan '21st century learning spaces'. Although there have been several studies from the 1970's investigating the acoustics of open

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plan classrooms, there have been few studies conducted in these new '21st century learning spaces'.

Additionally, there have been only a small number of studies that directly compare the acoustics of open plan compared to enclosed classrooms and those that have been conducted give varying results (Airey et al., 1998; Barnett, Nichols, & Gould, 1982; Finitzo, 1988; Fitzroy & Reid, 1963; Kyzar, 1971). Many of these results depend on the definition of an 'open plan classroom', such as how many children and/or class bases share the space, the configuration of the space (e.g. linear: where class bases are in a line; cluster: where class bases are around a central resource point; or annular: where class bases are in a ring around an enclosed space [see Greenland & Shield, 2011]), and whether there are partitions that can be used to separate the spaces (i.e. fully open plan versus semi-open plan). Rather than trying to group together classrooms that are very different, my research presents case studies of four different types of classrooms currently found in Sydney, Australia: an enclosed classroom with 25 children, a double classroom with 44 children, a linear fully open plan triple classroom with 91 children, and a purpose-built semi-open plan Kindergarten-to-Year 6 '21st century learning space' with 205 children. Furthermore, most of the previous research into open plan classrooms focuses solely on measuring the acoustic parameters of the classrooms (i.e. the noise levels, SNRs, STI scores, and reverberation times). To my knowledge, there have been no speech perception studies that have been conducted *live* in open plan classrooms to directly assess how real-life noise affects children's ability to hear the words their teacher is saying. For that reason, it is timely that evidence-based research is carried out in these new open plan classrooms to assess how the acoustic parameters directly affect children's ability to perceive their teacher's speech.

Therefore, the goal of this thesis is to provide a more in depth view of how different types of 21st century open plan and traditional enclosed classrooms compare as listening environments for young children. My more in depth approach is achieved both *objectively* by incorporating *quantitative* research on the acoustics of the room with how children perform on a speech perception test conducted live in their classroom, as well as *subjectively* by

qualitatively investigating how the children and teachers perceive their listening environments. The findings of this research potentially have major implications for policy makers – studies have shown that children who have been in classrooms with poor acoustics have lower literacy and numeracy skills, are less productive in the workforce, and tend to be in lower paid jobs than those who were from classrooms with good acoustics (Anderson, 2001; James, Stead, Cliftonbrown, & Scott, 2012). Ensuring classrooms have good acoustics is therefore vital for increasing children's future opportunities. Furthermore, workplace ergonomics research has shown that the physical properties of the work environment can contribute to workplace stress (McCoy & Evans, 2005; Vischer, 2007). Therefore, it is important that classrooms are suitably designed to increase teachers' job performance and job satisfaction.

Organisation of Thesis

Chapters 2-6 of this thesis present five studies (in journal article form) that aim to provide an in depth view of how the acoustics of the four different sized open plan and enclosed classrooms mentioned above affect children's speech perception. Each article reviews the relevant literature, outlines the methodology used for the study, presents and discusses the results, and draws conclusions from the research. Below is an outline of each paper.

Chapter 2: Investigating the acoustics of a sample of open plan and enclosed Kindergarten classrooms in Australia (Mealings, Buchholz, Demuth, & Dillon, 2015). This paper measures the noise levels, reverberation times, SNRs, and STI scores of the four different classrooms and compares these measurements to the recommended classroom acoustic conditions for 5-6-year-old children. It also provides insight into what noise sources are problematic in the different classrooms. This is achieved by i) measuring the unoccupied ambient noise levels to identify excessive noise levels from air-conditioning units and equipment etc., ii) measuring the intrusive noise levels from adjacent classes (this is vital in open plan classrooms as this noise can be present during critical listening activities since the teacher of one class has no control over the noise coming from the other classes in the area), and iii) measuring the occupied background noise levels when the class is engaged in group work activities, which typically produce the most amount of noise (Shield & Dockrell, 2004). This study is important as it provides initial insight into the appropriateness of the different classroom designs from a physical acoustics perspective. The impact of these physical acoustic conditions is then expanded on in the next two chapters to examine how these conditions directly affect children's ability to hear their teacher's speech.

Chapter 3: The development of the Mealings, Demuth, Dillon, and Buchholz Classroom Speech Perception Test (Mealings, Demuth, Buchholz, & Dillon, 2015a). The aim of this study was to develop a new Australian speech perception test (the Mealings, Demuth, Dillon, and Buchholz Classroom Speech Perception Test [MDDB CSPT]) that was engaging and could be conducted live and efficiently in the real classroom listening environment to assess how intrusive noise affects children's speech perception. Although there are already a number of speech perception tests available, many of these tests have several limitations such as being developed in the United States or the United Kingdom (hence using American or British English rather than Australian English words and pronunciations), having the words presented in isolation (which does not reflect typical teaching practices), using multitalker babble as the noise source (which is not representative of typical classroom noise), and only being able to test one child at a time. For these reasons, I decided it would be valuable to develop the MDDB CSPT. This test was created especially for 5-6-year-old children in an Australian context. It also has the advantage of being able to be conducted live in the real classroom environment to test a whole class of children at once through the use of Personal Response Systems. This chapter describes how the test stimuli were developed and evaluates the effectiveness of using the test in one of the open plan classrooms. As it was found to be an engaging and effective tool to assess speech perception live in the classroom, it was used to test the children's speech perception abilities in the four different classrooms while the adjacent class bases were engaged in quiet versus noisy activities as described in the next chapter.

Chapter 4: The effect of open plan and enclosed classroom acoustic conditions on speech perception in Kindergarten children (Mealings, Demuth, Buchholz, & Dillon, 2015b). This paper compares the results of the MDDB CSPT across all four classrooms to assess how the different acoustic conditions and noise levels in these classrooms affect the children's speech perception accuracy and speed. It also assesses how the child's distance from the loudspeaker affects their speech perception abilities when the adjacent class/es are engaged in quiet versus noisy activities. To my knowledge, this is the first study to assess speech perception live in the classroom environment with live noise from the children in the other classes. This study provides a significant contribution to the current literature as these results are more representative of listening in real classrooms rather than in an artificial laboratory setting. These results are also an important complement to Chapter 2 as they show how the physical acoustics of the classrooms directly affect children's ability to hear the words their teacher is saying.

Chapter 5: An assessment of open plan and enclosed classroom listening environments for young children: Part 1 – Children's questionnaires (Mealings, Dillon, Buchholz, & Demuth, in press). This paper assesses children's perceptions of their classroom listening environment through a questionnaire. The questionnaire included questions on whether the children can hear and/or are annoyed by different sound sources when they are in the classroom and how well they can hear their teacher/classmates in different listening scenarios. Considering the perceptions of the children is important as their brains are still neurologically immature, so they are more affected by poor classroom acoustics than the adults who design the classrooms (Boothroyd, 1997; Nelson & Soli, 2000; Wilson, 2002). This paper also evaluates the appropriateness of current acoustic recommendations for classrooms with 5-6-year-old children by outlining the acoustic conditions needed for children to rate that they can hear their teacher "well". These results are important as they have the potential to influence national acoustic standards and recommendations for educational settings. In addition, this chapter correlates the children's perceptions with the acoustics of the classrooms measured in Chapter 2 and the children's performance on the speech perception test in Chapter 4.

Chapter 6: An assessment of open plan and enclosed classroom listening environments for young children: Part 2 – Teachers' questionnaires (Mealings, Demuth, Buchholz, & Dillon, under review). This paper reports the results of how the teachers perceive their classroom listening environment. The questionnaire included questions about their teaching background and style, the demographics of the children in their classroom, what characteristics of the classroom they find most important, what internal/external noise sources are present, how they cope with noise, and their perceptions of open plan versus enclosed classrooms. This paper also assesses how these results compare to the children's responses and how the teacher's perceptions relate to the acoustics of their classroom. Additionally, this paper investigates vocal strain and voice problems among the teachers which can be a direct consequence of poor acoustics that is often overlooked. Considering the teachers' opinions of the classroom environments is important as they are often not consulted in the decision-making process when classrooms are converted to open plan designs (Hickey & Forbes, 2011).

Finally, **Chapter 7** draws this thesis together by discussing what the results of the five journal articles reveal in terms of the appropriateness of each classroom as a listening environment for young children, examining what the implications of these findings are for educators, architects, and policy makers, outlining the limitations of the studies, and suggesting future directions for research.

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CHAPTER 2: INVESTIGATING THE ACOUSTICS OF A SAMPLE OF OPEN PLAN AND ENCLOSED KINDERGARTEN CLASSROOMS IN AUSTRALIA

This chapter is based on the following published paper:

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

All components of this paper, both experimental and written, have been completed by me, with advice from the co-authors (my supervisors) when needed.

ABSTRACT

Open plan classrooms, where several class bases share the same space, have recently reemerged in Australian primary schools. This study compared the acoustics of four different Kindergarten classrooms: an enclosed classroom with 25 students, a double classroom with 44 students, a linear fully open plan triple classroom with 91 students, and a semi-open plan K-6 classroom with 205 students. Ambient noise levels, intrusive noise levels, occupied background noise levels, and teacher's speech levels were recorded during different activities. Room impulse responses using logarithmic sweeps were also recorded for different teaching scenarios. From these recordings, signal-to-noise ratios, speech transmission index scores, and reverberation times were calculated. The results revealed much higher intrusive noise levels in the two largest open plan classrooms, resulting in signal-to-noise ratios and speech transmission index scores to be well below those recommended in classrooms with students of this age. Additionally, occupied background noise levels in all classrooms were well above recommended levels. These results suggest noise in classrooms needs to be better controlled, and open plan classrooms are unlikely to be appropriate learning environments for young children due to their high intrusive noise levels. The impact of noise on children's learning and teacher's vocal health are discussed.

Key words: Open plan classrooms; classroom acoustics; primary school

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1. INTRODUCTION

Primary school is a child's first experience of formal education, preparing them for higher education and life through literacy, numeracy, and other diverse skills. As the principal modes of communication in the educational setting are speaking and listening, it is important that the acoustic learning environment is conducive from these early stages to enhance future opportunities for these children. On average, children spend 45-60% of their time at school listening and comprehending, so they need to be able to discriminate the speech signal from the vast variety of other irrelevant noises present in the classroom environment (Rosenberg et al., 1999). Interfering noises include external noises from outside the classroom (e.g. traffic and construction), intruding noises from adjacent rooms and corridors (e.g. talking and movement), and internal noises from within the classroom (e.g. talking, movement, and air-conditioning unit and appliance noise). High noise levels result in poor signal-to-noise ratios (SNRs), which is a direct measurement of the intensity of the signal (e.g. the teacher's voice) compared to the background noise level. In addition, the use of sound-reflecting building materials creates long reverberation times of both the background noise and the speech signal. The synergistic combination of noise and reverberation results in masking and distortion of the speech signal, reducing speech intelligibility (Crandell & Smaldino, 2000; Finitzo-Hieber & Tillman, 1978).

Noise generated by other children is the major noise source found in classrooms (Shield & Dockrell, 2004). High noise levels adversely affect speech perception (Crandell & Smaldino, 2000; Finitzo-Hieber & Tillman, 1978), reading and language comprehension (Klatte, Lachmann, & Meis, 2010; Maxwell & Evans, 2000; Ronsse & Wang, 2013), cognition, concentration, and the psychoeducational and psychosocial achievement of the child (American Speech-Language-Hearing Association, 2005; Crandell & Smaldino, 2000; Shield, Greenland, & Dockrell, 2010). It is also suggested that poor acoustical conditions and noise places additional demands on children's learning effort. This reduces the resources available for linguistic and cognitive processing and can often result in children 'tuning out' from being overloaded by auditory stimuli (Anderson, 2001; Maxwell & Evans, 2000). Noise levels are

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reported to be highest in the classrooms of the youngest children (Jamieson, Kranjc, Yu, & Hodgetts, 2004; MacKenzie & Airey, 1999; Picard & Bradley, 2001; Wróblewski, Lewis, Valente, & Stelmachowicz, 2012) which is also the age group most affected (Johnson, 2000; Leibold & Buss, 2013; Nishi, Lewis, Hoover, Choi, & Stelmachowicz, 2010; Nittrouer & Boothroyd, 1990). As children's auditory systems are neurologically immature, they have greater perceptual difficulties than adults in discriminating and understanding speech, and cannot use years of previous communicative experience to fill in missing information (Wilson, 2002).

Acute groups of children, including those with hearing impairments who are now more commonly integrated into mainstream classes, are even more affected by poor acoustics (Crandell & Smaldino, 2000; MacKenzie & Airey, 1999). Studies in the United Kingdom have shown that on any given day 15% of children in classrooms suffer from hearing impairments, which include not only those who have permanent hearing loss, but also those who have a cold, otitis media (glue ear), an ear infection, or hay fever (Niskar et al., 1998). Middle-ear related hearing loss in Australia (usually caused by otitis media) affects 50% to 80% of Aboriginal and Torres Strait Islander school children (Nienhuys, Boswell, & McConnel, 1994). This creates feelings of inadequacy for the individual and adversely impacts their classroom performance (Massie, Theodoros, McPherson, & Smaldino, 2004; Nienhuys et al., 1994). Children with central auditory processing disorders also find it challenging to listen in the presence of background noise and reverberation (Keith, 1999). Other acute groups affected by poor acoustics include those for whom English is a second language (Nelson & Soli, 2000; Nelson, Kohnert, Sabur, & Shaw, 2005; Shield et al., 2010), children with sensory hypersensitivity (Greenland, 2009), and introverts, who find it difficult to concentrate and relate while doing group work in a noisy environment (Cassidy & MacDonald, 2007).

Furthermore, it is not only the students who suffer from poor classroom acoustics. While only 5% of the general population experience vocal fatigue, this is experienced by 80% of teachers, putting them at high risk of vocal abuse and pathological voice conditions from the need to constantly raise their voice above a comfortable level to be heard (Gotaas & Starr, 1993; Smith, Gray, Dove, Kirchner, & Heras, 1997). Noise also raises blood pressure, increases stress levels, causes headaches, and results in fatigue (see Anderson, 2001, and Shield et al., 2010, for a review). Teachers in classrooms with poor acoustics are more likely to have sick days off work and believe their job contributes to voice and throat problems (MacKenzie & Airey, 1999).

These adverse impacts indicate the importance of controlling noise levels for both students and teachers in the educational setting. However, several American studies have shown that classroom acoustic environments rarely have favorable listening conditions (American Speech-Language-Hearing Association, 2005; Knecht, Nelson, Whitelaw, & Feth, 2002). While it is generally recommended that unoccupied ambient noise levels should not exceed 35 dBA, unoccupied reverberation times should be less than 0.4 s, and SNRs should be greater than +15 dB (American National Standards Institute, 2002; Crandell & Smaldino, 2000; Shield et al., 2010), many studies have shown that ambient noise levels reach 60 dBA, SNRs are between -7 to +5 dB, and reverberation times range from 0.4 to 1.2 s (American Speech-Language-Hearing Association, 2005; Crandell & Smaldino, 2000; Finitzo, 1988). In occupied classrooms, student generated noise creates the highest noise levels measuring between 50-70 dBA (Crandell & Smaldino, 2000; Wilson, 2002). Additionally, it is generally recommended that speech transmission index (STI) scores (which take into account both noise and reverberation times) should be above 0.6 (MacKenzie & Airey, 1999; Shield et al., 2010), though Greenland and Shield (2011) suggest that this should be increased to 0.75 for children as young as 6 years. This, however, is rarely achieved (Airey, 1998; Greenland & Shield, 2011; MacKenzie & Airey, 1999). Particularly of concern is that, despite noise levels already being excessive in traditional enclosed classrooms with 20-30 children, there is a current trend of replacing these enclosed classrooms with new open plan '21st century learning spaces'. These open plan classrooms can result in up to 200 children sharing the same area (Stevenson, 2011).

Open plan style classrooms are not a new concept for educational institutions. This 'progressive' classroom style was popular during the educational reform of the 1960's and 1970's where traditional didactic teaching was replaced by a more 'child-centered' approach (Brogden, 1983; see also Shield, Greenland, & Dockrell, 2010). Additionally, building open plan spaces complemented post-war economic restraints (Bennett, Andrae, Hegarty, & Wade, 1980). However, because of noise and visual distraction, it was not long before the open spaces were converted back to enclosed classrooms (Shield et al., 2010). Nonetheless, the 21st century has seen a return to the child-centered educational philosophy, hence open plan classrooms have become popular once again, particularly in the United Kingdom and more recently in Australia (Greenland, 2009; Stevenson, 2011). There are several advantages in adopting an open plan style of classroom. Apart from being architecturally fashionable, these spaces create a more 'home-like' atmosphere and are perceived as being less authoritarian, creating a more secure feeling for the child (Maclure, 1984). They also allow for a range of activities to be carried out and facilitate group work and the child's social development (Brogden, 1983). Additionally, they promote the sharing of skills, ideas, and experiences amongst teachers, and allow for teamteaching which facilitates a more cooperative and supportive atmosphere (Brogden, 1983; Hickey & Forbes, 2011). However, due to large numbers of children sharing the area and being engaged in a range of activities, open plan classrooms result in high levels of fluctuating speech noise. The lack of acoustic privacy (and also lack of visual privacy) is distracting for teachers as well as children, but particularly those with behavioral, intellectual, and physical disabilities (see Shield et al., 2010). The American National Standards Institute (2002) strongly discourages the use of open plan classrooms since the high levels of background noise negatively impact the children's learning processes.

Despite this past evidence showing that high levels of noise are a common problem reported in schools with open plan designs, many Australian schools are currently choosing to adopt this classroom layout. Therefore, it is timely that evidence-based research is carried out in these Australian schools (where research is sparse) to assess whether converting to these open plan learning spaces is compromising acoustic privacy, hence potentially hindering educational development.

There have been only a small number of studies in the past that directly compare noise levels in open plan and enclosed classrooms, and they give varying results. In the United States, Finitzo (1988) found average noise levels to be significantly higher in open plan classrooms. whereas Airey, MacKenzie, and Craik (1998) found that noise levels in open plan classrooms in the United Kingdom were 5 dB lower than in enclosed classrooms. Airey et al. (1998) believed this was because teachers in open plan classrooms spent more time controlling noise and that these classrooms tended to have more sound absorptive materials installed. Other studies in the United States have reported no difference in noise levels between the two classroom designs (e.g. Barnett, Nichols, & Gould, 1982; Fitzroy & Reid, 1963; Kyzar, 1971). However, these three studies did show open plan classrooms have more fluctuations in noise levels which teachers and students find more annoying than consistent noise at the same average level (Choudhury, 1973). Many of these results depend on the definition of an 'open plan classroom', such as how many students and/or class bases share the space, the configuration of the space (e.g. linear, cluster, annular), and whether there are partitions that can be used to separate the spaces (i.e. fully open plan versus semi-open plan). Rather than trying to group together open plan classrooms that are very different, our study presents case studies of four different types of schools found in Sydney, Australia, including an enclosed classroom as a reference point. This way we can compare the different classrooms directly knowing that the same methods for the measurements have been used. This is more reliable than comparing the results across different studies which may have used different experimental procedures. Additionally, the goal of this research was to provide a more comprehensive view of how different types of open plan and traditional enclosed classrooms compare. Previously, many studies have focused on only one aspect of classrooms, such as the objectively measured acoustics. Our more comprehensive approach is achieved by incorporating research on the acoustics of the room with how children perform on a speech perception task conducted live in

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their classroom, as well as subjective measures on how the teachers and children perceive the listening environment. The current paper reports the results of the classroom acoustic measures. The other aspects will be reported in future papers and related back to the acoustics of the classrooms reported in this paper.

Therefore, the aim of the current study was to compare the classroom acoustic variables (e.g. noise levels, reverberation times, SNRs, STI scores) in open plan and traditional enclosed Australian Kindergarten classrooms using consistent experimental procedures across classroom types. It was hypothesized that, because of the lack of acoustic barriers in open plan classrooms, the intrusive noise levels from the adjacent class bases would be higher in the open plan classrooms compared to the traditional enclosed classroom. Additionally, due to the increase in children (i.e. noise sources) present in open plan classrooms, it was hypothesized that background noise levels when all students were engaged in group work activities would also be higher in the open plan classrooms. As a result of these predicted high noise levels, we expected the SNRs and STI scores in the larger open plan classrooms to be well below those recommended for Kindergarten children. Finally, it was predicted that the reverberation times would be longer in the larger classrooms (particularly those without acoustic treatment) due to their increased volume.

2. SCHOOLS INVOLVED

The study took place in Sydney, Australia in the second half of the school year as part of a comprehensive project investigating the acoustics and listening conditions in open plan and enclosed Kindergarten classrooms. (Note: Kindergarten is the first year of primary school in Australia so the children were five to six years old.) A wide range of potential primary schools were examined before the final selections were made. The number of students in the open plan classrooms that we examined ranged between 40-200 students, divided into class bases of 20-30 children. Therefore, three open plan classrooms across the 40-200 student range were chosen for this study, along with one enclosed classroom with 25 students. Effort was made to choose schools with a similar score on The Index of Community Socio-Educational Advantage (ICSEA) scale. This scale represents a school's level of educational advantage based on family backgrounds. ICSEAs range from 500-1300, with a mean of 1000 and standard deviation of 100. Higher ICSEA scores represent more advantaged schools. (More information about ICSEAs can be found on the *My School* website <u>http://www.myschool.edu.au</u>.) We used the values calculated for 2013 when the study was conducted. Further details on the participating classrooms are shown in Table I.

	Enclosed Classroom	Double Classroom	Triple Classroom	K-6 Classroom
Total number of students	25	44	91	205
in area				
School's ICSEA	1141	1133	1035	1090
Classroom type	Enclosed classroom with	Fully open double	Linear, fully open plan	Semi-open plan classroom
	shared concertina wall	classroom	classroom	
Class grades in area	Kindergarten	Kindergarten	Kindergarten	Kindergarten to Year 6
	(5-6-year-olds)	(5-6-year-olds)	(5-6-year-olds)	(5-12-year-olds)
Number of class bases in	1	2	3	5-7
area				(depending on activity)
Number of students in	25	21-23	30-31	30-50
each class base				
Room dimensions (m)	8 x 9	15 x 9	37 x 11	27 x 32
Total floor area (m ²)	72	135	407	864
Space per child (m ²)	2.9	3.1	4.5	4.2
Distance between edge of	N/A	2	6	7
class bases (m)				
Ceiling height (m)	3.0	2.8-4.2	3.3	3.2-6.0
Total room volume (m ³)	216	470	1340	3900

TABLE I: Building details of the participating classrooms.

2.1 Enclosed classroom: 25 students

This classroom consisted of 25 Kindergarten students in a classroom with 3 solid brick walls, a closed floor-to-ceiling 4 cm thick concertina wall with pin boards, and a shared storeroom with the adjacent Kindergarten class. The class area was carpeted with loop pile carpet and windows were located on both side walls (Figure 1). The ceiling was rough concrete textured. No acoustic treatment was evident. A survey of 50 primary schools in the region found that 60% of Kindergarten classrooms have a concertina wall between them and an additional 10% have a shared storeroom or door with another class. Only 30% of schools had fully enclosed classrooms with four solid walls. Therefore this classrooms found in the Sydney region, and hence was chosen for the study.



FIGURE 1: Floor plan of the enclosed classroom with 25 students.

2.2 Double classroom: 44 students

This space originally consisted of two separate classrooms with plasterboard walls, but the wall between had been removed at the start of the year to make it an open plan double classroom for the 44 Kindergarten students. The ceiling was made of plasterboard and was triangular in shape, and the top half of the wall still remained in this area between the two classrooms where the original wall had been. The class area was carpeted with loop pile carpet but the utility area was a hard surface. Windows were located on two walls and pin boards covered the other two walls (Figure 2). No other acoustic treatment was evident. The acoustic measurements were taken in class K1.



FIGURE 2: Floor plan of the double classroom with 44 students.

2.3 Triple classroom: 91 students

This open plan classroom consisted of 91 Kindergarten students grouped linearly into three classes (K1, K2, K3), with no barriers between them. This classroom represented a midrange student and class base number for an open plan space. The Year 1 and 2 classes were located off an adjacent corridor but had no doors/walls separating the spaces, hence noise from these classes could also be heard. Originally the space had consisted of separate enclosed classrooms with 30 children in each, but these walls had recently been removed to make the area fully open plan. The walls were plasterboard and the class area was carpeted with loop pile carpet, but the corridor floor was a hard surface. The ceiling was acoustically tiled. Windows were located on both the front and back walls and pin boards were on the other two walls (Figure 3). No other acoustic treatment was evident. The acoustic measurements were taken in class K2.



FIGURE 3: Floor plan of the triple classroom with 91 students.

2.4 K-6 classroom: 205 students

This classroom contained the entire primary school (205 students) in the one area representing one of the biggest types of open plan classrooms. It had been purpose-built to be a '21st century learning' open plan school. The children were separated into class stages with Kindergarten, Year 1, and Year 2 in a semi-open plan layout with dividers between them and only one open wall. Years 3/4 and 5/6 were fully open plan. The Kindergarten class was located in the corner in the acoustically most sheltered location, particularly for their whole class teaching area where the children are grouped together on the floor to listen to their teacher (see Figure 4). The ceiling height in this area was the lowest of the room measuring 3.2 m. The entire area was carpeted with loop pile carpet, and 3 cm thick pin boards along the walls and soft furnishings provided some acoustic absorption. The ceiling was acoustically tiled. Windows were located on the external wall.



FIGURE 4: Floor plan of the K-6 classroom with 205 students.

3. METHOD

3.1 Classroom activities

Previous research shows that noise levels in classrooms depend on the activity that the students are engaged in (Greenland & Shield, 2011; Shield & Dockrell, 2004). For our study we chose two different activities (one representing a quiet activity and the other a noisy activity) to record the noise levels in:

- Whole class teaching: This critical listening activity involves the children sitting on the floor in front of their teacher. During this activity only one person is speaking at a time – either the teacher or a child giving an answer.
- 2) Group work: This activity involves the children sitting at tables or on the floor working together on tasks. It may also involve children moving around the classroom. During this activity many people are speaking at the same time.

The proportion of time spent in each of these activities from a survey of the Kindergarten teachers at the schools involved is shown in Table II. These proportions are consistent with those found in previous studies (e.g. Greenland & Shield, 2011; Wilson, 2002).

Classroom	Whole class teaching (%)	Group work (%)	Other (%)
Enclosed	25	45	30
Double	15	75	10
Triple	40	40	20
K-6	15	45	40

TABLE II: Kindergarten teachers' report of proportion of time spent in various classroom

activities.

3.2 Equipment

The microphones used for the study included an omnidirectional DPA dual-ear lapel microphone and three ¹/₂" omnidirectional condenser microphones. The condenser microphones were used for both noise recordings as well as Room Impulse Response (RIR) measurements, and were calibrated in diffuse speech-shaped noise using a B&K 2250 sound level meter. The lapel microphone was used for recording the teacher's voice and calibrated as described in Section 3.5. The microphones were connected to a RME Quadmic 4-channel microphone preamplifier. A Tannoy VX8 concentrical loudspeaker connected to a Yamaha AX-350 hifi stereo amplifier was used for measuring the RIRs. The computer was a standard PC using RME Hammerfall HDSP 9632 internal soundcard inclusive expansion boards. Adobe Audition software was used for the recordings and MATLAB software was used for the RIR measurements.

3.3 Noise recordings

Noise recordings for four different scenarios were made in the main class base so that levels could be calculated and compared to acoustical guidelines:

 Unoccupied ambient noise levels: This recording was taken inside the classroom after school when the classes were completely vacated. It measured the sound levels generated by internal and external noise sources, for example, air conditioning units and road traffic. The recommended ambient noise level for classrooms is < 35 dBA as shown in Table III.

- Intrusive noise levels during quiet activities: This recording was taken when the main class base was empty and the other class bases were engaged in whole class teaching.
- Intrusive noise levels during noisy activities: This recording was taken when the main class base was empty and the other class bases were engaged in group work.
- 4) Occupied background noise levels: This recording was taken when the main class base was occupied and all class bases were engaged in group work. The recommended background noise level (hence intrusive noise level) for classrooms is < 50 dBA as shown in Table III.

For each condition, three omnidirectional condenser microphones on stands at 1 m height were placed around the class area of the main class base. Each recording was 2-10 mins in length depending on the activity. Adobe Audition software was used to record the noise levels at each microphone. Each recording was listened to and any artefacts (such as children touching or directly speaking into the microphone) were removed.

Measurement	Recommended value	Reference
Ambient Noise	< 35 dBA	(AS/NZS2107:2000, 2000)
Background/Intrusive Noise	< 50 dBA	(Berg, Blair, & Benson, 1996)
SNR	+ 15 dB	(Crandell & Smaldino, 2000)
STI	> 0.75 (for 6 year olds)	(Greenland & Shield, 2011)
Reverberation Time	< 0.4-0.5 s (unoccupied)	(AS/NZS2107:2000, 2000)

TABLE III: Recommended ambient, background, and intrusive noise levels, signal-to-noise ratios, speech transmission index scores and reverberation times for Kindergarten classrooms.

3.4 Room impulse responses and reverberation time

RIRs for three different teaching scenarios were measured in the main class base with 30 s long logarithmic sweeps using a Tannoy VX8 loudspeaker and three calibrated omnidirectional microphones. Based on these measurements, reverberation times and STI scores were calculated and compared to the acoustical guidelines summarized in Table III. The RIRs were also used to predict the teacher's voice levels inside the classrooms as further described in Section 3.5. RIRs were recorded for the following scenarios:

- 1) Whole class teaching: The loudspeaker at a height of 1.2 m (representing teacher sitting on a chair in front of students) was placed at the front of the class. Three microphones at an average height of 0.45 m (representing students sitting on the floor) were placed front to back in front of the loudspeaker.
- 2) Teacher addressing single table of students: The loudspeaker at a height of 1.5 m (representing teacher standing in front of students) was placed in front of the table. Three microphones at an average height of 0.7 m (representing students sitting on the chairs) were placed around the table.
- 3) Teacher addressing all tables and students: The loudspeaker at a height of 1.5 m (representing teacher standing in front of students) was placed at the front of the class. Three microphones at an average height of 0.7 m (representing students sitting on chairs) were placed around different tables.

Table IV shows the distance of the microphones from the loudspeaker for each school in each scenario. The distances chosen were those that best represented different positions of children in the class.

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Activity	Classroom	Distance of mic	oudspeaker (m)	
		Mic 1	Mic 2	Mic 3
Whole	Enclosed	1.0	2.3	2.9
class	Double	1.9	2.9	3.8
teaching	Triple	1.3	2.6	3.5
	K-6	2.0	2.0	3.0
	Average	1.55	2.45	3.3
Teacher	Enclosed	0.9	1.2	2.1
addressing	Double	0.7	1.4	2.2
single table	Triple	0.8	1.0	1.5
	K-6	0.8	0.8	0.8
	Average	0.8	1.1	1.65
Teacher	Enclosed	3.5	3.8	4.0
addressing	Double	2.7	3.0	6.0
all tables	Triple	3.2	3.8	4.5
	K-6	2.0	3.9	5.4
	Average	2.85	3.625	4.975

TABLE IV: Distance of microphones from the loudspeaker for each classroom in each

scenario.

The unoccupied reverberation time (T30) was derived from the measured RIRs according to ISO 3382-2 ("ISO 3382-2:2008(E). International Standard: Acoustics – Measurement of room acoustic parameters – Part 2: Reverberation time in ordinary rooms", 2008) using the Odeon software. The T30 was first derived in octave bands and then averaged across the bands with centre frequencies of 500, 1000, and 2000 Hz. For each scenario, the

broadband T30 was finally averaged across the three applied microphone locations. The recommended T30 for classrooms is < 0.4-0.5 s as shown in Table III.

3.5 Calculation of teacher's average speech levels

The teachers of the tested class bases had their speech recorded during whole class teaching. An omnidirectional DPA dual-ear lapel microphone was placed approximately 3 cm from the teacher's mouth and recordings were made using Adobe Audition software. These recordings were then convolved with the measured RIRs for the three teaching scenarios (Section 3.4) to estimate speech levels for each scenario at three listening positions. To remove voice level differences between teachers, speech levels were predicted by using concatenated and equally long speech samples from all teachers as input signal. To provide accurate speech level estimates, the involved equipment and signal processing was calibrated by comparison to a similar recoding performed in an anechoic chamber at the National Acoustic Laboratories, Australian Hearing Hub. Twelve talkers were recorded using the DPA lapel microphone as well as a calibrated B&K 4134 microphone placed 2 m in front of the talkers and attached to a B&K 2610 measurement amplifier. Additionally, the corresponding (anechoic) RIR was measured by replacing the talkers by the same Tannoy VX8 loudspeaker system used in the classroom measurements. Comparing the spectra (and RMS levels) of the direct speech recording at 2 m distance with the corresponding RIR-based simulation allowed the derivation of calibration filters that were then applied to the speech recordings and RIR measurements performed in the different teaching scenarios.

3.6 Calculation of signal-to-noise ratios

The signal-to-noise ratio (SNR) measures the difference between a speaker's speech level (described in Section 3.5) and the noise level. A positive SNR means that the speaker's speech level is higher than the noise level, while a negative SNR means the noise level is higher than the speaker's speech level. Average SNRs were derived for the different teaching scenarios between the teacher's speech level (in dBA) and the noise levels (also in dBA) described in Section 3.3. SNRs were calculated using the average teacher's speech levels at the front, middle, and back of the whole class teaching seating area (as described in Section 3.4) and the average noise levels recorded in the same areas and described in Section 3.3. SNRs were obtained for the three noise conditions that whole class teaching takes place in, i.e. ambient noise, intrusive noise when the other classes are engaged in quiet activities, and intrusive noise when the other classes are engaged in noisy activities. The recommended SNR for 6-year-olds is +15 dB as shown in Table III. This SNR should be achieved throughout the room (Association of Australian Acoustical Consultants, 2010).

3.7 Calculation of speech transmission index scores

The speech transmission index (STI) provides a guide to how intelligible speech is in a room by measuring the distortion introduced into the speech transmission channel from the source to the receiver, taking into account both reverberation and noise (MacKenzie & Airey, 1999). The STI is represented on a scale from 0 to 1, with 0 indicating that no speech would be understood and 1 indicating that all speech would be understood. STI scores were calculated using the AARAE MATLAB Toolbox (Cabrera, Lee, Leembruggen, & Jimenez, 2014). We calculated the STI scores at the front, middle, and back of the whole class teaching seating area using the RIRs without noise (to demonstrate the effect of the room's reverberation alone), and with the three noise conditions described in Section 3.3. STI scores were also calculated using the occupied background noise levels when the teacher was addressing a single table of students and when they were addressing the whole class doing group work at their tables. Recommended STI scores are shown in Table V (MacKenzie & Airey, 1999). It is important to note, however, that the STI was developed for adults. Given that children need more favourable listening situations, it is recommended that the STI score should always be > 0.75 for 6-year-olds, as shown in Table III (Greenland & Shield, 2011).

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STI Value	Rating
0.000 - 0.300	Bad
0.301 - 0.450	Poor
0.451 - 0.599	Fair
0.600 - 0.749	Good
0.750 - 1.000	Excellent

TABLE V: Speech Transmission Index rating scale.

4. RESULTS

4.1 Noise levels

The average noise levels recorded for the four different scenarios described in Section 3.3 are shown in Figure 5. As shown in Table III, the recommended unoccupied noise level is < 35 dBA, and the recommended intrusive noise level and occupied background noise level is < 50 dBA.

4.1.1 Unoccupied ambient noise levels

None of the classrooms achieved the recommended unoccupied ambient noise limit, however, the double and triple classrooms were only just above it measuring 36.7 dBA and 36.0 dBA respectively. The enclosed classroom measured a level of 41.8 dBA, but of most concern was the K-6 classroom, which had an average ambient noise level of 46.3 dBA. This high ambient noise level is most likely to be due to the heating, ventilation, and air conditioning units used in this classroom.

4.1.2 Intrusive noise levels

Inspection of the intrusive noise levels is where the problem with open plan classrooms becomes most apparent. As shown in Figure 5, there is a steep rise in both types of intrusive noise levels from the two smaller classrooms to the larger open plan classrooms. As predicted, a statistically significant difference in the intrusive noise levels while the adjacent classes were engaged in quiet activities as determined by oneway ANOVA (F(3,8) = 52.68, p < .0005, $\eta^2 = .95$) was found between classrooms, with a Tukey post-hoc test revealing significantly higher intrusive noise levels for the K-6 and triple classrooms compared to the double and enclosed classrooms ($p_{K-6 vs. double} <$ 0.0005; $p_{K-6 vs. enclosed} < 0.0005$; $p_{triple vs. double} = 0.001$; $p_{triple vs. enclosed} < 0.0005$). A second one-way ANOVA also revealed a significant difference in the intrusive noise levels while the adjacent classes were engaged in noisy activities (F(3,8) = 31.91, p < .0005, $\eta^2 = .92$) with a Tukey post-hoc test again revealing significantly higher intrusive noise levels for the K-6 and triple classrooms compared to the double and enclosed classrooms $(p_{K-6 \ vs. \ double} = 0.002; p_{K-6 \ vs. \ enclosed} = 0.001; ; p_{triple \ vs. \ double} = 0.001 \ p_{triple \ vs. \ enclosed} <$ 0.0005). Figure 5 shows that while the two smaller schools stayed within the recommended 50 dBA limit for both types of intrusive noise, this was well exceeded by the two larger classrooms. (Note that the average intrusive noise levels during quiet and noisy activities were the same for the K-6 classroom as, due to the large number of class bases in the area, quiet and noisy activities could not be coordinated across the whole school. Therefore this classroom experienced consistent noise levels throughout the day.)

4.1.3 Occupied background noise levels

Interestingly, as shown in Figure 5, the occupied background noise levels when all children became engaged in group work activities stayed relatively constant across all classrooms, independent of how many children were in the area. The background noise levels were well above recommended levels irrespective of the classroom size, ranging between 67.7-72.4 dBA. These results show that the noise levels when all children are doing group activities can be problematic in each of the classroom types tested.



FIGURE 5: Average noise levels recorded during different scenarios as a function of how many children are in the classroom area. Note the enclosed classroom had 25 students, the double classroom had 44 students, the triple classroom had 91 students, and the K-6 classroom had 205 students.

4.2 Reverberation times

The average unoccupied reverberation times calculated in each classroom are shown in Figure 6. Only the enclosed classroom achieved a reverberation time within the recommended upper limit for classrooms (Australia/New Zealand Standard, 2000). The reverberation times for each of the other classrooms were outside of the recommended value of 0.4-0.5 s, but were not unusual compared to those found in previous studies examining classroom acoustics (Knecht et al., 2002). (Note, however, that due to the directivity of the loudspeaker used in our RIR measurement, our reverberation times may under-predict the reverberation times compared to if they were measured with omnidirectional sound sources, which most standards are based on.)



FIGURE 6: Average reverberation times for each classroom. Note recommended reverberation time is between 0.4-0.5 s as shown by the dotted lines. Error bars show standard error of the mean where applicable.

4.3 Teacher's average speech levels

The average speech levels for the teachers of the classrooms during whole class teaching are summarized in Table VI. These were used to calculate the SNRs given in the next section. These levels are consistent with the findings of Sato and Bradley (2008).

Teaching	Classr	Teacher's speech level (dBA)					Child's average	
scenario	oom	Front	Mid	Back	Mean	SD	Range	distance (m)
Whole class	Enclosed	60.6	60.1	59.0	59.9	0.8	59.0-60.6	2.1
teaching	Double	61.8	57.4	55.5	58.2	3.3	61.8-55.5	2.9
	Triple	62.0	58.2	55.2	58.5	3.5	55.2-62.0	2.5
	K-6	59.7	59.5	58.1	59.1	0.9	59.7-58.1	2.7
Teacher	Enclosed	61.3	64.1	59.0	61.5	2.6	59.0-64.1	1.4
addressing single	Double	65.2	62.7	60.4	62.8	2.4	65.2-60.4	1.5
table	Triple	65.4	62.3	59.7	62.5	2.9	59.7-65.4	1.1
	K-6	62.4	60.9	59.1	60.8	1.7	62.4-59.1	0.8
Teacher	Enclosed	56.2	56.8	52.2	55.1	2.5	52.2-56.8	3.8
addressing all	Double	57.5	54.2	53.1	54.9	2.3	57.5-53.1	3.9
tables	Triple	54.7	51.9	53.4	53.4	1.4	51.9-57.4	3.8
	K-6	60.4	55.2	53.0	56.2	3.8	60.4-53.0	3.8

TABLE VI: Teacher's speech levels for each classroom during different activities.

4.4 Signal-to-noise ratios

The measured SNRs during whole class teaching are summarized in Figure 7 for the three relevant noise types listed in Section 3.3. When the ambient noise in the room was the only noise source, the SNRs met the required criteria for all classroom designs except for the largest classroom, which were just below the recommended +15 dB. Note also that the SNRs were even better for the double and triple classrooms compared to the enclosed classroom. However, as soon as intrusive noise from other classes was introduced (even just from quiet activities), the SNRs dropped dramatically to well below the recommended level for the two largest open plan classrooms. This problem was further increased when the activities of the other classes changed to noisy group work activities, resulting in SNRs between +0.8 and -6.1 dB for the triple classroom, which is a very poor listening condition. For the double classroom, the SNR for the children sitting closest to the teacher was acceptable when the adjacent class bases were engaged in quiet activities, but fell below the recommended +15 dB for children sitting further away. This effect increased when the adjacent class bases were engaged in noisy activities with SNRs between +13.2 and +6.9 dB at the front and back of the room respectively. However, for the enclosed classroom, the SNRs stayed above +15 dB when the other classes were engaged in quiet activities, and only dropped as far as +12.7 dB (at the back of the room) when the other classes were engaged in noisy activities. This suggests that this was the only classroom design suitable for effective speech communication during critical listening activities such as whole class teaching.

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FIGURE 7: Signal-to-noise ratios for the child's seating position in different noise types for each classroom during whole class teaching.

The SNRs when all classes were doing group work activities are shown in Table VII. These SNRs are calculated based on the vocal effort of the teachers during whole class teaching. As seen in Figure 5, the background noise levels for all classrooms were well above the recommended noise level of 50 dBA. Table VII shows that if the teacher were to address the students when all classes are engaged in group work activities using the vocal effort they usually employ for whole class teaching, the SNRs would be extremely poor, suggesting little speech would be understood. To achieve SNRs at the recommended level of +15 dB, the teacher needs to raise their voice up to 31 dBA higher, which means they need to speak at a level above 82.7 dBA at 1 m which is equivalent to shouting (ANSI, 1997). Constant talking at this level is highly likely to result in vocal health problems. Therefore it is difficult for teachers in any classroom to address a whole table or tables during group work, but only a single student provided they are in very close proximity.

Teacher addressing:	Classroom	Average distance	Teacher's usual	Noise level	SNR (dB)	Required speech	Amount voice needs
		from child (m)	speech level	(dBA)		level for	to be raised by (dBA)
			(dBA)			+15 SNR (dBA)	
Single table	Enclosed	1.4	61.5	71.0	-9.6	86.0 ^a	24.6
	Double	1.6	62.8	69.7	-6.9	84.7ª	21.9
	Triple	1.1	62.5	67.7	-5.2	82.7ª	20.2
	K-6	0.8	60.8	72.4	-11.6	87.4 ^a	26.6
All tables	Enclosed	3.8	55.1	71.0	-16.0	86.0 ^a	31.0
	Double	3.9	54.9	69.7	-14.8	84.7ª	29.8
	Triple	3.8	53.4	67.7	-14.3	82.7ª	29.3
	K-6	3.8	56.2	72.4	-16.2	87.4ª	31.2

TABLE VII:	Teacher's	s speech parameters	when addressing a	single table of	f children and all table	es of children engaged i	in group work for each classroom

^aEquivalent to shouting (ANSI, 1997).

4.5 Speech transmission index scores

STI scores were calculated for the whole class teaching scenario in each classroom for no noise (which demonstrates the effect of room reverberation only) and the three other possible noise types that may be present during this critical listening activity (see Figure 8). For the enclosed classroom, the STI scores stayed above the recommended score of 0.75 for 6-yearolds for nearly all noise types, and only just slipped below it (but was still in the "good" range) for the middle and back seating positions when the other classes were engaged in noisy activities. Similarly, for the double classroom, the recommended STI was achieved at the front of the class for each noise type, and was still within the "good" range for the mid and back class positions when intrusive noise was present. In contrast, the STI was only at the acceptable level for the two largest open plan classrooms when there was no noise or only ambient noise. For the K-6 classroom, the STI scores were in the "poor" to "fair" range when intrusive noise was present. As soon as intrusive noise was introduced in the triple classroom, even just from quiet activities, only the children sitting at the front remained in the "good" range. When the other classes were engaged in noisy activities, the children seated at the back faced "bad" listening conditions, which is likely to have a major detrimental effect on their learning. The results of both the SNR and STI measurements strongly suggest that the tested open plan classrooms with 90 or more children are not appropriate for speech communication because of their high intrusive noise levels.



FIGURE 8: Speech transmission index scores for the child's seating position in different noise types for each classroom during whole class teaching.

5. DISCUSSION

The aim of this study was to investigate the acoustics of different types of open plan and enclosed Kindergarten classrooms to assess the appropriateness of open plan classrooms as learning spaces for young children.

The first major finding was that the intrusive noise levels (i.e. the noise coming from adjacent classes) in the classrooms with over 90 students (i.e. the triple and K-6 classrooms) were excessive and well above recommended levels, even when the other classes were engaged in only quiet activities. This resulted in SNRs and STI scores that were very poor during whole class teaching (a critical listening activity) which is likely to have a major detrimental impact on children's learning. While the intrusive noise levels were within recommended limits for the double classroom with 44 students, the SNRs and STI scores still slipped below the recommended values for this age group, particularly toward the back of the classroom. The enclosed classroom with 25 students was the only classroom to remain within or close to the recommended values, due to the acoustic barrier between the classes which minimized intrusive noise. Therefore, these results suggest that the enclosed classroom is the best learning environment for effective speech communication among young children.

Although there was a large difference in the intrusive noise levels between the two largest and two smallest classrooms, the second major finding of this study was that the background noise levels when all classes were engaged in group work activities were excessive independent of classroom size. We expected that, because of the greater number of students and high intrusive noise levels in the larger open plan classrooms, the noise levels when all classes were engaged in group work activities would be higher than those in the smaller classrooms as a result of the Lombard effect (Whitlock & Dodd, 2008). This, however, was not the case, with the noise levels in the enclosed classroom also reaching well above those recommended. It is possible that teachers of open plan classrooms make an extra effort to control noise from concern that it will distract the other class bases sharing the area. Therefore the background noise levels may not be as high as they otherwise could be in these classrooms. Although these excessive noise levels were reached mainly during group work rather than during critical listening activities, they are still a concern. This is not only because high noise levels increase stress and are thought to adversely affect both the psychoeducational and psychosocial achievement of the child (American Speech-Language-Hearing Association, 2005; Crandell & Smaldino, 2000; Finitzo-Hieber & Tillman, 1978; Sato & Bradley, 2008), but also because of the effect they have on the teacher. During these activities it is common for the teacher to move around helping different groups. Therefore, to achieve the recommended +15 dB SNR and be heard, teachers need to raise their voice up to 31 dBA higher than their comfortable teaching voice. This requires teachers to speak at which means they need to speak at a level above 82.7 dBA at 1 m which is equivalent to shouting (ANSI, 1997). This makes talking to more than a single child at a time very difficult. As group activities make up 40-75% of teaching activities (see Table II), constant talking at this level is likely to result in vocal abuse and pathological voice conditions as well as increase the number of sick days taken due to voice and throat problems (Gotaas & Starr, 1993; Smith et al., 1997). Therefore, it is important that teachers try to control the noise levels in all classrooms, and be careful not to raise their voice regularly to

get the children's attention. Clapping their hands or using a bell or other signal can be helpful alternatives to get the children's attention in these situations.

As mentioned previously, providing adequate speech perception is not the only reason for ensuring classrooms have good acoustics and minimal noise levels. Noise affects many aspects of children's education such as reading and language comprehension, cognition, attention, concentration, and motivation (Crandell & Smaldino, 2000; Shield et al., 2010). Consistent exposure to noise also has physiological effects on both the child and teacher including raised blood pressure, increased stress levels, headaches, and fatigue (see Anderson, 2001, and Shield et al., 2010, for a review). Therefore, there are many reasons to ensure classroom noise levels are kept to a minimum.

Minimizing noise levels in the classroom is not only important for typically developing children, but is essential for children with special education needs such as those with attention deficits, hearing impairments, auditory processing disorders, language delays, and English as a second language who are more affected by poor acoustics (Anderson, 2001; Crandell & Smaldino, 2000; Keith, 1999; Nelson & Soli, 2000). These children are increasingly being integrated into mainstream classrooms (Konza, 2008). For example, it is estimated that 83% of children with hearing impairments are now in a regular classroom (Punch & Hyde, 2010). It is important to note that the recommended levels in Table III are for 5-6-year-old children with typically developing hearing and language skills. Children with special educational needs are thought to require ambient noise levels to be < 20 dBA, intrusive and background noise to be < 40 dBA, signal-to-noise ratios to be > +20 dB and reverberation times to be < 0.3 s (Airey, 1998; Association of Australian Acoustical Consultants, 2010). The results of our study suggest that these levels are highly unlikely to be achieved in any classroom, let alone in open plan classrooms.

Although little research has been conducted in Australia, the idea that open plan classrooms are not adequate educational spaces has been recognized in other countries. The American National Standards Institute (2002) and the Canadian Standard for School Facilities (2001; see Wilson, 2002) strongly discourages open plan classrooms, stating that any advantage in teaching methodology is defeated by the negative impact on learning caused by their high noise levels. The results of this study support this, suggesting that it may be beneficial for Australia to have recommendations or restrictions for open plan classrooms.

We acknowledge, however, that as teaching methods are favoring a less authoritarian and more child-centered approach, more flexible learning spaces may be desirable (Brogden, 1983; Maclure, 1984; Norlander, Moås, & Archer, 2005; Shield et al., 2010). Shield et al. (2010) suggests that open plan classes may stay within appropriate noise levels as long as they have:

- A semi-open plan linear style with at least 1.6-2.0 m high partitions with separate quiet rooms that children can use when they need more favorable listening conditions
- A maximum of three class bases that coordinate activities, especially those involving critical listening, to minimize the effect of intrusive noise (Greenland & Shield, 2011)
- At least 6.5 m between the edges of the class bases and $4-5 \text{ m}^2$ per child.

It is important to recognize that these classrooms will still compromise on noise, hence speech perception, compared to an enclosed classroom. However, irrespective of design, it is highly recommended that *all* classrooms are acoustically treated to enhance speech perception (Siebein, Gold, Siebein, & Ermann, 2000). This includes:

- Having a maximum ceiling height of 3.5 m and 90% absorption on the ceiling and walls to control reverberation and reduce noise transmission (Shield et al., 2010; Siebein et al., 2000; Wilson, 2002)
- Having carpet to reduce footfall and furniture noise (Siebein et al., 2000)
- Installing heating, ventilation, and air conditioning systems and equipment that have low noise level ratings to reduce ambient noise levels (Wilson, 2002). (The problem with having high ambient noise levels is that speakers need to raise their voice more to

be heard above these levels. Therefore, due to the Lombard Effect, this results in higher and higher noise levels with each additional sound source (Whitlock & Dodd, 2008). Minimizing these levels is therefore important for maintaining low noise levels overall.)

- Using FM systems for hearing impaired children during critical listening activities (Wilson, 2002)
- Using sound field systems and/or gathering children as close as possible to the teacher. This will help maintain, for all children, higher SNRs, STIs and speech perception, commensurate with those normally enjoyed by children at the front of the class. As a result, this will enhance the children's learning and minimize teacher's vocal strain (Massie & Dillon, 2006a, 2006b). (Note, however, that amplification systems are not appropriate for open plan classrooms (where the SNR distance effect is even more apparent) because of their disturbance to other classes. This further suggests the shortcomings of this type of learning space.)

It is also important that each classroom is assessed on a case-by-case basis as the acoustics will differ depending on what building materials and fittings are used. Additionally, the age of the students needs to be taken into consideration. While the acoustic conditions may be suitable for older children, it is likely that younger children are still going to struggle in these environments, as are children with special educational needs. Therefore, the findings of both the previous research and our current study suggest that treated enclosed classrooms are likely to be the most suitable learning spaces.

6. CONCLUSIONS

The results of our study suggest that open plan classrooms with over 90 students are not appropriate learning environments for young children due to the high intrusive noise levels experienced in these types of spaces. These noise levels are likely to affect not only the children's learning, but also cause vocal health problems for the teachers from the need to constantly raise their voice above a comfortable level to be heard. These findings suggest that

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while a classroom with four solid fully enclosed walls is likely to be the best learning environment, a single classroom with a concertina wall should provide adequate listening conditions most of the time. This type of classroom also gives the flexibility of opening the concertina wall for the activities the teachers prefer to have a more open plan space for, but then closing it for critical listening activities to minimize intrusive noise and enhance speech perception. Additionally, a double classroom with 44 students in total may also be sufficient for speech communication provided critical listening activities are coordinated between classes and noise is controlled. While this study only provided case studies of four classrooms, the findings are similar to those few studies that have previously been conducted (e.g. Greenland & Shield, 2011). Further investigation is needed, however, to assess exactly what classroom types are suitable learning spaces for children at different ages. It is essential for this research to be conducted in a wide range of open plan and enclosed classrooms to assess which designs are appropriate in order to meet the recommended reverberation times and what the maximum number of students/class bases in an area should be to minimize noise levels and ensure adequate speech perception in the learning environment. Once this research has been conducted it may be beneficial for Australia to implement recommendations or restrictions for open plan classroom design so speech perception is not compromised in the educational setting.

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CHAPTER 3: THE DEVELOPMENT OF THE MEALINGS, DEMUTH, DILLON, AND BUCHHOLZ CLASSROOM SPEECH PERCEPTION TEST

This chapter is based on the following published paper:

Mealings, K. T., Demuth, K., Buchholz, J. M., & Dillon, H. (2015). The development of the Mealings, Demuth, Dillon, and Buchholz Classroom Speech Perception Test. *Journal* of Speech, Language, and Hearing Research, 58, 1350-1362. doi:10.1044/2015_JSLHR-H-14-0332

All components of this paper, both experimental and written, have been completed by me, with advice from the co-authors (my supervisors) when needed.

Abstract

Purpose: Open plan classroom styles are increasingly being adopted in Australia despite evidence that their high intrusive noise levels adversely affect learning. The aim of this study was therefore to develop a new Australian speech perception task (the MDDB CSPT) and use it in an open plan classroom to assess how intrusive noise affects speech perception.

Method: The first part of this paper describes how the online four-picture choice speech perception task materials were created. The second part focuses on the study involving 22 5-6-year-old children in an open plan classroom who completed the task while other classes engaged in quiet and noisy activities.

Results: Children's performance accuracy, number of responses, and speed were lower in the noise compared to quiet condition. Additionally, children's speech perception scores decreased the further away they were seated from the loudspeaker. Overall, the children understood and were engaged in the task, demonstrating it is an appropriate tool for assessing speech perception live in the classroom with 5-6-year-old children.

Conclusions: The results suggest the MDDB CSPT is a helpful tool for assessing speech perception in classrooms and it would be beneficial to use it in future research investigating how classroom design/noise affects speech perception.

The Development of the Mealings, Demuth, Dillon, and Buchholz Classroom Speech

Perception Test

Primary school provides children's first experience of formal education, preparing them for higher levels of literacy, numeracy, and other academic skills. The primary modes of communication in the educational setting are speaking and listening, with children spending on average 45-60% of their time at school attending and comprehending (Rosenberg et al., 1999). They therefore need to be able to discriminate the speech sounds they hear from the vast variety of other distracting noises present in the classroom environment.

Noise generated by other children is the major noise source found in classrooms (Shield & Dockrell, 2004). While it is generally recommended that signal-to-noise ratios (SNRs; a direct measurement of the intensity of the signal (e.g., the teacher's voice) compared to the background noise level) should be greater than +15 dB (American National Standards Institute, 2002; Crandell & Smaldino, 2000; MacKenzie & Airey, 1999; Shield, Greenland, & Dockrell, 2010; Wilson, 2002) many studies have shown they only reach between -7 to +5 dB (American Speech-Language-Hearing Association, 2005; Crandell & Smaldino, 2000; Finitzo, 1988). Noise levels in open plan classrooms (where multiple classes share the same space) can be particularly problematic (Shield et al., 2010). This type of classroom is becoming increasingly popular in the United Kingdom and now Australia (Shield et al., 2010; Stevenson, 2011). Noise levels are reported to be highest in the classrooms of the youngest children (Jamieson, Kranjc, Yu, & Hodgetts, 2004; MacKenzie & Airey, 1999; Picard & Bradley, 2001; Wróblewski, Lewis, Valente, & Stelmachowicz, 2012) which is also the age group most affected by noise (Johnson, 2000; Leibold & Buss, 2013; Nishi, Lewis, Hoover, Choi, & Stelmachowicz, 2010; Nittrouer & Boothroyd, 1990). As children's auditory systems are neurologically immature, they have greater perceptual difficulties than adults in discriminating and understanding speech, and cannot use years of previous communicative experience to fill in missing information (Nelson & Soli, 2000; Wilson, 2002). More specifically, consonant identification in noise, particularly of codas (which are less perceptually salient than onsets; Redford & Diehl, 1996,

1999) does not reach adult-like performance until the late teenage years (Johnson, 2000; Nishi et al., 2010). Children with hearing impairments, special educational needs, those who have English as a second language (ESL), and introverts are even more affected by high noise levels (Cassidy & MacDonald, 2007; Crandell & Smaldino, 2000; MacKenzie & Airey, 1999; Nelson & Soli, 2000; Nelson, Kohnert, Sabur, & Shaw, 2005; Shield, Greenland, & Dockrell, 2010). Aboriginal and Torres Strait Islander children are at greater risk of being affected by poor classroom acoustics because middle-ear related hearing loss (usually caused by otitis media) affects 50% to 80% of these children. This decreased ability to hear speech clearly adversely impacts classroom performance and creates feelings of inadequacy amongst these students (Massie, Theodoros, McPherson, & Smaldino, 2004; Nienhuys, Boswell, & McConnel, 1994). Children with central auditory processing disorders also find it challenging when listening in the presence of background noise and reverberation (Keith, 1999).

Speech intelligibility in the classroom is influenced by a number of factors, including room geometry, reverberation time, the teacher's voice level, and background noise (MacKenzie & Airey, 1999). Excessive noise levels, however, is the most significant contributor affecting speech perception (Sato & Bradley, 2008; Yang & Bradley, 2009). Many studies have shown the detrimental effect of noise on children's speech perception, reading and cognition, concentration, learning, psychoeducational, language comprehension, and (American Speech-Language-Hearing Association, psychosocial development 2005: Anderson, 2001; Crandell & Smaldino, 1995; Dockrell & Shield, 2006; Finitzo-Hieber & Tillman, 1978; Jamieson et al., 2004; Klatte, Lachmann, & Meis, 2010; Ronsse & Wang, 2010, 2013; Shield et al., 2010; Vickers et al., 2013).

There are already a number of tests assessing speech perception available (e.g., Word Intelligibility by Picture Identification (WIPI; Ross & Lerman, 1970); Northwestern University - Children's Perception of Speech (NU CHIPS; Elliott & Katz, 1980); Pediatric Speech Intelligibility Test (PSI; Jerger & Jerger, 1982); Early Speech Perception Test (ESP; Geers & Moog, 1990); Chear Auditory Perception Test (CAPT; Marriage & Moore, 2003); and WordsIn-Noise (WIN; Wilson, 2003)). These tests, however, give only gross speech perception scores so little can be said about what the *specific* aspects of speech are that make particular words difficult to perceive in noise. In addition, most of these speech tests were developed in the United States or the United Kingdom, so the recordings are in an American or British English accent, and many of these tests were created years ago, so the words are not always appropriate for the current Australian context. Several of these tests also present the target words in isolation rather than as part of a sentence. This presentation style is not only more difficult perceptually as it does not provide an auditory grouping cue or prior exposure to how speech is reverberated in the room (Bonino, Leibold, & Buss, 2012; Brandewie & Zahorik, 2010), but it is also not representative of teaching practices or typical conversation patterns as we tend to speak using phrases rather than individual words. Given these issues, we decided it would be valuable to develop a new, Australian-focused speech test that allowed both gross speech perception scores to be calculated, but also some finer grained, word-specific analysis to be conducted. Additionally, we wanted the test to be conducted in the 'real' classroom environment as many previous speech perception tests use multitalker babble which is not representative of the background noise present in the classroom (Jamieson et al., 2004).

Testing in the 'real' classroom environment, however, can be very challenging. Many speech perception tests (e.g., WIPI (Ross & Lerman, 1970), NU CHIPS (Elliott & Katz, 1980)) require children to be tested individually by pointing to or repeating back what they hear. This, however, is very time consuming if the goal is to test large numbers of children. Verbal response methods are also subject to human error; young children often have poor articulation so their answer may be easily misinterpreted (Ross & Lerman, 1970).

One way of testing a larger group of children is by a traditional pen-and-paper method. Children are presented with the stimuli at the front of the class and after each question they write down their answers. While this allows the whole class to be tested at once, the children's responses have to be collected and marked individually. This again is time consuming and there is greater possibility for human error by misunderstanding handwriting (Jamieson et al., 2004), adding up scores incorrectly, or the children misaligning their answers with the stimuli, which can easily occur if they fail to answer one question. Additionally, this method is not suitable to test younger participants, such as the Kindergarten children (i.e. 5-6-year-olds) as they are too young to write. It also allows only for 'accuracy' of selecting the appropriate response, but no information about response time (i.e. how long it took listeners to determine the appropriate answer).

A recent study by Vickers et al. (2013) piloted a new, more efficient way of testing speech perception in the classroom. In their study, Personal Response Systems (PRS) were used to simultaneously test all children live in the classroom. These systems are often used in university teaching but this was the first time they were used to effectively assess speech perception in the classroom. Using this method, questions are presented to the students visually at the front of the classroom using TurningPoint software (Turning Technologies, Youngstown, OH), and the children respond to each question using their PRS. Responses are recorded in a file via a universal serial bus (USB) receiver and exported in .tpzx format so they can be later analysed. Each child is linked to a PRS code so anonymity is preserved, and within the software demographic details for each child can be added to be included in the analysis. Additionally, TurningPoint software records response times, which is an important variable for understanding children's ability to process information in a way that traditional pen-and-paper or pointing/speaking methods are unable to capture. While response time measures do provide insight into children's speed of processing, it is also important that these results are interpreted with caution as they can sometimes represent 'contemplation' time rather than 'reaction' time, or may reflect different cognitive processes (see Bess and Hornsby (2014), Jiang (2012), and Schwartz (2009)). Asking participants to respond as quickly as possible can help avoid this.

Therefore, the two main aims of this study were to (a) develop a new Australian speech perception task – the Mealings, Demuth, Dillon, and Buchholz Classroom Speech Perception Task (MDDB CSPT) – that was engaging and could be conducted live and efficiently in the real classroom listening environment through the use of PRSs and (b) evaluate the effectiveness

of using the MDDB CSPT in an open plan classroom to assess how intrusive noise affects speech perception.

PART ONE: DEVELOPMENT OF THE MDDB CSPT SPEECH MATERIALS Word lists

Consonant perception is vital to understanding speech. Below is an example from MacKenzie and Airey (1999) of speech with 100% loss of vowels (1) and 100% loss of consonants (2):

(1) 100% loss of vowels

_ll ch_ldr_n h_v_ t_ _tt_nd pr_m_ry sch__l

(2) 100% loss of consonants

A___i_e__a_e_o a_e___i_a___oo_

Note that when there is 100% loss of vowels, it is still relatively easy to make out the sentence "All children have to attend primary school". However, when 100% of the consonants are missing, it is nearly impossible to understand what has been said. This is problematic as consonants are more likely to be lost in noise than vowels (Wilson, 2002), and consonant identification in noise and reverberation does not reach adult-like performance until late teenage years (Johnson, 2000; Nishi et al., 2010). As a result, young children are vulnerable to missing a lot of information in classrooms with poor acoustics. Our speech test therefore focuses on consonant perception in noise.

The word lists we created for the test were based on the same idea as the Chear Auditory Perception Test (Marriage & Moore, 2003) used in a similar classroom speech perception task by Vickers et al. (2013). Vickers et al. (2013) used five of Marriage and Moore's (2003) seven lists which each consisted of four monosyllabic words using minimally contrastive confusion groups to test consonant perception. Consonant discrimination occurred on either the onset or coda of the word. Table 1 shows the five lists used by Vickers et al. (2013).

Table 1. CAPT word lists.

List 1	List 2	List 3	List 4	List 5
Bu <u>d</u>	<u>M</u> at	<u>Wh</u> ite	Wi <u>pe</u>	<u>St</u> ork
Duzz	Cat	Nicht	Wice	Fork
	<u>C</u> at	<u>IN</u> Igin	W1 <u>8e</u>	<u>r</u> 01k
Bun	Fat	Right	White	Talk
_	_	=0		
Bug	<u>B</u> at	<u>L</u> ight	Wi <u>ne</u>	<u>Ch</u> alk

The motivation behind redeveloping the CAPT lists for our studies was to allow for more control of the onset and coda changes so a more fine grained analysis could be completed. This would allow for direct, controlled comparisons to be made between the lists. That is, we wanted to be able to compare the perception of onsets and codas without having the confounding problem of different phonemes having different perceptual saliencies due to their different acoustic properties (Stevens & Keyser, 1989; Stevens, 2002; Stevens & Keyser, 2010). The three features, continuant (i.e. speech sounds that allow air to pass through the vocal tract), sonorant (i.e. speech sounds where the air pressure inside the mouth is equal to the air pressure outside the mouth so there is no turbulence), and coronal (i.e. speech sounds produced by raising the tongue to the teeth or hard palate), are the most perceptually salient features for consonants, so consonants that have these primary features are more perceptually salient than consonants without them (Stevens & Keyser, 1989). For example, /j/ which has all three features is more salient than /s/, which has two features, which is more salient than /m/, which has one feature, which is more salient than /k/, which has none of these features (Stevens & Keyser, 1989). We therefore constructed our lists so that the types of phonemes used for the onset consonants, but not necessarily the same specific consonants, were then also used as the coda consonants in the subsequent list. This allowed us to compare onset and coda perception directly, with the hypothesis that performance on codas would be poorer due to their decreased acoustic and therefore perceptual saliency (Redford & Diehl, 1996, 1999). We also wanted to be able to compare the perception of different types of onset and coda consonants across lists. For our test we developed six word lists. Three of these lists had onset contrasts with (C)(C)VC phonemic structures, and the other three had coda contrasts with CV(C)(C) phonemic structures. Lists contrasting onsets were given the prefix 'O' and lists contrasting codas were given the prefix 'C'. The same long vowel (or diphthong as used for List C1) was used for each word in a particular list. Note that the vowel qualities used are for Australian English (Harrington, Cox, & Evans, 1997). Below is a description of how the word lists were developed:

- List O1 & C1: Tests *voiceless* consonant perception with manner/place changes occurring for the onset in List O1 (no initial consonant, initial alveolar stop, initial velar stop, initial fricative) and for the coda in List C1 (no final consonant, final bilabial stop, final velar stop, final fricative).
- List O2 & C2: Tests *voiced* consonant perception with manner/place changes occurring for the onset in List O2 (no initial consonant, initial bilabial stop, initial bilabial nasal, initial alveolar nasal) and for the coda in List C2 (no final consonant, final alveolar stop, final bilabial nasal, final alveolar nasal).
- List O3 & C3: Tests consonant perception of stops versus fricatives versus affricates versus clusters with the changes occurring in the onset and coda position respectively.

The target words chosen were high frequency, picturable nouns or verbs that would be familiar to Australian Kindergarten children. The frequencies (shown in Table 2) were extracted via ChildFreq from the CHILDES database which calculates the child's frequency of saying the target word per million words between ages 4;0-6;0 (Bååth, 2010; MacWhinney, 2000). Effort was made to choose words which had high frequencies and as similar frequencies for all words within the list as possible, though given the phonemic restraints this was difficult to fully control.

List	Word	Transcription	Frequency	Range	Average
01	_Art	/eːt/	18	1-91	34
	<u>T</u> art	/te:t/	1		
	<u>C</u> art	/keːt/	26		
	<u>H</u> eart	/heːt/	91		
02	_Eat	/iːt/	1753	63-1753	539
	<u>B</u> eat	/bi:t/	171		
	<u>M</u> eat	/miːt/	170		
	<u>N</u> eat	/niːt/	63		
03	<u>T</u> alk	/toːk/	531	10-531	162
	<u>F</u> ork	/fo:k/	91		
	<u>Ch</u> alk	/t∫oːk/	14		
	<u>St</u> alk	/sto:k/	10		
C1	K_	/kæɪ/	84	31-332	129
	Ca <u>pe</u>	/kæıp/	31		
	Ca <u>ke</u>	/kæık/	332		
	Ca <u>se</u>	/kæıs/	69		
C2	Bee_	/biː/	60	1-60	29
	Bea <u>d</u>	/biːd/	7		
	Bea <u>m</u>	/biːm/	1		
	Bea <u>n</u>	/biːn/	48		
C3	Bea <u>t</u>	/biːt/	171	2-171	75
	Bee <u>s</u>	/biːs/	27		
	Bea <u>ch</u>	/biːtʃ/	101		
	Bea <u>st</u>	/biːst/	2		

From Table 2, note that List O3 is the same as List 5 the CAPT stimuli, but 'stork' has been changed to 'stalk' which is easier to picture and higher in frequency (10 per one million words compared to 1 per one million).

Pictures

Each target word was represented by a picture for the stimulus display. The pictures were real-life (i.e. not cartoon) photos with no background to avoid distraction. In contrast to Vickers et al. (2013), we did not display the written form of the target words with the pictures during the testing phase as we did not want those children who had better reading skills to have an advantage when doing the task. All pictures were vetted by adults first, and modifications were made until all the pictures were considered to be clear and appropriate.

Carrier sentences

Each target word was placed in a carrier sentence for the test. In their study, Vickers et al. (2013) used isolated words only, but we decided to put the target words in a sentence as this is more realistic to how teachers speak in the educational environment. Word recognition scores are generally higher when the word is presented in a carrier phrase compared to isolation as it provides an effective auditory grouping cue when there is substantial perceptual masking (Bonino et al., 2012). Additionally, prior exposure to speech through a carrier sentence in reverberant rooms aids speech intelligibility (Brandewie & Zahorik, 2010). One carrier sentence was chosen for each list (e.g., *Katie wants the <u>cake</u>; Sally likes the <u>bead</u>). Effort was made to make the carrier sentences as neutral as possible so all words in the list could be potential answers. Each complete sentence was five syllables in length and had the same syntactic and rhythmic structure. The target word always appeared utterance-finally as this is the most salient utterance position due to phrase-final lengthening in English (Oller, 1973).*

Audio recordings

The 24 sentences were recorded in clear speech by an adult native female speaker of Australian English who was instructed to speak as if she was teaching 5-to-6-year-old children. The recording took place in an anechoic chamber using a headset condenser microphone (DPA d:fine) that was placed approximately 2 inches from the speaker's mouth and routed to a preamplifier (RME QuadMic). Between the preamplifier and the PC there was an RME M-32 AD converter which was connected via an optical MADI cable to the RME HDSPe MADI FX sound card of the PC. Test stimuli were digitally recorded using Adobe Audition software at a sampling rate of 48 kHz (32 bits, mono). Afterwards, each sentence was segmented and normalised using Praat software (Boersma & Weenink, 2011) so each sentence had the same average root mean square value.

Stimulus display

For the stimulus display, the four pictures of a particular list appeared on a PowerPoint slide (created within the TurningPoint software ("Turning Technologies," 2013)) accompanied by the pre-recorded spoken sentence audio containing one of the target words. The sentence was also orthographically displayed at the top of the slide, but with the target word missing (e.g., *Sally likes the* ...). Below each picture was a coloured dot corresponding to the colour-coded dot options on the PRS. This layout was repeated for all 24 sentences, with the picture positions swapped around each time a particular list was displayed. The List order was pseudo-randomised (e.g., 1, 4, 6, 3, 5, 2) and the lists were rotated through four times so each word in each list was presented.

PART TWO: MDDB CSPT CLASSROOM STUDY

The main aim of this study was to evaluate the effectiveness of using the MDDB CSPT to test children's speech perception live in the classroom. In this study we wanted to compare children's speech perception in an open plan classroom when the other class bases were engaged in quiet versus noisy activities to assess how intrusive noise affects speech perception. It was hypothesised that both the children's performance *accuracy* and *speed* would be poorer when the other class bases were engaged in noisy compared to quiet activities, and that performance accuracy would decrease the further away the child was seated from the loudspeaker (simulating the teacher's voice) due to the decreasing SNR. Additionally, it was

hypothesised that the children would perform more poorly at discriminating coda consonants compared to onsets due to the lower perceptual salience of coda consonants.

Method

Involvement

School. The participating open plan Sydney school consisted of 91 Kindergarten students grouped linearly into three classes (K1, K2, K3), with no barriers between them. This classroom represented a mid-range student and class base number for an open plan space. The Year 1 and 2 classes were located off an adjacent corridor but had no doors/walls separating the spaces; hence noise from these classes could also be heard. Originally the space had consisted of separate enclosed classrooms with 30 children in each, but these walls had recently been removed to make the area fully open plan. The class area was carpeted but the corridor was a hard surface. Windows were located on both the front and back walls and pin boards were on the other two walls (Figure 1). No other acoustic treatment was evident. The average unoccupied reverberation time (T30) of this classroom was 0.70 s, which is above the recommended time of 0.4-0.5 s (Australia/New Zealand Standard, 2000).



Figure 1. Classroom floor plan showing Kindergarten class bases and openings to Year 1 and 2 classes.

Participants. Twenty-two students (9 male, 13 female) out of the 91 students in the 3 classes were randomly selected to participate as one class in the classroom speech perception

task. The remaining children made up the other two classes to provide the intrusive noise. Of the 22 students, 11 had ESL, and an additional 4 were multilingual. No children were reported by their parents to have otitis media, or intellectual or behavioural disabilities. The age range of these participants was 5;4-6;6 years (M = 5;9). An additional 2 children participated in the study but were excluded as they did not finish the task.

Stimuli

The Mealings, Demuth, Dillon, and Buchholz Classroom Speech Perception Test (MDDB CSPT) stimuli described above was used for the study.

Listening conditions

There were two listening conditions in order to assess how intrusive classroom noise impacts students' listening abilities; one when the other two Kindergarten classes and the Year 1 and 2 classes were engaged in quiet activities (e.g., whole class teaching) and the other when they were engaged in noisy activities (e.g., group work with movement). To counterbalance possible learning effects, the participants were split into two groups. Group 1 completed the experiment during quiet activities and then noisy activities, whereas Group 2 completed the experiment during noisy activities and then quiet activities. The noise from each activity was recorded using a calibrated omnidirectional condenser microphone (placed behind the back row of the children completing the task) connected to a USB sound card and Toshiba Satellite U940 Ultrabook (Toshiba, Tokyo, Japan) running Audacity software. This allowed us to calculate the average noise levels for each activity offline. The back row of students was approximately 13 m away from the closest class engaged in quiet/noisy activities, and the front row was approximately 15 m away. At this distance in a reverberant room the difference in noise level from the adjacent classes between those in the back and front row of the tested class is minimal (i.e., <1 dB), so recording the noise level behind the back row of children provided a reasonable estimate of the noise level experienced by all the tested children.

Procedure

Participants were each assigned a seating position in one of six straight rows of four children in front of an interactive whiteboard with boys and girls and ESL students evenly distributed front to back (this is shown by the "floor teaching area" label on Figure 1). Two students were at each of the following distances from the loudspeaker which was placed front and centre: Row 1: 1 m and 1.25 m; Row 2: 1.4 m and 1.6 m; Row 3: 1.8 m and 1.95 m, Row 4: 2.2 m and 2.3 m; Row 5: 2.6 m and 2.7 m; Row 6: 3 m.

PowerPoint presentation

The speech perception test (introduced as a 'listening game') comprised of a PowerPoint presentation created within the TurningPoint software consisting of the following sections: Familiarisation with target words and pictures, Familiarisation with the PRS, and the Testing phase. The visual stimuli were projected onto the 77 inch 4:3 aspect ratio interactive whiteboard via a Toshiba Tecra Notebook and the audio was played through an 8020B active studio monitor loudspeaker (Genelec, Iisalmi, Finland) positioned at the front of the classroom. The audio volume was adjusted so that the average sound level presentation was 60 dBA at 2 m (which represents a teacher's average speech level (Sato & Bradley, 2008) as measured by a Q1362 sound level meter (Dick Smith Electronics, Chullora, New South Wales, Australia). Based on acoustic measurements that were previously performed in the same classroom but in other locations, the approximate sound pressure levels can be estimated to about 64 dBA at 1 m and about 57 dBA at 3 m which covers the range of seating distances of the children from the loudspeaker.

Familiarisation with target words and pictures. The test began with all participants completing a familiarisation phase to ensure they understood the target word represented by each picture. The children saw the picture accompanied by the pre-recorded audio of the single target word for each of the 24 stimuli. The children were instructed to repeat each word back as a group after they heard it. The orthographic text was included in the familiarisation phase

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to aid the initial picture identification, but it was removed during the testing phase to avoid those children with better reading skills having an advantage when doing the task

Familiarisation with the PRS. The children were then instructed on how to use their interactive TurningPoint ResponseCard RF LCD Keepads and had several multiple choice practice questions (e.g., *Which balloon is red?*) to become comfortable with using the device. During the practice questions the correct answer and results graph showing the children's answers was displayed after each question so children could monitor their responses. High performance accuracy (*mean* = 96%) by the children during this phase demonstrated the children's ability to understand the task and to use their PRS.

Testing phase. Once the children were familiarised with the stimuli and their PRS, the testing phase began. The children were instructed to listen to the audio and then select which picture they heard using their PRS. They were also encouraged not to say their response aloud or copy other children's responses. As motivation to attend to and complete the whole task, the children were told that there would be a prize at the end. (This was a mathematics question where the first child to record their answer correctly won the prize, but all participating students were also given a smaller prize for encouragement). The children then completed online the four-picture forced choice speech perception task for all 24 items using their PRS. The Lists were pseudo-randomised and rotated through throughout the experiment rather than having all four words of a List presented consecutively which makes it easier for children to use a process of elimination. A maximum of 15 seconds was allowed to respond to each sentence. The children completed the test in both a quiet condition (e.g., when the other classes were engaged in whole class teaching or individual work) and noise condition (e.g., when the other classes were completing group work and/or moving around) with the noise levels recorded for each condition. The students involved in the testing were split into two groups: Group 1 completed the task in the quiet condition first while Group 2 left the testing area. Group 1 and 2 then completed the testing phase in the noisy condition together (to ensure the noise level was the same for both groups tested) before Group 1 left Group 2 to do the test in the quiet condition. Having two Groups complete the test in different orders helps minimise learning effects. The whole procedure including familiarisation took around 45 minutes to complete.

Post-test analysis

The TurningPoint software recorded all of the children's responses via a USB receiver and exported them in .tpzx format for later analysis. Using this software we collated and analysed the children's correct/incorrect answers how long it took the children to give their answer (which was calculated from the onset of each stimulus display).

Results

Noise levels

The noise levels during each condition were recorded so the difference between quiet versus noisy activities could be measured. The average noise level when the other classes were engaged in quiet activities was 57.4 dBA. When the other classes were engaged in noisy activities, the average level was 10.3 dBA louder at 67.7 dBA. Both of these levels are above the recommended 50 dBA maximum for classrooms (Berg, Blair, & Benson, 1996).

Overall speech perception scores

The average speech perception scores from the children was 67% when the adjacent classes were engaged in quiet activities (*range* = 50%-88%, *SD* = 13) and 45% when they were engaged in noisy activities (*range* = 8%-79%, *SD* = 18). All children performed worse in the noisy condition compared to the quiet condition (*range* = 4%-46% worse, *SD* = 13), except for one child seated up the front who had the same score for both conditions. A linear mixed effects analysis assessed whether the factors of quiet versus noisy activities, onsets versus codas, ESL, and distance from the loudspeaker (using log base 2 as sound decay is generally calculated per doubling of distance) contributed to the children's speech perception scores. As predicted, noise condition, onset versus codas, and distance from the loudspeaker were significant factors in the model (*F_{noise condition}* (1,79) = 64.09, *p* < .0005; *F_{onsets versus codas* (1,79) = 6.15, *p* = .015; *F_{distance}* (1,79) = 67.04, *p* < .0005). If all other predictor variables are held constant, scores are predicted to be 22% lower when the other classes are engaged in noisy compared to quiet activities.}

Additionally, the model estimated that the children's performance is 7% lower when perceiving codas compared to onsets. Similarly, if all other predictor variables are held constant, scores are estimated to decrease by 26% for each doubling of distance the child is seated away from the loudspeaker (i.e. 1 m, 2 m, 4 m etc.). Further analysis of these two factors can be found below. ESL was also a significant factor – if the other predictor variables are constant, those who have ESL scored 9% lower overall compared with those who have English as their first language (F(1,79) = 8.49, p = .005). Two-sample t-tests were also conducted to assess if presentation order had an effect on the children's scores. No significant difference was found, however, between the scores of Groups 1 and 2 for either in the quiet or noisy conditions ($t_{quiet}(20) = -.36$, p = .719, d = -.16; $t_{noisy}(20) = -.71$, p = .486, d = -.32).

List analyses. As a significant difference was found on the children's perception of onsets versus codas, we conducted a finer grained analysis to compare the effect of noise on individual lists. A series of paired t-tests was run to determine significant differences between speech perception while the other classes were engaged in quiet versus noisy activities for each list. Bonferroni corrections were used to account for the multiple comparisons ($\alpha = .05/6 = .008$). Performance was significantly poorer in the noisy condition for Lists O1, O2, O3, C2, and C3, but not for List C1, although it trended in that direction (Figure 2). Indeed, the effect of noise was not significantly different from 22% (the mean effect of noise for the test as a whole) for any list, as indicated by the lack of interaction in a two-way ANOVA with condition (quiet versus noisy activities) and list as repeated measures factors (*F*(5,252) = 0.44, *p* = .820).

Two one-way ANOVAs with post hoc Tukey's honestly significant difference (HSD) tests were then conducted to determine significant differences between the children's scores on the lists during quiet activities and then noisy activities. The ANOVA results were significant for both the quiet (F(5,126) = 7.97, p < 0.0005, $\eta_p^2 = .23$) and noisy conditions (F(5,126) = 7.90, p < 0.0005, $\eta_p^2 = .22$) with post hoc Tukey HSD tests showing List C2 to be significantly more difficult than the other lists when adjacent classes were engaged in noisy activities, and

significantly more difficult than three of the other lists when adjacent classes were engaged in quiet activities (Figure 2). No significant differences were found between other lists.



Figure 2. Children's mean number of correct responses by list while adjacent classes were engaged in quiet activities versus noisy activities. Error bars indicate standard error of the mean. Lines and asterisks show significance at p < .008 level.

The following section breaks this analysis down further to see what other factors may contribute to the children's performance, and in particular, to explore what may have driven the poor performance on List C2. This was carried out by examining lexical frequency effects for both the correct answers, and what the children tended to choose if their original choice was incorrect.

Word analyses

Lexical frequency effects. A series of correlations was conducted to assess if performance accuracy was related to the word's lexical frequency given in Table 2 (using a logarithmic transform) because higher frequency words tend to be recognised better in speech tests (Massie & Dillon, 2006). Word frequency was treated as a continuous variable and correlations were conducted for each list while the other classes were engaged in quiet and in noisy activities and

for all lists combined in the quiet and noisy conditions. Significant correlations were found in the quiet condition for List C1 (r = .958, p = 0.042) and List C2 (r = .982, p = 0.018). No significant correlations for any lists were found in the noisy condition. Correlations were also not significant in the quiet or noisy condition when all lists were combined.

Correlations were also conducted to assess if the proportion of times a word was chosen was related to its lexical frequency (using a logarithmic transform). No significant correlations were found, however, for any list or when all lists were combined, in the quiet or noisy condition.

Confusion matrices. As the previous analysis focused on the contributing factors for *correct* responses, an additional analysis was conducted to further understand patterns in word selection when the child got the word *incorrect*. The children's performance on each word of each list and the confusion patterns are shown in Table 3.

For List O1, *art* was often mistaken for *heart* when the other classes were engaged in both quiet and noisy activities. *Heart* is the higher frequency word spoken by children of this age group, and is also easier to picture. Given that /h/ is a low energy sibilant, it is possible that children think they have heard this onset consonant between the words *the* and *art* at the end of the carrier sentence.

In List O2, *neat* was often mistaken for *meat* during both quiet and noisy activities. This is expected due to their perceptual similarity as they are both nasals. In this case there was a bias towards selecting *meat* as it is the higher frequency word spoken by this age group and is also easier to picture.

Interestingly, in the noise condition for List O3, the poorest performance occurred for the target word *talk* which is the highest frequency word in this list. However, it is likely that this high frequency relates to when it is used as a verb rather than a noun as it appears in this context. The nominal form it is probably much less familiar to children. For this target word, *chalk* was chosen equally as often. Not only is *chalk* easier to picture than *talk*, but *chalk* /tfo:k/

also has an affricate that begins with the stop occlusion /t/, so the perceptual similarity of these words is likely to contribute to their confusion in noise.

For List C1, *cape* was often mistaken for *cake* during quiet activities but even more so during noisy activities. Both of these voiceless final stop consonants are acoustically weak (Stevens & Keyser, 1989) and place of articulation is the only difference between them making them similar perceptually (Dillon & Ching, 1995). Hence, when confused, *cake* tended to be chosen due to its higher frequency.

Similar to List O2, List C2 had a high confusion rate between the nasals in *bean* and *beam*. This is again expected due to their perceptual similarity, with a bias towards selecting *bean* as it is the higher frequency word spoken by this age group. In the noise condition, however, performance was particularly poor across all four words in the list. Performance on List C2 was significantly poorer than all other lists in noisy conditions, and three other lists in quieter conditions as shown in Figure 2.

In List C3, performance was generally high for all four words during quiet activities, but confusions did increase for all four words when other classes were engaged in noisy activities. Fricatives are acoustically salient consonants which is likely to explain the generally high performance on this list particularly in quieter conditions (Stevens & Keyser, 1989).

Overall, increased confusion for all words as well as an increase in non-responses was the general pattern for all lists in the noisy condition. It was also more common in noisier conditions for phonemes to be perceptually epenthesised (e.g. *heart* /<u>h</u>v:t/ for *art* /v:t/, *meat* /<u>mi</u>:t/ for *eat* /i:t/, *cape* /kæɪp/ or *cake* /kæɪk/ for *K* /kæɪ/) or omitted (e.g. *bee* /bi:/ for *bead* /bi:<u>d</u>/, *beat* /bi:t/ for *beach* /bi:tf/; see Table 3).

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participants while other classes were engaged in quiet versus noisy activities for each word

List		Stimuli	Response (% of children)				
01			Art	Tart	Cart	Heart	None
	Quiet	Art	41	14	0	32	14
	Activities	Tart	5	73	5	14	5
		Cart	9	18	59	14	0
		Heart	0	0	0	100	0
	Noisy	Art	36	5	14	41	5
	Activities	Tart	18	50	5	18	9
		Cart	23	23	27	9	18
		Heart	5	5	14	59	18
O2			Eat	Beat	Meat	Neat	None
	Quiet	Eat	91	0	5	0	5
	Activities	Beat	0	95	0	0	5
		Meat	5	5	77	5	9
		Neat	9	0	64	14	14
	Noisy	Eat	36	9	36	0	18
	Activities	Beat	5	77	5	5	9
		Meat	14	0	77	5	5
		Neat	18	0	41	14	27

list. Note values may not add to 100% due to rounding.

03			Talk	Fork	Chalk	Stalk	None
	Quiet	Talk	55	0	18	14	14
	Activities	Fork	0	86	0	5	9
		Chalk	0	5	73	5	18
		Stalk	9	5	5	82	0
	Noisy	Talk	27	9	27	5	32
	Activities	Fork	0	45	36	5	14
		Chalk	0	9	77	0	14
		Stalk	5	9	9	55	23
C1			K	Cape	Cake	Case	None
C1	Quiet	K	К 64	Cape 9	Cake	Case 0	None 14
C1	Quiet Activities	K Cape	К 64 9	Cape 9 50	Cake 14 36	Case 0 0	None 14 5
C1	Quiet Activities	K Cape Cake	К 64 9 0	Cape 9 50 9	Cake 14 36 73	Case 0 0 5	None 14 5 14
C1	Quiet Activities	K Cape Cake Case	К 64 9 0 0	Cape 9 50 9 27	Cake 14 36 73 0	Case 0 0 5 55	None 14 5 14 18
C1	Quiet Activities Noisy	K Cape Cake Case K	К 64 9 0 0 45	Cape 9 50 9 27 32	Cake 14 36 73 0 18	Case 0 0 5 55 0	None 14 5 14 18 5 5
C1	Quiet Activities Noisy Activities	K Cape Cake Case K Cape	К 64 9 0 0 0 45 9	Cape 9 50 9 27 32 27	Cake 14 36 73 0 18 55	Case 0 5 55 0 9	None 14 5 14 18 5 0
C1	Quiet Activities Noisy Activities	K Cape Cake Case K Cape Cake	К 64 9 0 0 0 45 9 18	Cape 9 50 9 27 32 27 23	Cake 14 36 73 0 18 55 45	Case 0 5 55 0 9 5	None 14 5 14 18 5 0 9

			Bee	Bead	Beam	Bean	None
	Quiet	Bee	68	23	0	5	5
	Activities	Bead	14	45	14	23	0
		Beam	5	14	0	82	5
		Bean	5	14	5	73	5
	Noisy	Bee	14	14	5	55	9
	Activities	Bead	45	9	0	14	32
		Beam	5	5	0	68	5
		Bean	0	18	9	50	18
				_			
C3			Beat	Bees	Beach	Beast	None
C3	Quiet	Beat	Beat 86	Bees 0	Beach 0	Beast 14	None 0
C3	Quiet Activities	Beat Bees	Beat 86 0	Bees 0 91	Beach 0 0	Beast 14 0	None 0 9
C3	Quiet Activities	Beat Bees Beach	Beat 86 0 5	Bees 0 91 0	Beach 0 0 73	Beast 14 0 9	None 0 9 14
C3	Quiet Activities	Beat Bees Beach Beast	Beat 86 0 5 5	Bees 0 91 0 0	Beach 0 0 73 0	Beast 14 0 9 91	None 0 9 14 5
C3	Quiet Activities Noisy	Beat Bees Beach Beast Beat	Beat 86 0 5 5 59	Bees 0 91 0 0 27	Beach 0 0 73 0 5	Beast 14 0 9 9 91 0	None 0 9 14 5 9
C3	Quiet Activities Noisy Activities	Beat Bees Beach Beast Beat Bees	Beat 86 0 5 5 59 5	Bees 0 91 0 0 27 55	Beach 0 73 0 5 5	Beast 14 0 9 9 91 0 5	None 0 9 14 5 9 32
C3	Quiet Activities Noisy Activities	Beat Bees Beach Beast Beat Bees Beach	Beat 86 0 5 5 59 5 23	Bees 0 91 0 0 27 55 0	Beach 0 73 0 5 5 5 68	Beast 14 0 9 9 11 0 5 5 5	None 0 9 14 5 9 32 5

Although it was not a robust finding, these results suggest that lexical frequency may play a part in the performance accuracy on a word, and in particular, may help explain which word is likely to be chosen if the original choice is incorrect. It is also likely that lexical frequency, in addition to perceptual confusion, may in part explain the poor performance on List C2 in particular.

Response times

In addition to decreased performance accuracy, we also predicted that there would be a decrease in the speed of the children's response in noisier conditions. As anticipated, a paired

t-test revealed a significant difference in the children's response times (measured from the onset of the stimulus display) with slower responses when the other classes were engaged in noisy activities (M = 7.28 s, SD = 1.70) versus quiet activities (M = 6.17 s, SD = 1.08, t(21) = -3.90, p < .0005, d = -0.80, see Figure 3).



Figure 3. Children's mean response times while other classes were engaged in quiet versus noisy activities. Error bars indicate standard error of the mean. * p < .0005.

A one-way ANOVA was run to compare response times across lists, however no significant difference was found indicating the children had similar response times for all lists during both quiet (F(5,481) = 0.81, p = 0.544, $\eta_p^2 = .01$) and noisy activities (F(5,439) = 0.31, p = 0.905, $\eta_p^2 = .00$).

A correlation analysis was also conducted to asses if performance accuracy was related to reaction time. The results were not significant, however, for the quiet condition (r = .06, p = .788) or the noisy condition (r = .08, p = .712).

Additionally, a correlation analysis was conducted to asses if reaction time was related to lexical frequency (using a logarithmic transform). The results were not significant, however, for either the quiet condition (r = .20, p = .358) or the noisy condition (r = .10, p = .633).

Performance by seating distance

Due to the decreasing SNR, it was predicted that performance accuracy would decrease the further away the child was seated from the loudspeaker. A correlation analysis was conducted to assess how the children's scores changed for each doubling of distance the children were seated away from the loudspeaker (i.e. the change from 1 m to 2 m to 4 m etc., as this represents the decay of sound). When the other classes were engaged in quiet activities, a moderate negative correlation was found between children's performance and their seating distance (r = -0.63, p = 0.002) with children's score decreasing by 16% per doubling of distance from the loudspeaker. On average, scores at the front were (1 m) 82% compared to 56% at the back (3 m). When these activities changed to noisy activities, this relationship increased to a strong negative correlation (r = -0.80, p < 0.0005). In this noisy condition, children's scores decreased by 30% per doubling of distance from the loudspeaker, with average scores at the front being 72% compared to 25% at the back (see Figure 4).



Figure 4: Children's percentage of correct responses as a function of how far they were seated away from the loudspeaker (using log base 2 for the line of best fit) while the other classes were engaged in quiet activities versus noisy activities.

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Discussion

The two main aims of this study were to (a) develop a new Australian speech perception task (the MDDB CSPT) that was engaging and could be conducted live and efficiently in the real classroom listening environment through the use of PRS and (b) evaluate the effectiveness of using the MDDB CSPT in an open plan classroom to assess how intrusive noise affects speech perception.

Evaluation of the MDDB CSPT

Appropriateness of the MDDB CSPT stimuli. One way of determining the appropriateness of a test examining the effects of different noise levels and seating distances on speech perception is by examining the range of scores received by the participants. If most participants are scoring close to 100%, this indicates that the test is likely to be too easy. Conversely, if most of the participants are scoring close to 0%, the test is likely to be too difficult. The results of the classroom study revealed a large range of scores on the task, particularly in the noisy condition. Having this range of scores rather than the children predominantly performing at ceiling or at floor demonstrates the appropriateness of the speech materials for this test design and age group.

Appropriateness of the MDDB CSPT procedure. Another aim of creating this new speech test was to make it engaging. The children participating in the task generally stayed focused for its entire duration and said they had fun or wanted to play it again when asked at the end. The teachers who observed the task also noted that the children were engaged in and enjoyed the task. High performance accuracy (*mean* = 96%) by the children on the multiple choice questions in the PRS familiarisation phase demonstrated the children's ability to understand the task and use their PRSs. This suggests this technology as a reliable, effective, and engaging way to assess speech perception in the classroom among this age group.

Possible factors influencing participant answers. Although careful consideration was taken in developing the stimuli, it is not possible to control for everything. Below is an evaluation on three possible factors that may have influenced the children's answers:

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- 1) Lexical frequency: Although it was not a robust finding, an analysis of the classroom study results suggested that lexical frequency may play a part in the performance accuracy on a word, as in some cases, better performance occurred on the words with higher lexical frequencies. More evident, however, was that lexical frequency may help explain which word is chosen if the child's original choice is incorrect. Krull, Choi, Kirk, Prusick, and French (2010), found that words that have higher lexical frequencies are better recognised by children than those with lower lexical frequencies. They also found that words that have many neighbours (i.e. similar sounding words) are more poorly perceived than words with fewer neighbours. Both of these factors are therefore likely to have influenced our results. Unfortunately it was not possible to better control lexical frequency in the word lists due to our phonemic constraints. However, an advantage of having words with different lexical frequencies is that it provides more insight into what may influence children's speech perception.
- 2) Picturability: Although a target word's ability to be represented pictorially was part of the selection criteria, due to our phonemic constraints, some words chosen were still more challenging to picture than others (e.g., *neat*, *talk*, and *beam*). While it is possible that this may have contributed to their poorer performance, we believe that this factor was minimised as much as possible by having the active familiarisation phase where the children saw, heard, and repeated back what each picture was.
- 3) Carrier phrases: In creating this test, we decided to put each of the target words in a carrier sentence rather than presenting them in isolation. This method better represents teaching in the classroom and draws the children's attention to the speaker's voice prior to the target word being spoken (as it appears at the end of the sentence), hence aiding the perception of the target word (Bonino et al., 2012). We decided to have a different descriptive sentence for each list rather than using one completely neutral sentence (e.g., *Click on ...*) to make the task more interesting. That is, we decided to compromise on complete experimental control to make the task more engaging and fun for the children.
Using descriptive sentences does, however, bring in the possibility of predictability effects if some words fit better with the list's carrier sentence than others, even though effort was made to make the sentence as neutral as possible. For example, it could be argued that Sally is more likely to 'like' the *bead* rather than the *bee, beam,* or *bean.* However, as the main aim of this study was to compare the children's speech perception while the adjacent classes were engaged in quiet compared to noisy activities and the same carrier sentences were used for each condition, sentence predictability is unlikely to be a major problem with the test design.

A further limitation to the design of the test is the use of auditory-only speech that was recorded under quiet conditions. We decided to pre-record the auditory stimuli rather than present it live to control for the intensity of the speech and ensure it was presented consistently across conditions. However, in the real classroom environment, the children and the teacher are often interacting face-to-face which provides a visual speech element to the communication setting. It has been well established that seeing the talker's face facilitates speech perception, particularly in noisy listening conditions where talkers exaggerate spoken articulation (Kim, Sironic, & Davis, 2011; Sumby & Pollack, 1954). In particular, potential consonant confusions can often be clarified through visual clues (Dillon & Ching, 1995). Hence the results of our study may underestimate children's speech perception abilities in an auditory-visual listening scenario like the classroom (though it does represent the times when the teacher is writing on the whiteboard or the children themselves are writing or looking away). However, there is conflicting evidence as to whether children of this age group can benefit from visual speech cues – other studies suggest that processing a speaker's face may be distracting to young children, particularly when the auditory cues are highly salient (Doherty-Sneddon, Bonner, & Bruce, 2001; see also Sekiyama & Burnham, 2008). It would therefore be interesting to conduct a follow-up study which, in addition to the current test format, also uses a video recording of the speaker's face saying the sentences. This would help assess if there is a benefit of auditoryvisual compared to auditory-only speech perception by children in quiet and noisy conditions.

Despite the limitations mentioned above, we believe that the MDDB CSPT overcomes many of the drawbacks found in the previous speech tests reviewed. Overall, these results suggest that the MDDB CSPT is an engaging and effective tool to efficiently assess speech perception in the classroom listening environment through the use of PRSs.

MDDB CSPT study results from an open plan classroom

The second aim of this study was to use the MDDB CSPT to assess the impact of intrusive noise on speech perception in an open plan classroom. In light of the previous findings, it was hypothesised that both the children's performance *accuracy* and *speed* would be poorer when other classes were engaged in noisy compared to quiet activities, and that performance accuracy would decrease the further away the child was seated from the loudspeaker (simulating the teacher's voice) due to the decreasing SNR. Additionally, it was hypothesised that the children would perform more poorly at discriminating coda consonants compared to onsets due to their lower perceptual salience.

The results revealed poorer performance accuracy (including an increase in nonresponses) when the other classes were engaged in noisy activities compared to quiet activities. Children's response time was also significantly slower during the noisy condition compared to the quiet activities condition (though further investigation is needed to assess if the duration of this delay would significantly impact the children's learning). Additionally, children's perception of coda contrasts was poorer compared to onset contrasts. A finer grained analysis revealed that voiced stops and nasals, especially when in the less perceptually salient coda position, were particularly hard to discriminate.

The results also suggest that children may have a bias towards choosing words that have a higher lexical frequency, especially if they are unsure which word it was they heard. While word familiarity may enhance its perception, the converse is that new words are likely to be misperceived. This is a major concern given that school is a vital time for children to learn *new* concepts and words, so they need to be able to hear clearly what their teacher is saying.

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These findings suggest that when there is noise coming from other classes in the room, the children engaged in active listening are likely to misunderstand or even miss entirely what their teacher is saying. Even if they initially hear the teacher, the presence of noise results in slower processing of a sentence, which means they are likely to miss the following information while they try to process what has previously been said. We would therefore expect noise to impact greatly on children's educational development since their auditory systems are neurologically immature and world knowledge and experience cannot yet be used to fill in with top-down information (Wilson, 2002).

In addition, the results of our study showed how speech perception decreases the further away the child is seated from the loudspeaker. This was significant in both listening conditions, but particularly for the noisier condition, where the scores of a child sitting at the front compared to the back dropped from 72% to 25%. These poor results for the children sitting at the back are most likely due to the lower SNR, as they are further away from the loudspeaker and closer to the noise from the other classes. These results emphasise the importance of gathering children (especially those more vulnerable to the impact of noise) close to the teacher during critical listening tasks. In enclosed classrooms, sound field amplification systems can be used to help minimise this distance effect. However, these systems are not practical in open plan classrooms as they would be too distracting for the adjacent classes which demonstrates another shortcoming of these learning spaces.

The findings of our study provide further evidence for the importance of having optimal listening conditions in Kindergarten classrooms to enhance children's access to new words and ideas. As this study involved only one school, it is essential that future research using the MDDB CSPT is conducted in a wide range of schools to assess which designs and teaching methods are appropriate and what the maximum number of students in an area should be in order to maintain adequate speech perception in the classroom.

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Overall Conclusions

The main aim of this study was to create the MDDB CSPT and evaluate the effectiveness of using it in an open plan classroom. The appropriateness of the speech materials for this age group to demonstrate the impact of classroom noise and listening distance on speech understanding was shown by the large range of scores on the task, particularly in the noisy condition (rather than the majority of children performing at ceiling or at floor). Additionally, observation of the participating children during the procedure showed they were overall engaged in and enjoyed the task. The results of the study in the open plan school revealed poorer accuracy (including an increase in non-responses) and slower reaction time when other classes were engaged in noisy compared to quiet activities. The results also showed that the children's speech perception scores decreased the further the child was from the loudspeaker, particularly when the adjacent classes were engaged in noisy activities. This study demonstrates that the MDDB CSPT is a reliable, effective, and engaging way to assess speech perception in the classroom for 5-6-year-olds. Therefore, the MDDB CSPT would be a helpful tool to be used in future research involving a wide range of schools to assess which designs and teaching styles are appropriate and what the maximum number of students in an area should be in order to maintain adequate speech perception in the classroom.

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CHAPTER 4: THE EFFECT OF DIFFERENT OPEN PLAN AND ENCLOSED CLASSROOM ACOUSTIC CONDITIONS ON SPEECH PERCEPTION IN KINDERGARTEN CHILDREN

This chapter comprises of the following published paper:

Mealings, K. T., Demuth, K., Buchholz, J. M., & Dillon, H. (2015). The effect of different open plan and enclosed classroom acoustic conditions on speech perception in Kindergarten children. *Journal of the Acoustical Society of America*.

All components of this paper, both experimental and written, have been completed by me, with advice from the co-authors (my supervisors) when needed.

ABSTRACT

Open plan classrooms, where several classes are in the same room, have recently re-emerged in Australian primary schools. This paper explores how the acoustics of four Kindergarten classrooms (an enclosed classroom (25 children), double classroom (44 children), fully open plan triple classroom (91 children), and a semi-open plan K-6 '21st century learning space' (205 children)) affect speech perception. Twenty-two to twenty-three 5-6-year-old children in each classroom participated in an online four-picture choice speech perception test while adjacent classes engaged in quiet versus noisy activities. The noise levels recorded during the test were higher the larger the classroom, except in the noisy condition for the K-6 classroom, possibly due to acoustic treatments. Linear mixed effects models revealed children's performance accuracy and speed decreased as noise level increased. Additionally, children's speech perception abilities decreased the further away they were seated from the loudspeaker in noise levels above 50 dBA. These results suggest that fully open plan classrooms are not appropriate learning environments for critical listening activities with young children due to their high intrusive noise levels which negatively affect speech perception. If open plan classrooms are desired, they need to be acoustically designed to be appropriate for critical listening activities.

I. INTRODUCTION

Ensuring young children can adequately perceive speech in the classroom is essential for their learning. In Australia, Kindergarten is children's first experience of formal primary school education. In this grade children are introduced to the basic concepts of literacy and numeracy. As children are estimated to spend 45-60% of their time at school listening, it is vital that they can hear and comprehend their teacher's and classmate's speech amongst the other distracting noises heard in the classroom (Rosenberg et al., 1999). The main noise source present in the classroom is the noise generated by other children (Shield & Dockrell, 2004). High noise levels not only adversely affect children's speech perception (Crandell & Smaldino, 2000; Finitzo-Hieber & Tillman, 1978), but also their reading and language comprehension (Klatte, Lachmann, & Meis, 2010; Maxwell & Evans, 2000; Ronsse & Wang, 2013), cognition, concentration, and their psychoeducational and psychosocial achievement (American Speech-Language-Hearing Association, 2005; Crandell & Smaldino, 2000; Shield, Greenland, & Dockrell, 2010). Furthermore, continuous noise exposure places additional demands on children's listening effort which reduces the resources available for linguistic and cognitive processing (Anderson, 2001). As a result, children can 'tune out' from the auditory overload (Anderson, 2001; Maxwell & Evans, 2000).

Classes with young children tend to have the highest noise levels (Jamieson, Kranjc, Yu, & Hodgetts, 2004; MacKenzie & Airey, 1999; Picard & Bradley, 2001; Wróblewski, Lewis, Valente, & Stelmachowicz, 2012). Young children are also more affected by noise compared to older children and adults (Johnson, 2000; Leibold & Buss, 2013; Nishi, Lewis, Hoover, Choi, & Stelmachowicz, 2010; Nittrouer & Boothroyd, 1990). This is because children's auditory systems are neurologically immature so they cannot discriminate speech or use linguistic knowledge or experience to fill in missing information as adults can (Boothroyd, 1997; Nelson & Soli, 2000; Wilson, 2002). More specifically, children's consonant perception in noise does not become adult-like until the late teenage years (Johnson, 2000). Similarly, it has been shown that sentence recall performance is significantly reduced in young children

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compared to adults, in particular when the target sentences are presented in a spatially separated speech background (Cameron & Dillon, 2007). Children with hearing impairment and/or those who have English as a second language (ESL) are even more adversely affected by poor classroom acoustics (MacKenzie & Airey, 1999; Nelson & Soli, 2000; Shield et al., 2010) and these children are now often integrated into mainstream classes rather than being in smaller, specialized schools (Konza, 2008). High noise levels also increase annoyance and stress levels for the teachers (Kristiansen, Lund, Nielsen, Persson, & Shibuya, 2011).

In the 1970's there was a trend of converting enclosed classrooms into open plan classrooms, where multiple class bases share the same area. These spaces were thought to create a more secure feeling for the child as they are perceived as more 'home-like' and less authoritarian (Maclure, 1984). They also allowed for a range of activities to be carried out, facilitating group work and social development (Brogden, 1983). Additionally, they promoted the sharing of skills, ideas, and experiences amongst teachers, and allowed for team-teaching which is thought to facilitate a more cooperative and supportive atmosphere (Brogden, 1983; Hickey & Forbes, 2011). However, these classrooms resulted in high noise levels due to large numbers of children sharing the same area and being engaged in a range of activities, so they were soon abandoned (see Shield et al., 2010, for a review). Now, the American National Standards Institute (2002) strongly discourages the use of open plan classrooms as the high levels of background noise negatively impact children's learning processes. Additionally, studies have shown that smaller class sizes are linked to higher student achievement, and the lower exposure to noise provides a better environment for both students and teachers (Glass & Smith, 1979; Pelegrín-García, Brunskog, & Rasmussen, 2014).

Despite these previous findings, new-style open plan classrooms have recently been emerging in Australia and other countries such as New Zealand, the United States, the United Kingdom, Japan, Norway, Sweden, Portugal, and Denmark, renamed as '21st century learning spaces' which center around group work. These can have up to 200 children sharing the same area (Stevenson, 2011). It is important to note, however, that while these open plan classrooms

are primarily designed for group activities, Kindergarten teachers in these classrooms can still spend up to 40% of the time teaching in a traditional didactic-style method (Mealings, Buchholz, Demuth, & Dillon, 2015), so it is vital that children are able to hear the new concepts that are being taught. Therefore, these new-style open plan classrooms need to be assessed to see if they are an improvement on the open plan classrooms from the 1970's. As several schools in Australia are currently converting to these layouts, it is timely to conduct some of the first Australian research in these classrooms to assess how the acoustic parameters of these classrooms directly affect children's speech perception *accuracy* and *speed*.

Although there is evidence from Europe and the United Kingdom that high noise levels were a common problem in open plan schools, to our knowledge there have been no speech perception studies conducted *live* in open plan classrooms to directly assess how real-life noise and the classroom's design affects how well the children can hear their teacher. Most previous research focuses on measuring the acoustic parameters (e.g., noise levels, SNRs, speech transmission index (STI) scores, and reverberation times) of open plan classrooms and comparing these to acoustic standards/recommendations, rather than directly investigating how these acoustics affect children's ability to hear the words their teacher is saying. While many studies have investigated speech intelligibility in traditional classrooms (e.g., Astolfi, Bottalico, & Barbato, 2012; Finitzo-Hieber & Tillman, 1978; Jamieson et al., 2004; Johnson, 2000; Klatte et al., 2010; Neuman, Wroblewski, Hajicek, & Rubinstein, 2010; Vickers et al., 2013; Wróblewski et al., 2012), they usually do so using a virtual environment and/or headphones. Such studies are not representative of natural listening environments, which contain a binaural advantage (see Bradley and Sato (2008)). Other studies have used simulated classroom noise/multitalker babble which is not representative of the children's/teacher's voices and movement, furniture noise, air-conditioning unit noise and other equipment noises that are present in the classroom (Jamieson et al., 2004). Both Astolfi et al. (2012) and Bradley and Sato (2008) raise the need for speech perception studies to be conducted in live classrooms.

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The goal of the present study, therefore, was to investigate the practical implications of the classroom acoustics measured by Mealings, Buchholz, et al. (2015) on the children's ability to hear and understand their teacher. This was achieved via a word discrimination test conducted live in the real classroom environments using the Mealings, Demuth, Dillon, and Buchholz Classroom Speech Perception Test (MDDB CSPT; Mealings, Demuth, Buchholz, & Dillon, 2015), which was especially designed for live open plan classroom speech perception studies. In this test Personal Response Systems (PRSs) were used to simultaneously test all children live in the classroom. This method not only records accuracy, but also response times, which is an important variable for understanding children's ability to process information in noise that many intelligibility tests do not capture. Such a method of testing is expected to provide strong ecological validity, generalizing into real-world learning/speech perception. (More information on the use of PRSs live in the classroom can be found in Mealings, Demuth, et al. (2015), and Vickers et al. (2013). Using this type of live test will give a better indication of how well children can hear their teacher in different types of open plan classrooms.

Therefore, the aim of this study was to compare children's speech perception abilities in different open plan and enclosed classrooms when the other class bases were engaged in quiet versus noisy activities. In light of previous findings by Astolfi et al. (2012) and Bradley and Sato (2008), it was hypothesized that the children's speech perception accuracy would be poorer for lower SNR/STI values. In our study, this was determined by two factors: (i) an increase in the *noise level* from the adjacent class(es) (which we predicted would largely be related to the number of children in the classroom area), and (ii) an increases in the *distance* the child was seated from the loudspeaker (which simulated the teacher's voice). In addition to measures of speech perception accuracy, we also investigated a new parameter – the children's response times. This gives extra insight into children's ability to process information in the classroom. It was hypothesized that the children's response times would be slower in noisier conditions due to increased cognitive load. Finally, it was also hypothesized that the design of the classroom might be a factor affecting children's speech perception (not just the number of children in the classroom area). Therefore, we predicted that the children in the purpose-built, '21st century' semi-open plan K-6 classroom would perform better than those in the untreated, fully open plan triple classroom despite the K-6 classroom having over twice the number of children.

II. METHOD

A. Schools involved

The study took place in Sydney, Australia in the second half of the school year. The same schools that were involved in the classroom acoustic measures study by Mealings, Buchholz, et al. (2015) were involved in this study. As described in Mealings, Buchholz, et al. (2015), a wide range of potential primary schools were examined before the final classrooms were selected. As the number of children in the open plan classrooms we examined ranged between 40-200 children (divided into class bases of 20-30 children), we chose three open plan classrooms across the 40-200 child range as well as one enclosed classroom with 25 children. A subset of Kindergarten children (i.e. 5-6-year-olds in their first year of primary school) in each classroom participated in the speech perception test. When selecting the schools, effort was made to choose those with similar scores on The Index of Community Socio-Educational Advantage (ICSEA) scale which represents a school's level of educational advantage based on family backgrounds. ICSEA scores range from 500-1300 (M = 1000; SD = 100) where higher scores represent more advantaged schools. (More information about the ICSEA can be found on the My School website http://www.myschool.edu.au.) We used the school's ICSEA scores calculated for 2013 when the studies were conducted. Below are the descriptions of each of the classrooms involved in the study as found in Mealings, Buchholz, et al. (2015). Further details on the participating classrooms are shown in Table I. More details on the room acoustics can also be found in Mealings, Buchholz, et al. (2015).

	Enclosed Classroom	Double Classroom	Triple Classroom	K-6 Classroom
Total number of students	25	44	91	205
in area				
School's ICSEA	1141	1133	1035	1090
Classroom type	Enclosed classroom with	Fully open double	Linear, fully open plan	Semi-open plan classroom
	shared concertina wall	classroom	classroom	
Class grades in area	Kindergarten	Kindergarten	Kindergarten	Kindergarten to Year 6
	(5-6-year-olds)	(5-6-year-olds)	(5-6-year-olds)	(5-12-year-olds)
Number of class bases in	1	2	3	5-7
area				(depending on activity)
Number of students in	25	21-23	30-31	30-50
each class base				
Room dimensions (m)	8 x 9	15 x 9	37 x 11	27 x 32
Total floor area (m ²)	72	135	407	864
Space per child (m ²)	2.9	3.1	4.5	4.2
Distance between edge of	N/A	2	6	7
class bases (m)				
Ceiling height (m)	3.0	2.8-4.2	3.3	3.2-6.0
Total room volume (m ³)	216	470	1340	3900

TABLE I: Details of the participating classrooms (from Mealings, Buchholz, et al., 2015).

1. Enclosed classroom: 25 children

This classroom consisted of 25 Kindergarten children in a classroom with 3 solid brick walls, a closed floor-to-ceiling 4 cm thick concertina (i.e. operable) wall with pin boards, and a shared storeroom with the adjacent Kindergarten class. The class area was carpeted with loop pile carpet and windows were located on both side walls (Figure 1). The ceiling was rough concrete textured. No acoustic treatment was evident. A survey of 50 primary schools in the region found that 60% of Kindergarten classrooms have a concertina wall between them and an additional 10% have a shared storeroom or door with another class. Only 30% of schools had fully enclosed classrooms with four solid walls. Therefore this classroom with its concertina wall and shared storeroom was more typical of those enclosed classrooms found in the Sydney region, and hence was chosen for the study. The average unoccupied reverberation time (T30^a) of this classroom was 0.50 s, which is within the recommended time of 0.4-0.5 s (Australia/New Zealand Standard, 2000).



FIGURE 1: Floor plan of the enclosed classroom with 25 children.

^a Note a Tannoy V8 loudspeaker was used for measuring the room impulse responses which were used to calculate the T30s for the classrooms (see Mealings, Buchholz, et al., 2015). Hence, the directivity of this loudspeaker may have resulted in a slight underestimation of the T30 when compared to measurements with an omni-directional sound source which most standards are based on. However, the directivity of the applied loudspeaker better resembled the directivity of a teacher's voice and thus, provided more realistic predictions of the STI which is why it was used.

2. Double classroom: 44 children

This space originally consisted of two separate classrooms with plasterboard walls, but the wall between had been removed at the start of the year to make it an open double classroom for the 44 Kindergarten children. The ceiling was made of plasterboard and was triangular in shape, and the top half of the wall still remained in this area between the two classrooms where the original wall had been. The class area was carpeted with loop pile carpet but the utility area was a hard surface. Windows were located on two walls and pin boards covered the other two walls (Figure 2). No other acoustic treatment was evident. The average unoccupied reverberation time (T30) of this classroom was 0.60 s, which is above the recommended time of 0.4-0.5 s (Australia/New Zealand Standard, 2000).



FIGURE 2: Floor plan of the double classroom with 44 children.

3. Triple classroom: 91 children

This open plan classroom consisted of 91 Kindergarten children grouped linearly into three classes (K1, K2, K3), with no barriers between them. This classroom represented a midrange number of children and class bases for an open plan space. The Year 1 and 2 classes were located off an adjacent corridor but had no doors/walls separating the spaces, hence noise from these classes could also be heard. Originally the space had consisted of separate enclosed classrooms with 30 children in each, but these walls had recently been removed to make the area fully open plan. The walls were plasterboard and the class area was carpeted with loop pile carpet, but the corridor floor was a hard surface. The ceiling was acoustically tiled. Windows were located on both the front and back walls and pin boards were on the other two walls (Figure 3). No other acoustic treatment was evident. The average unoccupied reverberation time (T30) of this classroom was 0.70 s, which is above the recommended time of 0.4-0.5 s (Australia/New Zealand Standard, 2000).



Windows

FIGURE 3: Floor plan of the triple classroom with 91 children.

4. K-6 classroom: 205 children

This classroom contained the entire primary school (205 children) in the one area representing one of the biggest types of open plan classrooms found in Sydney. It had been purpose-built to be a '21st century learning' open plan school. The children were separated into class stages with Kindergarten, Year 1, and Year 2 in a semi-open plan layout with dividers between them and only one open wall. Years 3/4 and 5/6 were in a fully open plan area. The Kindergarten class was located in the corner in the acoustically most sheltered location, particularly for their whole class teaching area where the children were grouped together on the floor to listen to their teacher (see Figure 4). The ceiling height in this area was the lowest of

the room measuring 3.2 m. The entire area was carpeted with loop pile carpet, and 3 cm thick pin boards along the walls and soft furnishings provided some acoustic absorption. The ceiling was acoustically tiled. Windows were located on the external wall. The average unoccupied reverberation time (T30) of this classroom was 0.58 s, which is above the recommended time of 0.4-0.5 s (Australia/New Zealand Standard, 2000), but lower than the reverberation times of the double and triple classrooms.



FIGURE 4: Floor plan of the K-6 classroom with 205 children.

B. Participants

Twenty-four Kindergarten children from each school were randomly selected to participate in the classroom speech perception test. No children were reported by their parents to have otitis media, or intellectual or behavioural disabilities in the enclosed, triple, and K-6 classrooms. One child in the double classroom was reported to have a sensory processing disorder, but as their performance did not deviate from their peers, they were included in the analysis. For both the double and K-6 classrooms, one child was absent on the day of testing so only 23 children were included in the study. For the triple classroom, two children who

participated in the study were excluded as they did not finish the test. For the enclosed classroom, one child only scored 8% in the quiet condition so was excluded from the analysis as they failed to demonstrate an ability to understand and complete the test. Table II shows the demographics of the participating children. The remaining Kindergarten children in each of the classrooms made up the class/es to provide the intrusive noise.

Classroom	Number of	Number of	Number of	Age range	Number who have	Number who
	children in	participants	males/females	and mean	ESL	have attended
	area					preschool
Enclosed	25	23	13M; 10F	5;3-6;7	12	23
				<i>M</i> = 6;0		
Double	44	23	12M; 11F	5;7-6;9	0	20
				M = 6;3		
Triple	91	22	9M; 13F	5;5-6;6	11	19
				<i>M</i> = 5;9	(+4 multilingual)	
K-6	205	23	12M; 11F	5;0-6;5	4	21
				<i>M</i> = 5;10	(+ 6 multilingual)	

TABLE II: Demographic information for participating children.

C. Stimuli

The MDDB CSPT word lists were used for the study (Mealings, Demuth, et al., 2015). This test was chosen as it was developed especially to be conducted live in real classroom environments, efficiently testing a whole class of children simultaneously through the use of PRSs. Additionally, this test was developed in Australia, so the words are appropriate for an Australian context and the stimuli are presented in an Australian accent. This test is based on the Chear Auditory Perception Test (Marriage & Moore, 2003). The test consists of 6 lists of 4 minimally contrastive monosyllabic words, with Lists O1, O2, and O3 having onset consonant contrasts and Lists C1, C2, and C3 having coda consonant contrasts (Table III). Phonemically, the types of contrasts are balanced between list pairs with Lists O1 and C1 contrasting voiceless stops and fricatives, Lists O2 and C2 contrasting voiced stops and nasals, and Lists O3 and C3 contrasting voiceless stops, fricatives, affricates, and clusters. Each word is pictorially represented and appears in one of six 5-syllable carrier sentences (one sentence for each list, e.g. *Sally likes the ...*).

List O1	List O2	List O3	List C1	List C2	List C3
_Art	_Eat	<u>T</u> alk	K_	Bee_	Bea <u>t</u>
<u>T</u> art	<u>B</u> eat	<u>F</u> ork	Ca <u>pe</u>	Bea <u>d</u>	Bee <u>s</u>
<u>C</u> art	Meat	<u>Ch</u> alk	Ca <u>ke</u>	Bea <u>m</u>	Bea <u>ch</u>
<u>H</u> eart	<u>N</u> eat	<u>St</u> alk	Ca <u>se</u>	Bea <u>n</u>	Bea <u>st</u>

TABLE III: MDDB CSPT word lists.

The test uses audio recordings of the 24 sentences by an adult Australian-English female speaker using teacher-like speech. These recordings were made in an anechoic chamber using a DPA headset microphone and the intensities were normalized so that each sentence had the same average root mean square value. (For more information on how the test was developed, see Mealings, Demuth, et al. (2015)).

D. Listening conditions

The aim of the experiment was to assess how intrusive classroom noise impacts children's listening abilities. There were two listening conditions; one when the other classes were engaged in quiet activities (e.g. whole class teaching or quiet individual work) and the other when they were engaged in noisy activities (e.g. group work with movement). The study was run in the afternoon after the lunch break and the teachers of the other classes were instructed to choose typical quiet and noisy activities for their classes to engage in. To counterbalance possible learning effects, the participants were split into two groups. Group 1 completed the experiment in quiet then in noise, whereas Group 2 completed it in noise and then in quiet. The noise from each activity was recorded using an omnidirectional condenser microphone (calibrated in diffuse speech-shaped noise using a B&K 2250 sound level meter) connected to a USB sound card and Toshiba Satellite U940 Ultrabook running Audacity software. This allowed us to calculate the average noise levels for each activity could be calculated.

E. Procedure

Participants were each assigned a seating position in one of six rows of four children in front of a Smart Board with males/females and ESL children evenly distributed front to back. The distance of the children from the loudspeaker ranged from 1-3 m. The visual stimuli were projected onto a Smart Board via a Toshiba Tecra Notebook and the audio was played through a Genelec 8020B (active studio monitor) loudspeaker positioned at the front of the classroom under the center of the Smart Board. The audio volume was adjusted so that the average sound level presentation was 60 dBA at 2 m (which represents a teacher's average speech level (Sato & Bradley, 2008)) as measured by a calibrated Dick Smith Electronics Q1362 sound level

meter. The test began with all participants completing a familiarization phase of the target words, pictures, and their PRS. When the children were ready the testing phase began. The children saw the four pictures of a particular list appear on the screen, accompanied by the audio sentence that contained one of the words of that list. They were instructed to select the picture they heard via the colour-coded buttons on their PRS. The List order was pseudo-randomised (e.g. 1, 4, 6, 3, 5, 2) and the lists were rotated through four times. Pseudo-randomisation was used rather than having all four words of a list presented consecutively to make it harder for children to use a process of elimination. This procedure was repeated for all 24 stimuli (pseudorandomized) in both conditions. A maximum of 15 seconds (from the start of each stimulus display) was allowed for the children to record their response. Group 1 completed the test in the quiet condition first while Group 2 left the testing area. Group 1 and 2 then completed the testing phase in the noisy condition together (to ensure the noise level was the same for both groups tested) before Group 1 left Group 2 to do the test in the quiet condition. Having two Groups complete the test in different orders helps minimise learning effects. The responses were then collated and analyzed for both performance accuracy and speed using the TurningPoint software.

III. RESULTS

A. Noise levels

The noise levels were recorded during the test in each classroom as described in Section II.D. Figure 5 shows a comparison of the levels recorded for each school while the other classes were engaged in quiet versus noisy activities. It is recommended that classroom noise levels should be kept below 50 dBA (Berg, Blair, & Benson, 1996). This was only achieved for the two smaller classrooms in the quiet condition. (Unfortunately the open-door shared store room in the enclosed classroom allowed additional noise transmission between classrooms, resulting in above recommended noise levels during its noisiest periods). The noise levels generally increased as class size increased, however, the noise levels in the K-6 classroom did not reach

the high level of noise that the triple classroom did during the noisy condition. Notice also that the noise levels were consistent for the K-6 classroom across conditions. As with the other schools, we asked the surrounding classes at this school to engage in quiet activities and then noisy activities so we could measure the difference between the two conditions. However, due to the large number of class bases in the area, it was not possible to coordinate this across the whole classroom. Hence the recorded noise levels were the same for both conditions in the speech perception test demonstrating that the noise levels in this classroom stay fairly constant in contrast to the changing noise levels in the other three classrooms.



FIGURE 5: Average recorded noise levels for each classroom while adjacent classes were engaged in quiet activities and noisy activities.

B. Overall speech perception scores

1. Linear mixed effects model results

A linear mixed effects analysis was conducted using IBM SPSS Statistics software (version 21) to assess what factors may contribute to the children's speech perception scores. The fixed factors of classroom type (which included factors such as room volume, design, number of children, reverberation time, ICSEA etc.), noise level, test order (i.e. quiet/noise

condition order), gender, ESL, time in preschool (using the square root of total hours) and distance from the loudspeaker (using log base 2) were entered into the model with participant as the random factor. This model was used to predict the change in score relative to that in the enclosed classroom. As predicted, noise level and distance from the loudspeaker were significant factors in the model (F(1,87) = 70.92, p < .0005; F(1,79166) = 30.47, p < .0005respectively). As shown in Table IV, if all other predictor variables were held constant, every increase in noise by 10 dBA resulted in scores being 14.3% lower, which was approximately the difference in noise levels between the quiet and noisy condition in the classrooms. Similarly, if all other predictor variables were held constant, scores were estimated to decrease by 12.8% for each doubling of distance the child was seated away from the loudspeaker (i.e. 1 m, 2 m, 4 m etc). Further analysis of these two factors for each classroom can be found below. Interestingly, classroom type was also a significant factor (F(3,99) = 5.24, p = .002). The scores of the K-6 classroom were estimated to be 8.2% higher than the enclosed classroom, 13.0% higher than the double classroom, and 9.4% higher than the triple classroom, when all other predictor variables, including noise level, were held constant. Test order, gender, and time in preschool were not significant factors in the model (F(1,79) = 2.99, p = .088; F(1,79) = 0.00, p)= .967; F(1,79) = 0.47, p = .495, respectively). Additionally, ESL was not a significant factor in the model (F(1,79) = 0.34, p = .560) despite previous research suggesting these children are more affected by noise (Nelson & Soli, 2000). (Note, however, that Astolfi et al. (2012) who conducted a similar speech perception study in Italy also did not find a significant difference between children who had Italian as their first language with those who did not.)

Parameter	Estimate	SE	df	t	р
Intercept	163.58	10.46	146	15.64	.000*
K-6 Classroom	8.17	3.65	113	2.24	.027*
Triple Classroom	-1.25	3.72	127	-0.34	.737
Double Classroom	-4.80	3.54	79	-1.36	.179
Enclosed	0.00	0.00			
Classroom					
Noise Level	-1.43	0.17	87	-8.42	.000*
Distance	-12.81	2.32	79	-5.52	.000*
Test order	-3.94	2.27	79	-1.73	.088
Gender	-0.10	2.30	79	-0.04	.967
ESL	-1.66	2.84	79	-0.59	.560
Preschool	0.03	0.05	79	0.69	.495

TABLE IV: Estimates of fixed effects for speech perception scores. (*p < .05).

2. Speech perception scores by classroom type

Figure 6 shows the children's average percentage of correct responses by classroom type for both the quiet and noisy conditions. Paired t-tests were conducted to compare the children's performance for each classroom in the two conditions. Performance was significantly better while adjacent classes were engaged in quiet compared to noisy activities for the enclosed classroom (t(22) = 5.34, p < .0005, d = 1.31), the double classroom (t(22) = 5.16, p < .0005, d = 1.26), and the triple classroom (t(21) = 7.70, p < .0005, d = 1.43) as expected following the trend of the noise levels shown in Figure 5. Note, however, that there was no difference in performance for the K-6 classroom between the two conditions. As mentioned previously, there was no difference in noise levels for the two conditions in this classroom as quiet versus noisy activities were unable to be coordinated across classes because of its size. Noise levels therefore

tended to stay at a consistent level (and reliability of the test is shown by the children having similar group mean scores both times they participated in the test). As the K-6 classroom does not have the two noise conditions like the other classrooms, we report the average results from the two conditions to compare with the other classrooms for the remaining analyses, as shown by the different shading in Figures 6, 7, and 9.

A significant difference in speech perception scores was found between classrooms in the quiet condition as determined by one-way ANOVA (F(3,87) = 6.48, p = .001, $\eta^2 = .18$) with a Tukey post-hoc test revealing significantly better performance by children in the enclosed classroom compared to the triple and K-6 classroom ($p_{enclosed vs. triple} = .004$, $p_{enclosed vs. K-6} = .003$). A second one-way ANOVA also revealed a statistically significant difference between classrooms in the noisy condition (F(3,87) = 8.76, p < .0005, $\eta^2 = .23$) with a Tukey post-hoc test revealing significantly poorer performance by children in the triple classroom (which had the highest noise levels) compared to the other classrooms ($p_{enclosed vs. triple = .001$, $p_{double vs. triple}$ = .009, $p_{K-6 vs. triple} < .0005$; see Figure 6).



FIGURE 6: Children's average percentage of correct responses for each classroom while adjacent classes were engaged in quiet activities and noisy activities. Note that the K-6 classroom did not have different quiet/noise conditions as activities could not be coordinated across all classes. Error bars show standard error of the mean. The dashed lines indicate pairs

of classrooms which significantly differed in average scores, and the asterisks indicate classrooms for which the average score in the noisy condition was different from the average score in the quiet condition, both with p < .05.

C. Performance by seating position for each classroom

Figure 7 shows the children's speech perception scores as a function of how far they were seated away from the loudspeaker simulating the teacher's voice. A correlation analysis was conducted for each classroom to assess how the children's scores changed for each doubling of distance the children were seated away from the loudspeaker (i.e. the change from 1 m to 2 m to 4 m etc). For the enclosed and double classrooms, no correlation between children's performance and seating distance was found for the quiet condition, with children performing consistently well front to back (which were also the conditions that reported noise levels within the 50 dBA recommended limit). For the noisy condition, however, both classrooms reported a moderate negative correlation ($r_{enclosed} = -0.59$, $R^2_{enclosed} = 0.35$, $p_{enclosed}$
= .003; $r_{double} = -0.54$, $R^2_{double} = 0.29$, $p_{double} = .012$). (Note that we excluded two outliers in the noise condition for the double classroom for this analysis as the unusually low scores clearly did not fit the linear trend when plotted, i.e. it is likely that these two children did not attend to the whole test.) On average, scores at the front were 80% compared to 53% at the back for the enclosed classroom and 79% at the front compared to 52% at the back for the double classroom. For the triple classroom, a moderate negative correlation was found between children's performance and seating distance in the quiet condition (r = -0.63, $R^2 = 0.40$, p = .002). On average, scores at the front were 82% compared to 56% at the back. When the other classes changed to noisy activities, this relationship increased to a strong negative correlation (r = -0.80, $R^2 = 0.65$, p < .0005). In this condition, children's scores decreased by 30% per doubling of distance from the loudspeaker, with average scores at the front being 72% compared to only 25% at the back. Overall (as there was no difference in noise levels for the two conditions) the K-6 classroom reported a weak-to-moderate negative correlation (r = -0.49, $R^2 = 0.24$, p = .001). On average, scores at the front were 83% compared to 55% at the back. These results show the detrimental effect of reduced SNRs on speech perception as a result of being seated further away from the teacher, especially in high noise levels.



FIGURE 7: Children's speech perception scores as a function of how far they were seated away from the loudspeaker (using log base 2 for the line of best fit) while the others classes were engaged in quiet activities and noisy activities for each classroom. Note that the K-6 classroom did not have different quiet/noise conditions as activities could not be coordinated across all classes.

To compare the measured children's speech perception scores to corresponding STI scores, the noise recordings of the quiet and noisy conditions that were taken during the speech test were used in a STI calculation together with the room impulse responses (RIRs) previously measured in the same four classrooms (see Mealings, Buchholz, et al., 2015). Thereby, target speech levels were predicted by convolving the (calibrated) RIRs with the speech-test material, which was presented at an SPL of 60 dBA at a distance of 2 m. Since RIRs were only available

at three different distances per class room, only speech scores were considered for children that were sitting at a similar distance (within 10 cm) to the measured RIRs. As a consequence, 52 out of the total of 182 speech perception scores were considered in this analysis and plotted in Figure 8.

A sigmoidal function was used to fit the data by minimizing the RMS error between measured and predicted scores using MATLAB. This function was given by:

$$y = \frac{a}{1 + e^{-c(x-d)}} + b$$
 (1)

where a = 67, c = 6.1, d = 0.4, x = STI score, y the predicted children's speech perception score, and

$$b = 25 - \frac{a}{1 + e^{c \cdot d}} = 19.6 \tag{2}$$

Equation (2) ensured that for an STI value of zero the chance level of 25% was reached. The RMS error between measured and predicted scores was 13% and the function is shown in Figure 8. There is a reasonable fit between the sigmoidal function and the data, especially considering that the data was collected with young children live in the classrooms.



FIGURE 8: Children's speech perception scores as a function of predicted STI scores together with a fitted sigmoidal function.

D. Response times

In addition to decreased performance accuracy, we also predicted that there would be a decrease in the speed of the children's response (measured from the onset of the stimulus display) in noisier conditions. Therefore, a linear mixed effects analysis was conducted using IBM SPSS Statistics software (version 21) to assess this as well as investigate what other factors may affect the children's response times. The fixed factors of classroom type (which included factors such as room volume, number of children, reverberation time, ICSEA etc.), noise level, test order (i.e. quiet/noise condition order), gender, ESL, time in preschool (using the square root of total hours) and distance from the loudspeaker (using log base 2) were entered into the model, with participant as the random factor. This model was used to predict the change in response time relative to that in the enclosed classroom. As predicted, noise level was a significant factor in the model (F(1,87) = 70.92, p = .003. As shown in Table V, if all other predictor variables were held constant, every increase in noise by 10 dBA resulted in response times being 364 ms longer. Distance was also a significant factor in the model (F(1,79) = 18.62, p < .0005. If all other predictor variables were held constant, response times were estimated to

increase by 844 ms for each doubling of distance the child was seated away from the loudspeaker (i.e. 1 m, 2 m, 4 m etc. Classroom type, test order, gender, ESL, and time in preschool were not significant factors in the model (F(3,94) = 1.84, p = .048; F(1,79) = 0.01, p = .925; F(1,79) = 0.97, p = .328; F(1,79) = 1.03, p = .314; F(1,79) = 2.31, p = .133, respectively).

Parameter	Estimate	SE	df	t	р
Intercept	2.94	0.78	160	3.78	.000*
K-6 Classroom	0.12	0.30	103	.41	.682
Triple Classroom	0.44	0.30	114	1.48	.143
Double Classroom	0.58	0.30	79	1.93	.057
Enclosed	0.00	0.00			
Classroom					
Noise Level	0.04	0.01	87	3.06	.003*
Distance	0.84	0.20	79	4.32	.000*
Test order	0.02	0.19	79	.10	.925
Gender	-0.19	0.19	79	98	.328
ESL	0.24	0.24	79	1.01	.314
Preschool	0.01	0.00	79	1.512	.133

TABLE V: Estimates of fixed effects for response times. (*p < .05).

Figure 9 presents children's average response times for each classroom while adjacent classes were engaged in quiet activities and noisy activities. Note in particular the slow response times by the children in the triple classroom in the noisy condition.



FIGURE 9: Children's average response times for each classroom while the others classes were engaged in quiet activities and noisy activities. Note that the K-6 classroom did not have different quiet/noise conditions as activities could not be coordinated across all classes. Error bars show standard error of the mean. The dashed lines indicate pairs of classrooms which significantly differed in average response times, and the asterisks indicate classrooms for which the average response time in the noisy condition was different from the average response time in the quiet condition, both with p < .05.

IV. DISCUSSION

Open plan style classrooms have recently been re-emerging as '21st century learning spaces'. The main issue with open plan classrooms is the intrusive noise coming from the other classes sharing the space. This is particularly problematic when one class is trying to engage in critical listening activities; while the teacher can tell their own class to be quiet, they have no control over the noise levels of the other classes. As school is a vital time for children to learn new concepts and words, they need to be able to hear clearly what their teacher is saying. Therefore, the aim of this study was to assess and compare Kindergarten children's speech perception *accuracy* and *speed* live in different types of open plan and enclosed classrooms when the other class bases were engaged in quiet versus noisy activities.

Measurements of the noise levels during the test revealed acceptable listening conditions only in the enclosed and double classrooms while the other classes were engaged in quiet activities (although it is likely that they would have remained acceptable in the enclosed classroom during noisy activities if the shared store room door was closed). The noise levels in the triple classroom, however, were problematic especially when the other classes were engaged in noisy activities. The noise levels were also high in the K-6 classroom, but did not reach the high levels found in the triple classroom despite the K-6 classroom having over twice the number of children.

The speech perception test revealed, as expected, that higher noise levels significantly decrease children's speech perception *accuracy* and *speed* also decreased the further away the child was seated from the loudspeaker (simulating the teacher's voice), but only when the noise level was over the recommended 50 dBA (Berg et al., 1996). In quiet conditions, the children in the two smaller classrooms performed consistently well front to back. However, in the larger classrooms, the children seated at the back were at a disadvantage as the noise levels during the 'quiet' condition were still high. Most concerning, however, was the triple classroom which had particularly high noise levels when the other classes were engaged in noisy activities. This resulted in very poor speech perception scores for the children seated at the back. The distance effect in the K-6 classroom, however, was less severe and more similar to the smaller classrooms during the noisy condition.

It was also found that the K-6 classroom had consistent intrusive noise levels throughout the day, rather than the changing quiet and noisy periods that the other three classrooms had depending on what activities the adjacent classes were engaged in. Interestingly, the children in this classroom also had significantly better speech perception scores overall compared to the children in the other three classrooms, if noise levels were to be held constant across all the classrooms. It is unlikely that socio-economic status contributed to this difference in

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performance as this school had the second lowest ICSEA of the schools tested. It is possible that the children in this classroom have learned to work in the consistent noise levels and are less distracted both auditorily and visually because it is consistent rather than dynamic or impulsive. This possible explanation needs to be considered with caution, however, as mixed results have been found regarding the age at which children are able to habituate to noise (e.g. Anderson, 2001; Barnett, Nichols, & Gould, 1982; Maxwell & Evans, 2000; Shield et al., 2010). This issue therefore needs further investigation.

The most likely explanation for these better scores is that the design of the K-6 classroom aided the children's speech perception – this classroom was newly purpose-built as a '21st century open plan learning space'. The Kindergarten class was located in the corner with a semi-open plan style (i.e. only one open wall), so the extra barriers may have helped remove some of the visual distraction as well as providing some acoustic shielding. It was also equipped with pin boards and other furnishings for absorption which helped reduce reverberation and hence the effect of noise as the two combine synergistically to mask speech (Crandell & Smaldino, 2000; Klatte et al., 2010). This contrasts with the double and triple classrooms where they had just knocked down the original wall/s between the existing classrooms and no proper acoustic modifications were put in place to help reduce reverberation and noise. The K-6 classroom also had the greatest spatial separation between classes. This means that the speech coming from the children in other classes was likely to be less intelligible/distracting.

These results suggest that the new architectural style of the '21 century learning spaces' are an improvement on the open plan classrooms that simply add classrooms together by removing walls. This is shown by the higher scores and quicker response times by the children in the K-6 classroom compared to those in the triple classroom, despite it having over twice the number of children. However, this classroom still needs to reduce noise levels to be within the recommended 50 dBA maximum to eliminate the distance effect, and add acoustic absorption to bring the reverberation time within 0.4-0.5 s (Australia/New Zealand Standard, 2000). It is

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also important to note that although classroom type was a significant factor in the speech perception scores linear mixed effects model (with the children in the K-6 classroom having better performance than children in the other classrooms if noise was held constant), noise was also a significant factor. Additionally, the children in the K-6 classroom still had lower scores than the children in the enclosed classroom during the quiet condition. Therefore, the children in the K-6 classroom would still perform better in a quieter environment even though they still performed fairly well in this noisy open plan setting.

These results suggest that if open plan classrooms are desired, they should be acoustically built as *flexible* learning spaces. That is, they should have operable walls that can stay open for group work and other activities that benefit from an open plan space, but can be closed for critical listening activities. This will create an acceptable environment like the enclosed classrooms tested, and we expect it will still be acceptable even if the other classes are engaged in noisy activities provided there are no other sound transmission channels like the open-door shared store room.

The results of this study clearly demonstrate the benefit of having acoustic barriers (i.e. enclosed walls) between classes to minimize the transmission of intrusive noise from adjacent classes and enhance speech perception. This is especially important for younger children as their auditory systems are neurologically immature and world knowledge and experience cannot as effectively be used to fill in the missing pieces with top-down information (Boothroyd, 1997; Wilson, 2002). The results of the study generally support those found by Pelegrín-García, Brunskog, and Rasmussen (2014) who conclude that "no acceptable acoustic conditions can be achieved for more than approximately 40 students without exposing the teacher to talk uncomfortably or the students to experience noticeably degraded speech intelligibility". This is shown by the poor speech perception accuracy and speed by the children in the triple classroom, even when the other classes were engaged in only quiet activities.

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classrooms. Although the noise levels in the K-6 '21st century learning space' with 205 children were still too high, they were not as high as those in the triple classroom, and the children's performance on the speech perception test was actually better. This suggests that purpose-built semi-open plan classrooms may be able to provide tolerable listening environments for more than 40 children if they are appropriately designed (which future research needs to determine). Is it important to note, however, that they will still compromise acoustic privacy compared to an enclosed classroom and children may still find it hard to concentrate in these environments.

Overall, the results suggest that when there is noise coming from other classes in open plan classrooms, the children engaged in active listening are likely to misunderstand their teacher. Even if they initially hear their teacher, the presence of noise results in slower processing of the sentence, which means they are more likely to miss the following information while they try to understand and integrate what has previously been said. The distance effect further emphasizes the importance of controlling noise levels and gathering children close to the teacher during critical listening tasks. One limitation of this study it that it used a loudspeaker with constant gain, whereas talkers tend to increase their speech level as function of the distance to the listener and the effect of the room (Pelegrín-García, Smits, Brunskog, & Jeong, 2011). The advantage of this is an increased SNR (hence increased speech intelligibility), however, it is likely to result in the teacher speaking above a comfortable level which may contribute to vocal health problems (Gotaas & Starr, 1993; Smith, Gray, Dove, Kirchner, & Heras, 1997). Using sound field amplification systems in classrooms are one way of decreasing the distance effect without requiring teachers to speak louder. Note, however, that amplification systems are not appropriate for open plan classrooms because of their disturbance to other classes. This further suggests the shortcomings of this type of learning space as it is in these classrooms that speech perception is even more affected by the child's distance from the teacher because of the high intrusive noise levels.

Minimizing noise levels in the classroom is not only important for typically developing children, but is essential for children with special educational needs such as those with attention deficits, hearing impairment, language delays, auditory processing disorders and ESL (Anderson, 2001). These children are increasingly being integrated into mainstream schools (Konza, 2008). For example, it is estimated that 83% of children with hearing impairment are now in a regular classroom (Punch & Hyde, 2010). These children are even more affected by poor acoustics, so it is vitally important to ensure the listening environment for these children is good (Crandell & Smaldino, 2000; MacKenzie & Airey, 1999). Future research is needed to investigate how the acoustics of open plan classes may affect these populations. This will assist people in making informed decisions when choosing the most appropriate schools for these children to attend. The results of our study suggest that favourable listening conditions for young typically developing children are unlikely to be achieved in fully open plan classrooms, so we would expect that they are even more problematic for children with special educational needs. Minimizing noise levels is also important for the teachers as high noise levels raises blood pressure, increases stress levels, causes headaches, results in fatigue, increases annoyance, and puts them at high risk of vocal abuse and pathological voice conditions from the need to constantly raise their voice above a comfortable level to be heard (Airey, MacKenzie, & Craik, 1998; Anderson, 2001; Evans & Lepore, 1993; Gotaas & Starr, 1993; Kristiansen et al., 2011; Leão, Oates, Purdy, Scott, & Morton, 2015; Shield et al., 2010; Smith et al., 1997). As this study only involved four classrooms, it is important that future research is conducted in a wide range of open plan and enclosed schools. This will help provide a better understanding of what noise levels, reverberation times, and classroom sizes/designs are needed to provide adequate speech perception in the classroom for all children at their different ages. Acoustic modelling can then be used for designing new classrooms or determining the treatment needed for existing classrooms so they achieve these acceptable conditions. Once this research has been conducted it may be beneficial for Australia and other countries to implement

recommendations or restrictions for classroom acoustic conditions and classroom design so speech perception is not compromised in the educational setting.

V. CONCLUSIONS

The results of this study revealed acceptable listening conditions for the enclosed and double classrooms, but only when the adjacent class was engaged in quiet activities. For the two larger open plan classrooms, the noise levels were excessive irrespective of the activity of the other classes. Higher noise levels resulted in decreased speech perception *accuracy* and *speed*, especially for the children seated towards the back of the class when the noise level was over the recommended 50 dBA limit (Berg et al., 1996). Interestingly, however, the noise levels and children's speech perception scores were better in the K-6 '21st century learning space' compared to those in the untreated converted triple classroom, despite it having over twice the number of children. This demonstrates that the new-style open plan classrooms are an improvement on the open plan classrooms that simply add rooms together by removing walls. However, it is important to note that the statistical model still suggested children would perform better in a quieter environment.

Overall, the findings of this study provide further evidence for the importance of having optimal listening conditions in Kindergarten classrooms to enhance children's access to new concepts. The results suggest that classrooms that are unable to control the ingress of noise from nearby classes do not provide appropriate learning environments for critical listening activities with young children due to the adverse effects of this noise on children's speech perception.

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CHAPTER 5: AN ASSESSMENT OF OPEN PLAN AND ENCLOSED CLASSROOM LISTENING ENVIRONMENTS FOR YOUNG CHILDREN: PART 1 – CHILDREN'S QUESTIONNAIRES

This chapter comprises of the following published paper:

Mealings, K. T., Dillon, H., Buchholz, J. M., & Demuth, K. (in press). An assessment of open plan and enclosed classroom listening environments for young children: Part 1 – Children's questionnaires. *Journal of Educational, Pediatric & (Re)Habilitative Audiology.*

All components of this paper, both experimental and written, have been completed by me, with advice from the co-authors (my supervisors) when needed.

Abstract

Purpose: Open plan classrooms, where several classes share the same area, have recently reemerged in primary schools. This study investigated Kindergarteners' perceptions of noise and how it affects speech perception in four classrooms: an enclosed classroom (25 children), double classroom (44 children), fully open plan triple classroom (91 children), and a semi-open plan K-6 classroom (205 children).

Method: Ninety-five Kindergarteners ($M_{age} = 5$;6) split over the four schools completed a questionnaire with the researcher assessing whether they could hear/were annoyed by sound sources (using yes/no) and how well they could hear their teacher/classmates in different listening scenarios (using simple ordinal ratings). Children's responses were also compared to the classroom's acoustic conditions.

Results: Most children were annoyed by noise from other children/teachers, and it significantly affected how well they could hear their teacher, especially in the open plan classrooms with only a small distance between class bases. Children in all classrooms had difficulty hearing their teacher when their own class was noisy. The children's responses of how well they could hear their teacher correlated well with the noise levels, signal-to-noise ratios, and speech transmission index scores measured in the classrooms.

Conclusions: Noise was problematic, particularly in the open plan classrooms, and it negatively impacted the children. These results show the importance of meeting the recommended acoustic limits for classrooms with 5- to 6-year-old children to ensure they can hear their teacher "well".

An assessment of open plan and enclosed classroom listening environments for young

children: Part 1 - Children's questionnaires

Open plan classrooms, often renamed as '21st century learning spaces', have recently been re-emerging in primary schools (Shield, Greenland, & Dockrell, 2010). This is despite evidence from the 1970s that suggests noise can be a major problem in these spaces (see Shield et al., 2010, for a review). Therefore, it is timely to assess whether or not these new open plan classrooms are appropriate learning environments for young children. This paper is the first part of two qualitative studies which investigated i) the 5- to 6-year-old Kindergarten children's perceptions of how noise affects their ability to hear their teacher/classmates and ii) the teachers' perceptions of noise and its effect on learning and teaching in different types of classrooms.

Classroom Configurations

The most common classroom type over the past 30-40 years has been a traditional enclosed classroom with four walls and 20-30 children and their teacher occupying the space. However, a current trend in Australia and other countries such as New Zealand, the United States, the United Kingdom, Japan, Norway, Sweden, Portugal, and Denmark is to replace these classrooms with new open plan '21st century learning spaces' which have up to 200 children sharing the same area (Stevenson, 2011). Open plan style classrooms were first popular during the educational reform in the 1960's and 1970's due to traditional didactic teaching methods being replaced by a more 'child-centered' approach where the emphasis is placed on child-directed learning rather than the teacher being the instructor (Brogden, 1983; see also Shield et al., 2010). However, many of these classrooms were converted back to enclosed classrooms towards the end of the 20th century due to noise problems and visual distraction, and a return to more traditional teaching methods (Shield et al., 2010). Despite this, the 21st century has seen a re-emergence of open plan classrooms due to the child-centred educational philosophy again being favoured (Shield et al., 2010).

In addition to being architecturally fashionable, these spaces are perceived as being less authoritarian, hence creating a more secure feeling for the child (Maclure, 1984). This type of space also allows for a range of activities to be carried out and is thought to better facilitate group activities, the children's social development, and make the children take more responsibility of their work (Brogden, 1983; Hickey & Forbes, 2011). Despite these claims of benefits, several studies have shown high noise levels are a problem in open plan classrooms (see Shield et al., 2010, for a review). The American National Standards Institute (2002) strongly discourages the use of open plan classrooms since the high levels of background noise has a "negative impact on the learning process and tends to defeat any teaching methodology advantages that may accrue from their use" (p. 24). Nonetheless, recent years have seen open plan '21st century learning spaces' growing in popularity, especially in Australia. Therefore, it is important to assess whether these new-style open plan classrooms can provide adequate listening environments for young children.

Noise in Classrooms and its Effect on Learning

Speaking and hearing are the primary modes of communication in the educational setting, so it is essential that children find their teacher's and classmates' speech intelligible (Rosenberg et al., 1999). The major noise source found in classrooms is the noise generated by other children (Picard & Bradley, 2001; Shield & Dockrell, 2004), and this is also the most distracting noise type compared to tapping and traffic noise due to its speech masking effects (Prodi, Visentin, & Feletti, 2013; see also Leibold & Buss, 2013). Classrooms with the youngest children tend to be the loudest and younger children are also more affected by noise (Picard & Bradley, 2001; Prodi et al., 2013). Many experimental studies have shown that younger children have greater perceptual difficulties than older children and adults in discriminating and understanding speech (Crandell & Smaldino, 2000; Finitzo-Hieber & Tillman, 1978; Johnson, 2000; Leibold & Buss, 2013; Nelson & Soli, 2000; Nishi, Lewis, Hoover, Choi, & Stelmachowicz, 2010). Young children are also more affected than adults by the "café effect" (i.e. the increasing noise level from people raising their voices so they are heard by themselves

and others) which happens in the classroom especially when children are engaged in group work activities (Whitlock & Dodd, 2008). Furthermore, large untreated rooms and soundreflecting surfaces and can result in long reverberation times. When noise and reverberation combine, it results in the speech signal being masked which reduces speech intelligibility (Crandell & Smaldino, 2000; Finitzo-Hieber & Tillman, 1978). Children's poorer speech perception abilities compared to adults is largely because they cannot use accrued linguistic knowledge, context, or top-down processes to fill in missing information, as their auditory systems are neurologically immature (Boothroyd, 1997; Nelson & Soli, 2000; Wilson, 2002). For this reason, it is important to consider children's perceptions of noise in the classroom rather than relying solely on adults' perceptions as they may not accurately reflect those of the children.

High noise levels not only adversely affect children's speech perception, but also affect children's psychoeducational and psychosocial achievement, including their reading and language comprehension, cognition, concentration, behavior, and anxiety levels (Klatte, Lachmann, & Meis, 2010; Maxwell & Evans, 2000; Ronsse & Wang, 2013; see also reviews by American Speech-Language-Hearing Association, 2005; Crandell & Smaldino, 2000; Klatte et al., 2010; Maxwell & Evans, 2000; Ronsse & Wang, 2013; Shield et al., 2010). Poor acoustical conditions and noise can result in children 'tuning out' and giving up on tasks as a result of being overloaded by auditory sounds (Anderson, 2001; Cohen, Evans, Krantz, & Stokols, 1980; Maxwell & Evans, 2000).

Furthermore, children with special educational needs are even more affected by poor classroom acoustics and noise (see Nelson & Soli, 2000, for a review). This includes i) children with hearing impairments and/or otitis media, who need more favourable classroom acoustics to perceive speech compared to their normal hearing peers (Crandell & Smaldino, 2000; Nelson & Soli, 2000), ii) children with auditory processing disorders, who find listening challenging when there is background noise and/or reverberation (Keith, 1999), iii) children who have English as a second language (ESL), who are poorer at perceiving and comprehending speech

in noise (Nelson, Kohnert, Sabur, & Shaw, 2005; Wang, 2014), and iv) introverts, who find it difficult to concentrate in noisy environments (Cassidy & MacDonald, 2007).

Recommended Acoustic Conditions for Classrooms

The effects of poor classroom acoustics on children emphasize the importance of controlling classroom noise. Many countries including Australia have acoustic standards for classrooms (e.g. Australia/New Zealand Standard, 2000, which recommends that the unoccupied noise level should be < 35-45 dBA, and the unoccupied reverberation time should be < 0.4-0.5 seconds), but these are not enforced and are only for unoccupied rather than occupied classrooms.

There are, however, recommendations in the academic literature about what acoustic conditions should be achieved in occupied classrooms. It is generally recommended that the signal-to-noise ratio (SNR; a direct comparison of the teacher's speech level with the noise level), should be > +15 dB throughout the classroom to ensure that children can clearly hear speech (American Speech-Language-Hearing Association, 2005). This value has been derived from studies which show speech perception for people with sensorineural hearing loss remains fairly constant above a +15 dB SNR, but deteriorates at lower SNRs (Crandell & Smaldino, 2000). As a result, it is recommended that occupied noise levels should be < 50 dBA (Berg, Blair, & Benson, 1996) to ensure an SNR of +15 dB given that an average speaking voice is 65 dBA. Furthermore, Greenland and Shield (2011) have demonstrated that speech transmission index scores (STI scores; a 0-1 scale of how intelligible speech is in a room by measuring the reduction in fidelity introduced into the speech transmission channel from the source to the receiver, caused by both reverberation and noise (MacKenzie & Airey, 1999)) should be > 0.75for 6-year-old children for satisfactory speech intelligibility. However, many studies assessing the acoustic conditions of classrooms reveal that these noise level, SNR, and STI recommendations are rarely achieved (see American Speech-Language-Hearing Association, 2005, for a review). This raises the question of whether these recommendations are too conservative and/or unrealistic, or if they are not achieved because schools have not been required to make the necessary modifications. Therefore, it would be valuable to correlate children's reports of how well they can hear their teacher in different listening scenarios with the classroom acoustic conditions measured during these scenarios. This would allow us to determine what acoustic conditions are needed for children to rate they can hear their teacher "well".

The main problem created by open plan classrooms is that there are no walls to reduce the intrusive noise from the classes entering into other class spaces. This is particularly problematic when one class is engaged in critical listening activities (hence the children need quiet conditions), but the teacher of that class cannot control or shut out the noise coming from the other classes. Enclosed classrooms, in contrast, minimize this noise as there are walls that reduce sound transmission between classes. A recent study by Mealings, Buchholz, Demuth, and Dillon (2015) found much higher intrusive noise levels from the adjacent classes in a triple classroom with 91 children and a K-6 classroom with 205 children compared to an enclosed classroom with 25 children and a double classroom with 44 children. These high noise levels directly affected children's ability to discriminate words on the Mealings, Demuth, Dillon, and Buchholz (MDDB) Classroom Speech Perception Test (Mealings, Demuth, Buchholz, & Dillon, 2015a) which was conducted live in these classrooms while the other class/es in the area engaged in quiet versus noisy activities (Mealings, Demuth, Buchholz, & Dillon, 2015b). Interestingly, however, the noise levels when the tested classes were engaged in group work activities were excessive irrespective of classroom size. Little research, however, has been conducted directly comparing the children's perceptions of noise in different types of classrooms.

Children's Reports of Noise in Classrooms

Although little research has been conducted comparing the experiences of children in open plan versus enclosed classrooms, one study in the United Kingdom (Shield, Greenland, Dockrell, & Rigby, 2008) investigated children's perceptions of noise in semi-open plan primary classrooms and compared these with a different study investigating the perceptions of noise from children in enclosed classrooms. The results from the open plan classrooms study suggested that intrusive speech (primarily from the children, but also from the teachers) from adjacent classes was the most annoying sound source for children with an unacceptable proportion (defined as over 32%) of children reporting annoyance. Additionally, the ability of the children to hear their teacher decreased as the activity level of the adjacent classes (hence intrusive noise level) rose and was unsatisfactory when adjacent classes were working in groups and moving around the classroom. Children in open plan classrooms with more than three class bases were significantly more likely to hear children's and teachers' voices from other classes and be annoyed by the teachers' voices than children in the enclosed and double classrooms. The ability to hear their classmates was not a problem for children in either open plan or enclosed classrooms. Children in enclosed classrooms when all classes were quiet. Unfortunately, because different questionnaires were used by Shield et al. (2008) for the open plan and enclosed classroom studies, few other comparisons between the classroom types were able to be made.

Present Study

The purpose of this study, therefore, was to investigate how the children in the four different sized open plan and enclosed classrooms used in the classroom acoustics study by Mealings, Buchholz, et al. (2015) perceive their listening environment using the same questionnaire and methodology across participants. The aim of this study was to answer the following research questions:

- Are the children in open plan classrooms more annoyed by noise generated by the children and teachers in the adjacent classes, and do they have more difficulty hearing their teacher and classmates than children in enclosed classrooms?
- 2) If so, is this annoyance and difficulty hearing their teacher related to the number of children and/or class bases in the area, or do other factors such as the classroom layout and acoustic treatment affect this?

3) Do the children's perceptions of noise match the objective acoustic measurements by Mealings, Buchholz, et al. (2015), and what acoustic conditions are required for a child to rate they can hear their teacher well?

Method

Schools Involved

The study took place in Sydney, Australia during the second half of the school year as part of an in depth project investigating the acoustics and listening conditions in open plan and enclosed Kindergarten classrooms. The same schools that were involved in the acoustic measures study by Mealings, Buchholz, et al. (2015) and the speech perception test by Mealings, Demuth, et al. (2015b) were involved in this study. As described in Mealings, Buchholz, et al. (2015), three open plan classrooms representing the range of classroom sizes found in Sydney were chosen for this study, along with one enclosed classroom with 25 children. During the selection process, effort was made to choose schools with similar scores on The Index of Community Socio-Educational Advantage (ICSEA) scale. The ICSEA scale represents a school's level of educational advantage based on family backgrounds. The scores range from 500-1300, with a mean of 1000 and standard deviation of 100. Higher ICSEA scores represent more advantaged schools. (More information about ICSEAs can be found on the My<u>School</u> website <u>http://www.myschool.edu.au</u>.) We used the ICSEA scores calculated for 2013 when the study was conducted. Below are the descriptions of the classrooms as found in Mealings, Buchholz, et al. (2015). The building details and acoustic conditions of the participating classrooms as measured in Mealings, Buchholz, et al. (2015) are shown in Table 1 and Table 2. Table 2 also shows the average scores the children achieved on the MDDB Classroom Speech Perception Test for each classroom when the adjacent class/es were engaged in quiet versus noisy activities (Mealings, Demuth, et al., 2015b).

Enclosed Classroom: 25 Kindergarten Children. This classroom consisted of 25 Kindergarten children in a classroom with 3 solid brick walls, a closed floor-to-ceiling 4 cm thick operable wall with pin boards, and a shared storeroom with the adjacent Kindergarten

class. The class area was carpeted with loop pile carpet and windows were located on both side walls (Figure 1). The ceiling was rough concrete textured. No acoustic treatment was evident. A survey of 50 primary schools in the region found that 60% of Kindergarten classrooms have an operable wall between them and an additional 10% have a shared storeroom or door with another class. Only 30% of schools had fully enclosed classrooms with four solid walls. Therefore, this classroom with its operable wall and shared storeroom was more typical of those enclosed classrooms found in the Sydney region, and hence was chosen for the study. The average unoccupied reverberation time (T30) of this classroom was 0.50 s, which is within the recommended time of 0.4-0.5 s (Australia/New Zealand Standard, 2000).



Figure 1: Floor plan of the enclosed classroom with 25 children.

Double Classroom: 44 Kindergarten Children. This space originally consisted of two separate classrooms with plasterboard walls, but the wall between had been removed at the start of the year to make it an open double classroom for the 44 Kindergarten children. The ceiling was made of plasterboard and was triangular in shape, and the top half of the wall still remained in this area between the two classrooms where the original wall had been. The class area was carpeted with loop pile carpet but the utility area was a hard surface. Windows were located on two walls and pin boards covered the other two walls (Figure 2). No other acoustic treatment

was evident. The average unoccupied reverberation time (T30) of this classroom was 0.60 s, which is above the recommended time of 0.4-0.5 s (Australia/New Zealand Standard, 2000).



Figure 2: Floor plan of the double classroom with 44 children.

Triple Classroom: 91 Kindergarten Children. This open plan classroom consisted of 91 Kindergarten children grouped linearly into three classes (K1, K2, K3), with no barriers between them. This classroom represented a mid-range child and class base number for an open plan space. The Year 1 and 2 classes were located off an adjacent corridor but had no doors/walls separating the spaces, hence noise from these classes could also be heard. Originally the space had consisted of separate enclosed classrooms with 30 children in each, but these walls had recently been removed to make the area fully open plan. The walls were plasterboard and the class area was carpeted with loop pile carpet, but the corridor floor was a hard surface. The ceiling was acoustically tiled. Windows were located on both the front and back walls and pin boards were on the other two walls (Figure 3). No other acoustic treatment was evident. The average unoccupied reverberation time (T30) of this classroom was 0.70 s, which is above the recommended time of 0.4-0.5 s (Australia/New Zealand Standard, 2000).



Figure 3: Floor plan of the triple classroom with 91 children.

K-6 Classroom: 205 Kindergarten to Year 6 Children. This classroom contained the entire primary school (205 children) in the one area representing one of the biggest types of open plan classrooms found in Sydney. It had been purpose-built to be a '21st century learning' open plan school. The children were separated into class stages with Kindergarten, Year 1, and Year 2 in a semi-open plan layout with dividers between them and only one open wall. Years 3/4 and 5/6 were in the fully open plan area. The Kindergarten class was located in the corner in the acoustically most sheltered location, particularly for their whole class teaching area where the children are grouped together on the floor to listen to their teacher (see Figure 4). The ceiling height in this area was the lowest of the room measuring 3.2 m. The entire area was carpeted with loop pile carpet, and 3 cm thick pin boards along the walls and soft furnishings provided some acoustic absorption. The ceiling was acoustically tiled. Windows were located on the external wall. The average unoccupied reverberation time (T30) of this classroom was 0.58 s, which is above the recommended time of 0.4-0.5 s (Australia/New Zealand Standard, 2000), but lower than the reverberation times of the double and triple classrooms.



Figure 4: Floor plan of the K-6 classroom with 205 children.

	Enclosed Classroom	Double Classroom	Triple Classroom	K-6 Classroom
Total number of students	25	44	91	205
in area				
School's ICSEA	1141	1133	1035	1090
Classroom type	Enclosed classroom with	Fully open double	Linear, fully open plan	Semi-open plan classroom
	shared concertina wall	classroom	classroom	
Class grades in area	Kindergarten	Kindergarten	Kindergarten	Kindergarten to Year 6
	(5-6-year-olds)	(5-6-year-olds)	(5-6-year-olds)	(5-12-year-olds)
Number of class bases in	1	2	3	5-7
area				(depending on activity)
Number of students in	25	21-23	30-31	30-50
each class base				
Room dimensions (m)	8 x 9	15 x 9	37 x 11	27 x 32
Total floor area (m ²)	72	135	407	864
Space per child (m ²)	2.9	3.1	4.5	4.2
Distance between edge of	N/A	2	6	7
class bases (m)				
Ceiling height (m)	3.0	2.8-4.2	3.3	3.2-6.0
Total room volume (m ³)	216	470	1340	3900

Table 1: Building details of the participating classrooms (from Mealings, Buchholz, et al., 2015).

Noise Type	Classroom	Average	Average	Average STI	Average
		Noise Level	SNR (dB)	Score	MDDB
		(dBA)			Score (%)
Unoccupied	Enclosed	42	+18	0.86	
ambient noise	Double	37	+26	0.83	
	Triple	36	+24	0.92	
	K-6	46*	+12*	0.84	
Intrusive noise	Enclosed	43	+18	0.73*	80
(adjacent	Double	46	+14*	0.75	76
class/es doing	Triple	57*	+2*	0.54*	67
quiet activities)	K-6	60*	-1*	0.45*	66
Intrusive noise	Enclosed	49	+14*	0.73*	64
(adjacent	Double	50	+10*	0.68*	60
class/es doing	Triple	62*	-3*	0.41*	45
noisy activities)	K-6	60*	-1*	0.45*	68

Table 2: Average noise levels, signal-noise ratios (SNRs), speech transmission index (STI)scores and MDDB Classroom Speech Perception Test scores in each classroom duringdifferent scenarios (see also Mealings, Buchholz, et al., 2015 and Mealings et al., in press).

Note. * indicates acoustic conditions are outside of the recommended 45 dBA unoccupied and 50 dBA occupied maximum noise level, +15 dB minimum SNR, and 0.75 minimum STI score (Australia/New Zealand Standard, 2000; Berg et al., 1996; Crandell & Smaldino, 2000; Greenland & Shield, 2011).

Participants

Twenty-three to twenty-five Kindergarten children from each school ($N_{total} = 95$) whose parents gave consent for their child to participate in the study completed the questionnaires

approved by Macquarie University ethics. No children from the triple or K-6 classroom were reported by their parents to have otitis media, a hearing loss, or intellectual or behavioural disabilities. One child in the double classroom was reported to have a sensory processing disorder, and one child in the enclosed classroom had a history of otitis media, but was not currently suffering from it. Table 3 shows the demographics of the participating children as reported by their parents.
Classroom	Number of	Number of	Age Range	Number Who	Number Who	Average Time
	Participants	Males/Females	and Mean	Have ESL	Have Attended	Spent in
					Preschool	Preschool
						(years, hours
						per week)
Enclosed	24	14M; 10F	5;1-6;3	13	23	2.4, 23
			<i>M</i> = 5;6			
Double	23	12M; 11F	5;1-6;3	0	20	2.7, 18
			<i>M</i> = 5;5			
Triple	25	11M; 14F	5;1-6;3	12	23	2.3, 21
			<i>M</i> = 5;6	(+ 4 multilingual)		
K-6	23	13M; 10F	4;11-6;1	4	22	2.6, 22
			<i>M</i> = 5;7	(+ 7 multilingual)		

Table 3: Demographic information for participating children.

Questionnaire Design

The children's questionnaires were based on previous questionnaires used in similar studies with a similar age group by Canning (1999), Greenland (2009), Shield and Dockrell (2004), and Shield et al. (2008). The questionnaire consisted of three main sections (see appendix). The first section asked children whether they could hear a particular sound source when they were in the classroom, and then if they could, whether or not it annoyed them. Each question was in a dichotomous yes/no format to make it easy for young children. The sound sources assessed were traffic, children outside, fans/air conditioning units, computers/iPads, TVs/Smart Boards, children in other classes, and teachers of other classes.

The second section examined how well children could hear their teacher in different listening scenarios. These scenarios included when all classes were quiet, when adjacent classes were working at their tables, when adjacent classes were doing group work and moving around, when there was outside noise, when the child could not see their teacher's face, and when their own class was being noisy. The third section assessed how well the children could hear their classmate when they were answering their teacher, and when their class was engaged in group work. These two sections used a five point Likert scale (1 = not at all, 2 = not very well, 3 = ok, 4 = well, and 5 = very well) represented as a smiley face scale as used by Canning (1999).

Questionnaire Procedure

Given the young age group, the questionnaires were administered individually to the participating children to ensure each child understood the task. Each participating child was introduced to the researcher and taken individually out of the classroom during the school day to complete the questionnaire. The child was told that he/she was going to fill in a worksheet together with the researcher. The researcher explained that they would ask the child to answer some questions about what they hear in the classroom, and were assured that there were no right or wrong answers. The child was then asked if he/she was happy to participate (which all children were) before commencing the questionnaire. Each question was read out loud by the

researcher to the child. For the first section, the child gave his/her answer by replying with a yes or no for each sound source. For the second and third sections, the child responded either verbally or by pointing to the relevant smiley faces indicating how well he/she could hear his/her teacher/classmate in each scenario. The whole procedure took 3-5 mins for each child.

Results

Noise Sources

The percentage of children who reported hearing each noise source is shown in Table 4. High percentages of children could hear the children of other classes, and this increased as class size increased.

 Table 4: Percentage of children in each classroom reporting they could hear a particular sound source.

Sound Source	Percentage of Children Hearing Sound Source						
	Enclosed	Double	Triple	K-6			
	(<i>N</i> = 24)	(N = 23)	(N = 25)	(N = 23)			
Traffic	33	17	68	30			
Children outside	67	65	76	61			
Fans/air conditioners	63	43	44	43			
Computers/iPads	33	39	56	30			
TVs/Smart Boards	54	30	76	43			
Children in other classes	79	87	88	100			
Teachers of other classes	63	65	72	57			

Figure 5 shows the percentage of children who found particular sound sources annoying. As described in Shield et al. (2008), previous research into noise annoyance in open plan offices and classrooms have proposed that a minimum of 68% of people need to be satisfied with the environment for it to be acceptable (see p. 12). This means that if over 32% of people are dissatisfied, the environment is unacceptable. In our analyses we call this maximum acceptable dissatisfaction rate the dissatisfaction criterion. As shown in Figure 5, the noise generated from children outside as well as the noise generated by children and teachers of other classes was unacceptable in every classroom. Additionally, traffic noise and noise from TVs/Smart Boards was unacceptable in the triple classroom. The triple classroom also had the highest percentage of children reporting annoyance for five out of the seven sound sources.



Figure 5: Percentage of children reporting annoyance of different sound sources for each classroom type. The dissatisfaction criterion is set at 32%.

A series of chi-squared tests were run to investigate possible differences in the proportion of children reporting each sound source as annoying between classrooms. There were no significant differences, however, for any of the sound sources $\chi^2(3, N = 95)_{traffic} = 2.18$, p = .54; $\chi^2(3, N = 95)_{children outside} = 2.92$, p = .40; $\chi^2(3, N = 95)_{fans} = 1.48$, p = .69; $\chi^2(3, N = 95)_{computers/iPads} = 4.07$, p = .25; $\chi^2(3, N = 95)_{TVs/Smart Boards} = 7.73$, p = .05; $\chi^2(3, N = 95)_{children in other classes} = 4.12$, p = .25; $\chi^2(3, N = 95)_{other teachers} = 0.73$, p = .87.

How Well Children Can Hear Their Teacher

Figure 6 shows the mean rating scores of how well children could hear their teacher in different listening scenarios, such as when all classes were quiet, when adjacent classes were working at their tables, when adjacent classes were doing group work and moving around, when there was outside noise, and when their own class was being noisy. A Friedman test combining all classrooms showed a significant difference in mean scores between scenarios $\chi^2(4) = 121.44$, p < .001. A post hoc Wilcoxen signed-rank test with Bonferroni correction applied p = .05/10 = .005 revealed significantly poorer hearing ratings when other classes were doing group work which involved movement or when their own class was noisy compared to the other three listening scenarios $Z_{outside noise vs. moving} = -4.03$, p < .001, r = 0.41; $Z_{tables vs. moving} = -3.91$, p < .001, r = 0.40; $Z_{all \ classes quiet vs. moving} = -7.53$, p < .001, r = 0.77; $Z_{outside \ noise vs. own \ class \ noisy} = -3.74$, p < .001, r = 0.38; $Z_{tables vs. own \ class \ noisy} = -3.87$, p < .001, r = 0.40; $Z_{all \ classes \ noisy} = -3.87$, p < .001, r = 0.40; $Z_{all \ classes \ noisy} = -7.52$, p < .001, r = 0.77. Hearing ratings were also significantly poorer when other classes were working at their tables or there was outside noise vs. quiet = -5.62, p < .001, r = 0.58. This means that the child's ability to hear their teacher in different scenarios ordered from best to worst was:

- 1) When all classes are quiet
- 2) When other classes are working at their tables or there is outside noise
- 3) When other classes are doing group work with movement or their own class is noisy.

A series of Kruskal Wallis tests were conducted to assess possible differences in the children's mean hearing ratings between classrooms. There were no significant differences between classrooms when all classes were quiet H(3) = 1.86, p = .60, when other classes were working at their tables H(3) = 6.716, p = .10, when there was noise from outside H(3) = 5.65, p = .13, or when their own class was being noisy H(3) = 2.06, p = .56. However, there was a statistically significant difference between the classrooms when other classes were doing group work and moving around the classroom H(3) = 9.72, p = .02. A post-hoc test using Mann-

Whitney U tests with Bonferroni correction p = .05/6 = .0083 showed that the hearing rating for the double classroom (where the classes were closest together) was significantly poorer than the enclosed classroom U = 150, Z = -2.75, p = .006, r = 0.40; see Figure 6.



Figure 6: Mean hearing ratings for different listening scenarios by classroom type (1 = not at all, 2 = not very well, 3 = ok, 4 = well, and 5 = very well). Error bars show the standard error of the mean. *p = .05/6 = .0083.

Figure 7 shows the percentage of children who reported not being able to hear their teacher very well or at all in different scenarios. These ratings represent those not satisfied with the listening environment. Again, the dissatisfaction criterion was set at 32% (see Shield et al., 2008), so if over 32% of children reported not being able to hear their teacher very well or at all, then the listening environment was considered unsatisfactory. Notice that the listening environment when a child was trying to hear their teacher while their own class was being noisy was unsatisfactory for all schools. This was also the case when adjacent classes were doing group work that involved movement, even for the enclosed classroom (which was just over the 32% dissatisfaction criterion at 33%). Although there were no significant differences in proportions between classrooms for any of the scenarios $\chi^2(3, N = 95)_{all \ classes\ quiet} = 0.99, p =$

.80; $\chi^2(3, N = 95)_{tables} = 6.31$, p = .10; $\chi^2(3, N = 95)_{moving} = 6.75$, p = .08; $\chi^2(3, N = 95)_{outside noise}$ = 5.81, p = .12; $\chi^2(3, N = 95)_{teacher's face hidden} = 2.40$, p = .49; $\chi^2(3, N = 95)_{own \ class \ noisy} = 1.80$, p = .62, there was a trend in the percentage of children who struggled to hear their teacher while adjacent classes were doing group work that involved movement that was related to the distances between classes. That is, the smaller the distance between classes (hence the more distracting the noise is expected to be) the higher the percentage of children was who could not hear their teacher very well or at all when the other classes were being noisy. Furthermore, it was only the double classroom (which had the least distance between classes) that reported an unsatisfactory listening environment when the adjacent class was working at their tables. Additionally, outside noise interfered with how well the children could hear their teacher for the double and triple classrooms, and not being able to see their teacher's face when they were talking was problematic in the enclosed classroom.



Figure 7: Percentage of children who reported not being able to hear their teacher very well or at all for different listening scenarios. The dissatisfaction criterion is set at 32%.

How Well Children Can Hear Their Classmates

Table 5 shows the children's mean hearing ratings of how well they could hear their classmate when i) their classmate was answering their teacher and ii) when they were working in groups. No significant difference was found between classrooms for either scenario as determined by a Kruskal-Wallis test (see Table 5). Table 5 also shows the percentage of children who reported that they could not hear their teacher very well or at all (i.e. those dissatisfied with the listening scenario). This exceeded the acceptable rate of 32% for the double classroom. This classroom had the least distance between classes and one of the smallest areas for the number of children, so the close proximity of the 44 children may explain why there was a high proportion of children who had difficulty hearing their classmates when the classes were carrying out group work activities.

 Table 5: Children's mean hearing ratings of how well they can hear their classmates and the dissatisfaction criterion (D; percentage of children who

 reported they cannot hear their teacher very well or at all) in different scenarios.

Scenario	Enclo	sed Cla	assroom	Doul	ole Cla	issroom	Trip	le Clas	ssroom	K-6	5 Class	room	Kruskal-W	Vallis Test
	М	SD	D (%)	М	SD	D (%)	М	SD	D (%)	М	SD	D (%)	H(3)	р
Answering teacher	4.38	0.88	4.17	3.83	1.15	13.04	3.92	1.15	8.00	3.87	1.22	13.04	4.02	0.26
Working in groups	3.79	1.10	17.67	3.13	1.46	43.48*	4.10	1.15	12.00	3.74	1.01	13.04	6.49	0.09

Note. * indicates percentage of children dissatisfied is unacceptable.

Comparison of Children's Ratings with Quantitative Acoustic Data

A series of correlations were run to assess the relationship between the mean hearing ratings by the children in each classroom and the average noise levels, SNRs, and STI scores reported for these classrooms in Mealings, Buchholz, et al. (2015) and shown in Table 2. The average unoccupied ambient noise levels were used with the children's ratings of how well they could hear their teacher when all were classes quiet, the average intrusive noise levels during quiet activities were used with the children's ratings of how well they could hear their teacher when other classes were working at their tables, and the average intrusive noise levels during noisy activities were used with the children's ratings of how well they could hear their teacher when other classes were doing group work with movement. A moderate-to-strong negative correlation was found between noise level and hearing rating r = -0.68, N = 12, $R^2 = 0.46$, p < .05, indicating that the children's report of how well they could hear their teacher decreased as noise level increased. A moderate-to-strong positive correlation was found between SNR and hearing rating r = 0.66, N = 12, $R^2 = 0.43$, p < .05, indicating that the children's report of how well they could hear their teacher increased as SNR increased. A moderate-to-strong positive correlation was also found between STI score and hearing rating r = 0.69, N = 12, $R^2 = 0.48 \ p < .05$, indicating that the children's report of how well they could hear their teacher increased as STI scores increased.

An additional reason for examining these relationships was to compare them to the current acoustic recommendations for classrooms with 5- to 6-year-old children (see Table 6). Figure 8 shows the regression lines for the average hearing rating of the children with the noise levels, SNRs, and STI scores. As there was error in both the noise levels/SNRs/STI scores and the hearing ratings and an assumption about how the noise conditions matched the questionnaire scenarios, we have plotted two regression lines: the regression of hearing rating on acoustic measurement (shown by the dotted line), which can be used to estimate the hearing rating given an acoustic measurement, and the regression of acoustic measurement on hearing rating (shown

by the solid line), which can be used to estimate the acoustic measurement needed to achieve a given hearing rating. To estimate what noise level/SNR/STI score is needed to get a rating of 4 (which means the child can hear their teacher "well"), we used the regression line of acoustic measurement on hearing rating (i.e. the solid line) and compared these values to the recommendations. As shown in Table 6, there was a close match between our values and those recommended in the literature, reinforcing the importance of meeting these recommendations to ensure adequate speech perception in the classroom.

Finally, a fourth correlation analysis was run to assess whether there was a relationship between the children's mean hearing ratings and their mean speech perception scores on the MDDB Classroom Speech Perception Test (Mealings, Demuth, et al., 2015a) for the relevant scenarios as reported in Mealings, Demuth, et al. (2015b) and Table 2. A strong positive correlation was revealed between the children's mean hearing rating and speech perception score r = 0.87, N = 8, $R^2 = 0.75$, p < .05, indicating that the children's report of how well they could hear their teacher in quiet and noisy conditions strongly represented their actual ability to hear their teacher in different listening situations. A speech perception score of 71% corresponds to a hearing rating of 4 (i.e. "well") as shown by the solid line in Figure 8.

Acoustic VariableMeasured ValueRecommended ValueNoise Level< 45.9 dBA</td>Occupied: < 50 dBA
(Berg et al., 1996)
Unoccupied: < 35-45 dBA
(AS/NZS2107:2000, 2000)SNR> +14.5 dB> +15 dB (Crandell & Smaldino, 2000)STI> 0.75> 0.75 (Greenland & Shield, 2011)

Table 6: Measured value versus recommended value for classroom noise level, signal-to-noise ratio (SNR), and speech transmission index (STI) score.



Figure 8: Children's mean hearing ratings of how well they can hear their teacher compared to previously measured classroom noise levels, signal-to-noise ratios (SNRs), speech transmission index (STI) scores, and MDDB Classroom Speech Perception Test scores for

similar scenarios. The dotted line shows the regression of hearing rating on acoustic parameter, and the solid line shows the regression of acoustic parameter on hearing rating, where a mean hearing rating of 1 = cannot hear teacher at all, 2 = cannot hear teacher very well, 3 = can hear teacher ok, 4 = can hear teacher well, and 5 = can hear teacher very well.

Discussion

The aim of this study was to compare how Kindergarten children in four different sized open plan and enclosed classrooms perceive their listening environment, how well they can hear their teacher and classmates in different listening scenarios, how their perceptions relate to the acoustics of these classrooms measured by Mealings, Buchholz, et al. (2015), and what acoustic conditions are required for children to rate they can hear their teacher well.

As predicted, a high proportion (60-76%) of children in the open plan classrooms were annoved by the children of other classes, which is well above the maximum acceptable rate of 32% (see Figure 5). Surprisingly, 46% of children in the enclosed classroom also reported being annoved by the children in the classroom next door despite there being an operable wall between them and intrusive noise levels being within those recommended (Mealings, Buchholz, et al., 2015). Although the 46% dissatisfaction rate for the enclosed classroom is markedly less than that for the other three classrooms, it is still substantially higher than the 32% dissatisfaction criterion used by Shield et al. (2008). Additionally, unacceptable proportions of children were annoyed by the teachers of other classes in the open plan classrooms (which was also found by Shield et al., 2008) but also in the enclosed classroom. It is likely that this noise annoyance in the enclosed classroom was largely due to the shared storeroom door always being open which allowed sound to be transmitted between classes. This annoyance is an important finding to take note of as it shows that some children are still sensitive to noise, even if it is thought to be at an acceptable level (Mealings, Buchholz, et al., 2015). Most concerning, however, was the triple classroom which had the highest proportions of children who found the noises annoying for five out of the seven sound sources examined. This classroom also had some of the highest noise levels which resulted in SNRs and STI scores to be well below those recommended (see Table 2). This is likely to be related to the classroom having no acoustic treatment, so these noises probably had a greater effect on the children. These results suggest that it is likely that a fully enclosed acoustically treated classroom is needed to achieve acceptable listening conditions for all children. The results also show the importance of closing doors/windows during critical listening activities, and making sure the teacher is facing the children when they are talking to aid speech perception. Furthermore, it may be beneficial for classrooms to install sound field amplification systems to increase the SNR throughout the

room. These systems are not suitable, however, for open plan classrooms as they will disturb the other classes, which is a further shortcoming of these spaces.

The results also revealed, as predicted, that the children in the enclosed classroom were able to hear their teacher better than those in the open plan classrooms when the other classes were engaged in group work and moving around the class. Following from Shield et al. (2008), we also predicted that the children in the larger open plan classes, which had higher noise levels, would have more trouble hearing their teacher than those in the smaller open plan classes. Interestingly, however, the reverse was true with the trend being related to the distance between class bases rather than the number of children in the area. That is, the smaller the distance between classes, the higher the proportion of children was who could not hear their teacher very well or at all when the other classes were being noisy. Although the noise levels were lower in the double classroom compared to the larger open plan classrooms (Mealings, Buchholz, et al., 2015), the closer proximity of the two classes meant that the speech from the adjacent class was likely to be more intelligible, hence more distracting. This because is harder for children to segregate the target and masker speech sounds when the masker is multi-talker babble compared to speech shaped noise or non-lingual noise, due to informational masking (Leibold & Buss, 2013; Prodi et al., 2013). In the larger classrooms, the noise should be more diffuse hence less intelligible. This is likely to explain why 70% of children in the double classroom, which only had 2 m separating the classes compared to 6-7 m in the other open plan classrooms, could not hear their teacher very well or at all when the other class was engaged in group work activities involving movement. This also helps to explain why it was only this classroom that reported an unacceptable proportion of children who could not hear their classmates very well or at all during group work activities. This shows the importance of having adequate separation (i.e. at least 6.5 m; Shield et al., 2010) between classes in open plan spaces, or more effectively, having acoustic barriers between classes to minimize noise transmission and enhance the children's ability to hear their teacher and classmates.

Another interesting finding from the study was that the mean score of how well the children could hear their teacher when their own class was being noisy was "not very well" to "ok" in all classrooms, irrespective of their size or design. These results show that noise during group work can be excessive in any classroom, so it is important that teachers try to control it. It also shows the importance of having sufficient acoustic absorption in classrooms as this will help minimize the effect of this noise (Siebein, Gold, Siebein, & Ermann, 2000).

An additional aim of this study was to relate the children's perceptions of the listening environment to the acoustic measures of the classrooms and the children's speech perception test results (Mealings, Buchholz, et al., 2015; Mealings, Demuth, et al., 2015b). This allowed us to examine whether the children's experiences in the classroom are reflective of the quantitative measures. Using this relationship we were also able to assess the appropriateness of current acoustic recommendations for classrooms with 5- to 6-year-old children. The moderate-to-strong negative correlation found between how well children reported hearing their teacher in different scenarios and the noise levels recorded during similar scenarios shows the direct effect of how high noise levels interfere with the children's ability to hear their teacher. The regression line for this relationship revealed that young children may need slightly lower noise levels than the recommended 50 dBA occupied noise limit suggested by Berg et al. (1996) to hear their teacher well. This may also explain why the higher than expected proportion of children in the enclosed classroom reported being annoved by the children in the adjacent class, as in the noisier periods this level was above the 45.9 dBA limit our study suggests (see Mealings, Buchholz, et al., 2015, and Table 2). The moderate-to-strong positive correlations between how well children reported hearing their teacher in different scenarios with the SNRs and STI scores for similar scenarios demonstrates that these measures provide a good estimate of how well speech is heard by children in the classroom. Additionally, the SNR and STI score that corresponded to children hearing their teacher "well" was very similar to those recommended in the literature (see Table 6), reinforcing the importance of meeting these recommendations to ensure adequate speech perception in the classroom. Finally, the strong positive correlation revealed between the children's mean hearing ratings and the MDDB speech perception scores indicate that the children's report of how well they can hear their teacher strongly represents their actual ability to hear their teacher.

Limitations of the Study and Future Directions

The main limitation of this study was that it involved children from only four schools, hence it only allowed a relatively small number of participants to be involved for a questionnaire design. It would therefore be beneficial to continue this study and examine a wide range of classrooms that could be grouped together by design type, hence providing more participants and more power for the statistical analysis. This would allow for more generalized conclusions to be drawn about how children cope in different types of classrooms. It would also allow us to better understand which designs and acoustic treatments are appropriate and what the maximum number of children in a classroom area, and/or minimum spacing between class bases is needed in open plan areas to maintain adequate speech perception. It is important that this future research uses multiple approaches that take into account the physical acoustic conditions in the classrooms (i.e. the noise levels, SNRs, and STI scores) as well as how the children perceive the listening environment as they are the ones who need to be able to function well in the classroom. It would also be worthwhile to explore children's perceptions of how well they can hear their teacher while taking into consideration the class activity, noise level, and the teacher's vocal quality. This is important as the loudness and quality of a teacher's voice is affected differently depending on the type and intensity of the background noise (Rantala, Hakala, Holmqvist, & Sala, 2015), so it is likely that this will also affect children's speech perception.

In addition, it would be beneficial to take this research further to assess how noise affects how well children function in the classroom. The results of the current study show that children's perceptions of noise and hearing is related to their ability to perceive speech, but

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future research is needed to examine how this affects their ability to learn new concepts during different activities and in different classrooms. Furthermore, a recent study by Valente, Plevinsky, Franco, Heinrichs-Graham, and Lewis (2012) showed that even if children recognize speech accurately, increasing background noise and reverberation can negatively affect secondary tasks such as comprehension. Therefore, examining this link between noise, speech perception, comprehension, and learning will help provide important insight into how classroom configuration may affect children's educational progression.

It would also be interesting to investigate the perceptions of classroom noise from children in different grades. A recent study by Prodi, Visentin, and Feletti (2013) demonstrated that older children can adapt better to different noise types and acoustical room conditions in relation to their speech perception accuracy and/or response time. Therefore, examining children's perceptions of noise and along with their speech perception abilities and learning outcomes would help us to further examine the different effects of classroom noise on children depending on their age. These results would provide further understanding about what classroom designs are appropriate for different grades.

In addition, it would be helpful to investigate how children with special educational needs such as hearing impairments, auditory processing disorders, language delays, and attention deficits find different classroom listening environments. These children are increasingly being integrated into mainstream schools and need noise levels to be 10 dBA lower than their peers, so it is vitally important to ensure the listening environment for these children is favourable (Crandell & Smaldino, 2000; Konza, 2008; MacKenzie & Airey, 1999; Nelson & Soli, 2000). A recent study by Connolly, Dockrell, Shield, Conetta, and Cox (2014) found that adolescents aged 11- to 16-years-old with special educational needs were more annoyed by noise and more sensitive to the negative effects of noise and its consequences than their peers. It would therefore be worthwhile to explore these effects in younger children. Furthermore, it would be beneficial to explore the perceptions of noise by children who have ESL, as noise has

been shown to have a greater impact on speech perception for this population (Nelson & Soli, 2000; Nelson et al., 2005). In the present study, 31% of the participants identified as having ESL. While we did run analyses comparing the perceptions of children with ESL to those who had English as their first language, we did not find any significant differences between the two groups. Furthermore, we did not have enough information on these children's language backgrounds to draw any firm conclusions about this effect, hence these results were not reported in this study. Therefore, further investigation involving a larger number of participants and more information on their language backgrounds is needed to fully examine this factor.

Overall, the results of this study suggest that it would be beneficial for Australia (and other countries) to implement the Australia/New Zealand Acoustics Standards (2000) for unoccupied classrooms and the recommended acoustic limits for occupied classrooms referred to and calculated in this paper. Modifications that can be made in classrooms to help achieve these acoustic limits include i) having 90% absorption on the ceiling and walls and limiting ceiling height to 3.5 m to control reverberation (Shield et al., 2010; Siebein et al., 2000; Wilson, 2002), ii) making sure air conditioning systems and equipment have low noise level ratings to reduce ambient noise levels (Wilson, 2002), iii) using sound field systems to increase the SNR and minimize teacher's vocal strain (Massie & Dillon, 2006a, 2006b), and iv) using FM systems with hearing impaired children (Wilson, 2002). The teachers should also gather children as close as possible to them and make sure the children can see their face to further aid speech perception in the classroom (Kim, Sironic, & Davis, 2011; Sumby & Pollack, 1954). Once more research has been conducted in a variety of schools and with different populations, it may also be worthwhile to have enforced criteria for classroom designs and acoustic treatment to ensure classrooms meet these standards so all children are comfortable and able to learn effectively in every educational setting.

Conclusion

The results of this study show that many of the children in open plan classrooms are annoyed by the noise generated by the children and teachers of other classes in the same open plan space. This noise significantly affects how well children can hear their teacher and classmates, especially when there is only a small distance separating the classes. The results also show the benefit of having an operable wall to separate classes and reduce noise transmission. Even then, however, some children may still be affected by noise in an adjacent class when it is engaged in loud activities, especially when, as in this case, the doors to a storeroom opening into both classrooms are left open. Additionally, children in all the classrooms examined found it difficult hearing their teacher when their own class was engaged in group work because of the high noise levels. The results of this study show the importance of meeting the recommended acoustic limits for classrooms with 5- to 6-year-old children to ensure children can hear their teacher well in the classroom. Therefore, controlling noise in all classrooms and ensuring that they are built in a suitable layout with appropriate acoustic absorption and adequate separation between classes is essential for children's educational progression.

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Appendix

Classroom Noise Worksheet

Date:

Your School:	
Your Class:	
Your Teacher's Name:	
Your Name:	



Date of birth:

What is your first language? English \Box Other \Box (Please specify):

Do you have problems hearing?



Do you wear a: Hearing aid \Box Cochlear implant \Box

What do you hear in the classroom?

	When you are in the classroom do	you eve	er hear no	ise fr	om
	traffic (please tick)?	Yes		No	
	If yes, does it annoy you?	Yes		No	
	When you are in the classroom do	you eve	er hear no	ise fr	om
3 North State	children outside at school?	Yes		No	
	If yes, does it annoy you?	Yes		No	
	When you are in the classroom do	you eve	er hear no	ise fr	om
	fans/air-conditioning units?	Yes		No	
0	If yes, does it annoy you?	Yes		No	
	When you are in the classroom do	you eve	er hear no	ise fr	om
2	computers?	Yes		No	
3	If yes, does it annoy you?	Yes		No	
\sim	When you are in the classroom do	you eve	er hear no	ise fr	om
0	televisions?	Yes		No	
	If yes, does it annoy you?	Yes		No	
	When you are in the classroom do	you eve	er hear no	ise fr	om
A server	children in other classes?	Yes		No	
	If yes, does it annoy you?	Yes		No	
and to School	When you are in the classroom do	you eve	er hear no	ise fr	om
	teachers in other classes?	Yes		No	
	If ves, does it annov you?	Yes		No	

How well do you hear your teacher?

Your class is quiet and you are listening to your teacher. The classes next to you are doing a test. How well can you hear your teacher?

Very well	Well	Ok	Not very well	Not at all

Your class is quiet and you are listening to your teacher. The classes next to you are working at their tables. How well can you hear your teacher?

				···
Very well	Well	Ok	Not very well	Not at all

Your class is quiet and you are listening to your teacher. The classes next to you are working and moving around the classroom. How well can you hear your teacher?

				() ()
Very well	Well	Ok	Not very well	Not at all

Your class is quiet and you are listening to your teacher. Other classes are quiet but there is a lot of noise outside the classroom from traffic and children. How well can you hear your teacher?

				() ()
Very well	Well	Ok	Not very well	Not at all

Your class is quiet and you are listening to your teacher but you cannot see her face. How well can you hear your teacher?

				1.1
Very well	Well	Ok	Not very well	Not at all

Your class is packing up, moving around, and whispering. How well can you hear your teacher?

):)
Very well	Well	Ok	Not very well	Not at all

How well do you hear your classmates?

Your teacher is asking a question and one of your classmates is giving an answer. How well can you hear your classmate?

Very well	Well	Ok	Not very well	Not at all

You are working in groups. How well can you hear what the people in your group are saying?

Very well	Well	Ok	Not very well	Not at all

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE!

Questionnaires adapted from:

Canning, D. (1999). *Listening inventories for education*. Retrieved December 14, 2012, from http://www.avuk.org/LIFEUKIHP.pdf

Dockrell, J. E., & Shield, B. M. (2004). Children's perceptions of their acoustic environment at school and at home. *Journal of the Acoustical Society of America*, 115, 2964-2973.

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CHAPTER 6: AN ASSESSMENT OF OPEN PLAN AND ENCLOSED CLASSROOM LISTENING ENVIRONMENTS FOR YOUNG CHILDREN: PART 2 – TEACHERS' QUESTIONNAIRES

This chapter is based on the following paper which is currently in submission:

Mealings, K. T., Demuth, K., Buchholz, J. M., & Dillon, H. (under review). An assessment of open plan and enclosed classroom listening environments for young children: Part 2 – Teachers' questionnaires. *Journal of Educational, Pediatric & (Re)Habilitative Audiology*.

All components of this paper, both experimental and written, have been completed by me, with advice from the co-authors (my supervisors) when needed.

Abstract

Purpose: Recently open plan classrooms have been growing in popularity in primary schools. This paper is part of a two-part study that investigated how classroom noise affects teaching and learning in different types of open plan and enclosed classrooms. Part 1 of this research investigated Kindergarten children's perceptions. This study explored the teachers' perspectives.

Method: Sixteen Kindergarten and Year 1 teachers (four from enclosed classrooms, three from double classrooms, six from triple classrooms, and three from a Kindergarten-to-Year 6 classroom) completed a questionnaire about their teaching background and style, the demographics of the children in their class, how they perceive the classroom listening environment, what internal and external noise sources are present, how they cope with noise, and their perceptions of open plan versus enclosed classrooms.

Results: Teachers of larger classrooms (especially those that were not acoustically treated) were more distracted by noise and found speech communication significantly more difficult than the teachers of smaller classrooms. They also needed to elevate their voice and experienced vocal strain and voice problems more often.

Conclusions: These results suggest that noise is a problem particularly in large, untreated open plan classrooms, and it negatively impacts teachers. This suggests that smaller enclosed classrooms are more appropriate learning spaces for teachers of young children. Differences between the teacher's and children's perceptions of the classroom environments from Part 1 of this study are also discussed.

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An assessment of open plan and enclosed classroom listening environments for young

children: Part 2 - Teachers' questionnaires

Recently there has been a trend of building more 'open plan' work environments which have replaced smaller, traditional enclosed office spaces (Kaarlela-Tuomaala, Helenius, Keskinen, & Hongisto, 2009). This trend has also seen open plan classrooms growing in popularity, particularly in primary schools (Shield, Greenland, & Dockrell, 2010). This paper is the second part of two qualitative questionnaire studies that aimed to provide insight into the acoustic suitability of open plan learning spaces for listening activities. The first study investigated the Kindergarten children's perceptions of noise and its effect on learning in different types of classrooms. The current paper investigated how the teachers of these different types of classrooms perceive their teaching environment and compares this to the children's perceptions.

Open Plan Workspaces

Recently there has been growing evidence that the physical work environment influences both the workers' performance and their job satisfaction (see Vischer, 2007, for a review). According to Vischer (2007), ergonomic factors such as lighting, noise, and space affect people's ability to work. When these factors are not suitably considered in the workspace design, they can elevate stress amongst workers (McCoy & Evans, 2005). This stress can result in decreased performance, motivation, comfort, and social interaction (see McCoy & Evans, 2005, and Vischer, 2007, for reviews). Lately, there has been a trend of favouring open plan office spaces due to the belief that they promote cooperation, allow for better communication and feedback between workers, and encourage the sharing of knowledge (Kaarlela-Tuomaala et al., 2009). An additional motivation for constructing open plan offices is that they are less expensive to build than individual office rooms, and they allow for a higher worker density (Kaarlela-Tuomaala et al., 2009). However, studies have shown that noise can be a major problem in these spaces; noise is one of the most common reported annoyances amongst workers in open plan offices with increased distraction, concentration difficulties, lower work performance, and loss of job satisfaction being some of the main issues experienced by these workers (Kaarlela-Tuomaala et al., 2009; McCoy & Evans, 2005).

Alongside this emergence of open plan office spaces has been a re-emergence of open plan classrooms. Open plan classrooms first became popular during the educational reform in the 1960's and 1970's when traditional didactic-style teaching was replaced by a more 'childcentered' style (Brogden, 1983; see also Shield, Greenland, & Dockrell, 2010). However, because of noise and visual distraction, many of these classrooms were converted back to enclosed classrooms in the later decades of the 20th century (Shield et al., 2010). Nonetheless, the 21st century has seen a return to this child-centred educational philosophy and as a result, there is a current trend of again replacing enclosed classrooms with new open plan '21st century learning spaces' (Shield et al., 2010). These spaces are thought to better suit the range of activities and group work focus of this more child-centred teaching philosophy (Hickey & Forbes, 2011). They are also thought to aid the children's social development and make them take more responsibility for their work (Brogden, 1983; Hickey & Forbes, 2011). Additionally, like open plan offices, open plan classrooms are seen to benefit teachers as they promote the sharing of skills, ideas, and experiences (Brogden, 1983). They also allow for team-teaching, joint planning and organisation, provide access to a wide range of resources and equipment, allow teachers to share children, thereby reducing child-teacher personality clashes, and facilitate a more cooperative and supportive teaching and learning atmosphere (Brogden, 1983; Hickey & Forbes, 2011). Not all teachers have a positive experience in open plan environments, however. Similar to open plan offices, one of the main problems with open plan classrooms are the high noise levels. A recent study by Mealings, Buchholz, Demuth, & Dillon (2015) investigated the acoustics of four different types of classrooms: an enclosed classroom (with 25 children), a double classroom (with 44 children), an untreated, fully open plan triple classroom (with 91 children), and a Kindergarten-to-Year 6 (K-6), purpose-built semi-open plan '21st century learning space' (with 205 children). They found much higher intrusive noise levels coming from the other classes sharing the space in the triple classroom and the K-6 classroom
compared to the double and enclosed classroom. When all classes including the participating class were engaged in group work activities, however, the noise levels were excessive in all classroom types.

Effects of Noise on Teachers

Many research studies have shown the adverse impact of classroom and environmental noise on teachers' (and students') health; noise raises blood pressure, increases stress levels, causes headaches, and results in fatigue (see Anderson, 2001, and Shield et al., 2010, for a review of these studies). The high noise levels that are especially present in open plan classrooms can make the environment seem chaotic (Hickey & Forbes, 2011). This can result in teachers feeling distracted, anxious, and stressed (Hickey & Forbes, 2011). Additionally, teachers in any classroom are already prone to experiencing vocal strain from their constant vocal use; research shows that while only 5% of the general population experiences vocal fatigue, it is experienced by 80% of teachers (Gotaas & Starr, 1993). This puts them at high risk of vocal abuse and developing pathological vocal problems from the need to continually raise their voice above what is comfortable so they are heard (Gotaas & Starr, 1993; Smith, Gray, Dove, Kirchner, & Heras, 1997). Teachers in classrooms with poor acoustics are more likely to believe their job contributes to voice and throat problems and take sick days from work (MacKenzie & Airey, 1999; Smith et al., 1997). We would therefore expect vocal health problems to be a major issue for teachers in poorly designed open plan classrooms.

Results from Previous Studies Involving Teachers

A recent study by Greenland (2009) assessed 84 teachers' perceptions of semi-open plan classroom environments from 12 schools in the United Kingdom. In general, teachers agreed that open plan classrooms enabled a wider range of activities for the children than enclosed classrooms, and that children were more independent and responsible, and benefited socially from the more open plan space. However, the teachers also agreed that children in open plan classrooms were more easily distracted visually and by noise compared to children in enclosed classrooms. While noise from their own class was the most common reported noise source (reported by 83% of teachers), noise from other classes was reported by 62% of teachers as a dominant noise source and noise from other teachers was reported by 37% of teachers. Twenty-five percent of teachers reported that the noise from other classes was highly distracting. Teachers in classrooms with more than four class bases were significantly more distracted by noise and reported higher perceived noise levels than teachers in classrooms with less than four class bases. Ten percent of teachers reported that they frequently or more often experienced voice/throat problems. Grouping the class closely around them was the most frequently reported coping strategy which was used by nearly half the teachers.

Another study assessing teachers' perceptions of classroom environments involved 122 teachers from seven schools in Auckland, New Zealand (Wilson, 2002). Most of the teachers were from enclosed classrooms, but the acoustic quality of these classrooms varied widely. The results showed the recent shift in teaching from the traditional didactic style which only made up 12% of teaching time, to group work which made up 38% of teaching time. This shift is one of the reasons why open plan classrooms are becoming popular as they are thought to better facilitate group work activities than enclosed classrooms (Brogden, 1983; Shield et al., 2010). The majority of teachers (71%) tended to walk around the class when teaching rather than teaching from the front (approximately 45%). Noise, however, was still a major problem in these classrooms with 71% of teachers reporting inside noise problematic and 59% of teachers attributed this to the children. Forty-seven percent of teachers said that noise from other classes was problematic. Significantly more teachers from classes with poor acoustic ratings reported that they needed to raise their voice often or always (55%) and experienced vocal strain (41%). Group work required the highest vocal level with 49% of teachers needing to raise their voice during this teaching style which is concerning as this was the most frequent teaching style.

The results of these studies indicate that noise can problematic for teachers in both semiopen plan classrooms and enclosed classrooms. However, because different surveys were used for these studies and a broad range of classrooms were clustered together for each study, it is difficult to make direct comparisons across the classroom types to determine which classrooms provide better teaching environments. Additionally, these studies only report qualitative data from the teachers' perspectives. It has long been known that young children are more affected by poor room acoustics than adults (Nelson & Soli, 2000; Picard & Bradley, 2001; Prodi, Visentin, & Feletti, 2013). Many studies have shown that children find it more difficult discriminating and understanding speech than adults especially in noisy and/or reverberant environments (Crandell & Smaldino, 2000; Finitzo-Hieber & Tillman, 1978; Johnson, 2000; Leibold & Buss, 2013; Nelson & Soli, 2000; Nishi, Lewis, Hoover, Choi, & Stelmachowicz, 2010; Whitlock & Dodd, 2008). This is because children's auditory systems are still developing neurologically, so they cannot use top-down processes to aid speech perception as adults can (Boothroyd, 1997; Nelson & Soli, 2000; Wilson, 2002). This raises the importance of considering the children's perceptions of noise in the classroom as well as the teachers' perceptions. However, there have been no studies to our knowledge that directly compare teachers' and children's perceptions of classroom environments. Therefore, comparing the teachers' and children's perceptions in the present study would provide valuable insight as to whether particular classrooms are suitable for *both* the teachers and children to successfully work in.

Present Study

The purpose of the present study, therefore, was to directly compare how the teachers in the four different types of open plan and enclosed classrooms used in the classroom acoustics study by Mealings, Buchholz, et al. (2015) perceive their teaching environment using the same questionnaire and methodology across participants. Investigating the perceptions of the teachers is of vital importance as they are often not consulted in the decision-making process when classrooms are converted to open plan designs (Hickey & Forbes, 2011). Additionally, this paper compares the teachers' perceptions to the children's perceptions reported in Part 1 of this two-part study (Mealings, Dillon, Buchholz, & Demuth, in press). This is an important comparison as children struggle listening in noisy environments more than adults (see Nelson & Soli, 2000), so this needs to be taken into consideration when adults are designing classrooms. Therefore, the aim of the current paper was to answer the following research questions:

- 1) Do teachers of open plan classrooms spend more time in group work activities and less time out the front in didactic teaching than teachers in enclosed classrooms, as open plan classrooms are thought to better facilitate group work (Brogden, 1983; Shield et al., 2010)?
- 2) Do the teachers of noisier open plan classrooms rate their classroom listening environment poorer than teachers in the quieter enclosed classrooms?
- 3) What noise sources can the teachers hear inside and outside their classrooms and are these similar to those identified by the children in Part 1 of this study (Mealings et al., in press)? Furthermore, are the teachers of the noisier open plan classrooms more distracted by these noises?
- 4) Do the teachers of the noisier open plan classrooms find speech communication significantly more difficult and think their children have more difficulty hearing them than the teachers of quieter enclosed classrooms think their children do? Do these perceptions match those of the children measured in Part 1 of this study (Mealings et al., in press)?
- 5) What strategies do teachers use to cope with noise? Do the teachers of the noisier open plan classrooms need to elevate their voice and experience vocal strain and voice problems more often than the teachers in quieter classrooms?
- 6) Do the teachers of open plan classrooms agree more with the positive aspects and less with the negative aspects of open plan classrooms than teachers in enclosed classrooms? Do these perceptions depend on the acoustic conditions of the different types of classrooms?

Method

Schools Involved

Four schools were chosen to be involved in the study. These were the same schools that were involved in an acoustic measures study (Mealings, Buchholz, et al., 2015), a speech perception test study (Mealings, Demuth, Buchholz, & Dillon, 2015b) and the children's questionnaires in Part 1 of this two-part paper (Mealings et al., in press). The first school had two enclosed Kindergarten classroom and two enclosed Year 1 classrooms with approximately 25 children in each class. Three of the classroom walls were solid brick and one wall was a closed operable wall which had an open door storeroom that was shared with the adjacent class. The second school had a double Kindergarten classroom which consisted of 44 children divided into two classes with two teachers. The third school had an untreated fully open plan triple Kindergarten classroom and an untreated fully open plan triple Year 1 classroom. The Kindergarten classroom had 91 children divided into three classes with three teachers and the Year 1 classroom had 83 children divided into three classes with three teachers. The fourth school consisted of one purpose-built '21st century learning space' that contained Kindergartento-Year 6 (i.e. 205 children in total split into 7 classes). This included one Kindergarten class with 29 children and one Year 1 class with 21 children. Both of these classes were located in a semi-open plan area (i.e. only one open wall). More details on the classrooms can be found in Part 1 of this study (Mealings et al., in press) and the classroom acoustics study by Mealings, Buchholz, et al. (2015).

Participants

The Kindergarten teachers of the children who had completed the children's questionnaires in Part 1 of this study (Mealings et al., in press) were invited to participate in the present study. In order to increase participant numbers, we also invited the Year 1 teachers to participate that had classrooms very similar to the Kindergarten classrooms tested. Sixteen out of 18 teachers invited became involved in the study: four from the school with enclosed classrooms (two Kindergarten teachers and two Year 1 teachers), three from the school with a

double classroom (two permanent Kindergarten teachers and one relief Kindergarten teacher), six from the school with triple classrooms (three Kindergarten teachers and three Year 1 teachers), and three from the K-6 school (one Kindergarten teacher and two part-time Year 1 teachers). All teachers were female. Details on the teachers and children are found in Table 1 along with the average noise levels and average unoccupied reverberation times recorded in the Kindergarten classrooms by Mealings, Buchholz, et al. (2015).

Classroom	room Teachers			Children			Acoustics			
	Number of	Years	Years	Total	Average	Average number		Noise level		Average
	participants	taught in	taught in	number	number in each	with special	All classes	Adjacent	All classes	unoccupied
		enclosed	open plan	in area	Kindergarten/	educational needs	unoccupied	classes	occupied	reverberation
		classrooms	classrooms		Year 1 class	in each	(dBA)	occupied	during	time (s)
						Kindergarten/		(dBA)	group work	
						Year 1 class			(dBA)	
Enclosed	4	3-7	0-1	25	25	6 ESL	41.8	43.1-48.8	71.0*	0.50
		<i>M</i> = 4.50	<i>M</i> = 0.25							
Double	3	5-10	1-3	44	22	1 learning disability	36.7	46.0-50.3*	69.7*	0.60*
		<i>M</i> = 7.67	<i>M</i> = 2.00							
Triple	6	0-5	0.5-5	91	30	21 ESL + 3	36.0	57.5*-62.1*	67.7*	0.70*
		<i>M</i> = 1.75	<i>M</i> = 2.25			learning disability				
K-6	3	0-15	1.5-15	205	25	2 ESL	46.3*	60.5*	72.4*	0.58*
		<i>M</i> = 5.33	<i>M</i> = 7.50							

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Note. * indicates unoccupied noise levels are outside 35-45 dBA limit (Australia/New Zealand Standard, 2000), occupied noise levels are outside of the maximum 50 dBA recommended level (Berg, Blair, & Benson, 1996) and/or reverberation time is outside 0.4-0.5 s limit (Australia/New Zealand Standard, 2000). These acoustic measurements are from the Kindergarten classrooms as found in Mealings, Buchholz, et al. (2015).

Questionnaire Design

The teachers' questionnaire was based on those used in similar studies (Greenland, 2009; Wilson, 2002) and consisted of the following eight sections:

- (i) Teaching background: Consisted of the questions shown Table1.
- (ii) Teaching style: Investigated teaching methods, use of the space, and how teachers use their voice. These questions involved ticking a box or writing a short answer.
- (iii) Room characteristics: Investigated what aspects teachers find important in classrooms, and how they perceive the listening environment. These questions involved tick-a-box answers and ranking options from most important to least important.
- (iv) Noise sources inside: Asked teachers to identify problematic internal sounds via tick-abox methods.
- (v) Noise sources outside: Asked teachers to identify problematic external sounds via ticka-box methods.
- (vi) Coping with noise: Investigated ease of speech communication in the classroom, what the worst noise sources were, and what methods the teachers use to overcome noise.Involved ticking boxes or choosing responses on a seven point Likert scale.
- (vii) Demographics of children in their class: Included questions about the number of children in the teacher's class and if any have hearing impairments, ESL, or learning disabilities (see Table 1).
- (viii) Perceptions of open plan versus enclosed classrooms: Asked teachers to rate how much they agree with general statements about open plan classes on a five point Likert scale from "strongly disagree" to "strongly agree". The statements were those used by Greenland (2009) which were based on a questionnaire developed by Bennett, Andreae, and Hegarty (1980).

Questionnaire Procedure

The questionnaires were distributed to each of the teachers before any of the testing in the classrooms that was part of this project took place. The teachers were given a consent form and information sheet outlining the project approved by Macquarie University ethics. The information sheet explained that the aim of the study was to "find out how the acoustics of open plan versus enclosed classrooms affect primary school children's ability to hear and learn from their teachers". The researcher also gave a brief summary verbally to each of the teachers and asked them if they had any questions. The teachers were asked to complete the questionnaire (which took less than 10 minutes) in their own time. The questionnaires were collected after a fortnight. On return of the survey, each teacher received a small gift as a thank you for their time.

Results

Teaching Style

The main teaching position for the surveyed teachers was walking around the classroom which was also found in the study of teachers in enclosed classrooms by Wilson (2002). This was the case for all surveyed Kindergarten/Year 1 teachers from enclosed and double classrooms. Two of the three surveyed teachers from the K-6 classroom reported that they usually walked around when teaching while the other teacher reported teaching mainly from the centre of the class. In the triple classrooms, three of the six teachers said their usual teaching position was walking around the classroom, two teachers said they mainly taught from the front of the room, and one teacher reported usually teaching from the centre of the classroom.

Figure 1 shows the average percentage of time Kindergarten/Year 1 teachers spend in different teaching styles for each classroom. Interestingly, the teachers of the larger open plan classrooms (i.e. the triple and K-6 classrooms) spent less time in group work than the teachers of the enclosed and double classrooms, despite the belief that open plan classrooms better facilitate group work (Brogden, 1983; Shield et al., 2010). The teachers in the large open plan classrooms, however, spent roughly an equal amount of time in each of the different teaching styles rather than favouring group work. While Figure 1 averages the teaching time over the Kindergarten and Year 1 teachers, it was interesting to note that the Kindergarten teachers in

the triple classroom spent 40% of their time in didactic-style teaching but then this dropped to 10% for the Year 1 teachers.



Figure 1: Average percentage of time teachers spend in different teaching styles by school. "Other" includes team teaching and teaching a small group separately. Error bars show range.

Room Characteristics

The participating teachers were asked to rank different aspects (lighting, ventilation, acoustics, equipment, and space) of their classroom from 1 (most important) to 5 (least important). The acoustics of the classroom was given the highest average rank in the K-6 classroom, the second highest rank after space in the double and triple classrooms, and the lowest rank in the enclosed classrooms.

The teachers were also asked to choose which descriptors (comfortable, clear, relaxing, confusing, echoes, harsh, irritating, or specify their own) represented their perceptions and experiences in their classroom. All teachers from enclosed classrooms said that the environment was comfortable (although it could be noisy at times). Two out of three teachers from double classrooms said that the environment was comfortable but the other teacher said it was

distracting. In contrast, five of the six teachers from the triple classrooms found the environment confusing and four of the six teachers said the classroom echoed. Two out of three teachers from the K-6 classroom said that the environment was comfortable, but one teacher said it echoed and was harsh.

Additionally, the teachers were asked to rate the classroom listening environment overall where 1 = very poor, 2 = poor, 3 = acceptable, 4 = good, 5 = very good (see Table 2). Interestingly, the best average rating was by the teachers of the double classroom (average rating of 4.3 = good to very good) despite it having some of the highest percentages of children who said they could not hear their teacher very well or at all, especially when the adjacent class was being noisy (Mealings et al., in press). The average ratings of the enclosed classrooms (4 = good) and triple classrooms (2.5 = poor to acceptable) were generally in consensus with the acoustics of the classrooms (Mealings, Buchholz, et al., 2015; see also Table 1) and the children's perceptions (Mealings et al., in press). Again, the triple classrooms had the worst report of the schools with four of the six teachers surveyed (i.e. 67%) rating the listening environment as poor which is well above an acceptable proportion of 32% (see Shield, Greenland, Dockrell, & Rigby, 2008). All of these teachers said that this was because the classrooms were open plan. Three of the four teachers said it was also because of the noise levels, and one of the teachers said it was also because it echoed. Interestingly, the teachers in the K-6 classroom thought their classroom was an acceptable listening environment (i.e. average rating of 3), however, the results from the classroom's acoustic measures (see Table 1) and children's questionnaires suggested noise is a problem (Mealings, Buchholz, et al., 2015; Mealings et al., in press).

Classroom	Pe	Average rating				
	1	2	3	4	5	
	Very Poor	Poor	Acceptable	Good	Very Good	
Enclosed	0	0	0	100% (4/4)	0	4
						Good
Double	0	0	0	67% (2/3)	33% (1/3)	4.3
						Good to very good
Triple	0	67% (4/6)	17% (1/6)	17% (1/6)	0	2.5
						Poor to acceptable
K-6	0	0	100% (3/3)	0	0	3
						Acceptable

Table 2: Teachers' ratings of their classroom listening environment.

Noise Sources Inside

In this section of the questionnaire, the teachers were asked whether they thought noise from inside the classroom was a problem. If so, they were asked to identify what noise sources they heard in the classroom and what proportion of noise was student generated. Three out of four teachers from enclosed classrooms, two out of three teachers from the double classroom, five out of six teachers from triple classrooms, and all three the teachers surveyed from the K-6 classroom believed internal noise was problematic. Three teachers from enclosed classrooms and two teachers from the double classroom thought that most of this noise was student generated. In the triple classrooms, three out of five teachers thought most internal noise was student generated while the other two thought only some of it was. For the K-6 classroom, one teacher thought most of this noise sources the teachers found problematic are shown in Table 3. The noise sources the teachers identified were a close match to those identified by the children in each of the classrooms (Mealings et al., in press). Noise from air-conditioning units and equipment were also recognized by Mealings, Buchholz, et al. (2015) as contributors to the high unoccupied ambient noise levels in the enclosed and K-6 classrooms.

Classroom	Percentage/proportion of teachers reporting noise source problematic						atic
	Air-	Equipment	Lights	Other	Other	Children	Traffic
	conditioning			teachers	classes	outside	
	units						
Enclosed	75% (3/4)	0	0	50%	25%	25%	25%
				(2/4)	(1/4)	(1/4)	(1/4)
Double	0	0	0	66%	0	33%	0
				(2/3)		(1/3)	
Triple	50% (3/6)	33% (2/6)	0	83%	83%	67%	17%
				(5/6)	(5/6)	(4/6)	(1/6)
K-6	33% (1/3)	33% (1/3)	0	0	33%	33%	0
					(2/3)	(1/3)	

Table 3: Teachers' report of problematic internal and external noise sources.

Figure 2 shows what noise source the teachers reported as the most intrusive. All teachers chose either the children of other classes or the children of their own class. These were also the two main noise sources reported by teachers in semi-open plan classrooms in the study by Greenland (2009). Surprisingly, all of the teachers in the K-6 classroom reported that the children in their own class was the most intrusive noise rather than the children in the other classes despite this classroom reporting some of the highest intrusive noise levels from the other classes sharing the area (Mealings, Buchholz, et al., 2015; see also Table 1). Interestingly, however, the teacher percentages for the other classrooms followed a trend. As the number of children in the entire area increased, so did the percentage of teachers who reported other children as the most intrusive noise. Furthermore, as the number of children in the entire area decreased, the percentage of teachers who reported the children in their own class as the most intrusive noise increased. Noise from children in other classes was also the most frequently

reported noise source heard by the children in these classes and the proportion of children reporting this also increased as class size increased (Mealings et al., in press).



Figure 2: Teachers' report of what they find the most intrusive noise in the classroom.

Noise Sources Outside

The teachers were asked whether they thought noise from outside the classroom was a problem and if so, what noises they could hear. One out of four teachers from the enclosed classrooms, one out of three teachers from the double classroom, five out of six teachers from the triple classrooms, and two out of three teachers from the K-6 classroom believed external noise was problematic. The specific noise sources the teachers found problematic are also shown in Table 3. The most intrusive outside noise reported by the teachers was children outside for the enclosed, double, and K-6 classrooms, which supports the findings from the children's questionnaires (Mealings et al., in press). Other noise sources identified by teachers of the enclosed and triple classrooms included noise from children in other classes and noise from traffic which largely agree with the noise sources identified by the children in these classrooms (Mealings et al., in press).

The teachers were also asked whether internal or external noises were the most problematic, or if noise was not a problem when teaching in the classroom. In the enclosed classrooms, two teachers believed inside noise was the most problematic while the other two did not believe noise was a problem. One teacher from the double classroom reported outside noise the most problematic whereas the other two did not believe noise was a problem. Three out of six teachers from the triple classrooms reported inside noise the most problematic whereas the other three reported outside noise was. In the K-6 classroom, two out of three teachers thought inside noise was the most problematic noise while the other teacher thought outside noise was. Additionally, the teachers were asked to rate how distracting they find inside and outside noise. As shown in Table 4, there was lots of variability in the teachers' ratings, but the general trend was that the teachers of the triple and K-6 open plan classrooms found both inside and outside noise more distracting than the teachers of the enclosed and double classrooms.

Classroom	Teacher ratings								
		Inside noise	;	Outside noise					
	Mean	Range	SD	Mean	Range	SD			
Enclosed	3.50	1-5	1.91	2.50	1-5	1.91			
<i>n</i> = 4									
Double	2.67	2-3	0.58	1.67	1-3	1.15			
<i>n</i> = 3									
Triple	5.33	4-6	0.55	4.33	2-6	1.63			
<i>n</i> = 6									
K-6	4.33	3-6	1.52	4.00	1-6	2.65			
<i>n</i> = 3									

The teachers also rated whether they thought eliminating or reducing internal and external noises was unimportant, not very important, important, or critical for the children. All four teachers from enclosed classrooms believed it was important to eliminate noise. Only one teacher in the double classroom thought it was important to eliminate or reduce noise in the classroom. The other two teachers said it was not very important which is concerning as this classroom had some of the poorest ratings of how well the children reported they could hear their teacher, particularly when the adjacent class was being noisy (Mealings et al., in press). Three of the six teachers surveyed from the triple classrooms thought it was critical to eliminate noise and the other three teachers thought it was important. All three teachers in the K-6 classroom believed it was important to eliminate noise.

Speech Communication in the Classroom

The teachers were asked if they thought the children in their class had difficulty hearing them, and if the acoustics of their classroom had a direct effect on the children's learning. None of the teachers in the enclosed or double classrooms believed the children in their class had difficulty hearing them. It is important to note, however, that although none of the teachers from the double classroom thought their children had difficulty hearing them, the children's questionnaire results (Mealings et al., in press) revealed that 39% of children surveyed could not hear their teacher very well or at all when the other Kindergarten class was working at their tables, 70% of children could not hear their teacher very well or at all when the other Kindergarten class was engaged in group work that involved movement, and 43% of children could not hear their teacher very well or at all when their own class was being noisy. Each of these proportions is above an acceptable rate of 32% (see Shield et al., 2008). In contrast, all of the teachers from the triple classrooms believed that the acoustics had a direct effect on the children's learning. Additionally, all teachers from the triple classrooms believed that the children in their class had difficultly hearing them, with three of six teachers saying this was irrespective of where they stood. This is consistent with the children's perceptions as unacceptable proportions of children (i.e. 56-60%, which is over the acceptable proportion of 32% used by Shield et al., 2008) reported that they could not hear their teacher very well or at all when other classes or their own class was being noisy (Mealings et al., in press). In the K-6 classroom, all teachers believed that the children had difficulty hearing them, which was also revealed in the children's questionnaires, indicating that noise is perceived as a problem in this classroom (which is also shown objectively by the noise levels in Table 1).

Figure 3 shows the teachers' average ratings of how easy they find speech communication in the classroom for different scenarios. The trend shows that the teachers of the two larger classrooms (i.e. the triple and K-6 classrooms) found speech communication more difficult in each scenario compared to the teachers of the smaller enclosed and double classrooms. Figure 4 also combines the three teaching scenarios to give an overall average rating of ease of speech communication in the classroom. A Kruskal Wallis test revealed a statistically significant difference between the classroom types H(3) = 14.01, p = .003. A posthoc test using Mann-Whitney U tests with Bonferroni correction p < .05/6 = .0083 showed

speech communication in the enclosed classrooms was significantly easier than in the triple classrooms U = 40.00, Z = -2.97, p = .003, r = 0.43 and K-6 classroom U = 15.50, Z = -2.97, p = .004, r = 0.43.



Figure 3: Teachers' average ratings of ease of speech communication for different scenarios and the overall average rating (1 = very difficult, 7 = very easy). Error bars show range for the separate scenarios and standard error of the mean for the overall average. Brackets show significance at *p < .05/6 = .0083.

Coping With Noise

Figure 4 shows the actions teachers take to cope with noise in the classroom. All teachers reported using at least one strategy rather than taking no action. The actions taken included raising their voice, gathering the class close around them, arranging a compatible activity schedule with other teachers, changing the seating arrangement, stopping or changing the teaching activity, and using visual cues for attention. It was positive that the teachers in the K-6 classroom used many different strategies to cope with the high noise levels in their classroom rather than always raising their voice. It is concerning, however, that all teachers in the triple classrooms raised their voice to cope with noise. These teachers were also using other

coping strategies, but unfortunately they were not effective enough for the teachers to not have to raise their voice as well.



Figure 4: Actions teachers take to cope with noise in the classroom. "Other" includes ringing a bell to get the class's attention, using a traffic light noise scale, rewarding children for quiet voices, and gaining the class's attention to remind them to work more quietly.

Figure 5A shows the average percentage of teachers who reported that they needed to elevate their voice to be heard clearly for different teaching styles. All of the teachers in the two triple and K-6 open plan classrooms reported that they needed to elevate their voice during group work, compared to only 50% or less of the teachers in smaller enclosed and double classrooms. This figure for the enclosed and double classrooms is similar to the percentage reported by Wilson (2002) for teachers in enclosed classrooms.

Figure 5B shows the average ratings of how often teachers needed to raise their voice overall when teaching, and how often they experienced vocal problems. The surveyed teachers from the triple classrooms had to elevate their voice often, and also experienced vocal problems more than teachers in the other classrooms. All six teachers surveyed from this school reported that the level they needed to speak at strained their voice. This contrasts with the responses of the teachers in the enclosed and double classrooms; none of these teachers reported that the level they usually spoke at strained their voice and none of the teachers surveyed in the enclosed classrooms had ever experienced voice problems. Finally, the responses from the teachers in the K-6 classroom were in between those from the enclosed, double, and triple classrooms. Only one of the three teachers in this classroom experienced vocal problems, so it is likely that the acoustic treatment and semi-open plan style is beneficial for the teachers compared to the fully open plan non-treated triple classrooms.



Figure 5A: Percentage of teachers reporting they needed to elevate their voice to be heard clearly for different teaching styles. "Other" includes when trying to get children to stop a group activity or trying to control children while moving between learning spaces. *Figure 5B:* Average ratings of how often teachers needed to raise their voice overall and how

often they experienced vocal problems (1 = never, 2 = sometimes, 3 = often, 4 = always).

Error bars show range.

Perceptions of Open Plan versus Enclosed Classrooms

Teachers were asked to rate how strongly they agree or disagree (on a five point Likert scale) with the following statements about open plan classrooms compared with enclosed classrooms. The statements were those used by Greenland (2009) which were based on a questionnaire developed by Bennett, Andreae, and Hegarty (1980). For clarity, the statements

below are organized so statements 1-9 are the positive statements about open plan classrooms and statements 10-12 are the negative statements. Note, however, that these were randomized for the questionnaire.

- 1) The environment provides for a wide range of activities
- 2) The children are more independent and responsible
- 3) Standards of work tend to be higher
- 4) Children benefit socially
- 5) There is greater continuity for students
- 6) There is better pastoral care for students
- 7) Teachers feel more confident
- 8) The environment facilitates better student supervision
- 9) The environment makes students feel more secure
- 10) Children are more easily distracted by noise
- 11) Children are more easily visually distracted
- 12) There are discipline problems

Figure 6 collapses these results into the positive compared to negative statements about open plan classrooms. A Kruskal Wallis test revealed a statistically significant difference between classrooms for their agreement on positive statements about open plan classrooms H(3) = 33.97, p < .0005. Post-hoc Mann-Whitney U tests with Bonferroni correction p = .05/6 = .0083 showed the teachers of enclosed classrooms had significantly lower agreement with the positive statements about open plan classrooms compared to those teaching in them from the double U = 122.00, Z = -5.27, p < .0005, r = 0.66, triple U = 639.50, Z = -3.02, p < .003, r = 0.32, and K-6 classrooms U = 301.50, Z = -2.69, p = .007, r = 0.34. The teachers from the double classroom also had significantly better agreement on the positive open plan statements compared to the teachers of the triple classrooms U = 330.50, Z = -4.28, p < .0005, r = 0.48. No significant difference between schools was revealed for the negative statements about open plan classrooms H(3) = 7.74, p < .052.

A Wilcoxon signed-ranks test was run to determine significant differences between agreements on positive versus negative statements about open plan schools for each classroom type. The teachers of the double classroom agreed significantly more with the positive statements than with the negative statements which they generally disagreed with Z = -2.71, p = .007, r = 0.90. No significant difference was found for any of the other classrooms $Z_{enclosed} = -0.83$, p = .405; $Z_{triple} = -0.28$, p = .783; $Z_{K-6} = -0.53$, p = .595.



Figure 6: Mean ratings of teachers' opinions about positive and negative statements comparing open plan classrooms with enclosed classrooms where 1 = strongly disagree, 2 =disagree, 3 = neutral, 4 = agree, 5 = strongly agree. Error bars show standard error of the mean. Brackets and asterisks show significant differences at p < .05/6 = .0083.

Discussion

Recently open plan work spaces have been growing in popularity, which includes the re-emergence of open plan schools. This study investigated the teachers' perceptions of their classroom work environment in four different types of open plan/enclosed classrooms and compared these to the children's perceptions in Part 1 of this study (Mealings et al., in press).

The results of the teachers' questionnaires, like the children's questionnaires, showed that the main noise source heard in the classroom was child generated noise. In the enclosed classrooms, this was largely from children in the teacher's own class, while for the open plan classes (with the exception of the K-6 classroom) it was from children in the other classes sharing the same open plan area. Children outside, air-conditioning units, and equipment were other identified noise sources. The teachers in the triple and K-6 classrooms tended to find both inside and outside noise more distracting than the teachers in the enclosed and double classrooms. The teachers of the triple and K-6 classrooms also found speech communication significantly more difficult than the teachers in the enclosed and double classrooms, and all of the teachers surveyed from the triple and K-6 classrooms believed that the children had difficultly hearing them, whereas none of the teachers in the enclosed and double classrooms did. This is expected given the high intrusive noise levels from the adjacent classes in these open plan spaces (see Table 1) which require teachers to speak above a comfortable level to be heard (Mealings, Buchholz, et al., 2015).

Overall, the teachers of the K-6 classroom and even more so the untreated triple classrooms needed to elevate their voice more often than those in the enclosed and double classrooms and experienced vocal strain and voice problems more often. In response to this, these teachers tried to use other strategies to cope with noise including coordinating activities between classes (which minimizes intrusive noise if all classes are doing quiet critical listening activities at the same time) and using visual cues. All of the teachers in the double, triple, and K-6 classrooms also tried to group the children close to them when they were teaching. Grouping the class closer to them was the most common action taken by the teachers in the open plan classrooms. This is important as being far away from the teacher can be detrimental to the child's ability to hear and understand their teacher, especially in noisy conditions (Mealings, Demuth, Buchholz, & Dillon, 2015a; Mealings, Demuth, et al., 2015b).

It was positive that the teachers in the K-6 classroom used many different strategies to cope with the high noise levels in their classroom rather than always raising their voice.

Of most concern, however, were the responses from the teachers of the untreated fully open plan triple classrooms. Most teachers in these classrooms rated the listening environment as poor, and believed the children had difficultly hearing them. Despite using a range of other methods to cope with noise, the teachers still needed to raise their voice above a comfortable level to be heard and experienced vocal strain. This puts them at high risk of vocal abuse and developing pathological voice conditions (Gotaas & Starr, 1993; Smith et al., 1997).

The overall poor ratings of the listening environment from the teachers in the triple classrooms largely agreed with the children's perceptions of noise and their difficulty hearing their teacher. These poor ratings are even more concerning as this school has the largest proportion of children with special educational needs (see Table 1). These children are reported to be even more adversely affected by poor classroom acoustics so it is highly likely that they will struggle learning in this environment (MacKenzie & Airey, 1999; Nelson & Soli, 2000; Shield et al., 2010). Unfortunately, when the classrooms in this school were converted to open plan, no additional acoustic treatments were made. As a result, these classrooms have high noise levels and long reverberation times (Mealings, Buchholz, et al., 2015; see also Table 1). This is likely to explain why the teachers of this school struggled teaching in this environment and shows the impact of having poor classroom acoustics on the teachers and children. This suggests that this classroom should be acoustically modified to make speech communication easier. Furthermore, it is likely that improving the acoustic conditions in this classroom will help children to adequately progress in their education, and create a more positive environment for the teachers so they can teach more effectively. The K-6 classroom provides an example of a classroom that is still open plan, but has been purpose-built with some acoustic treatment and dividers between classes. This may explain why the teachers in this '21st century learning space' found the environment more acceptable than those in the triple classrooms. However, because it was still semi-open plan and had over 200 children sharing the area, it still had consistently

high noise levels (Mealings, Buchholz, et al., 2015; see also Table 1) which the teachers found problematic. As a result, some of the teachers still experienced vocal strain and believed the children had difficulty hearing them, which is consistent with the results of the children's questionnaires (Mealings et al., in press). Therefore, more acoustic modifications and better divisions between the classes would be beneficial to further reduce noise.

A positive finding of the study was that the teachers of the larger classrooms ranked the classroom's acoustics as being an important aspect of the learning space and thought that reducing or eliminating noise in the classroom was important for the children. It is likely that the low ranking from the teachers of enclosed classrooms is because the acoustics in the tested classroom were mostly acceptable (Mealings, Buchholz, et al., 2015). Therefore, the teachers may take the good acoustics for granted and not realize how detrimental poor acoustics can be on children's learning. Interestingly, however, two out of three teachers from the double classroom did not think noise was a problem, hence did not think it was important to reduce or eliminate it. The children in this classroom, however, thought very differently. Sixty-five percent of children found the noise from the children of the other class annoving, 43% found the noise from the teachers of the other class annoying, and 48% of found the noise from children outside annoying. These are all unacceptable proportions of children (i.e. over 32%) according to the dissatisfaction criterion used by Shield et al. (2008). Additionally, 70% of children said they could not hear their teacher very well or at all when the other class was doing group work that involved movement. This was the largest proportion of children of all the classrooms tested (Mealings et al., in press). This was also the only classroom type to have an unacceptable proportion of children who could not hear their classmates very well or at all when they were doing group work. Since this classroom had a smaller amount of space per child and a much smaller distance of only two meters between the classes compared to six to seven meters in the other open plan classrooms, it is likely that this close proximity combined with noise affects the children even more as the interfering speech would be intelligible. However, as shown by their greater agreement with the positive statements about open plan schools, the teachers of this school have very positive views about open plan learning spaces. The difference in the children's and teachers' perceptions about the listening environment show that we cannot rely completely on the teachers' perceptions as they may not accurately reflect how the children feel and how they cope with noise in the classroom. This is because children are more affected by poor acoustics than adults as their brain is neurologically immature (Boothroyd, 1997; Nelson & Soli, 2000; Wilson, 2002). Therefore, these findings emphasize the importance of considering children's perceptions and capabilities in the classrooms as well as the teachers' perceptions.

In contrast to the teachers of the open plan classrooms, all of the teachers surveyed from enclosed classrooms found the listening environments comfortable and none of the teachers had experienced vocal problems. This shows the benefit of having even just an operable wall between classes to minimize the intrusive noise from the adjacent class/es. However, even though intrusive noise from the other classes was minimized, the noise levels when their own class was engaged in group work were still excessive (Mealings, Buchholz, et al., 2015, see also Table 1). Most of the teachers reported that this noise was problematic, as did the children, with over half saying that they could not hear their teacher very well or at all during these noisy periods (Mealings et al., in press). Therefore, controlling noise during group work activities is still important in all types of classrooms.

One of the main reasons for having open plan classrooms is that they are thought to better facilitate group work (Brogden, 1983; Shield et al., 2010). However, it was interesting that the teachers in the two larger open plan classrooms only spent a third of their teaching time in group work compared to the teachers of the two smaller classroom types who spent 50-67% of time in group work activities. It is possible that the teachers of the larger open plan classes spend less time in these activities as they generate the most noise (Mealings, Buchholz, et al., 2015, see also Table 1) which makes listening difficult for both the children of that class and the other classes in the same area (Mealings et al., in press). Therefore, the benefit of having these classes which are designed to better facilitate group work also has the downfall that these activities produce high levels of noise. It was also interesting that the Kindergarten teachers of the triple classroom spent 40% of their teaching time in didactic-style teaching. This shows that didactic-style teaching can still be an essential way of teaching new concepts to young children especially when they are starting primary school. This further emphasizes the importance of having favourable acoustic conditions for these activities, which are hard to achieve in open plan classrooms (as shown in Table 1).

Overall, the results of these studies show the importance of having good acoustic conditions in classrooms. This is needed so young children can hear their teachers and classmates, but also to increase teachers' job performance and job satisfaction (McCoy & Evans, 2005; Vischer, 2007). The results suggest that the best classroom design is an enclosed classroom as it minimizes the intrusive noise from adjacent classes which is of vital importance when the children are engaged in critical listening activities. While a classroom with four solid fully enclosed walls is likely to provide the best listening environment, single classrooms with operable walls should provide adequate listening conditions the majority of the time. This type of classroom also gives the flexibility of opening the operable wall for the activities the teachers prefer to have a more open plan space for, but then closing it for critical listening activities to minimize intrusive noise and enhance speech perception. Having quiet rooms as suggested by Shield et al. (2010) is also a good idea so children who are more vulnerable to noise can work in those areas when needed.

Limitations of the Study and Future Directions

As this study compared the perceptions of teachers from four case study schools, it only allowed a relatively small number of participants to be involved for a questionnaire design. As a result, these findings need to be interpreted cautiously and not be overgeneralised. Therefore, it would be beneficial to examine a wider range of classrooms and group them together by type of design to provide more participants and hence more power for statistical analysis. This would allow us to draw more generalised conclusions about how teachers cope in different sized classrooms. It would also provide better information to help us understand how classrooms should be designed in order to maintain adequate speech perception and minimise vocal health problems for teachers.

Additionally, the results of this study show the importance of using multiple approaches when assessing the acoustics of classrooms to provide a more comprehensive view of the environment. In particular, the results of this two-part study also show the importance of considering how the *children* perceive and learn in the classroom environment, as teacher perceptions may not always accurately reflect that of the child. It is especially important to be aware of this in regard to new, innovative teaching methods which may excite the teacher but may not be beneficial for the child. Therefore, future research that examines the suitability of different types of classrooms needs to take into account the perspectives of the different people using the classroom in addition to the physical acoustic conditions and how they affect speech perception. Hopefully, with careful consideration of these results and the results of future studies, classrooms in the future will be designed with appropriate acoustics to enhance children's learning and improve teachers' vocal health and wellbeing.

Conclusion

The results of this study showed that teachers of the larger classrooms (especially those that were fully open plan and not acoustically treated) were more distracted by noise and found speech communication significantly more difficult than the teachers of the smaller classrooms. The teachers of the larger classrooms also thought their students had more difficulty hearing them than the teachers of the smaller classrooms thought their children did. These teachers also needed to elevate their voice and experienced vocal strain and voice problems more often. While the teachers in the K-6 classroom (which had been purpose-built with some acoustic treatment and dividers between classes) found the environment more acceptable than those in the triple classrooms, noise levels could still be problematic as reported by the teachers and children. These results suggest that noise is a problem particularly in large open plan classrooms, and it negatively impacts teachers. This suggests that smaller enclosed classrooms, or at least classrooms that have the flexibility to be enclosed for critical listening activities, are

more appropriate learning spaces both for the teacher's vocal health and for enhancing young children's learning.

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Appendix

Classroom Acoustics Study: Teacher's Questionnaire

Date: Name: Your School: Your Class: Age range of students in your class: Number of students in your class:

1.0 Educational and Teaching Background

1.1 What is your age?

21-25	36-45	56-60
26-35	46-55	60+

1.2 How long have you been qualified as a teacher?

Less than 2 years	5-10 years
2-5 years	10+ years

1.3 How long have you been teaching at this school?

Less than 1 year	5-10 years
1-5 years	10+ years

1.4 How many years teaching experience do you have in: Traditional enclosed classrooms _____ years Open plan classrooms _____ years

2.0 Teaching Style

2.1 Approximately what percentage of time do you spend teaching in the following styles?

- □ Didactic (teaching from the front of the class)
- □ Children working at their tables
- Group work with children moving around the class
- □ Other (please specify) _____
- 2.2 In what situations do you find it necessary to elevate your voice to be heard clearly?
 - \Box Didactic (teaching from the front of the class)
 - \Box Children working at their tables
 - \Box Group work with children moving around the class
 - □ Other (please specify) _____

2.3 How often is it necessary for you to elev	vate your voice to be heard clearly?
\Box Never \Box Sometimes	\Box Often \Box Always
2.4 Does the level at which you need to spe	ak seem to strain your voice?
\Box Yes \Box N	0
2.5 Do you ever suffer from voice or throat	problems?
\Box Never \Box Sometimes	\Box Often \Box Always
2.6 Do you think students have difficulty be	paring you?
\Box Yes \Box N	0
2.6.1 If was from where in the alassnoom	de students seem te have most difficultu
hearing you?	do students seem to have most difficulty
□ Difficult everywhere	
\Box Near the teacher	
\Box Far from the teacher	
\Box In the centre of the room	
\Box Near the back	
\Box At the sides	
2.7 Where is your usual position in the class	s?
\Box At the centre	
\Box At the front	
\Box Walking around	
2.8 Do you have a sound field amplification	system in your classroom?
□ Yes	□ No
2.8.1 If yes, how often do you use it?	
\Box Never \Box Sometimes	□ Often □ Always
2.9 Do you have the use of a quiet room?2.9.1 If yes, how often do you use it?	\Box Yes \Box No
□ Never	
□ Very occasionally	
\Box Once a week	
\Box Several times a week	
□ Every day	
- 2.10 Do you think the acoustics of your classroom have a direct effect on the student's learning ability?
 - □ Yes □ No

3.0 Room Characteristics

3.1 Rank the following aspects of your classroom from 1 (being most important) to 5 (being the least important).

Lighting	
Ventilation	
Acoustics (Listening environment)	
Equipment	
Sufficient room space	

- 3.2 How do you experience the listening environment in the classroom? (Please choose all the words that best describe your present room).
 - \Box Comfortable
 - \Box Confusing
 - \Box Echoes
 - □ Harsh
 - □ Clear
 - □ Irritating
 - □ Relaxing
 - □ Other (please specify)

3.3 How do you rate your classroom listening environment?

- \Box Very good
- \Box Good
- □ Acceptable
- □ Poor
- \Box Very poor
- 3.3.1 If you answered "poor" or "very poor", why do you think that it is hard for students to hear well in your classroom?
 - \Box Open plan style room
 - \Box Too much echo in room
 - \Box Too much noise from outside room
 - $\hfill\square$ Too much noise from students in the room
 - □ Other (please specify) _____

- 4.0 Noise Sources: Inside the Classroom
 - 4.1 Do you have any problems with noise created inside the classroom? (This includes the noise of students in your class or those from other classes in the room for open plan shared class spaces).
 - \Box Yes
- \Box No (Go to section 5)
- 4.2 What proportion of noise generated inside the classroom is student generated?
 - \Box None
 - \Box Some
 - □ Most
 - \Box All

4.3 Please identify all other sources of noise inside the classroom?

- \Box Teachers from other classes in the same open plan space
- □ Air Conditioning/Heaters/Fans
- □ Equipment (e.g. computers, fish tank, clocks)
- \Box Lights
- □ Other (please specify)

4.4 What is the most intrusive noise? (Select one only)

- \Box Students in your class
- $\hfill\square$ Students from other classes in the same open plan space
- \Box Teachers from other classes in the same open plan space
- □ Air Conditioning/Heaters/Fans
- □ Equipment (e.g. computers, fish tank, clocks)
- \Box Lights
- □ Other (please specify) _____

5.0 Noise Sources: Outside the Classroom

- 5.1 Do you have any problems with outside noise entering your classroom (this includes noise from adjacent rooms)?
 - \Box Yes \Box No (Go to section 6)
- 5.2 What are the sources of the outside noise?
 - \Box Traffic/industrial noise
 - $\hfill\square$ Noise from other classrooms
 - $\hfill\square$ Noise from children in the corridors or playground
 - □ Other (please specify) _____

- 5.3 What is the most intrusive noise? (Select one only)
 - □ Traffic/industrial noise
 - \Box Noise from other classrooms
 - □ Noise from children in the corridors or playground
 - □ Other (please specify) _____

6.0 Coping with Noise

- 6.1 How important do you think it is to eliminate or reduce internal and external noises for the students?
 - \Box Critical
 - □ Important
 - □ Not very important
 - □ Unimportant
- 6.2 Which is the worse source of noise problems for you?
 - \Box Noise made inside the classroom
 - \Box Noise coming into the classroom from outside?
 - \Box Noise is not a problem

6.3 How distracting is noise intruding from:

No	ot at al	1				E	xtremel	y
Inside the classroom	1	2	3	4	5	6	7	
Outside the classroom	1	2	3	4	5	6	7	

- 6.4 What do you do to cope with noise?
 - \Box Raise your voice
 - \Box Gather the class close around you
 - \Box Arrange a compatible activity schedule with other teachers
 - \Box Change the seating arrangement
 - \Box Stop or change the teaching activity
 - \Box Use visual clues for attention
 - \Box No particular action
 - □ Other (please specify)_____
- 6.5 How easy do you find speech communication with children in the following situations?

Very Difficult						Very Easy		
Talking individually	1	2	3	4	5	6	7	
Addressing small groups	1	2	3	4	5	6	7	
Addressing whole class	1	2	3	4	5	6	7	
		000						

7.0 Children in Your Class

7.1 How many children are there in your class?
 7.2 How many students have a hearing impairment? 7.3 How many wear: Hearing aid/s Cochlear implant/s 7.4 How easy is it for hearing impaired students to hear you? Very Difficult Very Easy 1 2 3 4 5 6 7.5 Do the hearing impaired students use an FM system? Yes No 7.5.1 How often do they use an FM system? Never Sometimes Often Always 7.6 How many children in your class have English as their second language? 7.7 How many children in your class have a learning disability? (Please specify disability and number of children)
 7.3 How many wear: Hearing aid/s Cochlear implant/s 7.4 How easy is it for hearing impaired students to hear you? Very Difficult Very Easy 1 2 3 4 5 6 7 7.5 Do the hearing impaired students use an FM system? Yes No 7.5.1 How often do they use an FM system? Never Sometimes Often Always 7.6 How many children in your class have English as their second language? 7.7 How many children in your class have a learning disability? (Please specify disability and number of children)
Hearing aid/s Cochlear implant/s 7.4 How easy is it for hearing impaired students to hear you? Very Difficult Very Easy 1 2 3 4 5 6 7 7.5 Do the hearing impaired students use an FM system? Inclusion No 7.5.1 How often do they use an FM system? Inclusion Never Sometimes Inclusion Always 7.6 How many children in your class have English as their second language?
7.4 How easy is it for hearing impaired students to hear you? Very Difficult Very Easy 1 2 3 4 5 6 7 7.5 Do the hearing impaired students use an FM system? Impaired students use an FM system? Impaired students use an FM system? Impaired Students use an FM system? Impaired Sometimes Impaired Sometimes Impaired Students 7.5.1 How often do they use an FM system? Impaired Sometimes Impaired Students Impaired Students 7.6 How many children in your class have English as their second language?
Very Difficult Very Easy 1 2 3 4 5 6 7 7.5 Do the hearing impaired students use an FM system? Impaired No Impaired No 9 Yes Impaired No Impaired No 7.5.1 How often do they use an FM system? Impaired Never Impaired No 7.6 How many children in your class have English as their second language? 7.7 How many children in your class have a learning disability? (Please specify disability and number of children)
1 2 3 4 5 6 7 7.5 Do the hearing impaired students use an FM system? □ No □ Yes □ No 7.5.1 How often do they use an FM system? □ Often □ □ Never □ Sometimes □ Often □ 7.6 How many children in your class have English as their second language?
 7.5 Do the hearing impaired students use an FM system? Yes No 7.5.1 How often do they use an FM system? Never Sometimes Often Always 7.6 How many children in your class have English as their second language? 7.7 How many children in your class have a learning disability? (Please specify disability and number of children)
 ☐ Yes ☐ No 7.5.1 How often do they use an FM system? ☐ Never ☐ Sometimes ☐ Often ☐ Always 7.6 How many children in your class have English as their second language? _ 7.7 How many children in your class have a learning disability? (Please specify disability and number of children)
 7.5.1 How often do they use an FM system? Never Sometimes Often Always 7.6 How many children in your class have English as their second language? 7.7 How many children in your class have a learning disability? (Please specify disability and number of children)
 Never Sometimes Often Always 7.6 How many children in your class have English as their second language? 7.7 How many children in your class have a learning disability? (Please specify disability and number of children)
 7.6 How many children in your class have English as their second language? 7.7 How many children in your class have a learning disability? (Please specify disability and number of children)
7.7 How many children in your class have a learning disability? (Please specify disability and number of children)
•

8.0 Perceptions of open plan verses enclosed classrooms

8.1 Please read each of the following statements about open plan classrooms compared with enclosed classrooms, and indicate how strongly you agree or disagree with them.

Statement: In an open plan school	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The environment provides for a wide range of activities					
The children are more independent and responsible					
Standards of work tend to be higher					
Children are more easily distracted by					
noise					
Children are more easily visually					
distracted					
Children benefit socially					
There is greater continuity for					
students					
There are discipline problems					
There is better pastoral care for					
students					
Teachers feel more confident					
The environment facilitates better					
student supervision					
The environment makes students feel					
more secure					

9.0 Further Information

Please feel free to comment further in the space provided or with attached documentation.

THANK YOU FOR TAKING THE TIME TO COMPLETE THIS QUESTIONNAIRE!

Please return by _____ to:

Miss Kiri Mealings Level 3 Australian Hearing Hub 16 University Avenue Macquarie University NSW 2101 Australia

Email: <u>kiri.mealings@students.mq.edu.au</u> Phone: +61 (0)2 9850 2936

Questionnaires are adapted from:

Greenland, E. (2009). Acoustics of open plan classrooms in primary schools. Ph.D. thesis, London South Bank University, London, UK.

- Wilson, O. (2002). Classroom acoustics: A New Zealand perspective. Wellington: The Oticon Foundation.
- 10.0 Office Use Only:
 - 10.1 Design
 - \Box Fully open plan
 - \Box Fully open plan with quiet rooms
 - \Box Semi open plan
 - \Box Full height walls
 - □ Partial height walls
 - \Box Semi open plan with enclosed rooms off main space
 - □ Flexible open plan (use of sliding partitions)
 - $\hfill\square$ Traditional enclosed classroom
 - □ Other _____
 - 10.2 Number of classes in unit

10.3 Total number of children in unit

CHAPTER 7: GENERAL DISCUSSION AND CONCLUSIONS

The aim of this thesis was to provide an in depth view of the acoustic environments of different types of open plan/enclosed classrooms and analyse whether they are appropriate listening environments for young children and teachers. This thesis presented the results of four case study schools found in Sydney, Australia: an enclosed classroom with 25 children, a double classroom with 44 children, an untreated linear fully open plan triple classroom with 91 children, and a purpose-built semi-open plan Kindergarten-to-Year-6 '21st century learning space' with 205 children. Most of the previous research into open plan classrooms was conducted in the 1970's and mainly focused on the acoustics of the room. Therefore, this research investigated some of the new '21st century learning spaces' to determine whether modern designs and advanced acoustic treatments have made these spaces more usable than those from the 1960's and 1970's.

Additionally, this thesis provided a more in depth approach of assessment rather than focusing solely on measuring the acoustic parameters in the classrooms. This more in depth approach included both *objective quantitative* studies and *subjective qualitative* studies. The *objective quantitative* studies measured the acoustics of the classrooms (Chapter 2) and the children's performance on a speech perception test I developed which was conducted live in the classrooms while adjacent classes engaged in quiet versus noisy activities (Chapters 3 and 4). Chapter 2 found much higher intrusive noise levels in the two largest open plan classrooms, resulting in signal-to-noise ratios (SNRs) and speech transmission index (STI) scores to be well below those recommended in classrooms with students of this age. Additionally, occupied background noise levels when the class was engaged in group work were well above recommended levels in all classrooms. Chapter 4 found that higher noise levels resulted in a decrease in the children's speech perception accuracy and speed, especially for those seated towards the back of the class when the noise level was above the recommended 50 dBA (Berg, Blair, & Benson, 1996).

The *subjective qualitative* studies of this thesis investigated how the children and teachers perceive their listening environments via questionnaires (Chapters 5 and 6). Chapter

5 revealed that most children were annoyed by the noise from other children/teachers, and believed it significantly affected how well they could hear their teacher, especially in the open plan classrooms with only a small distance between class bases. Children in all classrooms also reported difficulty hearing their teacher when their own class was noisy. These results correlated well with the acoustics of the classrooms measured in Chapter 2 and the children's performance on the speech perception test in Chapter 4. Furthermore, this chapter confirmed that the general classroom acoustic limits recommended in the literature need to be met for children to be able to hear their teacher "well" in the classroom. Chapter 6 showed that teachers in larger open plan classrooms (and especially those in the untreated triple classrooms) were more distracted by noise and found speech communication significantly more difficult than the teachers in the smaller classrooms. They also needed to elevate their voice and experienced vocal strain and voice problems more often.

In light of these results, the rest of this chapter will discuss the appropriateness of each classroom listening environment as well as the overall conclusions that can be drawn from the results of these studies. The chapter concludes with the limitations of this research and suggestions for future research.

Conclusions for Each Classroom

Enclosed classroom. This classroom provided the best listening environment of all of the classrooms tested in this study. It had the most favourable acoustic conditions and the children in this classroom had the highest speech perception scores as it was able to achieve the quietest environment. All of the teachers surveyed from this type of enclosed classroom found the listening environment comfortable and none of the teachers had experienced vocal problems. This shows the benefit of having even just a concertina wall between classes to minimise the intrusive noise from adjacent class/es. The main downfall of this classroom, however, was that the shared store room doors with the adjacent class were kept open. This became particularly problematic when the adjacent class was engaged in very noisy activities as the sound transmitted through to this classroom. This resulted in speech perception scores for the children seated in the mid-to-back regions to be below the 71% needed for children to rate they can hear their teacher "well" (see Chapters 4 and 5). Additionally, 33% of children reported that they could not hear their teacher very well or at all during these noisy periods. Shutting these shared store room doors would be an easy solution that would minimise this sound transmission and enhance the children's ability to perceive speech clearly. However, even though the intrusive noise from adjacent classes can be minimised in enclosed classrooms, the noise levels when their own class is engaged in group work may still be excessive as found in this study. Most of the teachers also reported that this noise was problematic, as did the children, with over half saying that they could not hear their teacher very well or at all during these noisy periods. Therefore, controlling noise during group work activities is still important in this type of classroom. Installing acoustic treatment in these classrooms would also help minimise the effect of this noise (Siebein, Gold, Siebein, & Ermann, 2000).

Double classroom. The acoustics measured in this classroom were mostly reasonable and the children's average speech perception scores remained above 71% (corresponding to children being able to hear their teacher "well") when the adjacent class was quiet. However, the children's speech perception scores did drop for those seated in the mid-to-back regions when the other class was engaged in noisier activities. This suggests that a double classroom is only sufficient for speech communication when the other class is quiet, which will not often be practical given 67% of the teachers' teaching time is spent in group work activities (Chapter 6). Additionally, there was a large disparity between the teachers' and children's perception of noise in this classroom. The teachers did not think that noise was a problem, but 70% of children found it difficult to hear their teacher when the other Kindergarten class was being noisy and 43% of children found it difficult to hear their classmates when their own class was engaged in group work activities. These were the highest proportions of all the classrooms tested. It is expected that the close 2 m proximity of the two classes in this classroom contributed to these high dissatisfaction proportions as the speech from the other

class is likely to be intelligible, hence more distracting. Therefore, future research is needed to determine if sufficient separation distance between class bases in a double classroom can minimise the noise distraction from the other class enough to provide adequate speech perception. Acoustic treatment in these classrooms would also help minimise the effect of the noise and bring the reverberation time down to be within the 0.4-0.5 s AS/NZS2107:2000 limit (Australia/New Zealand Standard, 2000; Siebein et al., 2000).

Triple classroom. This classroom provided the poorest acoustic environment of all of the classrooms tested. This classroom was converted to a fully open plan triple classroom by removing the existing walls between three classes without making additional acoustic modifications to compensate for the increased room volume and increased number of children in the same area. As a result, the classroom had long reverberation times and experienced high noise levels even when the other classes were engaged in only quiet activities. The children in this classroom had the worst speech perception scores and slowest response times of all the classrooms involved in this study as a result of having some of the highest noise levels. The children seated towards the back of this class were particularly disadvantaged - their speech perception scores averaged only 25% when the adjacent classes were engaged in noisy activities. These results are especially concerning as this school had the largest proportion of children with special educational needs who are reported to be even more adversely affected by poor classroom acoustics (MacKenzie & Airey, 1999; Nelson & Soli, 2000; Shield et al., 2010). The teachers in this classroom also really struggled in this environment with many of them experiencing vocal health problems from the need to constantly raise their voice above a comfortable level to be heard. This was despite using several other strategies to try to cope with the noise. These results strongly suggest that this type of classroom is not an appropriate learning environment because of the adverse effects the poor acoustics have on both the children and teachers.

K-6 classroom. The K-6 classroom provided an example of a classroom that had been purpose-built as a new '21st century open plan learning space' rather than removing walls

between existing classrooms. Despite this classroom reporting high noise levels in Chapter 2, the children's performance on the speech perception test (Chapter 4) was surprisingly high. The Kindergarten class was located in the corner of the room with a semi-open plan style (i.e. only one open wall), so the extra barriers may have helped remove some of the visual distraction as well as providing some acoustic shielding. It was also equipped with pin boards and other furnishings for sound absorption which helped reduce reverberation and hence the effect of noise, as noise and reverberation combine synergistically to mask speech (Crandell & Smaldino, 2000; Klatte et al., 2010). This contrasts with the double and triple classrooms where walls had been knocked down between the existing classrooms with no proper acoustic modifications put in place to help reduce reverberation and noise. The K-6 classroom also had the greatest separation between classes. This means that speech coming from the children in other classes is likely to be less intelligible/distracting, which may explain why less children had difficulty hearing their teacher when the other classes were being noisy compared to the double and triple classrooms. The children in this classroom also had higher speech perception scores and quicker response times compared to the children in the triple classroom, despite this classroom having over twice the number of children. This suggests that the new architectural style of the '21 century learning spaces' are an improvement on the open plan classrooms that simply put classrooms together by removing walls. This may also explain why the teachers in this school found the environment more acceptable than those in the untreated fully open plan triple classrooms. However, because it was still open plan and had over 200 children sharing the area, it still had constantly high noise levels above the recommended 50 dBA limit (Berg et al., 1996). This resulted in speech perception scores below the 71% needed for children to rate they can hear their teacher "well" for those children seated in the mid-to-back regions. The teachers also found these noise levels problematic and, as a result, some still experienced vocal strain. Additionally, all teachers believed the children had difficulty hearing them, which the children also reported in their questionnaires. Therefore, concertina walls that can be closed between classes during critical listening

activities would be beneficial to further reduce noise in this classroom. This classroom also reported high ambient noise levels, most likely from the heating, ventilation, and air-conditioning units. The problem with high ambient noise levels is that speakers need to raise their voice more to be heard above these levels due to the Lombard Effect (Whitlock & Dodd, 2008). This results in higher and higher noise levels with each additional sound source (Whitlock & Dodd, 2008). Therefore, it would be beneficial to install a system with a low noise rating to minimise this source of noise.

Overall Conclusions and Implications

The results of this thesis show that the noise levels from adjacent classes in the open plan classrooms tested are excessive and significantly reduce the children's ability to hear and comprehend their teacher. The high noise levels also adversely impact the teachers by making speech communication more difficult which results in more frequent vocal health problems compared to the teachers of enclosed classrooms. Although the K-6 '21st century learning space' did provide a better listening environment than the classrooms that added rooms together, the results still suggest that open plan classrooms that are unable to keep the noise from adjacent classes below 50 dBA are not appropriate learning environments for critical listening activities with young children. Therefore, if open plan classrooms are strongly desired, they need to be acoustically built as *flexible* learning spaces. That is, they should have acoustic operable walls that can stay open for group work and other activities that benefit from an open plan space, but can be closed for critical listening activities. This will create an acceptable environment like the enclosed classroom tested, and it is expected that it will still be acceptable even if the other classes are engaged in noisy activities provided there are no other sound transmission channels like the open shared store room doors. (Note, however, that it would still be beneficial for teachers to try to coordinate critical listening activities across classes when possible to minimise noise disturbance during these times.) Additionally, the equipment and heating, ventilation, and air-conditions systems installed in these (and all) classrooms should have low noise ratings to minimise ambient noise. It is also vital that these classrooms have proper acoustic treatment fitted to reduce reverberation times and hence the effect of the classroom noise (Siebein et al., 2000). Furthermore, it would be beneficial for these classrooms to be designed in a semi-open plan style to provide additional acoustic shielding and remove some of the visual distraction. There should also be at least 6.5 m between class base openings to minimise noise transmission (Greenland, 2009) and reduce the intelligibility of the intruding speech. Quiet rooms are also essential in these classrooms so children who have particular difficulty working in noisy conditions can quietly work away from the other children. Additionally, teachers need to be trained how to teach effectively in these environments so they know what activities are suitable for different learning spaces and how to look after their vocal health. There is, however, always going to be a trade-off between the positive effects of open plan classrooms with the negative effects of the noise levels. It is therefore important to remember that acoustically treated enclosed classrooms are likely to provide the best listening environments.

The findings of this research have major implications for educational institutions, principals, teachers, students, parents, clinicians, architects, builders, acoustic engineers, and, most importantly, policy makers. Studies have shown that children who have been in classrooms with poor acoustics have lower literacy and numeracy skills, are less productive in the workforce, and tend to be in lower paid jobs than those who were from classrooms with good acoustics (Anderson, 2001; James, Stead, Clifton-brown, & Scott, 2012). Ensuring classrooms have good acoustics is therefore vital for increasing children's future opportunities. Australia (like many other countries) currently has recommended acoustic standards for ambient noise levels and reverberation times in unoccupied classrooms as outlined in the Australia/New Zealand Standard (2000) *AS/NZS2107:2000, "Acoustics - Recommended design sound levels and reverberation times for building interiors"*. However, these standards are only recommended, not enforced. Additionally, these standards are only for unoccupied classrooms. As demonstrated in Chapter 2, the unoccupied ambient noise levels may be acceptable in open plan classrooms (and possibly even better than in enclosed

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classrooms as found for the double and triple classrooms), but this does not tell us much about how children perceive speech when the classes are occupied. It is when the children are in the classroom and engaged in their normal activities that we see the major problem with open plan classrooms that is missed if only unoccupied measurements are taken into consideration. There are currently no national recommendations in any country for occupied classrooms in regard to the noise levels, SNRs, and STI scores, despite the recommendations found in the literature (e.g. Berg, Blair, & Benson, 1996; Crandell & Smaldino, 2000; Greenland & Shield, 2011). The results of my research show that these unoccupied classroom standards and occupied classroom recommendations need to be met for children to be able to hear their teacher "well". Therefore, it may be beneficial for Australia (and other countries) to enforce the Australia/New Zealand Acoustics Standards (2000) for unoccupied classrooms and the recommended acoustic limits for occupied classrooms found in the literature referenced above and calculated in my research (see Chapter 5). It may also be worthwhile to develop and enforce criteria for classroom designs to ensure all classrooms meet these standards so children are comfortable and able to learn effectively in every educational setting. There also needs to be more emphasis placed on educating teachers about the importance of having good classroom acoustics and controlling noise. It may be beneficial for classrooms to have noise level monitors so teachers can keep the noise levels below 50 dBA. This will help ensure that children can perceive their teacher's speech clearly throughout the classroom without teachers having to risk their vocal health.

Study Limitations and Future Directions

This thesis provided case study examples assessing the appropriateness of four different sized Kindergarten classrooms as listening environments. The advantage of designing this series of studies using case studies is that it allowed an in depth view of each different classroom environment from different perspectives. The main limitation of this, however, is that it only involved four schools, and hence a relatively small number of participants especially for the questionnaires. Therefore, a large-scale investigation is needed

to assess exactly what classroom types are suitable learning spaces for Kindergarten children and children at different ages. It is essential for this research to be conducted in a wide range of open plan and enclosed classrooms to assess which designs are appropriate in order to meet the acoustic conditions recommended in the literature and calculated in Chapter 5. This research needs to include an investigation into what classroom designs and configurations work, what acoustic treatment is needed, what the maximum number of children and classes in an area should be, and what distance is required between different groups to minimise noise levels and ensure adequate speech perception in the learning environment. Acoustic modelling can also be used for designing new classrooms or determining the treatment needed for existing classrooms so they achieve these acceptable conditions. In this research, it would be beneficial to include fully enclosed classrooms with acoustic treatment as the enclosed classroom used in this thesis had an open shared storeroom door and a concertina/operable wall. This type of classrooms, but it would be interesting to investigate the benefit that a fully enclosed classroom with acoustic treatment may have for the children and teachers.

It is important that this future research takes multiple approaches to assess the appropriateness of the classroom listening environments. The research needs to include both *objective quantitative* measurements of the classroom's acoustics and how this affects speech perception, as well as *subjective qualitative* measurements that take into account the opinions of the teachers and children in the classroom. Teachers also need to be educated about the importance of having good acoustic conditions in classrooms and understand what they can do to control noise in classrooms. This includes closing doors and windows, turning off equipment when not in use, and monitoring the children's noise levels, as failing to take these measures will defeat the purpose of having acoustically treated classrooms.

In addition, it would be worthwhile to further investigate children's habituation to noise. This may help explain why the children in the K-6 classroom performed surprisingly well on the speech perception test in Chapter 4 as this classroom had consistently high noise levels throughout the day rather than the fluctuating noise levels found in the other classrooms. It would also be interesting to examine how length of time spent in the learning environment affects children's speech perception abilities and teachers' and children's perceptions of noise. This research could include comparisons of the children's and teachers' responses an results at the start of school year versus end of school year, or longitudinally over school grades. Furthermore, it would be beneficial to test children's speech perception and distraction from noise in different types of noise maskers such as intelligible versus non-intelligible speech, and noise at different distances from the child. This would help provide insight into why the children in the double classroom (which only had a small distance between class bases) reported being more affected by noise then the children in the larger classrooms even though they had higher noise levels. Additionally, it would valuable to investigate visual distraction in open plan classrooms. This thesis focused mainly on the acoustic distraction, so it would be interesting to tease apart how much distraction in the classroom is visual compared to acoustic, and examine the affect that these individual components have on the children and teachers.

Furthermore, we also need to better understand how children who have special educational needs, such as attention deficits, hearing impairments, auditory processing disorders, language delays and English as a second language (ESL) cope in these environments as they are more commonly being integrated into mainstream classes and are likely to be even more affected by classroom noise (Nelson & Soli, 2000). Once this research has been conducted it may be worthwhile for Australia (and other countries) to implement recommendations or restrictions for classroom acoustics and classroom design so speech perception is not compromised in the educational setting for any child. Hopefully, with careful consideration and dissemination of these results, classrooms in the future will be designed with appropriate acoustics to enhance children's learning and improve teachers' vocal health and wellbeing.

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Additionally, it would be beneficial to extend this research into day care centres and preschools where children below the age of five can spend up to 10 hours per day. These younger years are vital for children's language development so it is imperative that these spaces are built with good acoustics (Manlove, Frank, & Vernon-Feagans, 2001). This is especially important as these centres are prone to very high noise levels due to the young age of the children and the focus on play-like activities (see Manlove et al., 2001 and Picard & Bradley, 2001, for reviews). Furthermore, these spaces are often built with hard, sound reflecting surfaces and have few soft furnishings for hygiene reasons which exacerbate the noise problem. They also often have kitchen facilities and outside play areas which further add to the noise levels (Nixon, 2003). As a result, it can be very hard for children to perceive speech clearly and converse with other children and adults. This can be frustrating for the children and lead them to either withdrawing from using language, or displaying poor behaviour, which further increases the noise levels (Manlove et al., 2001; Nixon, 2003). Additionally, similar to school teachers, the workers in these centres are likely to be at risk of experiencing stress, fatigue, and vocal health problems. Therefore, it is essential for research to be conducted in these spaces so acoustical design criteria can also be developed and enforced in preschools and day care centres. This, in conjunction with enforced criteria for classroom design, will help ensure children develop the literacy, numeracy, and other diverse skills needed for their educational progression and future life opportunities.

Finally, it would be worthwhile to continue to refine the MDDB Classroom Speech Perception Test and evaluate its effectiveness and validity through psychometric testing and test-retest reliability with different populations. Through examination of these results, it would also be possible to further understand the effect of different vowel and consonant saliencies on children's speech perception in different types of noise and classroom environments. This refinement would help strengthen this test and make it possible to be used as a standard measure and useful tool to assess speech perception in the classroom and examine the suitability of different learning environments.

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Approved- Ethics application- Demuth (Ref No: 5201300038)

Ethics Secretariat <ethics.secretariat@mq.edu.au>

Mon, Mar 4, 2013 at 4:03 PM

To: Professor Katherine Demuth <katherine.demuth@mq.edu.au> Cc: Miss Aleisha Claire Davis <Aleisha.Davis@mq.edu.au>, Miss Kiri Trengove Mealings <kiri.mealings@students.mq.edu.au>, Dr Harvey Dillon <harvey.dillon@nal.gov.au>, Dr Jorg M Buchholz <jorg.buchholz@mq.edu.au>

Dear Professor Demuth

Re: "An investigation into the effects of classroom acoustics on speech perception and production in children with hearing impairments" (Ethics Ref: 5201300038)

Thank you for your recent correspondence. Your response has addressed the issues raised by the Human Research Ethics Committee and you may now commence your research.

This research meets the requirements of the National Statement on Ethical Conduct in Human Research (2007). The National Statement is available at the following web site:

http://www.nhmrc.gov.au/ files nhmrc/publications/attachments/e72.pdf.

The following personnel are authorised to conduct this research:

Dr Harvey Dillon Dr Jorg M Buchholz Miss Aleisha Claire Davis Miss Kiri Trengove Mealings Professor Katherine Demuth

NB. STUDENTS: IT IS YOUR RESPONSIBILITY TO KEEP A COPY OF THIS APPROVAL EMAIL TO SUBMIT WITH YOUR THESIS.

Please note the following standard requirements of approval:

1. The approval of this project is conditional upon your continuing compliance with the National Statement on Ethical Conduct in Human Research (2007).

2. Approval will be for a period of five (5) years subject to the provision of annual reports.

Progress Report 1 Due: 04 March 2014 Progress Report 2 Due: 04 March 2015 Progress Report 3 Due: 04 March 2016 Progress Report 4 Due: 04 March 2017 Final Report Due: 04 March 2018

NB. If you complete the work earlier than you had planned you must submit a Final Report as soon as the work is completed. If the project has been discontinued or not commenced for any reason, you are also required to submit a Final Report for the project.

Progress reports and Final Reports are available at the following website:

http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/ human_research_ethics/forms

3. If the project has run for more than five (5) years you cannot renew approval for the project. You will need to complete and submit a Final Report and submit a new application for the project. (The five year limit on renewal of approvals allows the Committee to fully re-review research in an environment where legislation, guidelines and requirements are continually changing, for example, new child protection and privacy laws).

4. All amendments to the project must be reviewed and approved by the Committee before implementation. Please complete and submit a Request for Amendment Form available at the following website:

http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/ human_research_ethics/forms

5. Please notify the Committee immediately in the event of any adverse effects on participants or of any unforeseen events that affect the continued ethical acceptability of the project.

6. At all times you are responsible for the ethical conduct of your research in accordance with the guidelines established by the University. This information is available at the following websites:

http://www.mq.edu.au/policy/

http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/ human_research_ethics/policy

If you will be applying for or have applied for internal or external funding for the above project it is your responsibility to provide the Macquarie University's Research Grants Management Assistant with a copy of this email as soon as possible. Internal and External funding agencies will not be informed that you have final approval for your project and funds will not be released until the Research Grants Management Assistant has received a copy of this email.

Please retain a copy of this email as this is your official notification of final ethics approval.

Yours sincerely Dr Karolyn White Director of Research Ethics Chair, Human Research Ethics Committee