

Research Article

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

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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 to develop a new Australian speech perception task (the Mealings, Demuth, Dillon, and Buchholz Classroom Speech Perception Test) and use it in an open-plan classroom to assess how intrusive noise affects speech perception.

Method: The first part of this article describes how the online 4-picture choice speech perception task materials were created. The second part focuses on the study involving twenty-two 5- to 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 noisy condition compared with the quiet condition. In addition, children's speech perception scores decreased the farther away they were seated from the loudspeaker. Overall, the children understood and were engaged in the task, demonstrating that it is an appropriate tool for assessing speech perception live in the classroom with 5- to 6-year-old children.

Conclusions: The results suggest that the Mealings, Demuth, Dillon, and Buchholz Classroom Speech Perception Test is a helpful tool for assessing speech perception in classrooms and that it would be beneficial to use in future research investigating how classroom design and noise affect speech perception.

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% to 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). Although 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 with 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; O. Wilson, 2002), many studies have shown that SNRs reach only between -7 and +5 dB (American Speech-Language-Hearing Association, 2005; Crandell & Smaldino, 2000; Finitzo, 1988). Noise levels in open-plan classrooms, in which 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; Nittroer & Boothroyd, 1990). Because children's auditory systems are neurologically immature, children 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). Consonant identification in noise, particularly of

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codas (which are less perceptually salient than onsets; Redford & Diehl, 1996, 1999), does not reach adultlike performance until the late teenage years (Johnson, 2000; Nishi et al., 2010). Children with hearing impairments or 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, Kohnert, Sabur, & Shaw, 2005; Nelson & Soli, 2000; Shield et al., 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 affects classroom performance and creates feelings of inadequacy among 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 level, 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 language comprehension, cognition, concentration, learning, and psychoeducational and psychosocial development (American Speech-Language-Hearing Association, 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, including Word Intelligibility by Picture Identification (Ross & Lerman, 1970), Northwestern University Children's Perception of Speech (Elliott & Katz, 1980), Pediatric Speech Intelligibility Test (Jerger & Jerger, 1982), Early Speech Perception Test (Geers & Moog, 1990), Chear Auditory Perception Test (CAPT; Marriage & Moore, 2003), and Words-In-Noise (R. H. 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 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 because 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 because 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 gross speech perception scores to be calculated but also allowed some finer grained, word-specific analysis to be conducted. In addition, we wanted the test to be conducted in the real classroom environment because 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., Word Intelligibility by Picture Identification and Northwestern University Children's Perception of Speech) 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 using a traditional pen-and-paper method. Children are presented with the stimuli at the front of the class, and they write down their answers after each question. Although 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 due to 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. In addition, this method is not suitable for testing younger participants, such as kindergarten children (i.e., ages 5;0–6;0 [years; months]), because they are too young to write. It also provides 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 analyzed. Each child is linked to a PRS code so that anonymity is preserved, and demographic details for each child can be added to be included in the analysis. In addition, TurningPoint software records response times, an important variable for understanding children's ability to process information, which traditional pen-and-paper or pointing/speaking methods are unable to capture. Although response time measures do provide insight into children's speed of processing, these results must be interpreted with caution

because they can sometimes represent contemplation time rather than reaction time or may reflect different cognitive processes (see Bess & Hornsby, 2014; Jiang, 2012; Schwartz, 2009). Asking participants to respond as quickly as possible can help avoid this.

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 (MDDDB 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 MDDDB CSPT in an open-plan classroom to assess how intrusive noise affects speech perception.

Development of the MDDDB CSPT Speech Materials

Word Lists

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

100% loss of vowels: ll ch ldr n h v t tt nd
pr m ry sch l

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 because consonants are more likely to be lost in noise than vowels (O. Wilson, 2002) and because consonant identification in noise and reverberation does not reach adultlike performance until the 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 CAPT used in a similar classroom speech perception task by Vickers et al. (2013). Vickers et al. 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 the coda of the word. Table 1 shows the five lists used by Vickers et al.

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 finely 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

Table 1. Chear Auditory Perception Test word lists.

List 1	List 2	List 3	List 4	List 5
Bud	Mat	White	Wipe	Stork
Buzz	Cat	Night	Wise	Fork
Bun	Fat	Right	White	Talk
Bug	Bat	Light	Wine	Chalk

phonemes having different perceptual salencies due to their different acoustic properties (Stevens, 2002; Stevens & Keyser, 1989, 2010). Continuant, sonorant, and coronal features 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 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). The following is a description of how the word lists were developed.

- Lists O1 and C1 test voiceless consonant perception. Manner and place changes occur 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).
- Lists O2 and C2 test voiced consonant perception. Manner and place changes occur 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).
- Lists O3 and C3 test consonant perception of stops versus fricatives versus affricates versus clusters. Changes occur in the onset position for List O3 and the coda position for List C3.

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 1,000,000 words between ages 4;0–6;0 (Bååth, 2010; MacWhinney, 2000). Effort was made to choose words that had high frequencies and as similar frequencies for all words within the list as possible, although this was difficult to fully control given the phonemic restraints. In Table 2, note that List O3 is the same as List 5 in the CAPT stimuli but that *stork* was changed to *stalk*, which is easier to picture and higher in frequency (10 per 1,000,000 words compared with one per 1,000,000 words).

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 because we did not want 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 because 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 with isolation because it provides an effective auditory grouping cue when there is substantial perceptual masking (Bonino et al., 2012). In addition, 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 *cake*,” “Sally likes the *bead*”). Effort was made to make the carrier sentences as neutral as possible so that 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 because this is the most salient utterance position due to phrase-final lengthening in English (Oller, 1973).

Audio Recordings

The 24 sentences recorded were spoken in clear speech by an adult native female speaker of Australian English who was instructed to speak as if she were teaching children ages 5;0–6;0. The recording took place in an anechoic chamber using a headset condenser microphone (d:fine; DPA Microphones, Alleroed, Denmark) that was placed approximately 2 in. from the speaker's mouth and routed to a preamplifier (QuadMic; RME, Haimhausen, Germany). Between the preamplifier and the personal computer 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 personal computer. Test stimuli were digitally recorded using Adobe Audition software (Adobe, San Jose, CA) at a sampling rate of 48 kHz (32 bits, mono). Afterward, each sentence was segmented and normalized using Praat software (Boersma & Weenink, 2011) so that 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 with TurningPoint software) accompanied by the prerecorded 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 colored dot corresponding to the color-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 pseudorandomized (e.g., 1, 4, 6, 3, 5, 2), and the lists were rotated through four times so that each word in each list was presented.

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

Table 2. Word lists and the spoken frequencies of the words per 1,000,000 words by children ages 4;0–6;0 (years;months).

List	Word	Transcription	Frequency	Range	Average
O1	_Art	/e:t/	18	1–91	34
	Tart	/tɛ:t/	1		
	_Cart	/kɛ:t/	26		
	Heart	/hɛ:t/	91		
O2	_Eat	/i:t/	1,753	63–1,753	539
	Beat	/bi:t/	171		
	Meat	/mi:t/	170		
	Neat	/ni:t/	63		
O3	Talk	/to:k/	531	10–531	162
	Fork	/fo:k/	91		
	Chalk	/tʃo:k/	14		
	Stalk	/sto:k/	10		
C1	K_	/kæɪ/	84	31–332	129
	Cape	/kæɪp/	31		
	Cake	/kæɪk/	332		
	Case	/kæɪs/	69		
C2	Bee_	/bi:/	60	1–60	29
	Bead	/bi:d/	7		
	Beam	/bi:m/	1		
	Bean	/bi:n/	48		
C3	Beat	/bi:t/	171	2–171	75
	Bees	/bi:s/	27		
	Beach	/bi:tʃ/	101		
	Beast	/bi:st/	2		

to compare children's speech perception in an open-plan classroom when the other class bases were engaged in quiet versus noisy activities in order to assess how intrusive noise affects speech perception. It was hypothesized that both the accuracy and speed of the children's performance would be poorer when the other class bases were engaged in noisy compared with quiet activities and that performance accuracy would decrease the farther away the child was seated from the loudspeaker (simulating the teacher's voice) due to the decreasing SNR. In addition, it was hypothesized that the children would perform more poorly at discriminating coda consonants compared with 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 with no physical 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 in an adjacent corridor, but no doors or walls separated the spaces; therefore, noise from these classes could also be heard. The space originally had consisted of separate enclosed classrooms with 30 children in each room, but the walls recently had 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 (see Figure 1). No other acoustic treatment was evident. The average unoccupied reverberation time of this classroom was 0.70 s, which is greater than the recommended time of 0.4 to 0.5 s (Australia/New Zealand Standard, 2000).

Participants. Twenty-two students (nine boys, 13 girls) out of the 91 students in the three 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 four were multilingual. No children were reported by their parents to have otitis media or intellectual or behavioral disabilities. The age range of

these participants was 5;4 to 6;6 years ($M = 5;9$). Two additional children participated in the study but were excluded because they did not finish the task.

Listening Conditions

The MDDDB CSPT stimuli described above were used for the study. We used two listening conditions in order to assess how intrusive classroom noise affects students' listening abilities. In one condition the other two kindergarten classes and the Year 1 and 2 classes were engaged in quiet activities (e.g., whole-class teaching), and in the other condition these classes 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 (<http://audacityteam.org/>). 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 or noisy activities, and the front row was approximately 15 m away. In a reverberant room, the difference in noise level from the adjacent classes between the back and front rows of the tested class was 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.

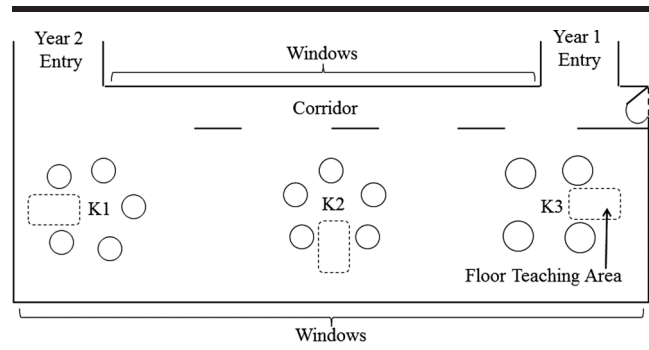
Procedure

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 from front to back (this is shown as the "floor teaching area" in Figure 1). Two students were seated at each of the following distances from the loudspeaker, which was placed front and center: row 1, 1.00 and 1.25 m; row 2, 1.40 and 1.60 m; row 3, 1.80 and 1.95 m; row 4, 2.20 and 2.30 m; row 5, 2.60 and 2.70 m; and row 6, 3.00 m.

PowerPoint Presentation

The speech perception test (introduced as a "listening game") comprised a PowerPoint presentation created with TurningPoint software consisting of three sections: familiarization with target words and pictures, familiarization with the PRS, and the testing phase. The visual stimuli were projected onto the 77-in. interactive whiteboard (4:3 aspect ratio) 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

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



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). On the basis of acoustic measurements that were previously performed in the same classroom but in other locations, the sound pressure levels are approximately 64 dBA at 1 m and approximately 57 dBA at 3 m, which covers the range of seating distances of the children from the loudspeaker.

Familiarization with target words and pictures. The test began with all participants completing a familiarization phase to ensure they understood the target word represented by each picture. The children saw the picture accompanied by the prerecorded 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 familiarization phase to aid the initial picture identification, but it was removed during the testing phase so that children with better reading skills would not have an advantage when doing the task.

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

Testing phase. Once the children were familiarized with the stimuli and their PRSs, the testing phase began. The children were instructed to listen to the audio and then, using the PRS, select which picture they heard. They were also encouraged to not 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. The first child to record the answer correctly won the prize, and all participating students were given a smaller prize for encouragement.) The children then completed the four-picture forced-choice speech perception task for all 24 items using the PRS. Rather than presenting all four words of a list consecutively, which makes it easier for children to use a process of elimination, the lists were pseudorandomized and rotated throughout the experiment. A maximum of 15 s 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 a noisy condition (e.g., when the other classes were completing group work and/or moving around), and the noise levels were 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. Groups 1 and 2 then completed the testing phase together in the noisy condition (to ensure that the noise level was the same for both groups tested), and then Group 1 left and Group 2 did

the test in the quiet condition. Having two groups complete the test in different orders helps minimize learning effects. The whole procedure, including familiarization, took around 45 min to complete.

Posttest 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 analyzed the children's correct and incorrect answers and how long it took the children to give their answer (time was calculated from the onset of each stimulus display).

Results

Noise Levels

The noise levels during each condition were recorded so that 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 noise 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 of the children were 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 with the quiet condition (range = 4%–46% worse, $SD = 13$), except for one child seated up 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 because sound decay generally is 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, $F_{\text{noise condition}}(1, 79) = 64.09, p < .0005$; $F_{\text{onsets versus codas}}(1, 79) = 6.15, p = .015$; $F_{\text{distance}}(1, 79) = 67.04, p < .0005$. If all other predictor variables are held constant, scores are predicted to be 22% lower when the other classes are engaged in noisy compared with quiet activities. In addition, the model estimated that the children's performance is 7% lower when perceiving codas compared with onsets. Similarly, if all other predictor variables are held constant, scores are estimated to decrease by 26% for each doubling of the distance the child is seated away from the loudspeaker (i.e., 1 m, 2 m, 4 m, and so on). 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-samples t tests were also conducted to assess if presentation

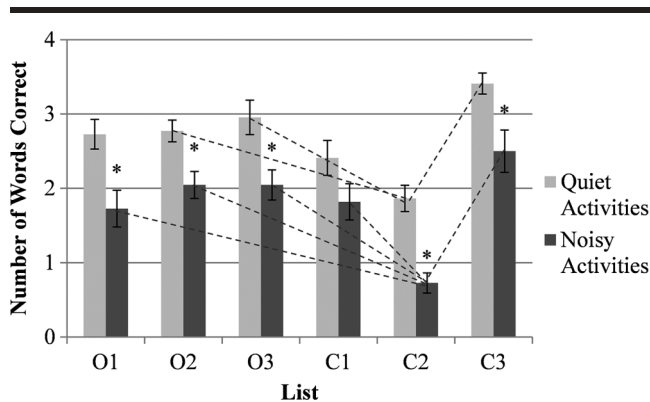
order had an effect on the children's scores. No significant difference was found, however, between the scores of Groups 1 and 2 for either the quiet or the noisy conditions, $t_{\text{quiet}}(20) = -0.36, p = .719, d = -0.16$; $t_{\text{noisy}}(20) = -0.71, p = .486, d = -0.32$.

List analyses. Because a significant difference was found on the children's perception of onsets versus codas, we conducted a more finely 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 (see 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 analysis of variance (ANOVA) with condition (quiet vs. 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 condition, $F(5, 126) = 7.97, p < .0005, \eta_p^2 = .23$, and noisy condition, $F(5, 126) = 7.90, p < .0005, \eta_p^2 = .22$. Post hoc Tukey's HSD tests showed that List C2 was 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 (see Figure 2). No significant differences were found between the other lists.

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

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 $p < .008$.



carried out by examining lexical frequency effects both for the correct answers and for 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 recognized 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 ($r = .958, p = .042$) and List C2 ($r = .982, p = .018$). 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 conditions.

Confusion matrices. Because 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 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; they are both nasals. In this case there was a bias toward selecting *meat* because it is the higher frequency word spoken by this age group and is easier to picture.

It is interesting to note that 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 of it is probably much less familiar to children. For this target word, *chalk* was chosen equally as often. *Chalk* is easier to picture than *talk*, and *chalk* (/tʃo:k/) 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

Table 3. Confusion matrices showing percentages of responses pooled over the 22 participants while other classes were engaged in quiet versus noisy activities for each word list.

List	Stimuli	Response (% of children)					
O1	Quiet activities	Art	Tart	Cart	Heart	None	
		41	14	0	32	14	
		5	73	5	14	5	
		9	18	59	14	0	
	Noisy activities	Heart	0	0	100	0	
		Art	36	5	14	41	5
		Tart	18	50	5	18	9
		Cart	23	23	27	9	18
O2	Quiet activities	Heart	5	14	59	18	
		Eat	Beat	Meat	Neat	None	
		91	0	5	0	5	
		0	95	0	0	5	
	Noisy activities	Meat	5	5	77	5	9
		Neat	9	0	64	14	14
		Eat	36	9	36	0	18
		Beat	5	77	5	5	9
O3	Quiet activities	Meat	14	0	77	5	5
		Neat	18	0	41	14	27
		Talk	Fork	Chalk	Stalk	None	
		55	0	18	14	14	
	Noisy activities	Fork	0	86	0	5	9
		Chalk	0	5	73	5	18
		Stalk	9	5	5	82	0
		Talk	27	9	27	5	32
C1	Quiet activities	Fork	0	45	36	5	14
		Chalk	0	9	77	0	14
		Stalk	5	9	9	55	23
		K	Cape	Cake	Case	None	
	Noisy activities	K	64	9	14	0	14
		Cape	9	50	36	0	5
		Cake	0	9	73	5	14
		Case	0	27	0	55	18
C2	Quiet activities	K	45	32	18	0	5
		Cape	9	27	55	9	0
		Cake	18	23	45	5	9
		Case	5	14	5	64	14
	Noisy activities	Bee	Bead	Beam	Bean	None	
		68	23	0	5	5	
		Bead	14	45	14	23	0
		Beam	5	14	0	82	5
C3	Quiet activities	Bean	5	14	5	73	5
		Bee	14	14	5	55	9
		Bead	45	9	0	14	32
		Beam	5	5	0	68	5
	Noisy activities	Bean	0	18	9	50	18
		Beat	Bees	Beach	Beast	None	
		86	0	0	14	0	
		Bees	0	91	0	0	9
C2	Quiet activities	Beach	5	0	73	9	14
		Beast	5	0	0	91	5
		Beat	59	27	5	0	9
		Bees	5	55	5	5	32
	Noisy activities	Beach	23	0	68	5	5
		Beast	0	9	5	68	18

Note. Values may not add to 100% due to rounding.

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 was again expected due to their perceptual similarity, with a bias toward

selecting *bean* because 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 that on all other lists in noisy conditions and that on 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 likely explains 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 nonresponses was the general pattern for all lists in the noisy condition. It was also more common in noisier conditions for phonemes to be perceptually epenthesized—for example, *heart* (/hɜ:t/) for *art* (/ɜ:t/), *meat* (/mi:t/) for *eat* (/i:t/), and *cape* (/kæɪp/) or *cake* (/kæɪk/) for *K* (/kæɪ/)—or omitted—for example, *bee* (/bi:/) for *bead* (/bi:d/) and *beat* (/bi:t/) for *beach* (/bi:tʃ/; see Table 3).

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.

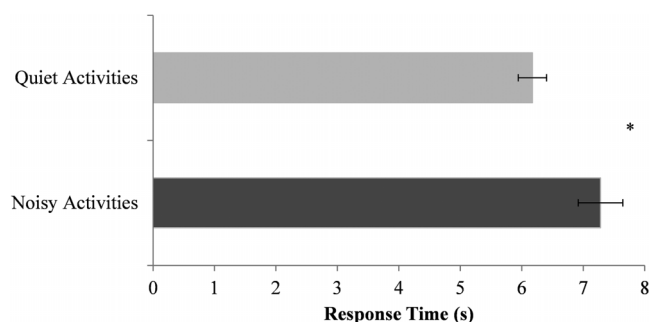
Response Times

In addition to decreased performance accuracy, we 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): Responses were slower 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).

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 activities, $F(5, 481) = 0.81$, $p = .544$, $\eta_p^2 = .01$, and noisy activities, $F(5, 439) = 0.31$, $p = .905$, $\eta_p^2 = .00$.

A correlation analysis was also conducted to assess if performance accuracy was related to reaction time. The results were not significant, however, for either the quiet

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. $*p < .0005$.



condition ($r = .06$, $p = .788$) or the noisy condition ($r = .08$, $p = .712$).

In addition, a correlation analysis was conducted to assess 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 ($r = .10$, $p = .633$).

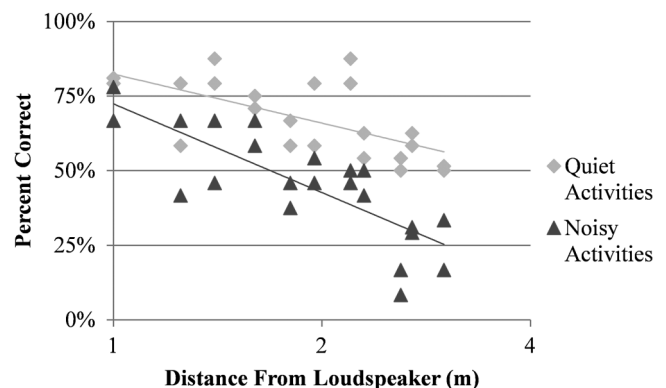
Performance by Seating Distance

Due to the decreasing SNR, it was predicted that performance accuracy would decrease the farther 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 and so on, 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 ($r = -.63$, $p = .002$), with children's scores decreasing by 16% per doubling of the distance from the loudspeaker. On average, scores at the front (1 m) were 82% and at the back (3 m) were 56%. When the other classes were engaged in noisy activities, this relationship increased to a strong negative correlation ($r = -.80$, $p < .0005$). In this noisy condition, children's scores decreased by 30% per doubling of the distance from the loudspeaker. Average scores at the front were 72% and average scores at the back were 25% (see Figure 4).

Discussion

The two main aims of this study were to (a) develop a new Australian speech perception task (the MDDDB 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 MDDDB CSPT in an open-plan classroom to assess how intrusive noise affects speech perception.

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 versus noisy activities.



Evaluation of the MDDB CSPT

Appropriateness of the MDDB CSPT stimuli. One way to determine the appropriateness of a test that examines the effects of different noise levels and seating distances on speech perception is to examine the range of scores received by the participants. If most participants are scoring close to 100%, this indicates that the test is likely too easy. On the other hand, if most of the participants are scoring close to 0%, the test is likely too difficult. The results of the classroom study revealed a large range of scores on the task, particularly in the noisy condition. This range of scores 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 the entire duration and, when asked at the end, said they had fun or wanted to play it again. The teachers who observed the task also noted that the children were engaged in and enjoyed the task. High performance accuracy ($M = 96\%$) by the children on the multiple-choice questions in the PRS familiarization phase demonstrated the children's ability to understand the task and use their PRSs. This suggests that this technology is 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. The following three factors may have influenced the children's answers.

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. 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 recognized by children than those with lower lexical frequencies. They also found that words that have many neighbors (i.e., words that sound similar) are more poorly perceived than words with fewer neighbors. Both of these factors are therefore likely to have influenced our results. It was not possible, unfortunately, 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, some words chosen were still more challenging to picture than others (e.g., *neat*, *talk*, and *beam*) due to our phonemic constraints.

Although this may have contributed to the poorer performance on these words, we believe that this factor was minimized as much as possible by the active familiarization phase, during which 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 present 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 (because it appears at the end of the sentence), thereby aiding the perception of the target word (Bonino et al., 2012). We decided to have a different descriptive sentence for each list rather than use 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, because the main aim of this study was to compare the children's speech perception while the adjacent classes were engaged in quiet compared with noisy activities and because 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 prerecord the auditory stimuli rather than present it live to control for the intensity of the speech and ensure that 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 in which 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 such as the classroom (though it does represent the times when the teacher is writing on the whiteboard or the children are writing or looking away). However, there is conflicting evidence about 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 that, in addition to the current test format, uses a video recording of the speaker's face saying the sentences. This would help assess if there is a benefit of auditory–visual compared with auditory-only speech perception by children in quiet and noisy conditions.

Despite the limitations mentioned previously, 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 for efficiently assessing 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 effect of intrusive noise on speech perception in an open-plan classroom. In light of the previous findings, it was hypothesized that both the accuracy and speed of the children's performance would be poorer when other classes were engaged in noisy compared with quiet activities and that performance accuracy would decrease the farther away the child was seated from the loudspeaker (simulating the teacher's voice) due to the decreasing SNR. In addition, it was hypothesized that the children would perform more poorly at discriminating coda consonants compared with onsets due to the lower perceptual salience of coda consonants.

The results revealed poorer performance accuracy (including an increase in nonresponses) when the other classes were engaged in noisy activities compared with quiet activities. Children's response time was also significantly slower during the noisy condition compared with the quiet condition (although further investigation is needed to assess if the duration of this delay would significantly affect the children's learning). In addition, children's perception of coda contrasts was poorer compared with their perception of onset contrasts. A more finely 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 toward choosing words that have a higher lexical frequency, especially if they are unsure which word they heard. Although word familiarity may enhance the perception of a word, new words are likely to be misperceived. Given that 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 findings suggest that the children engaged in active listening are likely to misunderstand or even entirely miss what their teacher is saying when there is noise coming from other classes in the room. Even if the children 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 have a great effect on children's educational development because their auditory systems are neurologically immature

and they cannot yet use world knowledge and experience to fill in information (Wilson, 2002).

In addition, the results of our study showed how speech perception decreases the farther away the child is seated from the loudspeaker. This was significant in both listening conditions, but particularly for the noisier condition, in which the scores of a child sitting at the front compared with the back decreased from 72% to 25%. These poor results for the children sitting at the back are most likely due to the lower SNR, because the children are farther away from the loudspeaker and closer to the noise from the other classes. These results emphasize the importance of gathering children (especially those more vulnerable to the effect 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. Because 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.

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 for demonstrating the effect of classroom noise and listening distance on speech understanding was shown by the large range of scores on the task (rather than the majority of children performing at ceiling or at floor), particularly in the noisy condition. In addition, 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 nonresponses) and slower reaction time when other classes were engaged in noisy compared with quiet activities. The results also showed that the children's speech perception scores decreased the farther 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 children ages 5;0–6;0. Therefore, the MDDB CSPT could 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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