Investigating the effect of intrusive noise levels on speech perception in an open-plan Kindergarten classroom

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Abstract

Open-plan classrooms have higher intrusive noise levels than enclosed classrooms. This case study assessed the impact of intrusive noise in an open-plan classroom on children's speech perception. Twenty-two children participated in an online four-picture choice speech perception task while other classes completed both quiet and noisy activities. Children's performance accuracy, including number of responses, and speed was lower when other classes engaged in noisy compared to quiet activities. Children's speech perception abilities also decreased the further away they were seated from the loudspeaker. These results raise the question of whether open-plan classrooms provide an appropriate learning environment for young children.

Index Terms: speech perception, classroom acoustics, open-plan classrooms

1. Introduction

Primary school provides a child's first experience of formal education, preparing them for higher levels of literacy, numeracy, and other 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 listening and comprehending. 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 [1]. Noise levels are reported to be highest in the classrooms of the youngest children [2] which is also the age group most affected by noise [3]. 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 [4]. More specifically, consonant identification in noise, particularly of codas (which are less perceptually salient than onsets [5]) does not reach adult-like performance until the late teenage years [3]. Children with hearing impairments, and/or those who have English as a second language (ESL), are even more affected by poor classroom acoustics [2], [4], [6].

Despite noise levels already being excessive in traditional enclosed classrooms with 20-30 children, a current trend in Australia and some other countries is to replace these classrooms with new open-plan 'flexible learning spaces' which have up to 200 children sharing the same area [7]. Reasons for adopting an open-plan classroom style (apart from it being architecturally fashionable) are that these spaces create a more 'home-like' atmosphere and are perceived as less authoritarian, hence creating a more secure feeling for the child. They also allow for a range of activities to be carried out, facilitating group work and social development [6].

However, due to large numbers of children sharing the same area and being engaged in a range of activities, open-plan classrooms result in high levels of fluctuating speech noise, decreasing the signal-to-noise ratio (SNR). This intrusive noise impacts on children's speech perception, cognition, and concentration, as well as increasing stress levels [6].

Despite evidence from Europe and the UK that high noise levels are a common problem in open-plan schools, many schools in Australia are still converting to this classroom layout. Little research, however, has been done in Australia to assess speech perception in these classrooms. Therefore, the aim of this study was to compare children's speech perception abilities in an open-plan classroom when the other class bases were engaged in quiet versus noisy activities to assess the impact of intrusive noise on learning. In order to do this effectively in the actual listening environment, Personal Response Systems (PRS) were used to simultaneously test all children live in the classroom. These systems are often used in university teaching but have only recently been used to assess speech perception in the classroom [8].

In light of the previous findings, it was hypothesized that both the children's performance *accuracy* and *speed* would be poorer in the noise compared to quiet condition, 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 hypothesized that the children would perform more poorly at discriminating coda consonants compared to onsets due to their lower perceptual salience.

2. Method

2.1. Involvement

2.1.1. 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. The room was 37 m by 11 m with a ceiling height of 3.3 m and approximately 6 m between each class base (Figure 1).

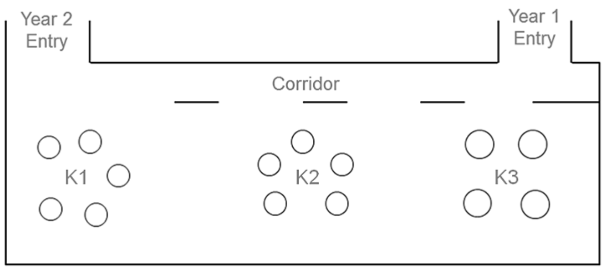

Figure 1: *Classroom floor plan showing Kindergarten class bases and openings to Year 1 and 2 classes.*

The Year 1 and 2 classes were located off an adjacent corridor but with no doors/walls separating the spaces. The class area was carpeted but the corridor was a hard surface. Windows were located on both the front and back walls.

2.1.2. Participants

Twenty-two students (9 male, 13 female) out of the 91 students in the 3 classes were randomly selected to participate in the classroom speech perception task. The remaining children made up the 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.

2.2. Stimuli

The Mealings, Demuth, Dillon, and Buchholz Classroom Speech Perception Test (MDDB CSPT) word lists were used for the study. This test is based on the Chear Auditory Perception Test [9] and 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 1). 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 …*).

Table 1: *MDDB CSPT word lists.*

List O1	List O2	List O3	List C1	List C2	List C3
_Art	_Eat	Talk	K_	Bee_	Beat
Tart	Beat	Fork	Cape	Bead	Bees
Cart	Meat	Chalk	Cake	Beam	Beach
Heart	Neat	Stalk	Case	Bean	Beast

The test uses audio recordings of the 24 sentences by an adult Australian-English speaker using child-directed 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.

2.3. Listening conditions

The aim of the experiment was to assess how intrusive classroom noise impacts students' listening abilities. There were two listening conditions; one when the other 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 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 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 offline.

2.4. Procedure

Participants were each assigned a seating position in front of a Smart Board with males/females and ESL students evenly distributed front to back. 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. The audio volume was adjusted so that the average sound level presentation was 60 dBA at 2 m as measured by a Dick Smith Electronics Q1362 sound level meter. This level represents a teacher's average speaking level [10]. The test began with all participants completing a familiarization phase where they saw and heard each of the 24 stimuli words and repeated them back as a group. The children then practiced using their interactive TurningPoint ResponseCard RF LCD Keepads to answer a series of multiple choice questions. When the children were ready the testing phase began. Group 1 completed the task in quiet first while Group 2 left the area. Group 1 and 2 then completed the test in noise. Finally, Group 1 left and Group 2 completed the test in quiet. During testing 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 the list. They were instructed to select the picture they heard via the colour-coded buttons on their Keepad. This procedure was repeated for all 24 stimuli (pseudo-randomized) in both conditions. A maximum of 15 seconds was allowed for the children to record their response. Responses were then collated and analyzed for performance accuracy and speed using TurningPoint software.

3. Results

3.1. Noise levels

The noise levels during each condition were recorded so the difference between quiet vs. noisy activities could be measured. The average noise level in the quiet condition was 57.4 dBA. In the noise condition, the average level was 10.3 dBA louder at 67.7 dBA.

3.2. Overall speech perception scores

A linear mixed effects analysis assessed whether the factors of quiet vs. noise condition, gender, ESL, Group (i.e. noise condition order), and distance from the loudspeaker contributed to the children's speech perception scores. As predicted, noise condition and distance from the loudspeaker were significant factors in the model ($F(1,36) = 47.35$, $p < .0005$; $F(1,36) = 45.95$, $p < .0005$). If all other predictor variables are held constant, the addition of noise results in scores being 22% lower. Similarly, if all other predictor variables are held constant, scores are estimated to decrease by 20% for each additional meter the child is away from the loudspeaker. Further analysis of these two factors can be found below. ESL was also a significant factor, with those who have ESL scoring 8% lower overall, if the other predictor variables are constant, compared to those who have English as their first language ($F(1,36) = 5.68$, $p = .023$). Neither gender or Group, however, significantly contributed to the model, ($F(1,36) = .42$, $p = .519$; $F(1,36) = .11$, $p = .744$).

3.3. Quiet vs. noise item effects analyses

3.3.1. Onset vs. coda analyses

As noise condition was a significant factor contributing to the children's speech perception scores, a follow up analysis was conducted. This analysis assessed not only the extent to which children's performance was poorer in noise compared to quiet, but also whether the children's performance was poorer on codas compared to onsets due to their reduced saliency. The mean number of correct responses across children was submitted to a repeated-measures ANOVA. The results showed a main effect for quiet vs. noise condition ($F(1,84) = 35.05$, $p < .0005$, $\eta_p^2 = .29$) with children's performance significantly poorer in noise ($M = 45\%$) compared to quiet ($M = 67\%$). There were also significantly more non-responses in noise than in quiet ($M_{\text{noise}} = 16\%$, $M_{quiet} = 8\%$ $t(23) = -3.29$, $p = .002$, $d = -1.04$). This indicates that a 10 dB increase in noise level results in a significant decrease in the speech perception score. The effect of onset vs. coda, however, was not significant ($F(1,84) = 3.01$, $p = .086$), indicating no difference between the children's performance on onsets (59%) and codas (53%). No interaction was found between quiet vs. noise and onset vs. coda ($F(1,84) = 0.00$, $p = 1$, see Figure 2).

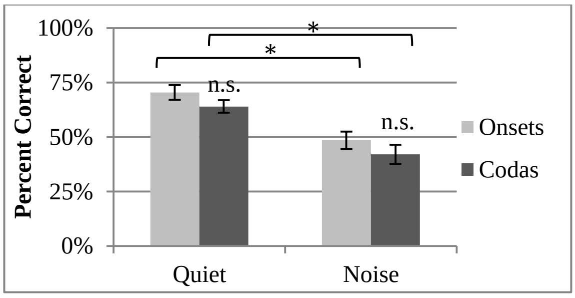

Figure 2: *Children's mean percentage of correct responses for onsets vs. codas in quiet and noise conditions. Error bars indicate standard error of the mean. * p < .0005.*

3.3.2. *List analyses*

As no difference was found on perception of onsets vs. codas, we conducted a finer grained analysis to compare individual lists. A series of paired t-tests was run to determine significant differences between quiet vs. noise conditions for each list. Bonferroni corrections were used to account for the multiple comparisons ($\alpha = .05/6 = .008$). Performance was significantly poorer in noise for Lists O1, O2, O3, C2, and C3, but not for List C1, although it trended in that direction (Figure 3).

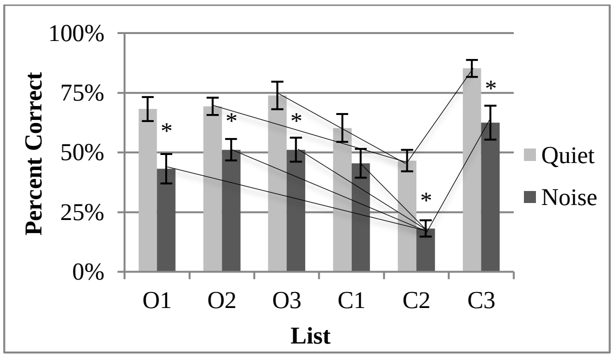

Figure 3: *Children's mean percentage of correct responses by list in quiet and noise. Error bars indicate standard error of the mean. Lines and asterisks show significance at p < .008 level.*

Two one-way ANOVAs with post hoc Tukey HSD tests were then conducted to determine significant differences between the lists in quiet and then in noise. The ANOVA results were significant for both quiet ($F(5,126) = 7.97$, $p < .0005$, $\eta_p^2 = .23$) and noise ($F(5,126) = 7.90$, $p < .0005$, $\eta_p^2 = .22$) with post hoc Tukey HSD tests showing List C2 to be particularly problematic, especially in noise (Figure 3).

Table 2 shows the confusion matrices for List C2 in quiet and in noise respectively. Note the high confusion rate between *bean* and *beam*. This is expected due to their perceptual similarity, with a bias towards selecting *bean* as it is a higher frequency word spoken by this age group (see ChildFreq from the CHILDES database, [11], [12]). In the noise condition, confusions not only increased for these two words, but for all four words in the list.

Table 2: *Confusion matrices showing percentages of responses pooled over the 22 participants in quiet and noise conditions. Note values may not add to 100% due to rounding.*

	Stimuli	Response (% of children)				
		Bee	Bead	Beam	Bean	None
Quiet	Bee	**68**	23	0	5	5
	Bead	14	**45**	14	23	0
	Beam	5	14	**0**	82	5
	Bean	5	14	5	**73**	5
Noise	Bee	**14**	14	5	55	9
	Bead	45	**9**	0	14	32
	Beam	5	5	**0**	68	5
	Bean	0	18	9	**50**	18

3.4. 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 the presence of noise. As anticipated, a paired t-test revealed a significant difference in the children's response times in quiet ($M = 6.17$ s) vs. noise ($M = 7.28$ s, $t(21) = -3.90$, $p < .0005$, $d = -0.80$, see Figure 4).

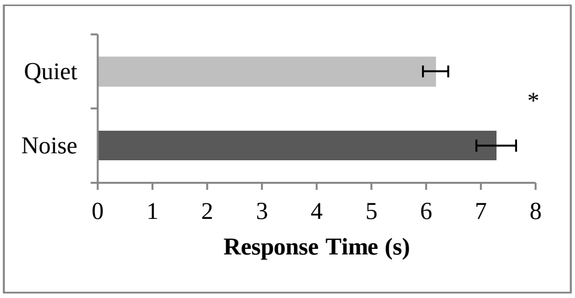

Figure 4: *Children's mean response times in quiet and noise conditions. Error bars indicate standard error of the mean. * p < .0005.*

3.5. Performance by seating distance

Recall that due to the decreasing SNR, it was predicted that performance accuracy would decrease the further away the child was seated from the loudspeaker. In quiet, a moderate negative correlation was found between children's performance and the seating distance ($r = -0.66$, $p = .001$) with children's score decreasing by 13% every additional meter. On average, scores at the front were 80% compared to 54% at the back. With the addition of noise, this relationship increased to a strong negative correlation (*r* = -0.82, *p* < .0005). In noise, children's scores decreased by 24% every additional meter they were from the loudspeaker, with average scores at the front (1 m) being 69% compared to 21% at the back (3 m; see Figure 5).

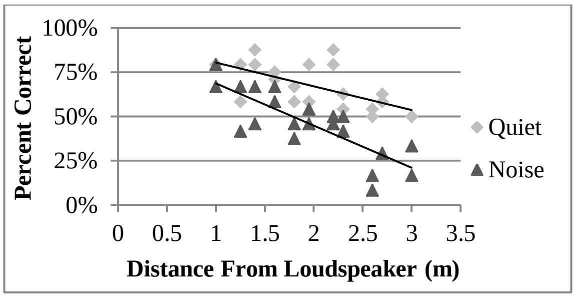

Figure 5: *Children's percentage of correct responses in quiet and noise conditions by seating position.*

4. Discussion

The aim of this study was to assess the impact of intrusive noise on children's speech perception in an Australian open-plan classroom. The results revealed poorer performance accuracy, including an increase in non-responses, and slower response time when the other classes were engaged in noisy activities compared to quiet activities. A finer grained analysis revealed that voiced stops and nasals, especially when in the less perceptually salient coda position, were particularly hard to discriminate.

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. These results suggest, however, 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 [4].

In addition, the results of our study showed how speech perception abilities decrease the further away the child is seated from the loudspeaker. This was significant in both listening conditions, but particularly for the noise condition, where the scores of a child sitting at the front compared to the back dropped from 69% to 21%. These results emphasize the importance of gathering children (especially those more vulnerable to the impact of noise) close to the teacher during critical listening tasks.

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. Although this study only involves one school, these results indicate the need for further investigation into whether open-plan classrooms are appropriate learning spaces for young children. As the layout and number of students in each open-plan classroom varies widely, it is essential for future research to be conducted in a wide range of schools. This research needs to assess which designs are appropriate and what the maximum number of students in an area should be in order to maintain adequate speech perception in the classroom.

5. Conclusions

The aim of this study was to assess the impact of intrusive noise on children's speech perception abilities in an open-plan classroom. The results revealed poorer accuracy, including an increase in non-responses, and slower reaction time when other classes were engaged in noisy activities. They also showed that children's speech perception abilities decreased the further the child was from the loudspeaker, particularly when noise was present. These results suggest that open-plan classrooms, which have higher noise levels, are not appropriate learning spaces for young children, as the children have difficulty understanding their teacher.

6. Acknowledgements

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7. References

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