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Investigating the acoustics of a sample of open plan and enclosed Kindergarten classrooms in Australia

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A B S T R A C T

Open plan classrooms, where several class bases share the same space, have recently re-emerged 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.

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 [50]. 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 [16,18].

Noise generated by other children is the major noise source found in classrooms [52]. High noise levels adversely affect speech perception [16,18], reading and language comprehension [28,38,49], cognition, concentration, and the psychoeducational and psychosocial achievement of the child [4,16,53]. 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 [5,38]. Noise levels are reported to be highest in the classrooms of the youngest children [25,33,47,59] which is also the age group most affected [26,32,43,45]. 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 [58].

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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 [16,33]. 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 [44]. Middle-ear related hearing loss in Australia (usually caused by otitis media) affects 50–80% of Aboriginal and Torres Strait Islander school children [42]. This creates feelings of inadequacy for the individual and adversely impacts their classroom performance [37,42]. Children with central auditory processing disorders also find it challenging when listening in the presence of background noise and reverberation [27]. Other acute groups affected by poor acoustics include those for whom English is a second language for [40,41,53], children with sensory hypersensitivity [21], and introverts, who find it difficult to concentrate and relate while doing group work in a noisy environment [14].

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 [20,55]. Noise also raises blood pressure, increases stress levels, causes headaches, and results in fatigue (see [5], and [53], 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 [33].

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 [4,29]. 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 [3,16,53], 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 [4,16,17]. In occupied classrooms, student generated noise creates the highest noise levels measuring between 50–70 dBA [16,58]. 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 [33,53], though Greenland and Shield [22] suggest that this should be increased to 0.75 for children as young as 6 years. This, however, is rarely achieved [1,22,33]. 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 [56].

Open plan style classrooms are not a new concept for educational institutions. This 'progressive' classroom style was popular during the educational reform of the 1960s and 1970s where traditional didactic teaching was replaced by a more 'child-centered' approach [12]; see also [53]. Additionally, building open plan spaces complemented post-war economic restraints [10]. However, because of noise and visual distraction, it was not long before the open spaces were converted back to enclosed classrooms [53]. 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 [21,56]. 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 [34]. They also allow for a range of activities to be carried out and facilitate group work and the child's social development [12]. Additionally, they promote the sharing of skills, ideas, and experiences amongst teachers, and allow for team-teaching which facilitates a more cooperative and supportive atmosphere [12,23]. 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 [53]). The American National Standards Institute [3] 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 is 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 [17] found average noise levels to be significantly higher in open plan classrooms, whereas Airey et al. [2] found that noise levels in open plan classrooms in the United Kingdom were 5 dB lower than in enclosed classrooms. They 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. [9,19,31]). However, these three studies did show more fluctuations in noise levels which teachers and students find more annoying than consistent noise at the same average level [15]. 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 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