CLASSROOM ACOUSTICS

A New Zealand Perspective

Research Team

Oriole Wilson (Project Coordinator)	National Audiology Centre
Joanne Valentine	Marshall Day Acoustics
Miklin Halstead	Acoustics Research Centre, University of Auckland
Ken McGunnigle	Prendos NZ Ltd
George Dodd	Acoustics Research Centre, University of Auckland
Anne Hellier	Group Special Education, Ministry of Education
John Wood	Group Special Education, Ministry of Education
Rod Simpson	Research Assistant

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PO Box 9128
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Phone 0800 OTICON (0800 684 266)
Fax 0800 FAX OTICON (0800 329 684)
email *info@oticon.org.nz*

TABLE OF CONTENTS

INTRODUCTION

This report presents the findings of a research project into the acoustic characteristics of New Zealand primary school classrooms. The study was initiated after complaints relating to the acoustic properties of relocatable classrooms.

The project was carried out by a multidisciplinary team of professionals who have a strong belief that good acoustics should be one of the prime design considerations for new classrooms.

The Oticon Foundation in New Zealand has funded the project. The Oticon Foundation is a charitable trust that provides grants for projects that increase awareness and knowledge about hearing loss.

The aims of the project were to:

- raise awareness of the necessity for good acoustics in New Zealand classrooms for all children but particularly for hearing-impaired children
- identify styles of classrooms with good and poor acoustics and to investigate these rooms in detail
- come up with practical and affordable building design recommendations to optimise the acoustics of primary school classrooms
- make the results of the study widely available to the Ministry of Education, teachers, principals and schools boards, architects, designers, and the general public.

Classroom listening environments were investigated in seven Auckland primary schools using:

- teacher survey questionnaires
- a survey of construction details of the rooms
- results from the above two surveys to identify 6 good and 6 poor rooms that were then investigated in detail using the methods listed below [1]
- speech perception tests in live and simulated background noise in classrooms
- daylong recordings of classroom noise levels
- acoustical measurements of clarity and Reverberation Time (R/T)
- modifications to the rooms that were identified by teachers as being poor acoustically. The addition of acoustic ceiling tiles and repeating the detailed measurements.

Parts of this work have been presented at conferences and published. Details are contained in the references. Wilson 2000A, Wilson 2000B, Valentine 2000 and Dodd *et al* 2001

[1] The original experiment selected only six schools but one of the schools had no rooms that were rated as having poor acoustics in any of its classrooms so a further school was chosen.

BACKGROUND

Much of what is learnt in school happens through hearing and listening. New Zealand primary school pupils are spending on average 4-5 hours per day in classrooms. It is vital that classroom learning environments have optimal acoustics for ease of listening and good intelligibility for all students.

Children, because they are neurologically immature and lack the experience necessary to predict from context, are inefficient listeners who require optimal conditions in order to hear and understand. Those who continually miss key words, phrases and concepts because of poor listening conditions are significantly disadvantaged.

Classroom design standards must consider what teaching activities occur inside the rooms during the course of a school day. Acoustical considerations must not inhibit teaching styles but facilitate the wide variety of teaching methods used. The ideal classroom should be acoustically friendly for all children regardless of abilities and for all the teaching styles in common practice today. Classrooms should not just be acoustically good when the child has normal-hearing and is sitting quietly on the mat close to the teacher. The room should also be acoustically friendly for the hearing-impaired student when there are high levels of noise because there is group discussion going on.

Noise levels in classrooms are undoubtedly higher than in the past, and this is because children are encouraged to communicate with each other. Educationalists have realised the value of what children learn from each other through gathering information casually, so called 'incidental learning', and good hearing conditions are crucial for the children to communicate easily, Flexer (1999).

There are a number of important factors that need to be considered when considering classroom acoustics from a New Zealand perspective:

Hearing Loss

We know that children with all types and degrees of hearing loss need better acoustics than normally-hearing students. New Zealand primary classrooms will frequently have significant numbers of hearing-impaired children in them. This is because of a high incidence of conductive hearing loss associated with middle ear disorder and because over 90% of children with permanent sensorineural hearing loss are mainstreamed. Data from the National Vision Hearing Screening Programme which screens the hearing of all new entrant children showed that the national average failure rate in 1999/00 was 7.7% overall, for Maori children 13.1% and for Pacific Island children 16.4%. A 'fail' means children have failed two hearing screening tests carried out 16 weeks apart.[2] (NAC 2000)

Children using hearing aids in the classroom face extremely hostile acoustic environments. They can be greatly assisted by the use of Radio Aids (FM systems) that improve the level of the teacher's voice over the background noise (Flexer 1999).[3]

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[2] Screening fail criteria are pure tone thresholds greater than 30 dB at 500 Hz and 20 dB at 1000, 2000 and 4000Hz. All flat tympanograms are classified as fails.

[3] In New Zealand at the current time it is acknowledged that educational support for children with mild to moderate degrees of hearing loss is limited. This has been due to staff shortages and policy changes affecting services especially those provided by the Advisors on Deaf and Hearing-impaired Children (AODCs) previously employed by Special Education Services (SES). These policy changes were initiated by the SES 2000 report. These service gaps are discussed in the Wylie Report and a review of the SES 2000 policy commissioned by the Ministry of Education and carried out by a team from Massey University.

Teaching Methods

New Zealand primary schools are recognised internationally for their innovative teaching methods. Much learning is done in small groups and a high emphasis is put on incidental learning. Because of this, noise levels are probably higher in these rooms than in some other countries where more traditional 'didactic' teaching methods are used. In New Zealand it is generally not considered desirable for primary pupils to sit quietly and listen to their teacher all day. Classrooms must be designed to accommodate these changes in teaching styles.

Ventilation

New Zealand primary schools generally do not have mechanical ventilation and air conditioning systems, which produce high levels of background noise. Such systems are widely used in North American and European schools and lead to classrooms having high background noise levels even when unoccupied. Conversely ventilation is a problem in the summer in New Zealand and rooms usually have a lot of windows that are typically open. This can be a problem if there are high levels of external noise from sources such as playgrounds, sports areas, halls and traffic.

Construction

Many new classrooms in New Zealand are constructed as 'relocatables' or 'pre-fabs'. These rooms are of lightweight (timber frame) construction and are often well elevated above the ground on supports. These buildings are designed so they can be moved when the demographics of an area change and consequently the number of rooms required on a school site change. They are built to Ministry of Education specifications and the design has varied over the years. A recent widely used design has given rise to a number of complaints from educators about the design's acoustic characteristics. This design lacked the acoustic ceiling treatment of many of its predecessors. Complaints had been received by the Advisors on Deaf and Hearing-Impaired Children on our team, particularly with respect to the ability of hearing-impaired children to function in these rooms. These complaints led to this research project.

The Ministry of Education's Health and Safety Code of Practice for State Schools (1993), updated in (1995), outlines requirements for egress, lighting, heating and ventilation but does not include acoustic standards for classrooms. The updated version does have some comment around the need for acoustical considerations when mechanical ventilation systems are being considered.

The project team, share a strong belief that good acoustics should be a prime design consideration for all new classrooms. McGunnigle and Dodd from the research team had the opportunity to include recommendations for classrooms in a new standard—Australian and New Zealand Standard AS/NZ2107: 2000 Acoustics – Recommended design sound levels and R/Ts for building interiors. They were able to specify *satisfactory*[4] (35 dBA) and *maximum*[5] (45 dBA) unoccupied noise levels and R/Ts[6] (0.4s–0.5s) for primary school teaching spaces. This is a significant step forward. Additionally the Ministry of Education has now begun to include some acoustical recommendations in its Design Standards Guidelines. These can be found on the Ministry of Education Website *www.minedu.govt.nz*

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[4] Satisfactory Design Sound Level – The level of noise that has been found to be acceptable by most people for the environment in question and also not to be intrusive.

[5] Maximum Design Sound Level – The level of noise above which most people occupying the space start to become dissatisfied with the noise.

[6] Reverberation Time (R/T) – time it takes for a sound to decay 60 dB after its source is turned off.

NEW ZEALAND RESEARCH

There have been several studies carried out of acoustic conditions in New Zealand classrooms (Coddington 1984, Blake & Busby 1994, and Harper 1995). These have shown noise levels and signal-to-noise (S/N) ratios[7], which are similar to those found in other international studies. S/N ratios in New Zealand classrooms in a variety of listening conditions have ranged from -5 to +10 dB. Blake & Busby (1984) reported median S/N ratios of +1 dB in multifunction activity (group) and +10 dB in single function teaching activities. American research by Sieben et al (1997) found that commonly reported S/N ratios in classrooms ranged from between -7 to +5 dB.

Coddington (1984) tested two rooms and found R/Ts of 0.73 and 0.76 seconds. Harper 1995 measured R/Ts in five Auckland Primary Schools and they ranged from 0.37–0.56s with a mean of 0.43s. Sieben et al 1997 reported on some American and European studies where R/Ts ranged from 0.4–1.2 seconds.

A detailed description of the New Zealand research is contained in Appendix 1 – page 32.

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[7] Signal to Noise (S/N) Ratio – This is a measure of the level of the signal which the listener wishes/needs to hear compared with the level of the noise they do not want/need to hear—the background noise, e.g. if speech was 65 dB and noise was 55 dB the S/N ratio would be +10 dB.

RESEARCH METHOD

Survey Questionnaire

A survey questionnaire was administered to 122 teachers in seven Auckland primary schools. The schools selected covered the full socio-economic range from Decile 1 to 10, and each school had a small number of hearing-impaired students who wear hearing aids. The survey was developed with the assistance of three architectural acoustics students from the University of Auckland and trialed in one additional primary school (University of Auckland 1999). Our team reworked the questionnaire to better serve the aims of the project. The same person administered the questionnaire in all schools. Staff were introduced to the questionnaire at a briefing session. The questionnaires then were required to be completed within a specified period (one-week) and returned for collection to a central point. Response rate was improved by follow up reminders when questionnaires were not returned. The overall response rate for the survey was 93%.

See Appendix 2 – page 35.

Building Survey

A plan of each school was obtained. All the schools had a variety of classrooms with different building designs, usually more than one room of each design type. One example of each of the room styles in each school was surveyed. The siting, dimensions, surface finishes and construction materials were recorded, in addition to photographic records of the interior and exterior, for correlation with the teacher survey questionnaires. The same person carried out all the building surveys.

Selection of Test Rooms for Detailed Study

The questionnaires in conjunction with the building surveys were used to identify 'test' rooms for further detailed investigation. The selection of the test rooms was made on the basis of:

(a) the teacher's answer to Question 3 on the Questionnaire

> *Q. How do you rate your classroom listening environment?*
>
> A. Good rooms had a rating of *very good*, or *good* and poor rooms had a rating of *poor* or *very poor*

(b) whether rooms of the same design in that school had a similar rating for Question 3

(c) the age of the children in the room. For speech testing purposes the children had to be between 8 and 11 years old

(d) twelve rooms were selected, two from each of five schools, one of which was identified by teachers as acoustically good (or v. good) and the other as acoustically poor (or v. poor). In the sixth school, there was only a good room, so a complementary poor room was selected from the seventh school.

Detailed Investigations

Detailed investigations included speech perception tests in live and simulated background noise for both normal-hearing and hearing-impaired children, measurements of acoustic parameters e.g. R/T and clarity, recordings of classrooms noise levels over an entire day, recording through a hearing aid and FM system.[8]

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[8] Data collected through the recordings from hearing aids and FM systems is available to be analysed.

Speech Perception Tests

SUBJECTS

Four children aged between 8 and 11 years were selected from each classroom for the speech testing. The teacher was asked to select children where the reading age matched or exceeded the chronological age for the normally-hearing children. It was also specified that no child should have: hearing loss, a learning disability or English as a second language.

A small number of hearing-impaired children who wore hearing aids were also tested in each of the schools. These were pupils who normally attended the schools. They were tested wearing their usual hearing aids and where applicable Radio (FM) Systems at normal settings. If an FM system was worn the transmitter microphone was placed at a distance of 20cm from the loudspeaker and slightly below to simulate the effect of a lapel microphone. If the child did not use an FM system, then they were tested with hearing aids alone. A total of 10 hearing-impaired children were tested. They ranged in age from 7 – 11 years. In some cases they were not in their normal classrooms but were brought into the test classrooms for the purpose of the experiment. They had hearing losses ranging from mild to severe.

See Appendix 3, for children's audiograms – page 42.

Two of the hearing-impaired children had English as a second language, both wore FM systems.

SPEECH MATERIAL

The speech material used was a University of Melbourne recording of BKB (Bamford-Kowal-Bench) sentence lists (Bamford-Kowal-Bench 1979). The test material consists of 21 lists of 16 sentences with an open set response (not predictable material) with each sentence carrying 3–5 key words that are scored, to give a total of 50 key words in each list. The sentences are based on the vocabulary and grammar of 8 to 16 year old hearing-impaired children. The University of Melbourne version is recorded by an Australian male speaker.

EQUIPMENT AND LEVEL CALIBRATION

A portable CD player connected via an amplifier to a directional loudspeaker approximating the directivity of the human voice was used to present the sentence material. The loudspeaker was set up at the front of the classroom, at a height of 1.5m from the floor. The sentence lists were calibrated using a 1kHz calibration tone so that at a distance of 1m at 0 degrees azimuth the level of the tone was 71 dBA (measured using a B&K 2260 SLM). This corresponded to the average peak level of the speech being 71 dBA. This level was chosen as being representative of an average teaching voice level (Carr 1996).[9] The test position was then located at a distance of 4m from the loudspeaker. This position was chosen to represent the seating position of a child in the ‘back’ 1/3 of the classroom. In a study of six hearing-impaired children Harper (1995) found the average distance between a hearing-impaired child and their teacher was 3.5 meters. The level of the signal actually measured at the test position ranged from 60–64 dBC, this level approximates normal conversational voice level at 1 metre. [10]

[9] The presentation level was chosen based on a survey of the literature by Carr 1996. This showed teachers’ voice levels ranging from 67 -78 dBA at 2-3 metres. Carr herself presented at 65 dBA at 2 metres.

[10] Final S/N ratio settings and noise level recordings were made in dBC which means that measurements are essentially unweighted. This was selected because the team wished to include in the measurements the low frequency noise caused by noise sources such as those generated by floor noise. This would allow the consideration of the effect low frequency noise has on speech intelligibility—a concept known as “upward spread of masking”, which means that loud low frequency noise masks out the quiet high frequency sounds in speech. The calibration was done using 1 kHz calibration tones.

TEST METHOD

The test subjects were asked to listen to a sentence list and repeat each sentence in turn to the tester seated alongside. For each child the number of key words correctly relayed to the tester was recorded and a score calculated out of 50. Testing was carried out in occupied classrooms and the background noise level recorded in dBC Leq for each sentence list. The mean number of students present in the classrooms was 25.6 with a standard deviation of 4.

The Speech Testing Was Carried Out in Two Conditions:

1. Simulated Classroom Noise

Recorded classroom noise was played through four loudspeakers placed close to the four corners of the room.[11]

The A-weighted Leq sound level of one sentence was measured at the test position and the level of classroom babble was adjusted to be equal to the speech signal, giving a Signal-to-Noise Ratio (S/N ratio) of 0 dB. The S/N ratio reflected a difficult but not atypical classroom listening environment. During the recorded background noise testing, the class was asked to read quietly. The noise levels were measured at the test site by a researcher and ranged from Leq 62–70 dBC.

2. Live Noise

In this experiment all children were given an age appropriate classroom activity sheet and asked to work in pairs. The same activity sheet was used in every class. The teacher told the children that normal working noise would be tolerated, and a 5-minute period was allowed to let the noise to settle to a 'normal' level. During the presentation of the sentence lists the Leq background noise level was measured at the test site and noted on the individual score sheets. The live noise levels measured at the test position ranged from Leq 63–77 dBC.

The hearing-impaired subjects were usually tested last in the recorded noise settings and first in the live background noise settings, to reduce the time they needed to take out of lessons. They were tested in both the 'good and bad' classrooms so that a comparison could be made. They were otherwise tested in the same manner as the normally-hearing children.

Reverberation Time and Clarity Measures

R/T and clarity measurements were carried out in the 12 test rooms in both occupied and unoccupied conditions, using the University of Auckland room acoustics measurement equipment. The measurements were made and analysed using the Midas room acoustics software package—a joint development by the Universities of Auckland and du Maine (Le Mans, France). This system generates a special test signal (Maximum Length Sequence) to measure the room's impulse response. This test signal permits modest sound levels during measurements hence avoiding unnecessary exposure of the children to high noise levels and uses coherent averaging to remove any influence of children's noise on the measurement.

The room impulse response is the ideal measurement from which all standard acoustical performance measures can be derived.

[11] Harper, 1995, initially developed the recorded classroom noise. Real classroom noise was recorded in a classroom with 33 students aged 10-12 yr. The noise recording includes voices, pens clicking, desktops banging, and movements around the classroom, doors shutting and chairs being moved. Sections of the recording were chosen where the levels fluctuate no more than 3-6 dB and dubbed five times to give a 46 minute recording. The tape has a 1Khz calibration tone. The range of level fluctuations actually encountered by Harper in this classroom was 10.8 dBA.

DAY LONG RECORDINGS

In 10 of the 12 classrooms a 'day in the life' of the classroom was recorded. Two microphones were used: one near the front of the room close to the teacher's desk; and one towards the rear of the room. These were suspended from the roof trusses where possible (at a height of approximately 2m from the floor), and mounted on microphone stands (1.5m from the floor) when this was not possible. The exact position varied between classrooms depending on the furniture layout and the need to position the equipment in secure and convenient locations.

The microphones were connected to either a digital audiotape (DAT) recorder type CASIO DA-R100 or an analogue recorder type NAGRA T. A calibration tone was recorded at the start of the day for each microphone. Teachers and children were instructed to ignore the equipment and to carry on 'as usual'.

A trained listener then logged the tapes using a categorisation system that identified the teaching activity that was occurring during the day. The categories used were mat work, didactic, one-one, group work, empty classroom and lunchtime. Analysis of the recorded levels during the different classroom activities was carried out using a Bruel and Kjaer sound level meter type 2260. This provided:

1. The equivalent continuous sound level, Leq, (sometimes referred to as the time-average level) which indicates the total noise exposure of both teacher and pupils.
2. Percentile levels. We propose that the difference between a high percentile level (e.g. L5) and a low percentile (e.g. L90) will provide a realistic measure of the signal-to-noise ratio of a classroom during periods of instruction by the teacher. This may also be a useful indicator of how this varies during the range of classroom activities.

Room Modifications

Based on the analysis of the detailed measurements for the good versus poor rooms, the six rooms that were rated as acoustically poor were modified by the installation of selected acoustic ceiling tiles to reduce their R/Ts to match the mean R/Ts in the 'good' rooms.

R/Ts were analysed for poor rooms to determine the room treatment required to achieve a 0.4-second R/T with a flat response across the speech frequency range. Three solutions were proposed:

1. Echophon Master F– beta finish (40mm thick) ceiling tiles direct fixed to the central area of the ceiling—approximately 35 m^2 of treatment in total
2. Rockfon Arktic mineral fibre ceiling tiles on a 200 mm airgap, to the central area of the ceiling (approx. half of the total ceiling area treated—35 m^2)
3. Softboard acoustic ceiling tiles to the underside of the trusses (entire ceiling area) This solution came directly from R/T measurements of relocatable classrooms already treated in this way, that were rated as good in the Survey Questionnaire).

Two rooms were treated with each solution. All classrooms were of the relocatable type.

<u>Solution 1</u>

This option has the least impact on the room visually. One teacher commented that you "hardly notice it is there". This is an ideal option for more complicated roof designs with clerestorey windows, raised skylights etc. where other options would not be possible. The tiles themselves have the highest cost per m^2 of the three solutions but as they can be direct-fixed, there was no requirement for a supporting grid system, and lighting fixtures did not require repositioning.

<u>Solution 2</u>

Visually this option has the effect of the trusses disappearing into a dropped ceiling. A suspension grid system was required, and lighting fixtures needed to be refitted to the new ceiling.

Solution 3

This option had the most impact on the room visually. We consider that this option is only suitable if the stud height is in the order of 3m or more, otherwise the ceiling feels oppressively low. When asked to identify any new problems created by the classroom modifications one teacher commented that she found the reduced ceiling height "slightly low".

REPEAT MEASUREMENTS / FOLLOW-UP QUESTIONNAIRE

Surveys and detailed measures were repeated in the modified rooms:

i. a follow-up teacher survey was carried out in the modified rooms, *Appendix 2 – page 35*
ii. speech testing
iii. measurements of acoustic parameters
iv. day-long recordings.

RESULTS

Survey Questionnaire Findings

Room Characteristics

Teachers were asked to give an importance rating to various aspects of their classroom. Adequacy of space was rated as the most important followed by lighting, acoustics, ventilation and finally equipment such as computers etc. When teachers were asked to rate their classroom listening environment on a scale from 1 being very good to 5 being very poor, The mean rating was 2.8, with the median and mode values being 3 (i.e. the 'acceptable' rating). 7% of teachers rated the listening environment as very good, 32% good, 34% acceptable, 21% poor and 6% very poor. Further details of these ratings in relation to building design are given in Table 1 and Figures 4–7. When asked why they rated a room as 'poor' or 'very poor' the majority listed "too much echo", and "noise level produced by students too high" or cited noise from outside the room as a problem rather than choosing "open plan rooms" as an option for why the noise was high. There were only a small number of open plan rooms included in the study and in many schools open plan rooms had been converted back to single cell rooms.

Teaching Style

One of the key findings highlighted by the Survey Questionnaire is the dramatic change in teaching style that has occurred in recent years. The traditional lecture-style teaching that today's adults experienced as children has been replaced with mat and group work.

Figure 1 shows that the main teaching style of the teachers surveyed across all primary age groups was group work (38% of teaching time on average) followed by mat work (31%). Lecture-style communication accounts for only 12% of teaching time.

The teaching style is a dynamic one with teachers spending a large part of their day walking around. 71% of the teachers surveyed described "walking around" as their usual position in the classroom. See Figure 2 below, some teachers gave more than one response to this question.

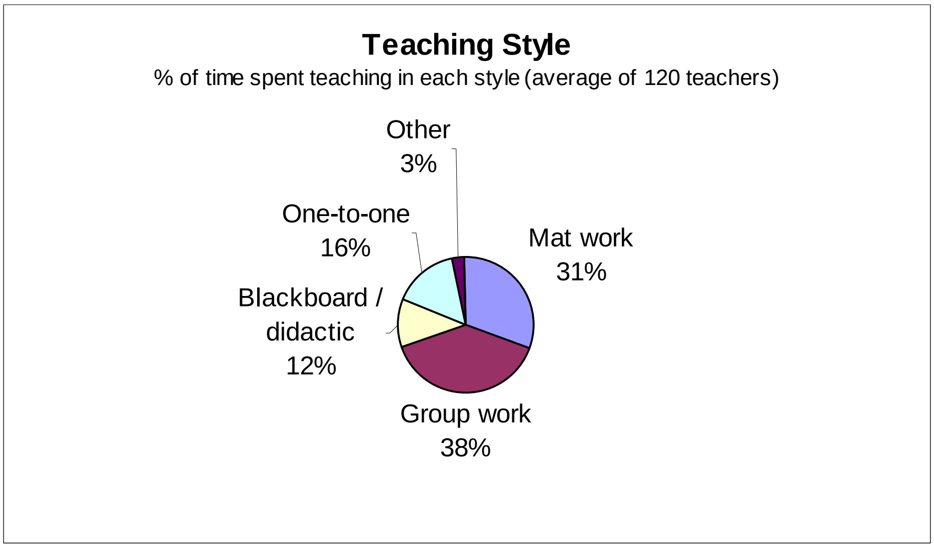


Figure 1: The proportion of time teachers spend teaching in each style

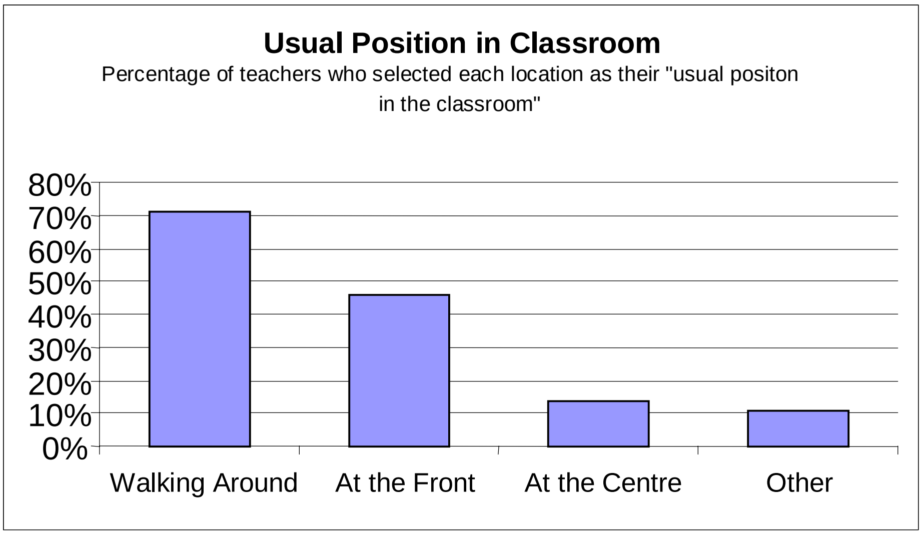


Figure 2: Location selected by teachers as their ‘usual position in the classroom’
(In response to the question "Where is your usual location in the classroom?")[12]

Noise levels

Classrooms are noisy places. 71% of the teachers surveyed reported that noise generated within the classroom is a problem.

59% of teachers reported that most or all of the noise created inside the classroom is student generated. Computers were the most commonly identified other source of noise generated within the classroom.

86% of the teachers surveyed have problems with noise generated outside the classroom e.g. from nearby classrooms, corridors, decks, sports fields, lawnmowers, and road traffic noise. Figure 3 shows the number of times teachers identified the above noise sources as being a problem. Rain noise, and toilets and hand dryers from cloakrooms, were commonly noted in the ‘other’ noise source category. Lawn mowing, noise from sports fields and from other classrooms were the most frequently reported external noise problems.

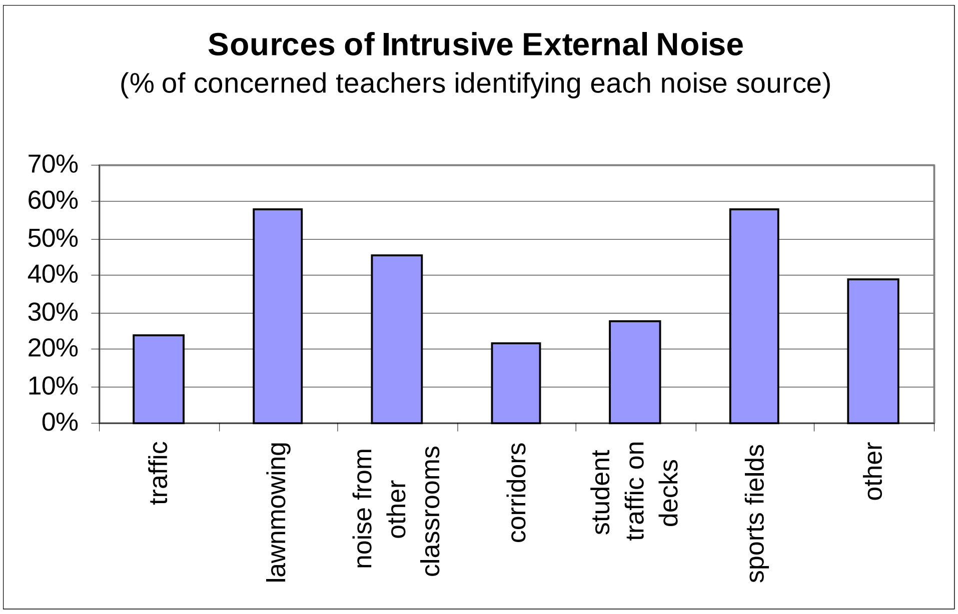


Figure 3: External noise sources identified as a problem

[12] Some teachers reported more than one location.

Vocal Effort

Vocal strain is a serious occupational hazard for teachers and occurs because the teachers need to speak for long periods of time at an elevated voice level. Teachers experience a higher incidence of voice problems than the general population. In a study, reported in Sapienza et al 1999, 80% of teachers reported vocal fatigue compared with 5% of the general population.

In this study 35% of teachers said the level at which they needed to speak strained their voices. 33% said they always or often had to elevate their voices to be heard.

The results showed that teachers in classrooms rated as very good or poor had similarly high rating of vocal strain of 43% and 45% respectively. The good (34%) and satisfactory (30%) ratings rested around the average for all the classrooms. Interestingly those teachers in the classrooms rated as very poor had the lowest level of vocal strain at 23%. In the classrooms which had the overall poorest rating by teachers (type 1: relocatables, with no acoustic treatment on ceilings) also had the highest rating of teacher needing to raise their voices. 55% of teachers reported having to always or often raise their voices to be heard and 41% reported that the level at which they needed to speak strained their voices. This was significantly above the average levels for all the classrooms.

Group work is the teaching style that was reported to require the highest voice level. This is also the most commonly reported teaching style with an average of 38% of the time spent in group work, and 49% of teachers reporting that they need to raise their voice in this teaching mode.

Correlation with Building Survey

Classroom types were categorised into four main types from the building survey. These were:

Type 1
Relocatable classrooms constructed from lightweight materials (timber framing, raised particle board floor) with an acoustically-hard, pitched ceiling following the line of the roof (central ridge and 15 degree pitch)

Type 2
Relocatable classrooms (lightweight construction) with softboard acoustic ceiling tiles fixed to the underside of the trusses, forming a horizontal ceiling plane

Type 3
The older style permanent classrooms with a concrete on grade floor construction and softboard acoustic ceiling tiles (perforated softboard) forming a horizontal ceiling

Type 4
The older style permanent classrooms with a concrete on grade floor construction and an acoustically hard, flat ceiling (plasterboard or fibre-cement).

Definition of categories of classroom in the study							
	1	**2**	**3**	**4**	**5**	**6**	**7**
Type	Relocatable	Relocatable	Permanent	Permanent	Permanent	Permanent	Open Plan
Ceiling	hard	acoustic	acoustic	hard	acoustic	hard	acoustic
Floor Construction	timber	timber	concrete	concrete	timber	timber	concrete
Floor covering	carpet	carpet	carpet	carpet	carpet	carpet	carpet
Walls-overlay	hessian faced softboard	hessian faced softboard	hessian faced softboard	hessian faced softboard	hessian faced softboard	hessian faced softboard	hessian faced softboard
Number of Responses (subjective rating of classroom listening environment) in each category							
	1	**2**	**3**	**4**	**5**	**6**	**7**
Subjective Rating							
Good or Very Good	2	23	19	3	5	0	0
Acceptable	7	9	15	8	0	0	1
Poor or Very Poor	12	2	3	4	1	3	2
Total number rooms of this type	21	34	37*	15	6	3	3

* includes 8 partially open plan classrooms (6 rated as 'acceptable', 2 rated as 'very good')

Table 1: Teachers' subjective ratings for different building types

Table 1 presents the range of building types in the survey, and the teachers' subjective ratings of the classroom listening environment for each classroom type.

Classrooms that were identified as having good acoustics were generally permanent older style classrooms with masonry floors and softboard acoustic ceiling tiles (Type 3), permanent classrooms with timber floors and softboard acoustic ceiling tiles (Type 5), or relocatable classrooms with a suspended softboard acoustic tile ceiling (Type 2). The classrooms identified as having poor acoustics were generally relocatable type classrooms with acoustically hard pitched ceilings, or permanent classrooms of a similar design. Permanent classrooms with hard ceilings and concrete floors were mainly regarded as acceptable

Figures 4–7 below show the teachers' subjective ratings for each of the main classroom types.

We speculate that the poor subjective ratings for relocatables with hard ceilings result from a combination of a hard pitched ceiling that is slightly sound-focussing and floor noise associated with the timber floors and attached timber decks. Floor noise and student traffic on decks were identified as problems in the extra comments section of many of the questionnaires relating to relocatable classrooms.

Overall, there is a strong correlation across all cellular classroom types between acoustic ceiling tiles and good subjective ratings of the classroom listening environment. 66% of classrooms with acoustic tile ceilings were rated as good or very good. see Figure 8.

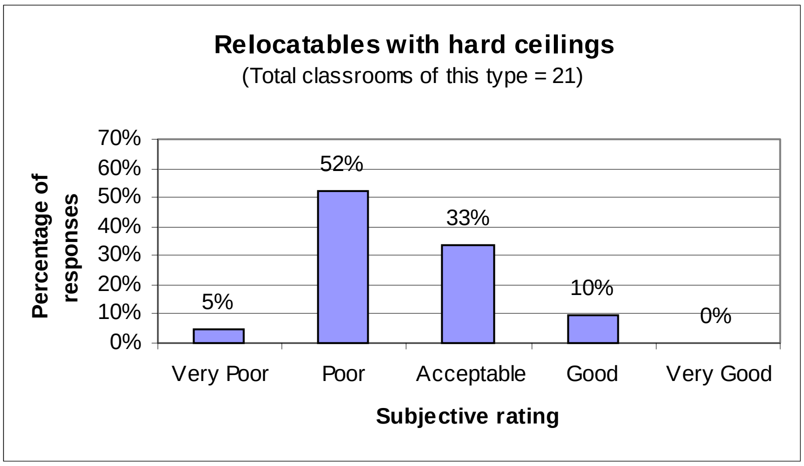


Figure 4: Subjective ratings for relocatables with hard ceilings

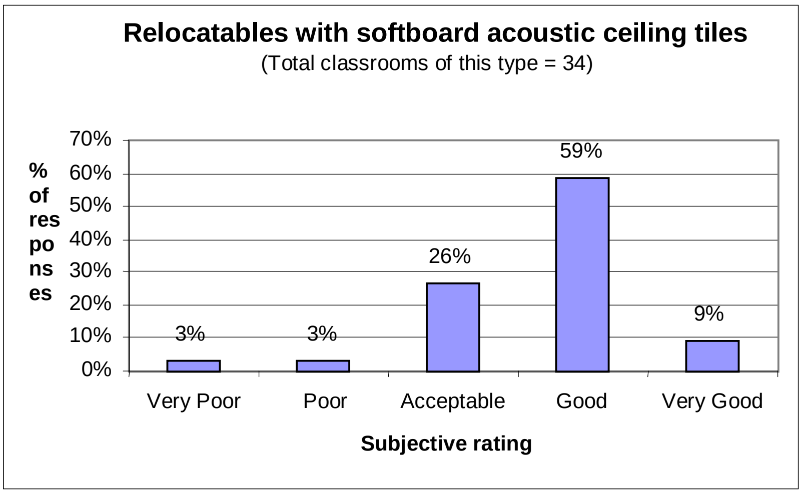


Figure 5: Subjective ratings for relocatables with softboard acoustic ceiling tiles

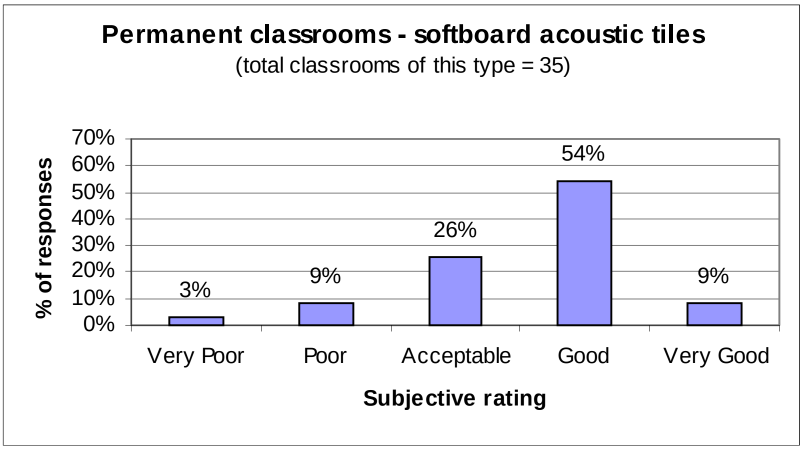


Figure 6: Subjective ratings for permanent classrooms with softboard acoustic ceiling tiles **(includes concrete and timber floor constructions but excludes partially open plan rooms)**

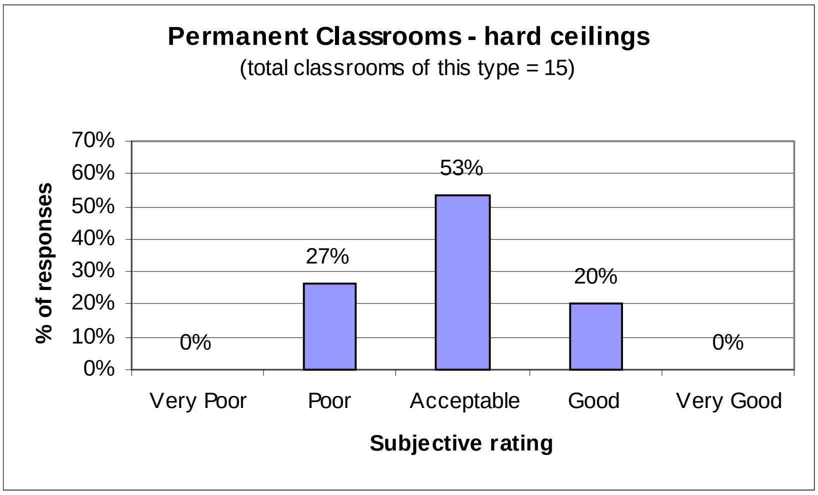


Figure 7: Subjective ratings for permanent classrooms with hard ceilings and concrete floors

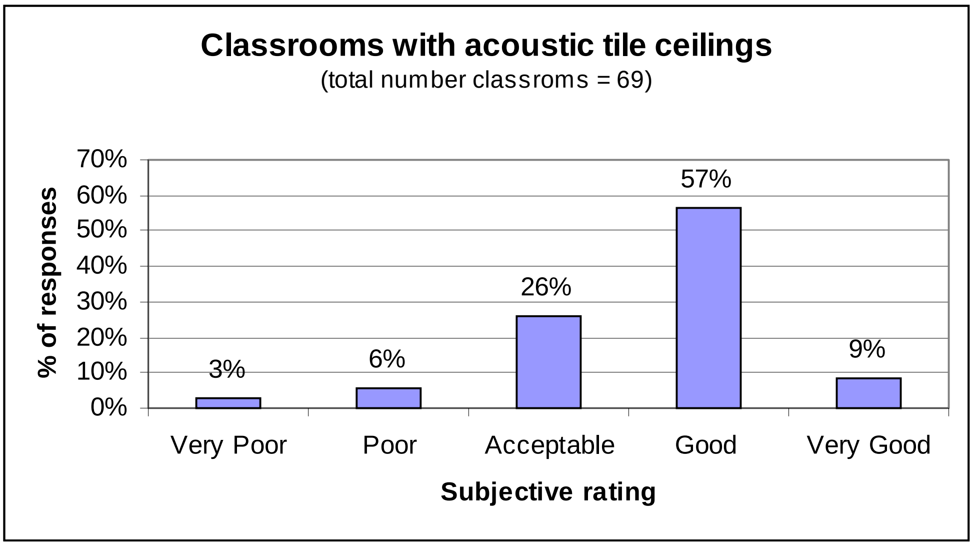


Figure 8: Subjective rating of cellular classrooms with softboard acoustic ceiling tiles

Detailed Measurements

Speech Testing

The mean age of the normally-hearing test subjects (n=49) was 9.4 years, with ages ranging from 8.2–11.9 years. Mean reading age was 11.3 with a range from 7.5–13.5 years.

The mean speech level was 62 dBC with a very small range from 60–64 dBC. The live noise levels were consistently higher than the simulated noise levels in both types of rooms. Table 2 lists the noise level measures and speech scores for the normally-hearing and hearing-impaired children.

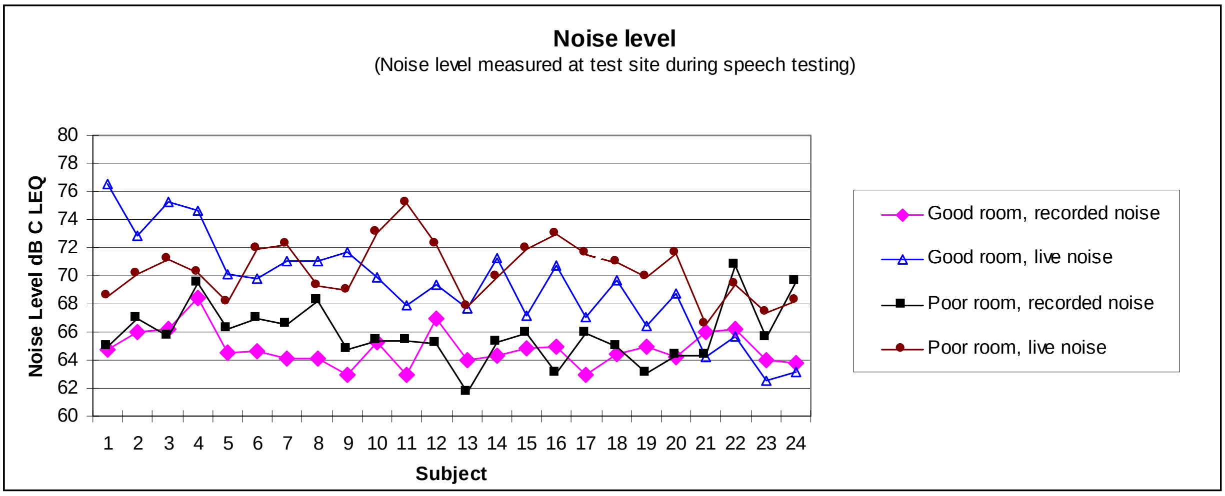
NORMALLY-HEARING	**GOOD ROOMS**	**POOR ROOMS**
Noise Level Recorded Noise	64.8 dBC (Range 62–71 dBC)	65.9 dBC
Speech Score Recorded Noise	89.8%	85.6%
Noise Level Live Noise	69.0 dBC (Range 63–77 dBC)	70.5 dBC
Speech Score Live Noise	56.8%	50.0%
HEARING-IMPAIRED		
Noise Level Recorded Noise	64.8 dBC	66 dBC
Speech Score Recorded Noise	52.8%	59.6%
Noise Level Live Noise	67.4 dBC	71 dBC
Speech Score Live Noise	49.8%	40.6%

Table 2: Mean speech scores and noise levels in good and poor rooms for hearing-impaired and normally-hearing children (equivalent ages and speech presentation levels 62 dBA)

The plot of noise levels and speech scores for normal-hearing subjects in both poor and good rooms are shown overleaf in Figure 10.

In summary the main findings of the speech perception testing in the normally-hearing group were:

- the results did not differ significantly between the good and poor rooms
- the live noise speech scores are highly negatively correlated (< 0.1% significance) with the live noise levels for both good rooms and poor rooms
- the mean S/N ratio in the live noise condition was –8 dB and in the recorded noise condition the mean S/N was –3 dB
- in the recorded background noise the speech scores results are relatively stable with the majority of scores falling in the range 80–100% (Mean 87%)
- in the live noise the scores fluctuate widely ranging from 0 – 98%, with more than 40% of the scores falling below 50% correct.



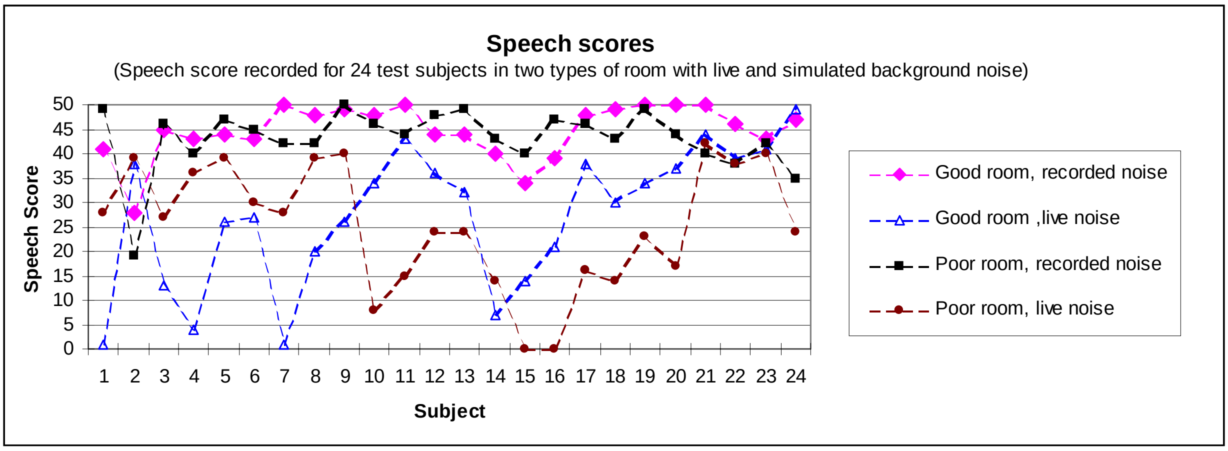


Figure 10: Plot of noise levels and speech scores for 24 normal-hearing subjects in both good and poor rooms.

Hearing-impaired Subjects

The mean age of the hearing-impaired subjects (n=10) was 9.4 years with the mean reading age being 8.5 years. This shows the hearing-impaired subjects to be on average one year behind their chronological age for reading, compared with the normally-hearing subjects selected who on average were two years ahead. The speech and noise levels during testing were consistent with those for the normally-hearing group, see Table 2. The children using FM systems obtained the best performance of the hearing-impaired children; despite these being the children with the greatest degree of hearing loss, see Figure 11. Children with degrees of hearing loss regarded as mild to moderate and fitted with conventional hearing aids only, performed very poorly in the speech testing, with the majority of scores ranging between 0–50%. Half of these children scored less than 20%. Children with severe hearing loss who were fitted with FM radio hearing aids in addition to their normal-hearing aids performed quite well, with the majority of scores ranging between 50–90%. There was no difference in scores in the recorded/live noise conditions in the children fitted with FM systems however those with hearing aids alone showed a much worse performance in the live noise condition, see Table 3.

FM / No FM	Recorded Noise	Live Noise
FM	67.5%	60.2%
No FM	39.5%	25%

Table 3: Mean speech test results for hearing-impaired children with and without FM systems

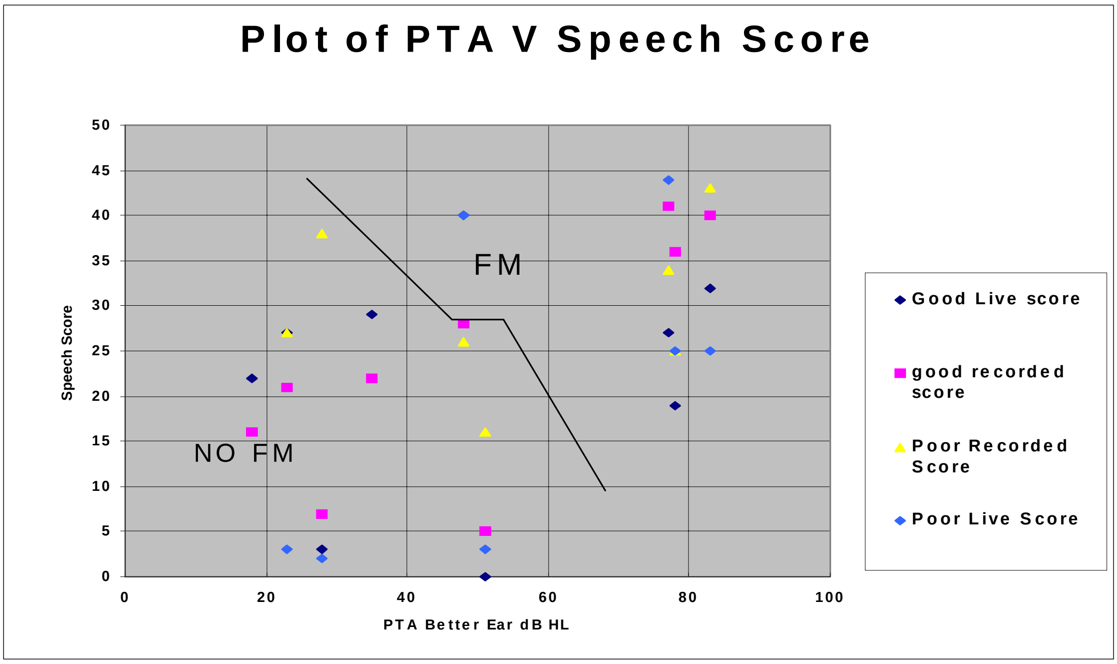


Figure 11: Speech scores of the hearing-impaired children plotted against their audiometric threshold. It shows the opposite trend to what would be expected in that the children with the worst hearing losses are scoring the highest. The points above the solid line indicate those children who are fitted with FM systems and shows clearly how those with the worst hearing losses are fitted with FM systems and these are the children who have the highest scores on speech perception testing.

Reverberation

The average R/Ts of the six good and six poor classrooms are shown in Figure 12. The 'good' classrooms typically had a mid-frequency (average of 500 Hz & 1kHz) R/T of 0.4 seconds, with the exception of one room, which was a permanent classroom with a concrete floor and a sprayed plaster finish (acoustically hard) ceiling. This classroom had a mid-frequency R/T of 0.56 seconds.

The mid-frequency R/T in the 'poor rooms' ranged from 0.53 to 0.63 seconds, with an average value of 0.57 seconds.

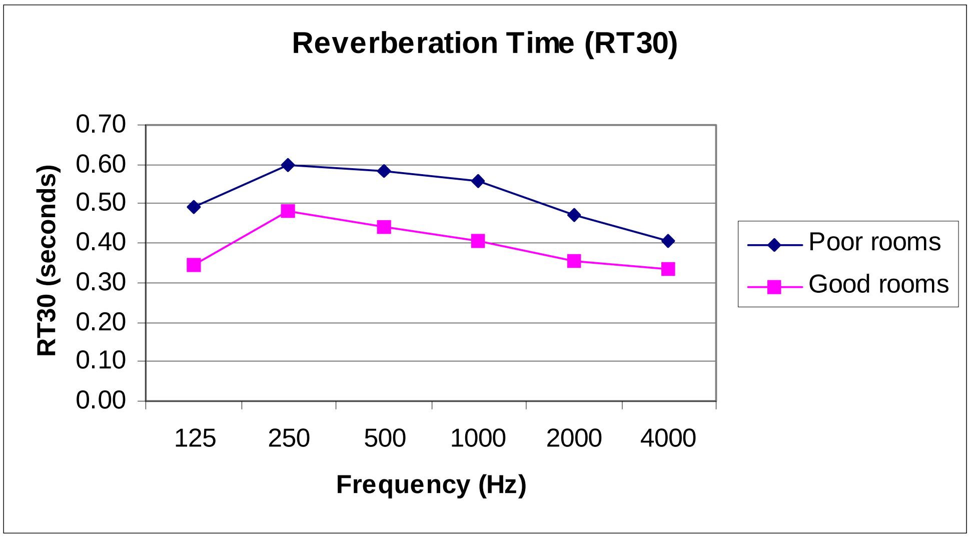


Figure 12: Average occupied R/T measurements for good and poor classrooms

Clarity

A further measure extracted from the room impulse responses is that referred to as Clarity[13] (C50). This is a standard quantity that has been used for the assessment of spaces for their suitability for communication between adults. However, the C50 values obtained in the classrooms did not differentiate between the good and the poor classrooms. One hypothesis for this is that strong reflections from a hard ceiling (usual in the poorly rated rooms) balance the effects of the higher level of reverberation in the poor rooms, thus keeping the C50 early-to-late ratio relatively constant.

Day Long Recordings

Preliminary analysis of the noise recordings in the classrooms indicate that average levels range between 50 and 70 dB(A) and, as would be expected, a typical classroom noise spectrum is quite broadband. The influence on the level and spectrum of the type of classroom is information we expect to come from the analysis of the daylong recordings but this work has yet to be completed so we cannot conclude on this matter. However, noise levels measured during the before and after speech perception tests in the modified classrooms suggest that there is probably a significant reduction in children-generated noise when the room R/T is reduced from 0.6 to 0.4s, see Figure 13.

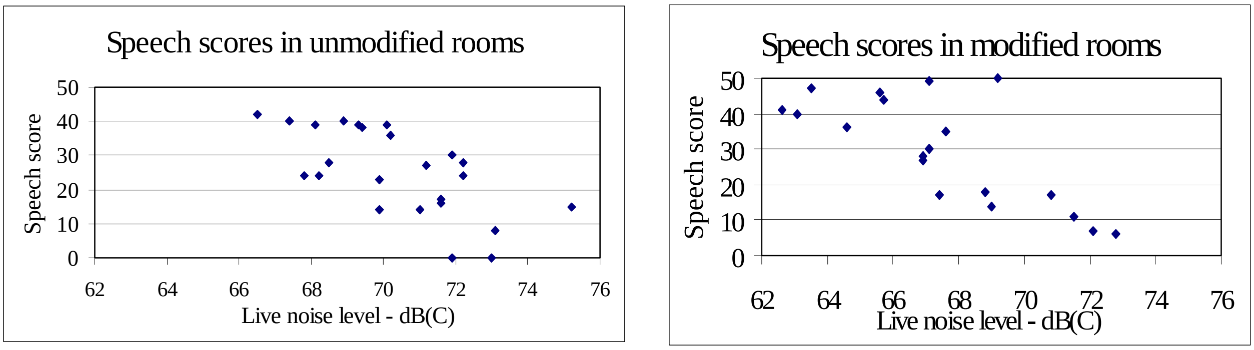


Figure 13: Speech scores in the originally rated ‘poor’ rooms before (left) and after (right) the addition of an absorptive ceiling (speech score of 50 = 100%)

Repeat Measurements

For two of the classrooms the teacher questionnaire, measurements, classroom modifications, repeat measurements and follow-up measurements were carried out within the same teaching year. Four of the classrooms were not modified until the following school year. Unfortunately this introduced some additional variables. In one school the original teacher was replaced with a new teacher—new to the room, and to the school. It was difficult for her to respond to the follow-up questionnaire as she had only experienced the unmodified room for a few weeks. The children changed in four of the classrooms.

Figure 14 shows the occupied R/T in the modified rooms compared with the original conditions. The results are the average for the six rooms treated.

In five of the modified rooms the mid-frequency R/T in the occupied rooms ranged from 0.34–0.39 seconds. These values are consistent with the predicted R/Ts. In the remaining room the mid-frequency occupied R/T was 0.52 seconds compared to a predicted value of 0.4 seconds.

[13] Clarity (C50) or the early-to-late sound energy ratio measured at a point in a room, is 10 log of the ratio of the integrated squared pressure, arriving before 50 milliseconds, to that arriving after 50 milliseconds:

$$C50 = 10 \log \frac{E(0 - 50 \text{ ms})}{E(50 - \infty \text{ ms})} \text{ dB}$$

During the tests prior to the modifications there were 25 children aged 6 to 7 years in this classroom and after the modifications there were a smaller number of younger children (22 aged 5 to 6 years) in the room. This may account for the difference between the predicted and measured values.

In the unoccupied rooms the average mid-frequency R/T prior to modification was 0.69 seconds, and after modification it became 0.43 seconds.

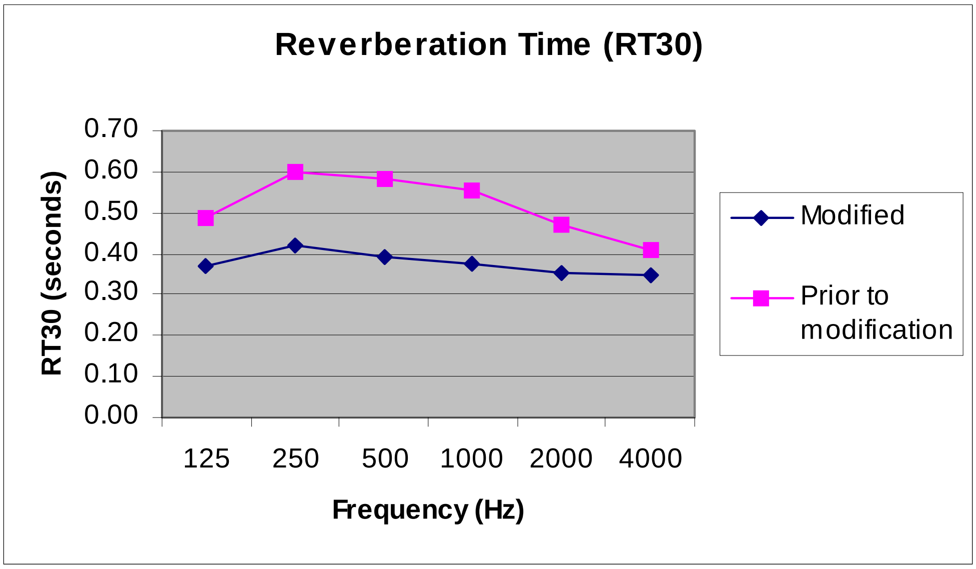


Figure 14: Average R/T in occupied classrooms before and after modification

Follow-up Survey

Teachers in the modified rooms were re-administered the original survey questionnaire and also asked to complete a follow-up questionnaire more specifically related to the classroom modifications. Overall the teachers and pupils were enthusiastic about the improvements.

Four out of five teachers rated the acoustic environment in the modified rooms as significantly better, and one teacher as slightly–significantly better. The teachers' subjective ratings of the classroom listening environment before and after modification are tabled below.

Teacher	**Teacher's Subjective Rating of Classroom Listening Environment**	
	Prior to modification August-Oct. 1999	After modification May 2000
1	Very Poor	Acceptable
2	Very Poor	Good
3	Poor	Good
4	Poor	Good
5	Poor	Good
6	Poor	Poor*

* This teacher commented: "some sound has been absorbed but the room still has problems, mainly from floor noise"

Table 5: Teachers' ratings of poor rooms

The follow-up survey asked teachers to subjectively rate the modified classrooms for different teaching styles. All teachers rated inside noise levels and students' hearing ability as better for group work and mat work. Four out of five teachers rated inside noise levels and students' hearing ability as better for one-one and didactic/blackboard teaching styles. The remaining teacher rated the classroom as the same for one-one and didactic/blackboard teaching.

Additional comments from teachers include: less noise, more on-task behaviour, reduced frustration, better hearing, and the ability to successfully work in small groups on different tasks. One teacher commented that the children's voices and movements were more muffled now and that she didn't feel that the children were yelling, as was the case previously. Similarly, another teacher commented on the ease of listening for the children now that the tiles had been installed. In the original survey prior to the modifications this teacher had described escalating noise levels due to the hard ceiling: "noise from children's voices seems to bounce back from the ceiling, then they raise their voices to hear each other, and so on." One teacher commented that this is the first year in this classroom that she hasn't suffered from voice strain; another commented that she was more aware of off-task behaviour now, whereas before all the children had seemed off-task.

Unprompted comments from children included: better hearing, less noise and a more peaceful environment. Comments from other colleagues included: "can I have the same for my room," reduced rain noise compared to adjacent rooms and a noticeable improvement in the acoustics of the room during after school meetings. A relieving teacher with hearing aids in both ears found his teaching days much easier. Some teachers commented that the floor needed to be treated now, and that floor noise and noise from adjacent classrooms was more noticeable now that the room was quieter.

The results for the speech perception tests (Fig.13) did not differ significantly between the poor and later modified rooms ($p=0.38$ for live noise, and $p=0.32$ for recorded noise) but class activity noise levels differed very significantly ($P<0.0001$) with the levels in the modified rooms being much lower.

DISCUSSION

The following discussion considers the results of the study in the light of other research and some of the theoretical discussions around classroom listening environments. The technical terms, which are used, have been defined earlier in the report.

Acoustical Considerations for Classrooms

Our initial findings with respect to noise levels classrooms are in line with the levels in classrooms reported by researchers from Herriot-Watt University in Edinburgh (McKenzie 1999). They measured noise levels, which averaged 55 dB(A) in rooms where children are 'quiet', and levels around 77 dB(A) when the pupils are working. They also found lowered levels when the rooms were treated by the addition of an absorbent ceiling. The measures of background noise levels in this study showed that the poor rooms had significantly higher levels of background noise and we hypothesise that this is due to the 'café effect'.[14] The additional acoustic absorption in the form of the ceiling tiles appeared to have had a calming effect seen in the noise levels and this was borne out by the teachers' and pupils' comments in the modified rooms.

This raises interesting and potentially important issues for further research, which are:

1. To distinguish whether this reduction has (in addition to the obvious component resulting from the effect of a reduced R/T on the room reverberation) a component resulting from the children instinctively reducing their sound output, and therefore reversing the 'café effect'.
2. To find out if proximity to an absorbing surface has an influence on the amount of sound that children produce. This has implications for whether an absorbent ceiling can substitute for having carpet on the floor.

Unoccupied background noise level is a measure that is often used in overseas research. This is important for rooms that have a constant background noise from heating, ventilation or air conditioning. In New Zealand classrooms that are naturally ventilated via open windows, unoccupied classroom noise levels fluctuate with intermittent external noise. Previous New Zealand research has shown unoccupied noise levels range from 28–60 dBA. In this study computers were identified as the main source of non-student generated noise and increasing use of computers in classrooms will raise the overall background noise level. Care should be taken in siting computers in classrooms and selecting models that have a low operating noise rating.

Compared with results from overseas studies, where R/Ts in untreated rooms were found to often exceed 1 second (Sieben et al 1997), the level of reverberation in the poor rooms in this study does not seem excessive. The effects of reverberation can easily be felt in a completely empty room when there is nothing to absorb the sound. Rooms which have long R/Ts are often described as 'echoy' or 'hollow'. The addition of the appropriate amount of absorbing material into a room removes this effect and lowers R/T.

The modifications to the ceilings of the poor rooms lowered the R/T from 0.6 to 0.4 seconds. Teachers in our survey have clearly indicated that this reduction is significant, and that acoustic absorption at ceiling level is desirable. The correlation between building type and teacher rating showed that teachers definitely preferred acoustic treatment of the ceilings.

Interestingly we have not been able to demonstrate by Clarity measures or even by the direct speech perception tests on children that speech communication is significantly different between the good and bad rooms. Either the sensitivity and resolution of the speech perception tests are inadequate for showing up the differences in intelligibility in the rooms or the

[14] The café effect is a term used to describe the escalation in noise levels in a listening environment when a speaker is required to raise their voice to be heard. In a café this is usually over the noise of plates and cutlery etc clanging and other diners' voices. In a classroom with poor acoustics it is due to the pupils speaking louder to be heard and then the teacher having to raise their voice leading to an escalation in noise levels.

intelligibility was equally good in both types of room and differences perceived between the acceptability of the rooms are caused by features which are not measured in a single source position speech test.

In New Zealand it is Ministry of Education standard to have a carpeted floor (albeit thin), which provides some degree of acoustic absorption at mid and high frequencies and also prevents excessive noise from chair scrape and footfall. In many other countries of the world hygiene regulations do not permit the use of carpet due to health concerns about increased incidence of asthma and allergies. Many overseas classrooms therefore have acoustically hard floors and acoustically hard ceilings, which result in a high R/T. All the classrooms in this study were carpeted so this was not a variable.

Lubman et al 1999 presented data which showed that the top rated ceiling tile is three to six time more efficient at absorbing sound than carpet, particularly in the low frequencies. Ceiling tiles are therefore much more effective than carpet in reducing reverberation

Acoustic tiles are specified in terms of Noise Reduction Coefficient (NCR). Because New Zealand classrooms have some high frequency absorption from carpet and soft-board they require a tile that offers balanced absorption over the entire speech frequency range (125Hz–4KHz). The best description is ‘broadband moderate performance tiles’. If floors are not carpeted then a broadband high performance tile is required (Valentine 2002, personal communication).

The American Acoustical Society has recommended a Reverberation Time for classrooms of 0.4–0.5 (ASA 2000). The good rooms in the study were within this range whilst the poor rooms largely exceeded it. The American Speech-Language-Hearing-Association (ASHA) Acoustical Guidelines (Kailes et al 1999) recommend that:

- unoccupied classroom noise levels should not exceed 30 dBA
- R/Ts should not exceed 0.4 seconds, and
- the signal-to-noise ratio at a student’s ear should exceed a minimum of +15 dB.

As an outcome of this research group McGunnigle and Dodd from the research team had the opportunity to include recommendations for classrooms in a new standard—Australian and New Zealand Standard AS/NZ2107:2000 Acoustics – Recommended design sound levels and R/Ts for building interiors. They were able to specify *satisfactory*[15] (35 dBA) and *maximum* [16](45 dBA) unoccupied noise levels and R/Ts[17] (0.4s–0.5s) for primary school teaching spaces. With a recommendation:

> "Certain teaching spaces, including those intended for primary school students, students with learning difficulties and students with English as a second language, should have R/Ts at the lower end of the specified range."

This is a significant step forward. The Ministry of Education has recently included Acoustics into its *Design Standard Guidelines* with some of the recommendations made in this report being included. These are available on the Ministry of Education Website *www.minedu.govt.nz*

Teaching Styles and Acoustics

The study showed that in primary schools 69% of teaching time was spent in mat work or group work and only 12% in didactic blackboard teaching. This means New Zealand classroom designers need to consider classrooms as being more similar to open plan offices than to lecture theatres. Sieben *et al* 1997 recommends acoustic treatment of ceilings, floors and possibly walls when this type of teaching predominates. Good acoustical absorption with short R/Ts gives conversational privacy for group work. During group teaching sessions children need to be able to hear each other and the noise levels need to be controlled so that the café

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[15] Satisfactory design sound level – The level of noise that has been found to be acceptable by most people for the environment in question and also not to be intrusive.

[16] Maximum design sound level – The level of noise above which most people occupying the space start to become dissatisfied with the noise

[17] Reverberation time – time it takes for a sound to decay 60 dB after its source is turned off.

effect, described earlier, does not occur. Group tables should be separated as widely as possible for privacy. Teachers reported that communicating during group work sessions was the most difficult and many had strategies such as ‘clapping of hands’ or even ringing a bell to ask for silence to address the whole class.

In many primary classrooms teachers add their own soft furnishings to rooms which adds to absorption. Cloth hangings and absorptive wall panels can also be used to increase absorption. Consideration must be given to fire and health hazards that these additions give and professionally installed acoustic ceiling tiles and acoustic wall panels are much better from a health and safety perspective and recommended over the use of soft furnishings

During mat teaching sessions the S/N ratio is usually extremely favorable because the teacher is close to the students. Additionally, noise levels are lower as the teacher is able to better control the pupils at such close proximity.

At Intermediate and Secondary level the amount of diadatic teaching invariably increases and the room design should be modified accordingly. The ASA (2000) has recommended a design which has absorption on the walls and perimeter of the ceiling with a sloping ceiling in reflector at the front to project the teacher’s voice when lecturing or doing diadatic teaching.

Speech Perception in Classrooms

Speech perception testing was chosen in the experimental design to try and quantify child hearing/ listening performance in the classrooms. The test selected is based on linguistic abilities of hearing-impaired children of a matched age. One criticism of using speech testing to measure performance is that children's performance in speech testing tasks is dependent to some extent on linguistic ability.

In this study the average reading age of the normally-hearing children was three years above the hearing-impaired children although they were matched for chronological age. This finding agrees with other studies reported in Bess et al (1998) of the effects of hearing loss, even mild degrees of hearing loss, on educational outcomes. In this American study they found 37% of children with minimal degrees of hearing loss failed at least one grade at primary level.

The speech scores the children exhibited in the recorded noise condition were very good given the unfavorable S/N ratio recorded. One explanation for this is that lower scores obtained by other researchers in laboratory conditions may be due to children not performing well in laboratory or clinical settings. Another explanation is that the reported S/N ratio is more unfavourable than in other studies due in part to the measurements being made in dBC. Using this scale means that loud low frequency noises such as floor scrape can significantly increase a dBC background noise level recording.

The difference between the results in recorded background noise and live background noise show the clear distinction between speech testing carried out in more controlled experimental conditions and speech testing carried out in a real classroom situation. Most speech testing previously reported in the literature has been carried out in laboratories or clinical controlled conditions.

Noise affects our ability to perceive speech. Low frequency noise has a particularly detrimental effect as it masks out the quieter parts of the speech signal, usually the consonants, which contain most of the information content of speech. The effect of loud low frequency noise making the quieter consonants hard to hear is called in audiological circles ‘upward spread of masking’ and it is experienced by most people in situations like parties and pubs etc. People with hearing loss are usually more affected by ‘upward spread of masking’ than normal-hearing people as they are less able to perceive the consonant components because their hearing loss is usually worse in the high frequencies.

Long R/Ts also affect the clarity of speech. This is due to the reflected signal over-lapping with the new direct signal, causing what is known as temporal masking or smearing. In rooms with very short R/Ts the noise decays quickly and cannot interfere with the direct signal (Nabelek & Robinson 1982).

Hearing-impaired subjects are more greatly affected by long reverberations times. Carr 1995 reviewed the literature where empirical research had led to recommendations that classrooms for children should have R/Ts of <0.4 sec for the young hearing-impaired listener. In Carr's own research she found longer R/Ts had a much greater effect on hearing-impaired than normally-hearing listeners (Carr 1995).

Implications for hearing-impaired children

In this study the positive benefits of personal FM for hearing-impaired children were clearly demonstrated.

The children with the most severe hearing losses achieved the highest scores in the speech tests and all were using FM systems. The children with milder degrees of hearing loss scored the worst and none were using FM systems. Thus there was a strong negative correlation between the degree of hearing loss and the speech score explained by the use/non use of a FM system. In New Zealand at present it is not common practice to supply children with mild and moderate hearing loss with FM systems. These systems are routinely supplied to children with more severe losses. FM systems reduce the effects of background noise and provide a +10–+15 dB S/N ratio. This finding is in agreement with numerous researchers and practitioners in the educational audiology field who strongly recommend the trial of personal FM systems for children with hearing losses ranging from mild–profound (Flexer 1999).

Teachers are advised to give hearing-impaired children ‘preferential’ seating. However in group activities and with teachers reporting spending much of the day walking around the classroom this is an ‘out-dated’ concept and makes the need for hearing-impaired children to use FM systems all the more pressing.

Classroom Amplification Systems

An option for improving S/N ratios that was not explored in this study was the use of classroom amplification systems. These systems function optimally in spaces which are well designed acoustically and do not perform well in rooms with long R/Ts (ASHA 2000).

They aim to amplify the teacher’s voice to improve the S/N ratio and to provide an even spread of sound through the classroom so that effectively there is no acoustical rear to the room. They work by:

- having loudspeakers (usually four) positioned strategically around a room.
- the teacher wearing a radio microphone, which transmits his/ her voice to a receiver then to the loud speakers
- the system amplifying the teacher's voice by 8–10 dB (thus providing a positive S/N ratio in most situations).

The intention is to use an amplification system when the teacher is addressing the class as a whole and for mat work and for gaining the attention of the whole class during group work.

All children in the class get access to the amplified signal and particular benefit is gained by children with:

- mild hearing loss especially with mild conductive and unilateral hearing loss
- auditory processing difficulties
- English as a second language
- learning difficulties.

Amplification systems are not designed to replace personal hearing aids and FM systems for children with more significant hearing loss, but can be successfully used together with these other systems.

Research done on these units both within New Zealand and overseas have shown excellent benefit (Crandell et al 1995, Allcock 1997).

Use of these systems must not be considered a substitute for ensuring that room designs are acoustically optimised.

Building Sites and Outside Noise

There are very few new schools being built in New Zealand—needed increases in capacity are usually provided by expanding existing schools. Most of the original rooms in the existing schools are situated on level ground and usually surrounded by tarmac and concrete areas used for play. As schools have expanded prefabs / relocatables have been added and in many schools these are now placed on sloping land with up to 2–3 metre piled foundations being necessary. These buildings usually have a light wooden frame construction and attached decks and this gives potential for problems with low frequency floor-noise. The adoption of modified construction techniques which avoid adjoined decks and building rooms on sloping land should minimise these problems.

Many of the teachers' complaints about outside noise due to open windows could be rectified by:

- siting rooms away from noise sources
- having as large a separation as possible between play areas and classrooms
- raising the awareness of staff and school administration to the potential risk of noise entering the classroom from outside, e.g. lawn mowing scheduled outside school hours.

SUMMARY / RECOMMENDATIONS

- **The research team believes all new teaching spaces in New Zealand schools should be designed to meet acoustical standards specified in AS/NZS 2107:2000.**
- Teacher training and in-service should include more information on: the incidence and effects of hearing loss in NZ primary schools, the importance of acoustics in learning environments, vocal strain and techniques to avoid its onset.
- For the predominant teaching methods of primary school teachers of group work and mat work, an absorptive ceiling (moderate broadband absorption to central ceiling) is strongly preferred. All new primary classrooms should be designed with absorptive ceilings. A reverberation time of 0.4 seconds which is flat across the frequency range 500–2000 HZ in occupied classrooms is recommended. When retrofitting of an acoustic ceiling is required, one of the designs used in this study will provide satisfactory reverberation times.
- Prioritise classrooms with untreated high or vaulted ceilings for retrofitting of acoustic ceiling tiles. Ensure that relocatable classrooms meet the same acoustic design standards as permanent construction rooms.
- In the siting of classrooms/school design, consideration should be given to outside noise sources, both within and outside of the school e.g. proximity to the bus stop, main roads, school hall, playing fields etc. Rooms should have a design (unoccupied noise level) sound level of 35 dBA.
- School staff and administration should be made aware of the risk of noise entering the classroom from outside, e.g. consider the possibility of scheduling lawn mowing outside school hours.
- External decks need to be supported independently from classroom structure, so that footfall on the deck is not transmitted into the classroom.
- Do not site relocatable classrooms on markedly sloping land so that high-piled foundations are avoided.
- Carpet over underlay is the recommended floor covering to reduce noise from footfall and furniture movement. However, we should note that some countries (e.g. Switzerland) do not recommend the use of carpets in classrooms because of their findings that their use results in a significant rise in the incidence of asthma and allergies in children.
- Further investigation into the optimisation of classroom furniture and fitting design to achieve acoustic performance requirements is desirable to avoid problems such as floor scrape with chairs.
- Purchase computers with the lowest noise ratings.
- Investigate noise levels of any heating/air conditioning system that is going to be installed and ensure that noise generated by the system in the classroom does not exceed the recommended design sound level for the classroom.
- Before sound reinforcement systems (soundfield amplification systems) are considered for use in classrooms, all possible avenues to improve the room acoustics and insulation against noise should be followed.
- A solid floor construction is recommended to reduce the drumming associated with light timber framed construction— two layers of particleboard or a concrete slab is recommended instead of one.
- All children who wear personal hearing aids should be considered as potential candidates for FM systems, regardless of their degree of hearing loss.
- Further recommendations from a Canadian standard are:
  1. open plan classrooms should be avoided
  2. provide a double stud wall between the washroom and instructional space. Ensure structural separation is maintained between each wall and specify that piping is attached to washroom side only.

FURTHER STUDY

Floor noise has been identified as worthy of further investigation. Another area that has been frequently raised by research teams including ours is furniture design. The team would recommend further investigation into optimisation of classroom furniture and fitting design to achieve acoustic performance requirements. Chair scrape is a well identified problem, would using a circular tubular leg reduce floor scrape?

We would also suggest investigating the effects of installing high performance broadband absorption to the entire classroom ceiling, and reducing R/T to 0.1–0.2 seconds. Recent research by Bradley/Bistafa 2000 on theoretical values for speech metrics for a 300m^3 classroom, suggest that for very quiet classrooms (S/N ratio 20–30 dB) an R/T in the region of 0.1–0.3s maximises speech intelligibility metrics. This poses the question “Can the classroom be made too dead?” As group work is one of the main activities in the classroom it seems reasonable that primary school classroom acoustics are more akin to ‘open plan offices’ than speech rooms, and perhaps should be treated as such. The effects of a very low level of reverberation on noise levels, child behaviour and speech perception in classroom environments requires further study.

Researchers from Heriot-Watt University recently carried out a study of the acoustics of primary school classrooms in the United Kingdom (McKenzie 2000). A Reverberation Time design guideline of 0.4 seconds was used for classrooms that were acoustically treated. It was considered that useful sound would not carry well enough in the classroom environment if the room was made “too dead”.

The use of speech perception tests was not a particularly helpful measure in separating the good and the poor rooms. An investigation of alternative indicators relating to speech perception is the subject of ongoing research. The team also discussed the need to determine how different our acoustical measurement criteria, and possibly our other measures, must be when catering for the immature hearing systems of primary school children.

APPENDIX 1

New Zealand Research Findings

This section contains a summary of New Zealand research carried out into Classroom Acoustics:

In 1984, Coddington carried out a small study in Auckland classrooms investigating classroom acoustics and their relationship to children with hearing loss in normal schools. The brief research report featured eight classrooms—four open plan and four single cell-rooms. The unoccupied L95 levels (the level below which the noise fell 95% of the time) ranged from a mean of 47 dBA in the single celled rooms to 60 dBA in the open plan room when the second class was operating. The average R/T (500, 1KHz and 2KHz) was 0.73 in the single celled room and 0.76 in the open plan room.

The S/N ratios were measured at +1 dB to +8 dB in the open plan room and in the single celled room at +4.5 dB–+7.5 dB depending on the teaching situation. It was not specified where the microphone was placed in the room. The children's' hearing and middle ear function was tested. A pass in audiometry was set at hearing better than 25 dB HL at 500Hz, 20 dB HL at 1kHz, 15 dB HL at 2kHz and 4kHz. To pass tympanometry the children had to have a middle ear pressure greater than –100mm$H_2$0 and a type A tympanogram shape, Jerger's classification.

Results

Pass/Fail tests	Percentage of children
Pass PTA and Tympanometry	58%
Pass PTA, fail Tympanometry	2.7%
Fail PTA, pass Tympanometry	8.3%
Fail PTA, fail Tympanometry	31%

Table 3: Outcome of Audiometry and Tympanometry test

Therefore 39% of the children failed the hearing test and 33% failed tympanometry on the day of testing. 78% of the hearing loss was associated with failed tympanometry. Coddington highlighted the poor awareness of teachers of hearing loss – even when it was quite significant. The classroom acoustics were highlighted as being inadequate for those 39% of children who were measured as having a hearing loss on the day of testing.

Blake and Busby (1994) measured S/N ratios in 106 classrooms in 51 primary schools in the Wellington Region, the children were 5–7 years. They positioned the sound level meter 3 metres from the teacher and slightly to the side, they defined the S/N ratio as the difference between the level of the teacher's voice in a teacher directed activity and the background noise measured when the teacher was not speaking. They found the overall median S/N ratio was +6 dB, when they separated out the teaching style they found in a single function teaching activity the median was +10 dB but in a multifunctional activity group it was +1 dB.

149 teachers were given a questionnaire and 81 replied (response rate 54%).

Researchers described the questionnaire as "soft" in terms of scientific validity but reported the following results:

Finding	Percentage response
Classrooms are too noisy	90%
Identifying hearing impairment was moderately to very difficult	90%
Classroom noise made educating a hearing-impaired child moderately to very difficult	90%
Noise levels interfered with effective communication	63%
It would be desirable to reduce noise levels	27%
An open ended question about Otitis Media indicated a poor level of knowledge and understanding	NA

Table 2 : Teacher Survey Questionnaire Findings – n=81

Blake and Busby concluded as a result of their study that not enough attention is paid to the acoustic design of classrooms, teachers are inadequately trained in the identification of hearing loss. Noise levels are a by-product of teaching methods and should be considered as such. Quieter teaching methods were recommended.

There have been three Masters of Audiology theses produced in the area of classroom acoustics, from the Audiology Section, University of Auckland.

The first research study Harper (1995) measured acoustic characteristics in five Auckland primary and intermediate school classrooms, the children were aged between 10 –13, see Table 3.

MEASURE	**RESULTS**
R/T (seconds)	Range 0.37–0.56, mean 0.43
Speech transmission index	Range 0.72–0.81, mean 0.76
Unoccupied noise levels	Range 28 dBA–55 dBA, mean 37 dBA
S/N ratio occupied	Range –5–+11 dB, Mean +6 dB

Table 3 : Results of Acoustics Tests in Primary Classrooms – n=5

The speech perception ability of six hearing-impaired children from these classrooms was then measured in a soundproof booth in a clinical environment. The test used was the Speech in Noise Test (SIN) recorded by Harper onto videotape. This is a sentence test and it was presented with and without visual cues, using a television screen and loudspeaker. The speech was presented at 70 dB SPL and the noise at 70 dB SPL and 64 dB SPL, giving a S/N ratio of 0 and +6 dB respectively. Harper recorded classroom noise and used this and multi-talker babble to simulate the classroom environment. This noise was used as the recorded background noise in the current research.

Performance in classroom noise at 0 dB S/N ratio was significantly poorer than both performance in quiet and multi-talker babble at +6 dB SNR. All other contrasts were not significant. Speech scores were significantly better with auditory visual presentation (mean 86%) than auditory alone (80.1%).

The recorded test materials were further refined for use with hearing-impaired children by Carr (1996), who re-recorded the materials, adding in simulated reverberation. She tested eight normally-hearing children and six hearing-impaired children in a variety of test conditions.

Speech Scores	Hearing-impaired	Normally-hearing
Hearing Level	70.7%	90.2%
	Anechoic	Reverberant
Reverberation Level	90.87%	72.8%
	Audio-visual	Auditory alone
Visual Cues	87.5%	77.3%
	SNR +6	SNR 0
S/N ratio	86.5%	77.3%

Table 4 : Speech Scores of normally-hearing (n=8) and hearing-impaired children (n=6)

She found reverberation had more effect on the hearing-impaired listeners and that they benefited more from the visual cues than the normally-hearing listeners. To score above 60% in reverberant conditions the hearing-impaired children required visual cues.

Heslop (1998) examined the relationship between receptive language development and speech perception scores for the SIN sentence material that Harper and Carr had developed to look at the effect language levels had on test results. He used the Peabody Picture Vocabulary Test Revised (PPVT-R). Sentence material was presented at 65 dB (A) Leq in a laboratory setting with simulated reverberation of 0.5 and at +3 dB SNR in reverberant classroom background noise. He found that there was a significant correlation between the two sets of scores for the normally-hearing group (n=25) and those with conductive hearing loss (n=11), but not for those with sensorineural hearing loss (n=6). He cited possible reasons for the poor correlation in the sensorineural group as; small number of subjects, lack of audibility, poor suitability of the PPVT-R for use with hearing-impaired children.

Appendix 2

Classroom Acoustics Survey:

Thank you for completing this questionnaire. We are investigating the opinions of teachers on the acoustics and noise levels of the classrooms that you teach in. We are particularly interested in the effects of classroom environments on students' speech understanding.

To protect privacy and maintain confidentiality the classrooms will only be identified by a study number when any of the research findings are presented.

Date ______________________________

School ____

Classroom Number ____________________

Age range of students in your class ________

School Year ___________________________

Number of students in your class _________

How many students in your class have a hearing loss that you are aware of? ______________

- **Please place a cross in the box of the appropriate answers.**

- **Please note this questionnaire is printed in a double-sided format.**

- **Thank you for your time and cooperation in completing this questionnaire please return it to the school office by the date noted on the attached letter.**

Room Characteristics:

1. In your opinion what aspects of your classroom are the most important. Rank those categories below with 1 being the most important and 5 the least important?

- ☐ Lighting ____
- ☐ Ventilation ____
- ☐ Acoustics (Listening environment) ____
- ☐ Equipment ____
- ☐ Sufficient room space ____

2. How do you experience the listening environment in the classroom?
   (Please choose all the words that best describe your present room)

- ☐ Comfortable
- ☐ Confusing
- ☐ Echoes
- ☐ Harsh
- ☐ Clear
- ☐ Irritating
- ☐ Relaxing
- ☐ Other (please specify) ____

3. How do you rate your classroom listening environment?

- ☐ Very good
- ☐ Good
- ☐ Acceptable
- ☐ Poor (go to 4)
- ☐ Very poor (go to 4)

4. If you answered “poor” or “very poor” why do you think that it is hard for students to hear well in your classroom?

- ☐ Open plan style room
- ☐ Too much echo in room
- ☐ Too much noise from outside room
- ☐ Noise level produced by students too high
- ☐ Other (please specify) ____

Noise Sources – Inside The Classroom:

1. Do you have any problems with noise created inside the classroom (this includes the noise the students themselves make)?

- ☐ Yes (go to question 2)
- ☐ No (go to the next Section – Noises outside classroom)

2. What proportion of noise generated inside the classroom is student generated?

- ☐ None
- ☐ Some
- ☐ Most
- ☐ All

3. Please identify all other sources of noise inside the classroom?

- ☐ Equipment, e.g. Computer, fish tank, clocks.
- ☐ Air conditioning
- ☐ Heaters
- ☐ Lights
- ☐ Fans
- ☐ Other (please specify) ____

4. Which is the most intrusive noise from the list in 3 above?______________________________

Noise Sources – Outside The Classroom:

1. Do you have any problems with outside noise entering your classroom (this includes noise from adjacent rooms)?

- ☐ ☐ Yes (continue)
- ☐ ☐ No (go to the section on Vocal Effort)

2. Identify the sources of the outside noise?

- ☐ Traffic noise
- ☐ Lawn mowing
- ☐ Noise from other classrooms
- ☐ Noise from sports fields
- ☐ Corridors
- ☐ Student traffic on decks
- ☐ Other (please specify) ____

3. Which is the most intrusive noise from the list in 2 above? ____________________________

4. How important do you think it is to eliminate or reduce these noises for the students?

- ☐ Critical
- ☐ Important
- ☐ Not very important
- ☐ Unimportant

5. What could be done to eliminate these noises from outside your classroom?

____

____

6. Which is the worse source of noise problems for you?

- ☐ noise made inside the classroom
- ☐ noise coming into the classroom from outside?

Vocal Effort:

1. When teaching would you consider yourself to have?

- ☐ A soft speaking voice
- ☐ A normal level speaking voice
- ☐ A loud speaking voice

2. How often is it necessary for you to elevate your voice to be heard clearly?

- ☐ Always
- ☐ Often
- ☐ Sometimes
- ☐ Never

3. Does the level at which you need to speak seem to strain your voice?

- ☐ Yes
- ☐ No

4. From where in the classroom do students appear to be able to hear your instructions best?

- ☐ Easy everywhere
- ☐ Near the teacher
- ☐ Far from the teacher
- ☐ In the center of the room
- ☐ Near the back
- ☐ At the sides
- ☐ Have not considered this

5. From where in the classroom do students seem to have most difficulty hearing?

- ☐ Difficult everywhere
- ☐ Near the teacher
- ☐ Far from the teacher
- ☐ In the center of the room
- ☐ Near the back
- ☐ At the sides
- ☐ Have not considered this

Teaching Style:

1. Approximately what percentage of time do you spend in the classroom teaching in each of these styles?

- ☐ Mat Work ______
- ☐ Group Work ______
- ☐ Blackboard/Didactic ______
- ☐ Other (specify) ______

Total 100 %

2. In what situations do you find it is necessary to elevate your voice to be heard clearly?

- ☐ Mat work
- ☐ Group work
- ☐ Blackboard
- ☐ Other (please specify) ____

3. Where is your usual position in the class?

- ☐ At the center
- ☐ In the front
- ☐ Walking around
- ☐ Other (please specify) ____

4. Do you think the acoustics in your classroom have a direct effect on the student's learning ability?

- ☐ Yes (go to question 5)
- ☐ No (go to question 6)
- ☐ Don't know (go to question 6)

5. Please explain in detail, why you think the acoustics in your classroom have a direct effect on the student's learning ability. Continue overleaf if more space is required.

____

____

6. Please note any further comments you would like to make on the subject of this questionnaire.

____

Classroom Acoustics Survey…….Questionnaire Supplement:

1. What is the number of the classroom you taught last year? ___________________________

2. Please describe in your own words how your classroom listening environment has changed since it has been modified.

---

3. Have the acoustics improved in your classroom since the ceiling was modified?

   - ☐ No
   - ☐ Slightly
   - ☐ Significantly

4. Have the ceiling modifications created any new problems for you?

   - ☐ Yes
   - ☐ No

   If `Yes' Please describe;

   ---

5. With respect to the two issues listed below, please rate your classroom for the different teaching styles.

   A. Inside Noise Levels Same……….Better……….Worse

   Group work
   Mat work
   Blackboard / didactic
   One to One

   B. Student's Hearing Ability Same……….Better……….Worse

   Group work
   Mat work
   Blackboard / didactic
   One to One

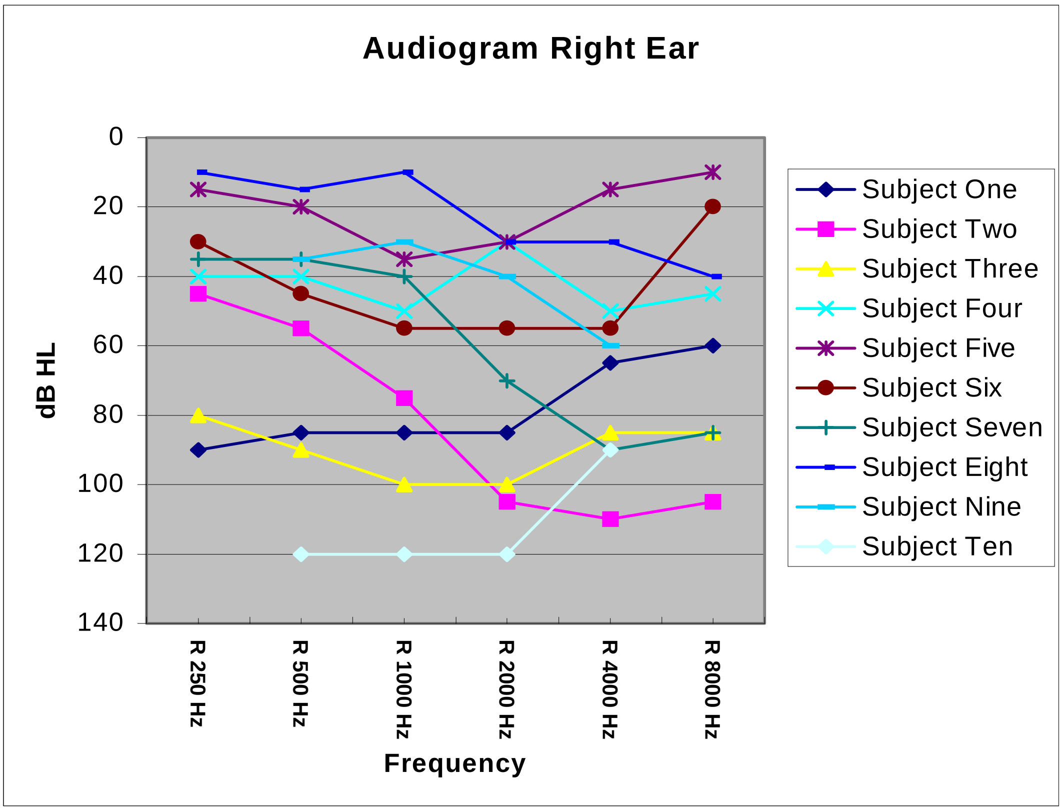
6. Have any of your colleagues (or student's) made any comment about the modifications?

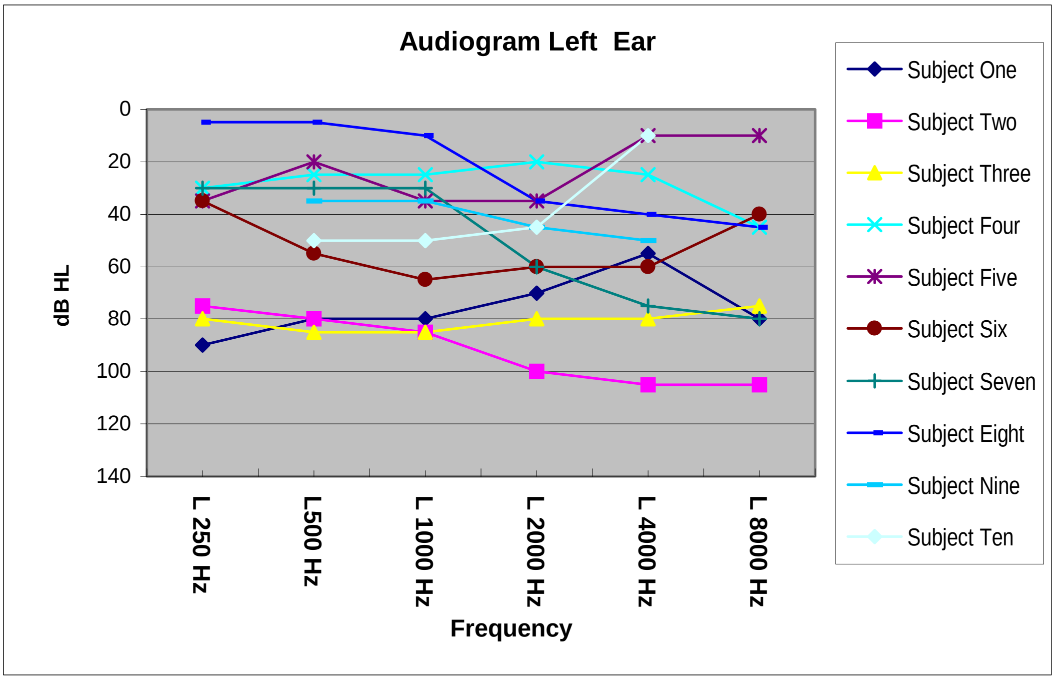
   If so, we'd really like to hear them………………………………………..

THANK YOU

APPENDIX 3

Hearing-impaired Children's Audiograms





REFERENCES

ASHA, Acoustical Society of America 2000, *Classroom Acoustics. – A resource for creating learning environments with desirable listening conditions*

Alberta Infrastructure – Standards and Guidelines for School Facilities, Alberta Canada, January 2001

Allcock J, 1997, *Evaluation of the benefits of classroom amplification in New Zealand Schools*. Report to the Oticon Foundation, 1997

Australian and New Zealand Standard: Dec 2000, *AS/NZS2107:2000, Acoustics – Recommended design sound levels and reverberation times for building interiors*

Bench J, Kowal A and Bamford J 1979b, "The BKB (Bamford-Kowal-Bench) Sentence Lists for partially hearing children", *British Journal of Audiology*, 13, 18–112

Bess F, (2000) "Classroom Acoustics: an overview", *The Volta Review,* Vol 101, No 5, pg 1–14

Bess, F.H., Dodd, J.D. and Parker, R.A. (1998), "Children with minimal sensorineural hearing loss: Prevalence, educational performance and functional status", *Ear and Hearing*, 19, 339–354

Bistafa S. R. & Bradley J. (1999), *Reverberation time and maximum background-noise level for classrooms from a comparative study of speech intelligibility metrics*, Institute for Research in Construction–Acoustics National Research Council–Canada.

Blake, P. & Busby, S. (1994) "Noise levels in New Zealand Junior Classrooms: Their impact on Hearing and Teaching", *New Zealand Medical Journal Complete Reference*

Carr C.J. (1996), *Speech Perception Abilities of Normal-Hearing and Hearing-impaired Children in Classroom Noise*, unpublished Masters Thesis, Department of Audiology, University of Auckland

Coddington, K.(1980), "Classroom acoustics and their relationship to children with hearing losses in normal schools", paper presented to NZ Acoustical Society, Auckland New Zealand

Crandell C (1998) Using Soundfield FM amplification in the educational setting, The Hearing Journal, Vol. 51, No 5

Crandell C, Smaldino J and Flexer C (1995) *Soundfield Amplification: Theory and Practical Applications.* San Deigo, California, Singular Publishing Group

Crandell C (1991), "The effects of Classroom Acoustics on Children with Normal Hearing: Implications for Intervention Strategies", *Educational Audiology Monograph,* 2, 18–38

Dodd G, Wilson O, Valentine J, Halstead M, McGunnigle K (2001), "Classroom Acoustics a New Zealand Perspective", paper presented at the 17th International Congress on Acoustics, Rome, August 2001

Flexer C (1999) *Facilitating Hearing and Listening in Young Children,* Singular Publishing Group, San Diego, USA

Harper M. (1995), *Mainstream Hearing-Impaired Children: Measurement of Classroom Acoustics and Speech Perception Abilities*, unpublished Masters Thesis, Department of Audiology, University of Auckland

Heslop, N.D.P. (1998) *Language Factors in the Speech Perception Abilities of Normally-hearing and Hearing-Impaired Children in Classroom Noise,* unpublished Master's thesis, University of Auckland, Auckland, NZ

Kailes,J.I., Architectural and Transportation Barriers Compliance Board, *The Federal Register*, Nov.1999, Washington USA.

Lubman D (1999), correspondence in Classroom Acoustics website*, classroomacoutics@onelist.com,* 8/12/99

MacKenzie, D.J., "Speech Intelligibility in Classrooms", Lecture presented to NZ Acoustical Society, March 1999

Ministry of Education, (1993) *Health and Safety Code of Practice for State Primary, Composite and Secondary Schools,* Wellington, New Zealand. Updated version is available on the Ministry of Education website *www.minedu.govt.nz*

Ministry of Education, (2000), *Special Education 2000: Monitoring and Evaluation of the Policy. Summary of Phase Two – Final Report,* ISBN 0-477-04721-1

Ministry of Education, 1996, *Special Education 2000,* Wellington, Learning Media

Nabelek A. and Robinson P. (1992), “Monaural and binaural speech perception in reverberation for listeners of various ages”, *Journal of the Acoustical Society of America,* 56, 628-639

National Audiology Centre, Auckland, New Zealand, *New Zealand Hearing Screening Statistics,* July 1999-June 2000. ISSN 1173-597X

Sapienza C, Crandell C, Curtis B (1999) “Effects of Soundfield Frequency Modulation Amplification on reducing teachers sound pressure level in the classroom”, *Journal of Voice,* Vol. 13, No 3, page 375–381

Sieben, Crandell and Gold 1997, “Principles of Classroom Acoustics: Reverberation, Educational Audiology Monograph (5)”, *Journal of Educational Audiology*

Valentine J, 3 August 2000 *“Classroom Acoustics: A New Zealand Perspective”,* Conference presentation at the New Zealand Acoustical Society Conference – August 2000 and later published in *New Zealand Acoustics,* Valentine J, Wilson O, Dodd G, McGunnigle K, Hellier A Wood J, (2000) *“Classroom Acoustics”,* Volume 14, No 2, June 2001

Wilson O, April 2000, *“Classroom Acoustics: a New Zealand Perspective Conference Presentation”,* NZ Speech and Language Therapists Conference, Napier, NZ

Wilson O, July 2000 *“ Classroom Acoustics a New Zealand Perspective”,* Conference presentation at the New Zealand Audiological Society Conference Rotorua, New Zealand

Wylie, C, *“Picking up the pieces: Review of Special Education 2000”*