An Assessment of Open Plan and Enclosed Classroom Listening Environments for Young Children: Part 1 – Children's Questionnaires

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Purpose: **Open plan classrooms, where several classes share the same area, have recently re-emerged 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 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".**

Introduction

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 that investigated (1) 5- to 6-year-old Kindergarten children's perceptions of how noise affects their ability to hear their teacher/classmates and (2) 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' that 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 was 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-centered educational philosophy again being favored (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 to make the children take more responsibility for 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 because the high levels of background noise have a "negative impact on the learning process and tend 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 sound-reflecting 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 that 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 > 0.75 for 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 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, however, reported hearing their teacher better than children in any of the open plan 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:

1) 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 School website http://www.myschool.edu.au.) 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).

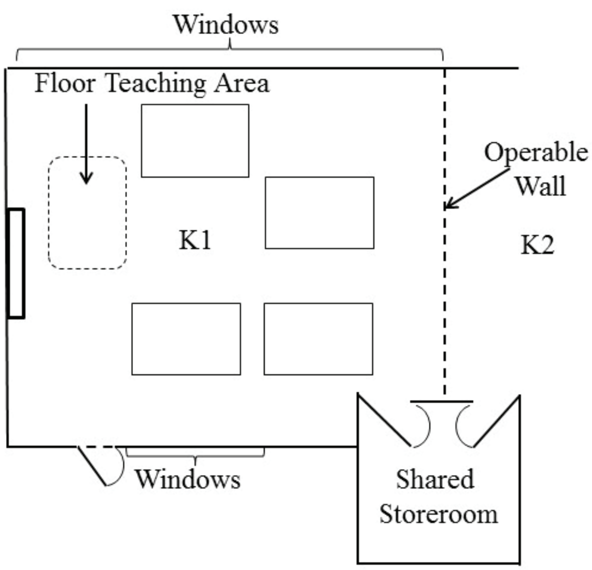

Figure 1. Floor plan of the enclosed classroom with 25 children.

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).

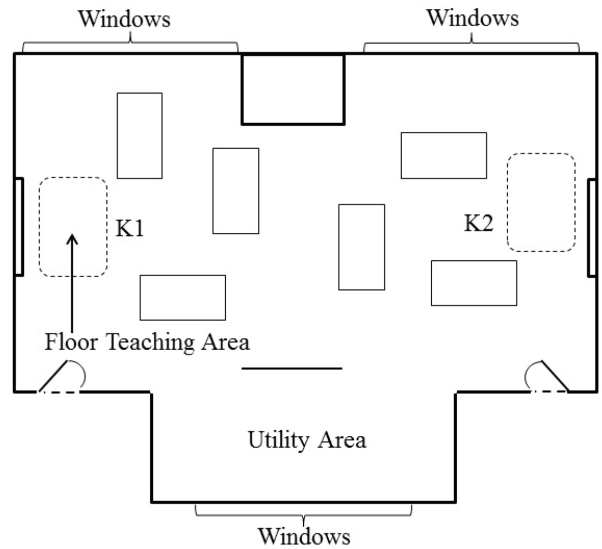

Figure 2. Floor plan of the double classroom with 44 children.

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).

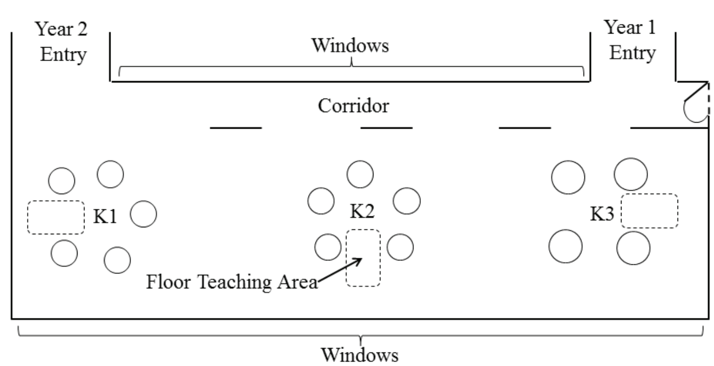

Figure 3. Floor plan of the triple classroom with 91 children.

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.

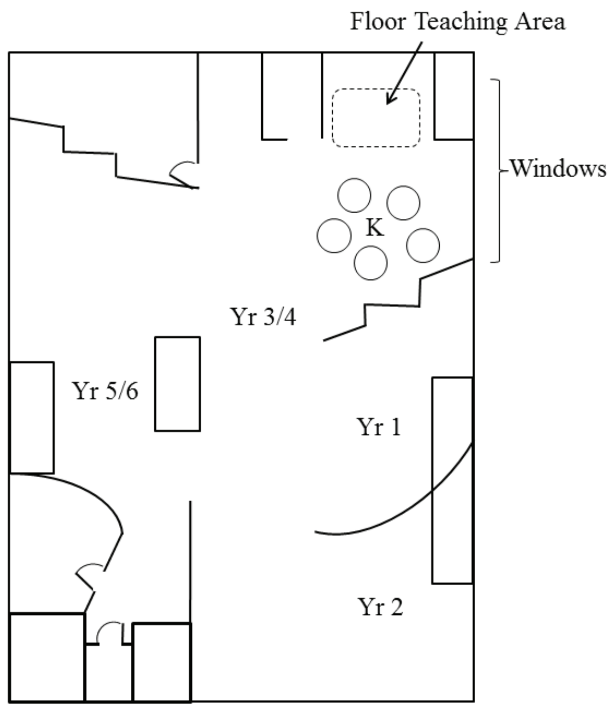

Figure 4. Floor plan of the K-6 classroom with 205 children.

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

	Enclosed Classroom	Double Classroom	Triple Classroom	K-6 Classroom
Total number of students in area	25	44	91	205
School's ICSEA	1141	1133	1035	1090
Classroom type	Enclosed classroom with shared concertina wall	Fully open double classroom	Linear, fully open plan classroom	Semi-open plan classroom
Class grades in area	Kindergarten (5- to 6-year-olds)	Kindergarten (5- to 6-year-olds)	Kindergarten (5- to 6-year-olds)	Kindergarten to Year 6 (5- to 12-year-olds)
Number of class bases in area	1	2	3	5-7 (depending on activity)
Number of students in each class base	25	21-23	30-31	30-50
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 class bases (m)	N/A	2	6	7
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 2. *Average noise levels, signal-noise ratios (SNRs), speech transmission index (STI) scores and MDDB Classroom Speech Perception Test scores in each classroom during different scenarios (see also Mealings, Buchholz, et al., 2015; Mealings, Demuth, et al., 2015b).*

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

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.

Table 3. *Demographic information for participating children.*

Classroom	Number of participants	Number of males/females	Age range and mean	Number who have ESL	Number who have attended preschool	Average time spent in preschool (years, hours per week)
Enclosed	24	14M; 10F	5;1-6;3 *M* = 5;6	13	23	2.4, 23
Double	23	12M; 11F	5;1-6;3 *M* = 5;5	0	20	2.7, 18
Triple	25	11M; 14F	5;1-6;3 *M* = 5;6	12 (+ 4 multilingual)	23	2.3, 21
K-6	23	13M; 10F	4;11-6;1 *M* = 5;7	4 (+ 7 multilingual)	22	2.6, 22

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. 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 ($N = 24$)	Double ($N = 23$)	Triple ($N = 25$)	K-6 ($N = 23$)
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.

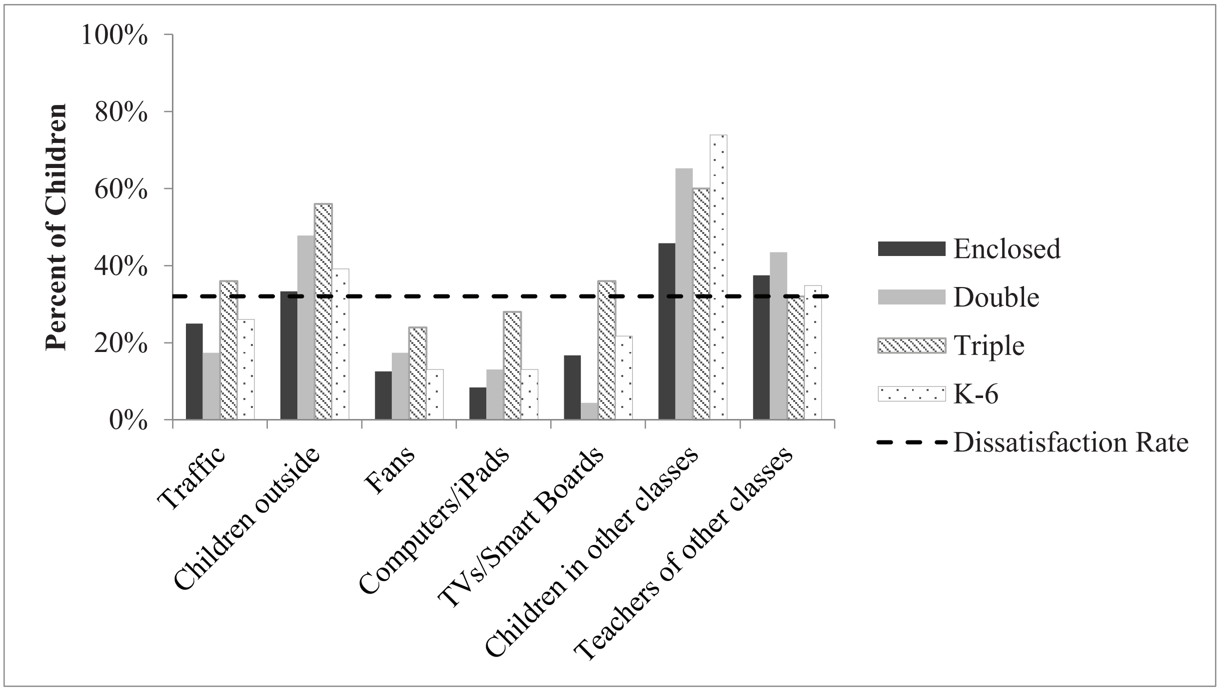

Figure 5. Percentage of children reporting annoyance of different sound sources for each classroom type. The dissatisfaction criterion is set at 32%.

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 $\chi2(3, N = 95)_{traffic} = 2.18$, $p = .54$; $\chi2(3, N = 95)_{children\ outside} = 2.92$, $p = .40$; $\chi2(3, N = 95)_{fans} = 1.48$, $p = .69$; $\chi2(3, N = 95)_{computers/iPads} = 4.07$, $p = .25$; $\chi2(3, N = 95)_{TVs/Smart\ Boards} = 7.73$, $p = .05$; $\chi2(3, N = 95)_{children\ in\ other\ classes} = 4.12$, $p = .25$; $\chi2(3, N = 95)_{other\ teachers} = 0.73$, $p = .87$.

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 $\chi2(4) = 121.44$, $p < .001$. 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 that involved movement or when their own class was noisy compared to the other three listening scenarios $Z_{outside\ noise\ vs.\ moving} = -4.03$, $p < .001$, $r = 0.41$; $Z_{tables\ vs.\ moving} = -3.91$, $p < .001$, $r = 0.40$; $Z_{all\ classes\ quiet\ vs.\ moving} = -7.53$, $p < .001$, $r = 0.77$; $Z_{outside\ noise\ vs.\ own\ class\ noisy} = -3.74$, $p < .001$, $r = 0.38$; $Z_{tables\ vs.\ own\ class\ noisy} = -3.87$, $p < .001$, $r = 0.40$; $Z_{all\ classes\ quiet\ vs.\ own\ class\ noisy} = -7.52$, $p < .001$, $r = 0.77$. Hearing ratings were also significantly poorer when other classes were working at their tables or there was outside noise compared to when all classes were quiet $Z_{tables\ vs.\ quiet} = -6.80$, $p < .001$, $r = 0.70$; $Z_{outside\ noise\ vs.\ quiet} = -5.62$, $p < .001$, $r = 0.58$. 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.

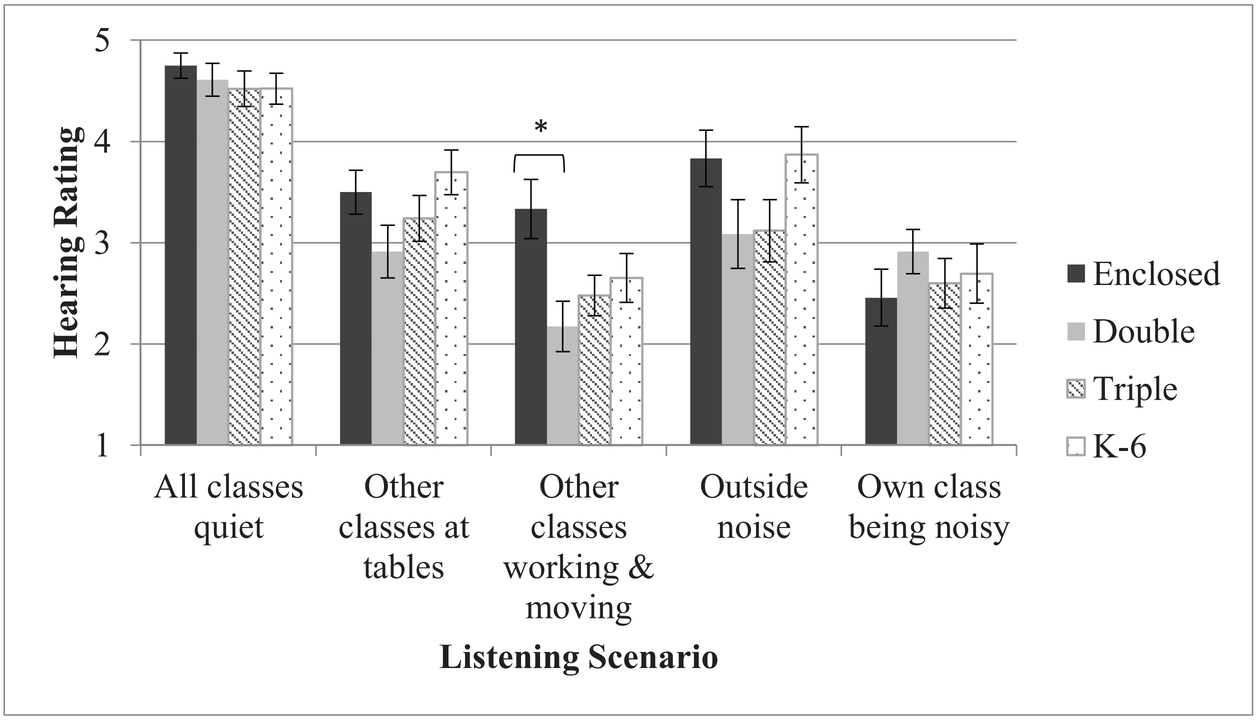

Figure 6. Mean hearing ratings for different listening scenarios by classroom type (1 = not at all, 2 = not very well, 3 = ok, 4 = well, and 5 = very well). Error bars show the standard error of the mean. $^*p = .05/6 = .0083$.

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 $\chi 2(3, N = 95)_{\text{all classes quiet}} = 0.99$, $p = .80$; $\chi 2(3, N = 95)_{\text{tables}} = 6.31$, $p = .10$; $\chi 2(3, N = 95)_{\text{moving}} = 6.75$, $p = .08$; $\chi 2(3, N = 95)_{\text{outside noise}} = 5.81$, $p = .12$; $\chi 2(3, N = 95)_{\text{teacher's face hidden}} = 2.40$, $p = .49$; $\chi 2(3, N = 95)_{\text{own class noisy}} = 1.80$, $p = .62$, 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.

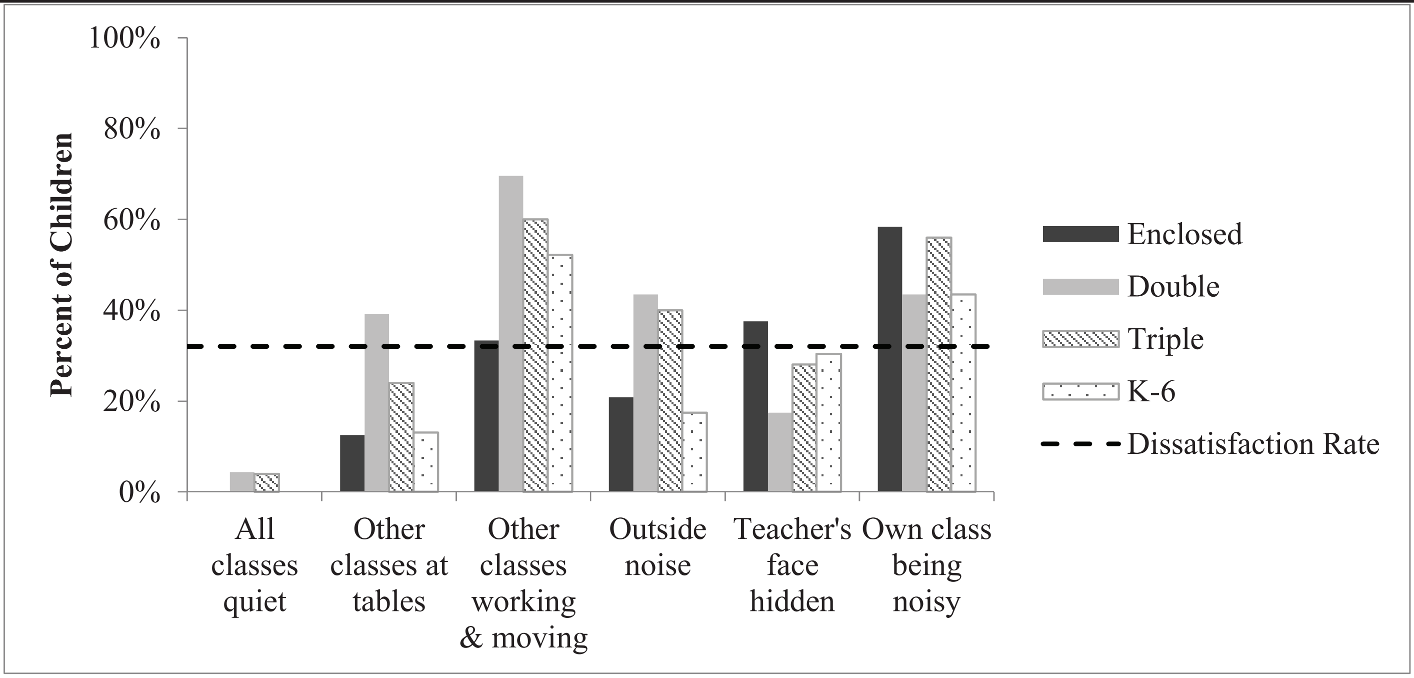

Figure 7. Percentage of children who reported not being able to hear their teacher very well or at all for different listening scenarios. The dissatisfaction criterion is set at 32%.

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 their classmate was i) 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	Enclosed Classroom			Double Classroom			Triple Classroom			K-6 Classroom			Kruskal-Wallis Test	
	M	*SD*	D (%)	*M*	*SD*	D (%)	*M*	*SD*	D (%)	*M*	*SD*	D (%)	*H*(3)	*p*
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 classes were 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.

Table 6. *Measured value versus recommended value for classroom noise level, signal-to-noise ratio, and speech transmission index score.*

Acoustic Variable	Measured Value	Recommended Value
Noise Level	< 45.9 dBA	Occupied: < 50 dBA (Berg et al., 1996) Unoccupied: < 35-45 dBA (Australia/New Zealand Standard AS/NZS2107:2000, 2000)
SNR	> +14.5 dB	> +15 dB (Crandell & Smaldino, 2000)
STI	> 0.75	> 0.75 (Greenland & Shield, 2011)

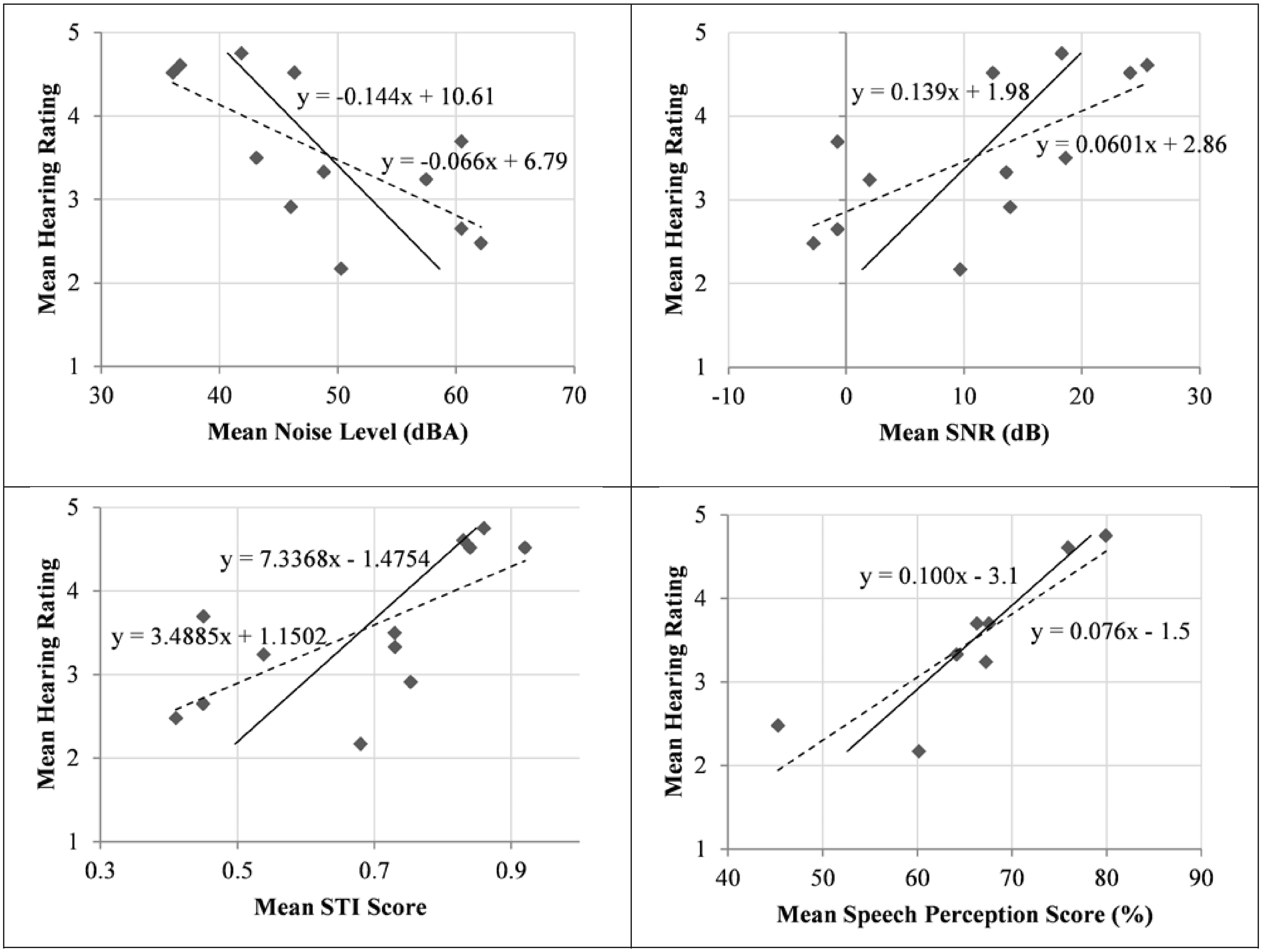

Figure 8. Children's mean hearing ratings of how well they can hear their teacher compared to previously measured classroom noise levels, signal-to-noise ratios, speech transmission index scores, and MDDB Classroom Speech Perception Test scores for similar scenarios. The dotted line shows the regression 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 annoyed 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 annoyed 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 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 in 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 is because it 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 annoyed 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 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, 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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