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Classroom Acoustics and the Performance of Secondary School Students

Anne Wilson

A thesis submitted in partial fulfilment of the
Requirements of
Sheffield Hallam University
For the Degree of Master of Philosophy

June 2006

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Abstract

The academic achievements of students in school are often reported in the media where successes and failures are highlighted and scrutinised.
The environments in which these students work is rarely reported, but is vitally important in the learning process.
Currently there is a huge school rebuilding programme with millions of pounds being invested in our educational establishments. Recent tightening up of building regulations relating to schools has meant that school planners and architects have to now conform to acoustic standards in classrooms.
One question that has to be asked is whether, in the mainstream classroom, the students can hear the teacher clearly.
In Sheffield six PFI funded schools were rebuilt in 2000-1. Four secondary age and two primary. These were built under BB87 regulations.
There were reports of problems in these schools immediately. Many of the problems were related to the acoustics in the classrooms; teachers unable to hear students and students unable to hear teachers, and an increase in background noise levels in the classrooms, amongst other issues. As a result this research was initiated to investigate selected classrooms. An initial pilot project was completed, then further research was done in another of the secondary schools.
This research included measuring and recording reverberation times and background noise levels, alongside classroom observations. Four rooms with different reverberation time profiles, but with many common factors, were then selected.
A speech discrimination test was devised and completed using year 7 students in the school. The test was designed so that typical seating positions in typical mainstream classrooms could be assessed and compared.
The aim was to see whether different reverberation time profiles would influence the ability of students to hear in the selected classrooms.
When the results of the speech discrimination testing was analysed there were certainly some speech discrimination difficulties apparent in some of the rooms and some of the seating positions of the students. These are discussed alongside the room profiles, the reverberation time, and background noise measurements completed in the rooms.

Anne Wilson. June 2006.

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List of abbreviations used in the text in alphabetical order

AB Arthur Boothroyd A word list to test speech intelligibility

BKB Bamford-Kowel-Bench A test of Speech Intelligibility

BPVS British Picture Vocabulary Scale A test of subjective vocabulary

L_{aeq} Equivalent continuous sound level measurement A-weighted

L_{afreq} Equivalent continuous sound level measurement A-weighted by frequency

L_{eq} Equivalent continuous sound level measurement

L_{aPeak} Loudest sound intensity measurement

WIPI Word Intelligibility by Picture Identification

Chapter One Introduction

1.1 Introduction to Thesis

Educational standards are always being discussed in the media and are regarded as being in the public domain. Academic attainments of school students are forever being questioned and compared, as are the standards in the perceived and actual behaviour of students. Standards in the classrooms themselves and the skills of teachers in maintaining these standards are often being reported particularly when unacceptable incidents hit the media headlines.

Politicians, teachers, parents, universities and colleges, and employers scrutinise the academic achievements of students in minute detail; and apparent failings are commented on. The education of our youngsters is always in the spotlight whether good or bad. Very little, however, is written in the media on the classroom environment in which the students work.

Noise surrounds us all. As adults we can generally quite effectively block out noise when we wish to, in order to concentrate on a task. We can focus on other speakers in noisy conditions and understand what is being said as we have a good grasp of language and can, if necessary, fill in any gaps in speech. Children and young adults cannot do this as effectively and therefore miss out on important parts of speech.

The classroom is a very important place for children to be able to listen and to learn.

1.2. The Problem of Noise

Within the field of education it has to be recognised that schools by their very nature are not quiet. An average secondary school population is often above one thousand, this population will always create noise but it is the manner in which this noise is controlled and the acoustics of the school and individual classrooms that hold the key to good listening environments. The problem of classroom acoustics is not restricted to that of pure background noise levels. Reverberation is a real problem in many classrooms. Long reverberation time increases the noise generated in a room.

1.2.1 The hearing impaired student in the classroom

Children under the age of 15 are classed as immature listeners. They have an immature auditory system alongside an immature linguistic system and as such are at the greatest risk from noise interference in classrooms. They require a speech signal that is 10-15dB above that of the background noise in order to hear clearly and then be able to process speech sounds.

Hearing-impaired students, already disadvantaged from their normally hearing peers due to their hearing loss, require a speech signal louder than that for normally hearing students and an acoustic background in the classroom that promotes good intelligibility. BATOD[1],

Deaf and hearing-impaired students in mainstream education are frequently further disadvantaged by the poor listening environments and often have to rely on strategies (copying, asking other students) other than direct listening to engage in classroom activities.[2] [3]

Researchers in the field of room acoustics and speech intelligibility agree that good classroom acoustics are amongst the most important factors in the education of all students. [4]

1.2.2 The special needs student in the classroom

It is not just hearing impaired students who suffer with poor acoustics in the classroom. Research that has been conducted, particularly in the United States, including Crandell[5], Flexer[6] and Nabelek[7] , has shown that poor classroom acoustics puts a wide range of children at high risk of poor academic achievement. These include

- Children with speech and language difficulties
- Children with learning difficulties
- Children with behavioural problems like ADHD
- Children with English as a second language

In a typical secondary school classroom each individual teacher organises and controls the class in their own manner. The layout of the room, the expectations for student behaviour, the activities and methods of teaching employed, the special needs of all the individual students, have to be managed by the individual teacher.

Current government policy is towards more integration of special needs students into the mainstream classroom; the classroom environment must therefore be adapted and the teachers and other school staff must be trained.

1.3 School Classrooms

1.3.1 Noise environment in and around classrooms

Internal noise generated within classrooms is generally that of speech (babble) from students themselves and is usually quite continuous in its nature. Teachers in the classrooms, and in the broader school environment, can control this noise by the application of whole school policies on classroom behaviour and movement between classrooms to give an environment that is generally quiet and calm.

External noise that can intrude into the classroom environment includes traffic noise, wind and rain, playground noise and the general noise generated in a school in the corridors and the building, for example heating and ventilation systems. These are totally beyond the control of the teachers.

Both internal and external noise that is present in a classroom interacts with the reverberation time within the room, to produce the acoustical characteristics of the classroom.

1.3.2 Classroom Layout

In general, classrooms in secondary schools do not vary much. Classrooms are usually regular shapes, generally rectangular and sometimes square, but vary in their dimensions. They seldom vary from this design. A room that is long from front to back means that the speech signal intensity of the teacher can be significantly reduced for the students seated at the back. The traditional classroom layout locates the teacher at the front of the classroom with the students set out in rows from front to back. Generally students are seated facing the front, but some teachers will deviate from this traditional layout by having desks set sideways on to the front, some prefer a more informal layout with desks in a horseshoe formation or in groups. Practical subjects, eg art, science, food technology, have specially equipped rooms that are often larger than the classrooms designed for the more academic subjects. These classrooms have often highly reflective and therefore inherently noisy, as the surfaces, floor and walls have to be easily cleaned and hygienic.

1.4 Current Issues

1.4.1 School Rebuilding

The present government has pledged to rebuild or refurbish the nation's schools. Millions of pounds has been set aside for this programme. Initiatives, including PFI, allow for private companies to invest in a new school and they are then contracted to run it and maintain it for an agreed time span before the building reverts back to local authority control. Building Schools for the Future and City Academies are other huge investments in the building of new schools; the first BSF is currently being built in Sheffield, with two City Academies coming online in September 2006. These initiatives tie in with the Children's Manifesto, which sees the remit of schools extending to become hubs of their local communities and offering greater provision of childcare. Schools will therefore need to be fit for many more purposes other than just the education of their students.

Building Bulletin 93[8] now requires that new school buildings adhere to new building standards that include standards of acoustics in classrooms. Under the current Disability Discrimination Act and the new Disability Discrimination Bill due to become law in 2006, local education authorities and schools have to take on planning duties for present and future disabled students. This includes making reasonable adjustments for disabled students. Any new schools or refurbishments of present buildings must look at the long term planning for access for disabled students, this includes those with hearing impairments. The ability to hear in the classroom for hearing-impaired students, therefore, has to be addressed in these plans.

1.4.2 School Location

Urban growth will have an impact on the noise levels of a community. More and more cars, vans and lorries clog up the streets bringing with them environmental pollution. As the population in towns and cities grows there is more pressure on building on brown field sites and also spilling over into green field sites. As the population increases so does the demand for all the local services in the area including the number of school places available.

The location of a school is critical when looking at the issue of noise in the classroom. A school situated next to a busy dual carriageway or main road will suffer from high external noise levels that need to be prevented from intruding into the classroom. Under a flight path from an airport also constitutes a poor location for a school.

Research has shown that this sort of environmental noise does impact on a child's education as Shields [9] has shown with her studies of schools in some London Boroughs.

1.5 Discussion

Teachers are the primary source of student learning for the entire curriculum in schools. The vast majority of the curriculum is presented through the spoken word.

'School children spend as much as 60% of the school day listening.'
Berg [10]

As was discussed in Section 1.3.2, the classroom layout does not vary a great deal in academic rooms, although practical rooms are different.

A teacher can decide on the layout to a certain degree depending on the physical characteristics of the room itself. Giving teachers information on students' ability to hear speech is very important, as the seating plans can be rearranged to become more suitable for the differing needs of these students. Hearing impaired students' come into this category as needing seats giving optimal speech intelligibility.

The acoustic characteristics of classrooms can cause problems for teachers, although they often do not know or understand the nature of this problem. Teachers in some recently built classrooms have reported excessive student noise, which escalates very quickly, and problems with hearing the students.

The conclusions from this are that teachers need to be given greater information not only on the needs of the students that they teach but also on the acoustics problems that may be present in their classrooms in order to be more effective with their speech.

This information on classroom's acoustics needs to be in terms that are easily understood by non-specialists in order for teachers to be more effective in their teaching. This study aims to do that. It does not look in great detail at the science of the acoustics but attempts to present an easily accessible research project that all teachers and other school staff will understand and can therefore help them to combat poor classroom acoustics, to some degree, by employing different teaching methods.

1.6 Aims and objectives

The aim of this research is to assess whether long reverberation time across different frequencies in mainstream classrooms, affects the speech intelligibility of normally hearing students particularly when there is background noise present.

This study includes

- objective measurements of reverberation times (Chapter 6)
- background noise levels (Chapter 6)
- speech discrimination testing of students in selected classrooms using a background of multi-talk babble noise (Chapter 7)
- comparisons are then be made between rooms with different reverberation times using the results from these speech discrimination tests (Chapter 7)

This research has developed from a previous study completed in another secondary school where there was a reported problem with classroom acoustics. This is discussed in Chapter 4.

1.7 Overview of Thesis

This thesis describes the nature of sound in Chapter two, including hearing, hearing loss and amplification. Chapter Three reviews literature relating to previous experimental research into room acoustics and speech intelligibility. Chapter Four looks at the previous study that led to this current research project. Speech intelligibility testing procedure is detailed in chapter Five. Chapter Six details the acoustic measurements of reverberation time and background noise in the selected classrooms. Chapter Seven gives the results from the speech discrimination tests. Chapter Eight is the concluding chapter with analysis, discussion and future developments.

1.8 REFERENCES

(1) BRITISH ASSOCIATION OF TEACHERS OF THE DEAF, 2002, *BATOD Magazine* February, 23-24

(2) BRADLEY J.S. 1986 Speech Intelligibility Studies in Classrooms. *Joournal of Acoustical Society America 80,* 846-854.

(3) BESS F.H. 2001 Classroom Acoustics: An Overview. *Volta Review* 101-5.

(4) FLEXER C. 2004 The Impact of Classroom Acoustics: Listening, Learning and Literature. *Seminars in Hearing 25.2* 131-140

(5) CRANDELL C., & SMALDINO J., 2000, Classroom Acoustics for children with normal hearing and with hearing impairment. *Language Speech and Hearing Services in schools, 31,* 362-370

(6) FLEXER C., & LONG S., 2003, Sound Field amplification: Preliminary information regarding special education referrals. *Communication Disorders Quarterley, 25,* 29-34.

(7) NABELEK A., & NABELEK I., 1994, Room Acoustics and speech perception. In J. Katz (Ed), Handbook of Clinical Audiology, (3rd Ed, pp834-846). Baltimore, MD: Williams & Wilkins.

(8) THE STATIONERY OFFICE, 2003, Building Bulletin 93 Acoustic Design of Schools.

(9) SHIELD B., DOCKRELL J., JEFFREY R., TACHMATZIDIS I. (2000) The Effects of Noise on the Attainments and Cognitive Performance of Primary School Children. South Bank University.

(10) BERG (1993) in Rosenberg and Blake-Rahter 1995

Chapter 2

The Nature and Behaviour of Sound

2.1 Introduction

This study examines the influence of room acoustics factors on the speech intelligibility of listeners in mainstream classrooms, it is vital therefore that there is an understanding of the nature and behaviour of sound. Sound and its perception in an enclosed space is influenced by many factors which are discussed here, particularly that of the reflections around the room, distance, noise from external sources and sound intensity.

For any listener it is important that all the sounds of speech are heard as clearly and as accurately as possible so that there is understanding of the spoken word. In classrooms this is vitally important. If there are any speech sounds that are unclear then there may be misunderstandings. Distance from the speaker, intensity of the initial signal, background noise, unwanted reflections from the room surfaces, all create difficulties for the listener. It is the speech intelligibility skills of students in mainstream classrooms that are the focus of this study so it is important that the nature and behaviour of sound is understood.

2.2 Sound

2.2.1 Sound Waves

Sound occurs when a vibrating source causes movement in the air.
The Roman architect Vitruvius in his volumes of writing on 'De Architectura' said that sound ' moves in an endless number of circular rounds, like the innumerably increasing circular waves which appear when a stone is thrown into smooth water.... but while in the case of water the circles move horizontally on a plane surface, the voice not only proceeds horizontally, but also ascends vertically by regular stages.'
Sound consists of small and rapid changes in air pressure that is detected through the ear mechanisms. Sound waves travel at a speed of 340m per second at a temperature of 20^0 C. Sound waves can consist of regular or irregular vibrations. Sound can travel through any material.

2.2.2 Frequency

These air movements, or sound waves, have to be in excess of twenty per second for the human ear to detect them. For human audible sounds the range of these waves is from around 20m in length at the low frequency to around 2cm length at the higher frequencies. The frequency of a sound is the rate of repetitions of these wavelengths. These sound waves are measured in Hertz and one Hertz is one cycle of this movement.
The range of human hearing is from 20Hz (low frequencies) to 20 000 Hz (high frequencies).
The speech frequency spectrum is from 125 to 8000Hz.

2.2.3 Pressure

Sound pressure rises above and falls below the level of normal atmospheric air pressure. This fall and rise is averaged and known as the root mean square pressure. The greater the root mean square pressure the louder the sound.

The pressure scale is not linear but rises in intervals of ten times which is necessary to cover the wide pressure range.

Sound pressure is defined as the total force acting in a normal manner to a surface then divided by the area of the surface. Such pressure measurement is measured as the Pascal.

The minimum audible sound is 20 millionths of a Pascal, the loudest, painfully so, is 20 Pascal.

2.2.4 Intensity and The decibel Scale

As sound energy travels out from the sound source it spreads in waves as described by Vitruvius earlier. The spread of sound depends on distance from the signal, the environment and the environmental conditions.

Sound is written as decibels (dB). It is easier to use the dB in calculations of sound pressure levels rather than using pascals as the numbers are within a smaller and more user friendly scale. The decibel scale is logarithmic and not linear. The decibel is used as it is representative of how our ears interpret sound. Most commonly heard sounds are represented through the scale of 0dB through to 140dB. This scale matches the subjective response of the human ear. The quietest detectable sound at 0dB, the threshold of hearing, to the pain threshold, at 140dB, is due to pressure changes by around ten million times which is why the decibel scale is used for convenience.

An increase in one decibel is just about perceptible by the human ear.

An increase of 10dB in sound intensity means it is twice as loud.
As the decibel is a logarithmic scale the simple addition of two or more decibel levels is not possible. The use of mathematical formulae or calculator is necessary.

2.2.5 Octave Bands

Sound can be divided into bands of frequencies. These frequencies are divided into octave bands having centre frequencies of 63, 125, 250, 500, 1000, 2000, 4000 and 8000Hz. Sound level meters are equipped with band pass filters that cover this audible range in a set of consequent stages, each octave covering twice the frequency of the previous stage. A further sub-division is into third octave band analysis. This gives a much more detailed break down of sound, as the bandwidths are smaller.
Octave band analysis is important for two reasons

1) the ear is not equally sensitive to all frequencies in the audio range
2) the frequency spectrum is important to enable identification of noise sources

2.2.6 A-Weighting scale of sound

As stated in Chapter 2.1.5 sound consists of a range of frequencies. Sounds of the same intensity but of differing frequencies do not sound equally loud to the human ear as the sensitivity of the human ear varies with frequency and with amplitude.
This A-weighting or bias is applied to sounds from the low and high frequencies, thereby attenuating these sounds to mimic the responses of the human ear. A sound level meter can be set to measure with an A weighting mimicking the human ear.

2.2.7 Sound Propagation -The effect of distance

In an unconfined environment, ie outside, for each doubling of the distance from the sound source, sound energy is distributed to four times the area so decreasing intensity by 6dB as shown in Figure 2.1. This is the inverse square law.

sound	1m	2m	4m	8m	16m
source of	70dB	64dB	58dB	52dB	46dB
76dB →					

Figure 2.1 The effect of distance

2.2.8 Echoes

One of the parameters by which the internal acoustic environment is characterised is the reverberation time.

Reverberation time is the time it takes for sound to decay by 60dB. This can be measured using a sound level meter measuring a sudden loud noise and the subsequent 60dB drop.

It can also be derived using mathematical equations such as the Sabine [1] Formula given below

$$RT = \frac{0.161V}{\Sigma S\alpha}$$

RT 60 = reverberation time in seconds

0.161 = a constant

V = room volume in m^3

$\Sigma S\alpha$ = the sum of surface areas x absorption coefficients at a given frequency.

There are other methods of calculating reverberation time for example Norris-Eyring, but the Sabine formula is the most commonly used so it was felt that this was the most suitable.

The RT differs across the frequency bands so a room can have long reverberation time in the low frequencies but shorter in the higher frequencies. The average reverberation time, as specified in BB93[2] is measured at 500Hz, 1000Hz and 1500Hz but this is not always an indication that the reverberation time is at acceptable levels across all the frequencies. Reverberation time should therefore be presented across all the frequency bands.

All rooms are different. The size of the room, the surfaces whether parallel, curved or straight, the ceiling or roof design whether flat, domed, pitched, all give rooms different reverberation times, as does the amount and location of any absorbent surfaces and the levels of absorbency for each.

When a person speaks and the original direct signal arrives at the ear at the same time as any reflected signal then the original signal is reinforced, however if the two signals arrive at different times the reflected energy- after x seconds of reverberation time - can affect speech discrimination because of the masking or smearing of the direct signal by the reflected reverberant signal, particularly the upward spread of masking by low frequency reverberation

The normal human ear can integrate repetitive sounds that arrive up to 0.08 seconds after the original wave has arrived. It is thought that waves reflected at an interval of 0.02-0.03 seconds enhance understanding of speech for listeners with normal hearing.

In confined environments the effect of reverberation needs to be taken into account. In an environment where there are effective absorptive materials, the intensity will similarly decrease, as in an unconfined environment, over distance. In a very reflective environment there will be little decrease in intensity as the sounds are reflected around the room rather than being absorbed and therefore reduced.

2.2.9 Critical Distance

Sound energy can be heard directly, or indirectly through reflected energy or a combination of both direct and reflected energy. So in a confined space where the direct sound and the reflected sound levels are equal, this is termed the critical distance. The total sound level at this distance is higher than either the direct or reflected sound energy separately. The critical distance in a classroom will vary according to the reverberation time. A long reverberation time will create a short critical distance between signal source and listener.

2.2.10 The measurement of sound

Objective measurement of sound is vital in order to understand duration of a sound, and when it occurs, whether it is continuous or intermittent, and whether it is the same sound or different sounds. All these factors affect people's perception and the impact of the sound on them. There is a difference between sound and noise. Unwanted sound could be classed as noise, this is very subjective. Sound that is irregular in its nature is often classed as unwanted therefore becomes noise. Steady continuous sound can be easily measured by reading the sound pressure level on a sound level meter.

Sound, however, does not always fit into this convenient category. Most sound varies so more detailed measurements are needed to analyse the variations.

There are different sound level meters that can measure the intensity and frequencies of sound. An integrated type one sound level meter is the industries required standard for these measurements. A Norsonic Type One sound level meter serial number 2893, and calibrator, type 1251 is used for the testing within this project.

2.2.11 L_{eq}, L_{Aeq}, L_{Afeq} L_{Apeak}

L_{eq} is the Equivalent Continuous Sound Level and can be measured by integrated sound level meters. This is a notional steady sound level that would deliver the same sound energy level in the same time as the measured sound.

L_{Aeq} is this measurement given A weighting.

L_{eq} and L_{Aeq} should be always given a duration for the measurement, for example L_{Aeq} (2 mins).

L_{Afeq} is the equivalent continuous sound level measurement with A weighting broken down into frequency bands to enable more detailed analysis of a sound measurement in particular whether the sounds measured are of low or high frequency components.

L_{Apeak} is the loudest sound intensity measured by a sound level meter within a certain time duration.

2.3 Building Bulletin 93[2]

Building Bulletin 93 replaces BB87[3], which although it gave the standards for school buildings was only in the form of recommendations and was rarely used or enforced. Acoustics was low on the list of priorities for school architects with the result that many school buildings were acoustically poor. BB93 represents a significant tightening of the regulations on acoustic design in schools, in response to much research into classroom acoustics. It has also has been updated to include the relevant requirements of the Disability Discrimination Act.

BB93 gives architects and designers a structured approach to school acoustic design at each stage of the planning and design process. However it applies only to new school buildings but states that 'it is desirable' for alterations and refurbishments to be considered for the upgrading of the acoustics.

"Where there is a need for upgrading the acoustic performance of an existing building or when refurbishment is happening for other reasons, then the designer should aim to meet the acoustic performance given in Section 1 of BB93 to satisfy the School Premises Regulations and the Disability Discrimination Act." [2]

Building Bulletin 93 states that classrooms should have reverberation times of between 0.6 and 0.8 seconds, for primary and secondary classrooms respectively. Where there are hearing impaired students present the reverberation time is shorter, at 0.4 seconds, as recommended by the British Association of Teachers of the Deaf (BATOD). [4]

2.4 The Mechanism of Hearing.

The human ear has evolved to become the familiar structure seen today. The external part of the ear or pinna, collects and traps sound to direct it down the ear canal to the tympanic membrane or eardrum. Our pinnas cannot turn towards sounds like that of a cat, as there are only 6 muscles involved rather than the 30 in a cat's ear, so we have to turn our heads to catch the sounds.

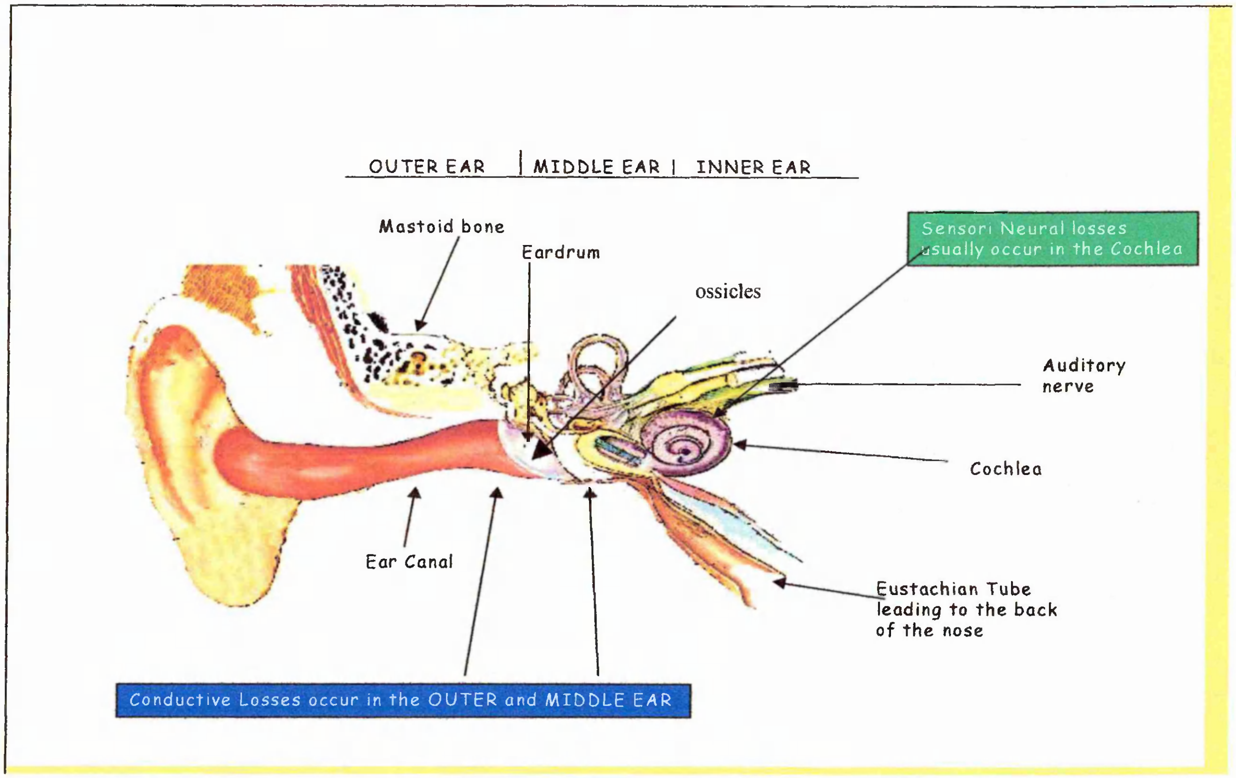


Figure 2.2 The mechanism of the ear (adapted from sources used for training by Sheffield Service for Sensory Impaired Children)

When the sound reaches the eardrum it vibrates causing the chain of the three ossicles to vibrate in turn. The linked movements of these bones transmit the vibrations to the oval window, which is a membrane similar to the eardrum, at the entrance to the cochlea or inner ear. The cochlea is filled with a liquid, which receives these vibrations from the middle ear and in turn causes small movement to the sensitive hairs lining the cochlea. Specific parts of the cochlea are sensitive to different pitches and intensities of sounds. These are translated into electrical impulses that are transmitted along the auditory nerve to the brain. The brain can then decipher these impulses into sounds that we understand.

2.4.1 Hearing loss

2.4.2 Conductive hearing loss

A conductive hearing loss occurs in the outer or middle ear, indicated in figure 2.1 above. It is a loss that prevents the normal conduction of sound through to the inner ear.
The commonest form of conductive hearing loss is that of glue ear and affects some 30%[5] of primary school children, many of these will continue to suffer into secondary school. Glue ear is when the Eustachian tube, which ventilates the middle ear, becomes blocked and a build up of excess fluid or 'glue' occurs in the middle ear preventing the ossicles and eardrum from vibrating efficiently. This condition is usually transitory but can be quite debilitating for children when their hearing fluctuates from normal.
Other forms of conductive hearing loss include perforated eardrums, ossicular malformation, or wax build up in the outer ear.
Sometimes persistent infections in the middle ear can require an operation to remove infected bone. This is called a mastoidectomy and will result in a permanent conductive hearing loss. A conductive loss can be a reduction of a maximum of 60dB from normal hearing levels.

2.4.3 Sensori-neural hearing loss

This cause of deafness is permanent, it is when the inner ear or nerve is damaged preventing the efficient transmission of the electrical impulses to the brain. Illness eg meningitis, head trauma or genetic factors can cause a sensori-neural deafness. Quite often the cause is unknown. A sensori-neural loss can be mild, moderate, severe or profound; it can affect any or all frequency sounds.

2.5 Use of amplification

Where a hearing loss is significant, in other words is creating a barrier to the understanding of speech, a hearing aid may be required. A hearing aid is an amplifier of sound, and although technology is improving with the introduction of digital aids, there is still no hearing aid that will just amplify the sounds of speech whilst filtering out the unnecessary noise that surrounds us all the time. Any child or adult who is fitted with a hearing aid has to learn to filter out these unwanted sounds to just focus on the necessary sounds usually those of speech.

Other amplification comes in the form of radio aids, which are attached to and used in conjunction with hearing aids; personal speaker systems that sit on the child's desk and receive transmissions from the teacher via an infra red link and a teacher worn transmitter; Edulinks, is a new personal amplifier system which fits into the ear and also uses an infra red link to the teacher with a transmitter.

2.5.1 Sound Field Systems.

In Sheffield schools sound field systems are also becoming more wide spread as teachers try to combat poor acoustics, namely that of background noise. These are speakers fitted to the walls, or ceiling, of the classroom linked to a teacher worn transmitter, which deliver a sound field around the whole classroom enabling the teacher's voice to be heard by all the students at equal intensity levels. Research done into sound field systems suggests that they are effective in dealing with background noise thereby enabling teachers to lower their voice levels to reduce strain to the voice and throat. However if long reverberation times are present in the room then the sound field system will not be effective.

2.6 Noise

Noise is defined as unwanted sound; this is subjective to individual listeners. To evaluate the effect of noise both subjective and objective measurements need to be recorded. Time, place, the nature of sound and its effects on the people around are all valid measurements.

2.6.1 Ambient Noise

Indoor ambient noise levels according to BB93[2]

"should include the sum of noise from all sources from outside the school along with any internal noise from heating and ventilation systems. The windows, if used for natural ventilation, should be open. This should be a maximum of 35dB measured over 30 minutes (L_{Aeq}, 30mins)."

This maximum background noise level does not include noise generated by the students

2.6.2 Background Noise

In this study background noise is the noise generated by the teacher and students themselves in a classroom. This is not just chatter but all of the noise produced by the occupants of the room, chairs scraping, footsteps, paper rustling, coughing to name but a few. Multi-talk babble noise is specifically the noise of general chatter only.

2.7 Speech Development

Speech is a developmental process for children. A child has to use acoustical clues to form his or her own speech and this knowledge base of speech grows with the child, becoming more complex with age.

The acoustical clues have to be clear for normal language development. Also a child needs to have normal hearing and mental functions to develop normal speech and language.

2.8 Speech Intelligibility

Airey and Mackenzie [6] defined speech intelligibility as, "*the process whereby a person can clearly hear what is being said and fully understand the context of the spoken word.*"

BB93[2] states that *"the intelligibility of speech depends upon its audibility as well as clarity. Audibility is affected by the loudness of the speech relative to the background noise level. An increase in the background noise will cause greater masking of speech and hence will decrease intelligibility."*

2.8.1 Speech intelligibility in noise

This is the relationship between the intensity of the original signal source for example the teacher's voice, against the intensity of the background noise in the room, for example the student chatter.

A positive signal to noise ratio indicates that the original sound source or signal is louder than the background noise at a given position. A negative figure, then the signal is less intense than that of the background noise. Aural information needs to be understood by the listener, a decreasing signal to noise ratio will reduce this understanding as the noise masks the sounds of speech.

Signal to noise ratio is constantly changing in the classroom, the teacher has to monitor the background noise levels and therefore adjust his/her voice intensity.

Figure 2.2 from Smaldino and Crandell [7] shows the impact that noise and reverberation has on the receipt of the signal to the individual listener in relation to processing of language. If the acoustic signal is distorted then the listener receives incomplete data. If the listener's language is well developed then the individual can 'add in' or make an informed guess to complete the information. Those with immature language systems, for example children or the hearing impaired cannot do this effectively and will therefore have gaps and poor understanding.

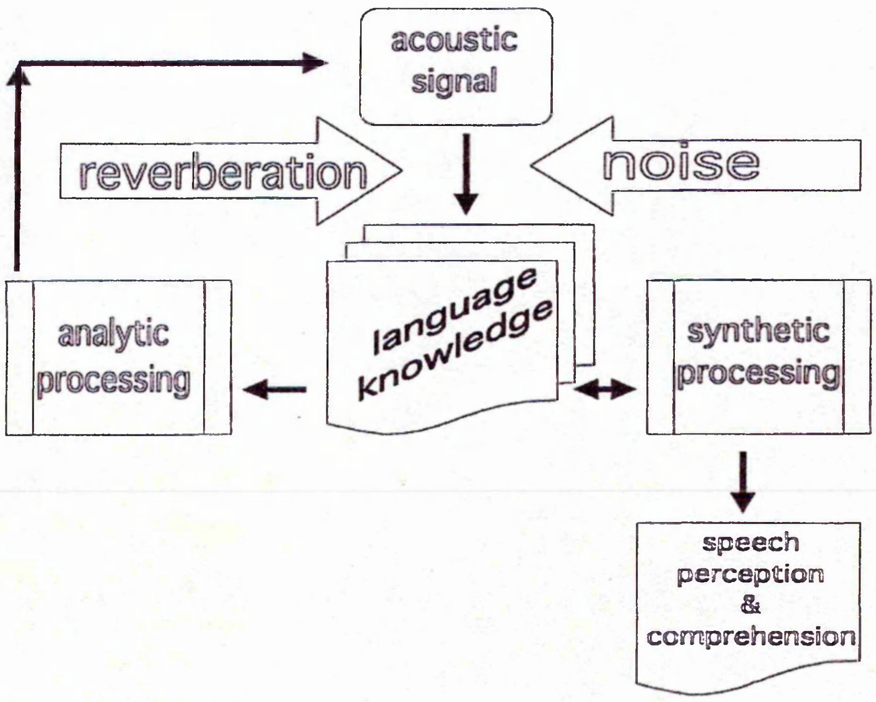


Figure 2.2 Conceptual model of speech comprehension from Smaldino and Crandell (2001) [7]

2.9 Conclusion

It is important to understand the nature and behaviour of sound and how we process and understand the sounds that we hear. School classrooms are inherently noisy because they contain students who are rarely silent so understanding about room acoustics and how it affects what the students hear is important for educators. Many school classrooms have poor acoustics, and teachers do not often understand about how acoustics influence listening in the classroom. This study aims to compare different acoustic characteristics, namely that of reverberation time, to see how this influences students' ability to hear in the classroom. Teachers can then be given strategies for use in rooms where the acoustic environment is poor.

2.9 References

[1] SABINE W.C. Collected Papers on Acoustics. New York, Dover publications. 1964.

[2] Building Bulletin 93 THE STATIONERY OFFICE Acoustic Design of Schools

[3] Building Bulletin 87 The Stationery Office

[4] BRITISH ASSOCIATION OF TEACHERS OF THE DEAF, 2002, *BATOD Magazine* February, 23-24

(5) ENT Consultants at Sheffield Children's Hospital 2003

(6) AIREY S., MACKENZIE D., (1999) Classroom Acoustics; A research Project. Heriot-Watt University.

(7) SMALDINO J.J., CRANDELL C.C. (2001) Speech Perception in the Classroom. Volta Review 101-105.

Chapter 3 Previous Research into Classroom Acoustics related to Speech Intelligibility

3.1 Introduction

In the developed countries of the world schooling is an accepted and expected part of a child's life. Everyone who has been through the education system has a view, a memory and knowledge of what happens in a classroom between teacher and students.

Technology has advanced rapidly in the last part of the twentieth century and into the classroom of the early twenty-first century bringing computer technology, amongst other advances, more and more into the everyday life of children. However, the predominant method of curriculum delivery is still that of the spoken word. So what is known about the acoustic characteristics of the classrooms of today's students to enable efficient and effective communication between teacher and student?

This chapter examines research on the issue of classroom acoustic conditions.

3.2 Reverberation time.

Reverberation times have been measured by different methods by different researchers, but now in England there are regulations that should lead to standardised testing. This legislation in England and Wales has been a long time in coming. The new Building Bulletin 93[1] now sets minimum standards for classroom acoustics, including reverberation time, and methods of testing for these standards. The document states classrooms should have a reverberation time of 0.6- 0.8 seconds at frequencies of 500Hz, 1kHz and 2KHz in unoccupied classrooms. In classrooms where there are hearing impaired students included the reverberation time is shorter, at 0.4 seconds, as recommended by the British Association of Teachers of the Deaf. [2]

In Britain there has been little published research on reverberation times in classrooms although there is undoubtedly more being done currently with the introduction of Building Bulletin 93 and its relevance to the acoustic climate in new classrooms. Although measurements have been taken of reverberation times in classrooms and many found to be unsuitable for speech discrimination due to the long reverberation times, there have only been a few attempts at using real classrooms for speech discrimination work.

In a study of Argentinean classrooms by Ercoli et al [3] measurements of reverberation times were taken with a spectrum analyser. This generated a wide spectrum noise and white noise over a frequency range of 20Hz to 20000Hz. The measurements were taken in two positions in each classroom. The results showing average reverberation times at 1000Hz of between 1.41 and 1.57 seconds occupied and 1.46 to 2.79 unoccupied. When the octave band analysis is studied rather than the average reverberation time at 1KHz then the recordings show long reverberation time in the low frequencies but tailing off going into the high frequencies indicating a low frequency reverberation problem that was not addressed in the conclusions of this research.

Crandell and Smaldino [4] used 110dB broadband noise and recorded the decay with a reverberation time meter. Three measurements around the centre of the rooms, beyond the critical distance in order to ensure measurements were in the reverberant field of the classroom. Measurements at each frequency were taken and averaged. The results showed that the reverberation times were slightly higher in the low frequencies and the range of reverberation was considerably higher in the lower frequencies. The authors did expect these results, as average classrooms do not have much in the way of absorptive surfaces and materials to absorb the low frequency reverberation. Only 9 of the 32 classrooms measured met the recommended level of 0.4 seconds for hearing impaired students in America. As reverberation, particularly at the low frequency levels, can adversely affect speech perception through the upward spread of masking of the direct speech energy, the listening environment in classrooms that do not meet the recommended level for reverberation time is affected detrimentally. Crandell and Smaldino recommend that reverberation time is measured 'at discrete frequencies from 125 to 8000Hz….' in order to enable remedial treatment to be effective.

In 1999 Mackenzie and Airey[5] completed a research project on classroom acoustics in over 70 assorted British primary school classrooms. They measured the reverberation times in these rooms both occupied and unoccupied. The RT was measured in ⅓ octave bands between 63 and 4000Hz. Random locations were selected around each room for 5 or 6 tests. The rooms were tested before and after acoustic treatment. The children used for testing were all primary with age ranges from 5-11; they were presented with the WIPI test (outlined in Chapter 5) under different conditions. This is a subjective test based on picture identification (one from six) from a spoken instruction. The background noise element was provided not by a multi-babble tape but by the class themselves and was recorded at a level of 61-65 dB(A). The reverberation time measurement in both occupied and unoccupied was to ascertain what difference a class made to the times. However the new Building Regulations 93 require that reverberation time is measured with only one occupant (the tester). Although Mackenzie and Airey for the purposes of their research measured occupied rooms and found that bodies in a classroom do reduce the reverberation time by an average of about a second in the mid frequency range, this should not be seen as a practical method of reduction of the reverberation time as classrooms are often used for withdrawal groups or one to one teaching when the reverberation time is not shortened by the presence of a whole class and therefore speech discrimination of students may be reduced.

Their research was to establish whether acoustic treatment to classrooms improved the reverberation times, the background noise levels and therefore the speech intelligibility. Average reverberation times showed a reduction after remedial acoustic treatment of between 0.2 and 0.3 seconds.

In a pilot study by Smythe and Bamford [6] noise and reverberation measurements were taken in classrooms and withdrawal rooms where hearing impaired students usually worked. These students were then tested in these rooms under various conditions, including the use of hearing aids and FM systems, using the BKB sentence lists. The BKB lists are lists comprising of 16 sentences, phonemically balanced, with 3 or 4 key words in each. The lists are spoken, and then repeated by the listener. A score is given depending on how many of the key words are repeated correctly. Then a percentage score is calculated. These sentences are used to assess speech discrimination of both normally hearing and hearing-impaired students. However experience suggests that these sentence lists are very time consuming both in presentation and in subsequent scoring. There is a problem with student motivation when sentences are used as the students tend to get bored which is why word lists were subsequently used in testing in preference to sentence lists.

Reverberation times in this study were calculated using the Sabine Formula. Noise levels were measured using a simple sound level meter. Acoustic conditions in the rooms were poor, none of the classrooms had a reverberation time of less than 0.4 seconds (for hearing impaired students as now required by BB93[1]), in fact they were averaged at 0.74 seconds, and signal to noise ratios were 0dBA in most of the classrooms. This is a very unsophisticated experiment used to merely highlight problems encountered by hearing impaired students in average school classrooms.

Studies around the world have been carried out and are continuing into the measurement of reverberation time in classrooms to try to quantify its effect on the discrimination of the spoken word.

In a study by Yacullo and Hawkins [7] working in one sound booth room with RT of 0.04 seconds, and a classroom with a measured RT of 0.8 seconds, 32 normally hearing children were tested. Their ages ranged from 8-10 years; an age equivalent of not less than the 50th centile (as a check for receptive language) of the Peabody Picture Vocabulary test; and grammar performance not more than one standard deviation from chronological age. They were given sentence identification tests via a loudspeaker at a height of 1 m, into one ear selected at random. The other ear was plugged and muffed. Speaker to distance ratio was different in the two rooms and was calculated using Peutz's[8] formula.

$CD = 0.2\sqrt{V/RT}$.

V = volume of room in m^3

RT = reverberation time

Blair's sentence materials were used as test material (six groups of sentences with 50 key words). The noise stimulus was 12 talk babble. The longer reverberation times were found to decrease the mean speech recognition scores by 41.1 %. A reduced signal to noise ratio further decreased the scores. This study shows the reduction in speech perception due to increased reverberation but again is not the usual listening situation as it involves normal binaural listeners being made to listen monaurally, which is an artificial situation. This research does however use a real classroom with a measured reverberation time that is common to many classrooms so therefore the results need to be considered with reference to this study.

Finitzo-Hieber and Tillman [9] used monosyllabic word discrimination lists for monaural hearing in normally hearing and hearing-impaired students between 8 and 14 years under conditions of differing reverberation time and signal to noise ratio. The testing was completed in an anechoic chamber or a reverberant room where the RT was 0.0, 0.4 and 1.2 seconds. The increase in reverberation time from 0 to 0.4 in the anechoic chamber was achieved by acoustically treating the walls of the reverberant room. This made the RT flat across the frequencies and therefore did not vary according to the distance from signal to source. Signal to noise ratio was a condition that was also varied. The background noise again comprised of multi-talk babble. The subjects, 12 normally hearing 8-12 years old, and 12 hearing-impaired 8-13 year old children, listened to monosyllabic word lists played at an intensity of 25dB above their listening thresholds. The normally hearing listened through a loudspeaker presented monaurally (presumably the other ear was muffed); the hearing impaired listened through a hearing aid.

Reverberation caused a statistically significant reduction in speech discrimination in both quiet and background noise, more so for the hearing-impaired children. It must however be stated that the room was created for this research giving a flat reverberation time. This is not the case in real classrooms where the reverberation will vary across the frequencies.

Nabelek and Robinson [10] describe reverberation as the most common everyday distortion and that various researchers have stated that speech levels for children need to be higher than they do for adults. Their study looked at speech perception in reverberation for listeners of various ages. They also looked into monaural and binaural listening to establish what advantage binaural listening gave. Nabelek and Robinson used Modified Rhyme Tests (the original list of sentences being randomised into these lists.) consisting of 18 lists of 50 sentences. The sentences each containing a key word that the subjects had to identify from a list of 6 displayed on a video screen. They used one room where the reverberation time could be controlled and altered, giving reverberation times of 0.4 secs, 0.8 secs and 1.2 secs measured at 0.5, 1 and 2kHz. Their study was primarily to compare the listening abilities of different age groups in reverberant conditions. Audiometric testing was completed to check the subjects had normal hearing. The sentence lists were played through a loudspeaker and the sound picked up and recorded by a microphone in a mannequin's ear canals, at a distance of 4m from the speaker. The sentence lists were then played to subjects through earphones to one and then both ears, to give mean recognition scores. Each listener listened to two sentence lists ie 100 words.

Unsurprisingly binaural listening proved to be better than monaural. The younger age (10 years) scored worst in all the different reverberant conditions than the older age groups of 27 years, 42 years and 54 years, after which the older groups scored worst as would be expected as age related hearing loss increases. This study shows the effect of reverberation alone on listening, particularly on immature listeners and therefore the importance of good acoustics in classrooms.

Nabelek and Pickett [11] looked at the combined effect of reverberation and signal to noise differences on monaural and binaural perception of consonants by college students. They used speech and noise generated by loudspeakers at a constant distance from the listener. Both normally hearing and hearing-impaired subjects were used. Speech was presented in a specially constructed room where the reverberation time could be manipulated. Two different reverberation times averaged at 0.6 seconds and 0.3 seconds were used. The listeners were within the critical distance. The speech was presented to the normally hearing at 50dB (considered to replicate a teacher's voice in the classroom) and to the hearing impaired at 60dB at reverberation times of 0.3 and 0.6 seconds with the signal to noise ratio of +10 to -15dB. The speech test material was a modified rhyme test consisting of 50 common one-syllable words testing either initial or final consonants. Masking noise was that of eight talk babble.

The purpose of this experiment was to try to specify optimum classroom listening conditions for hearing impaired students however the use of normal listeners in monaural listening conditions is artificial and not a relevant measure in a normal classroom situation. The signal decibel level of the test material is also open to criticism as it is at a low level compared with studies that have measured the actual voice levels of teachers in the classroom. The effect of an increased reverberation time was seen in the scores for binaural unaided listening in babble. When the room was treated to give a reverberation time of 0.3 seconds the percentage mean scores were 84.3 in signal to noise ratio of -5dB; 67.5 in -10dB; and 44.8 in -15dB. In the increased reverberation time of 0.6 seconds, the scores were 74.8, 51.6 and 20.7 respectively, a significant decrease. When compared to masking using impulsive noise rather than multi talk babble the respective scores were better suggesting that babble is a more effective masker of consonants than impulsive noise. Johnson [12] preferred to rerecord nonsense word lists (Danhauer Nonsense Syllable Test) in four manufactured listening conditions. An average reverberation time in a lecture hall (500Hz; 1000Hz; 2000Hz) of 1.3 seconds was measured. The word list was then recorded in this room but it is not clear at what distance or at what volume. This nonsense word list was also recorded in the non-reverberant conditions of an anechoic chamber. The subjects listened to these recordings monaurally through a headset and repeated what they heard. The researcher here was looking for the effect of the various conditions on vowel and consonant identification.

The subjects in this experiment were not in what one could call a normal listening environment. To listen monaurally through headphones to a pre-recorded tape does not mimic normal classroom listening conditions. All the subjects had normal hearing so this is very much an artificial and unfamiliar situation. The words being nonsense words also do not occur in normal teacher language.

Methods to assess speech discrimination in reverberant conditions have varied widely as have the ages of the subjects. Normally hearing and hearing impaired have been involved; adult and child. The method of presenting the spoken word has significantly varied, as has the method of listener reception. Some researchers have used sentences, some monosyllabic words, some consonant-vowel-consonant words and some nonsense words. All however agree that prolonged reverberation time has an effect on speech discrimination.

Many researchers have confined their research to rooms that have reverberation time artificially created ie in reverberation chambers, and that are flat across the frequency bands. In practice classrooms do not have reverberation times like this, there is fluctuation across the frequencies which must affect the speech discrimination abilities of the listeners due to the upward spread of masking.

As acoustic conditions in the classrooms are discussed and assessed more widely, there is a need for a test which can give data on speech discrimination in rooms with known measured reverberation times.

The test needs

- To give normative data;
- To be easily administered
- Be well tried.

Educators need to be aware of the implications of long reverberation time on receptive listening.

3.2.1 Early Decay Time

Early decay time is the time it takes for the reverberant energy in a room to decrease by 10dB, in other words the initial 10dB of decay. It is measured in the same way as is described in the previous section. This early decay time is *'shown to be better related to the subjective judgement of reverberation than the traditional reverberation time.'*[13] It is therefore more relevant to speech perception.

3.3 Background Noise

'Speech is infrequently transmitted to a child without interference from background noise' (Crandell and Smaldino,). [4]

Another parameter by which the internal acoustic environment is characterised is the background noise levels.
Background noise can originate from many different sources, both internal and external to the school environment.
Finitzo[14] states that internal background noise can be attributed to

1) the movement of children, teachers, desks,
2) noisy equipment and
3) different activities within the same classroom.

General moving about the classroom, fidgeting, fiddling with rulers, pencils, paper, books etc, general chat, working noise, and if in a specialist classroom for example a science laboratory or food technology room, the particular background noise of experimental and preparation work is present. What is internal noise in one classroom can become intrusive external noise in another especially if there is insufficient materials for absorption between adjacent rooms both above and below and to the side. Basically she is saying that the students are mostly responsible for noise in the classroom. However this is not a truly accurate assessment, being somewhat simplistic in its view. Noise generated by the class includes all the above but is generally that of speech or babble noise. This is a more continuous noise in its nature. It is this babble that produces the greatest decrease in speech intelligibility.

According to BB93 [1], indoor ambient noise levels should include the sum of noise from all sources from outside the school along with any internal noise from heating and ventilation systems. Heating and ventilation systems usually producing low frequency noise. The windows, if used for natural ventilation, should be open. Background noise levels in a classroom should be a maximum of 35dB measured over 30 minutes (Laeq, 30mins). In these regulations the maximum indoor ambient noise level does not include noise generated by the students.

Noise surveys suggest that noise levels are increasing. There are increasing amounts of traffic on the roads and more and more flights from more airports, which is creating noise pollution for more of the population.

Shields et al [15] looked at the internal and external noise levels in relation to SATs results at key stage one and key stage two. Their study of schools in some London Boroughs found that the average daily noise exposure for primary school children was $72dB_{Laeq}$. The predominant noise level being that of the children themselves involved in various classroom activities. The background ambient noise levels of unoccupied classrooms was found to be above the then recommended levels of BB87 by 7dB(A). In Shields study, in six London Boroughs, during a five-minute sampling period the noise was predominantly that of road noise. The children were asked to report on sounds they heard in the classroom from external sources and included as well as the usual traffic noise those of sirens, motorbikes, and horns. The external noise levels she measured were predominantly within the 56-60dB(A) bracket. The World Health Organisation guideline states that the noise levels in school playgrounds should be 55dB(A) $_{Laeq}$ during playtimes. This study shows that these

playgrounds in London exceed this level. Other sounds reported and within the sample included construction noise, trees, music and people. Rural schools and those on the edges of towns and cities probably suffer less with noise pollution, but may still have issues with noise from farm machinery, planes overhead and other noise peculiar to the area.
They tested groups of children in quiet (called base noise where the children were working quietly in their class), in simulated babble noise at 65dB(A) and again in simulated babble noise with environmental noises included eg motorbikes/emergency services sirens. Their study does not say how the sound was delivered and how or where it was measured in the classroom. There is no mention of any issue with reverberation time in the classroom. Their tests included perceptual reasoning, arithmetic, reading, speed of information processing, spelling and memory tasks.
There was a negative correlation between SATs and internal noise levels particularly at Key Stage Two. This study included questionnaires given to both teachers and pupils asking for their perception of noise in the classroom.
Noise according to Finitzo[14] '*is any unwanted disturbance that interferes with what we hear*'.
She measured noise levels in 6 school buildings using a sound level meter to record both dB(A) and dB(C). Unoccupied classrooms were the quietest area, with gymnasia the noisiest, as could be generally predicted. She does not explain how the measurements were obtained other than saying that they were taken at the same time of day during similar activities, and that she compared the A and C weighting. Her resulting data matches that of other researchers.
Crandell and Smaldino[4] measured the acoustic characteristics of 32 classrooms for hearing impaired students in a variety of schools in a

metropolitan district of America. They measured unoccupied background noise levels using a B & K sound level meter type 2209, during normal school hours. The researchers used both the dB(A) and dB(C) scales in order to establish whether there was low frequency background noise present. The sound level meter was located where students typically sat in the classrooms. The noise levels ranged from 34-62 dB(A) and 49-78 dB(C). The difference between the two scales it is suggested indicates a presence of low frequency noise, which the researchers felt emanated from electrical hums and general building vibrations.

None of the classrooms were within the level of 30dB(A) set as an acoustical guideline in America.

Markides [16] examined background noise levels in mainstream classrooms and rooms used solely by hearing impaired students. Sound level measurements were taken using a B & K Precision sound level meter type 2203. He identified three different types of noise labelling them as

1. <u>Short duration noise</u> ie footsteps, banging of doors, drawers, desk lids etc
2. <u>Non-stationary long duration noise</u> ie student's chatter during lessons
3. <u>Quasi stationary noise</u> ie machinery, cars, trains, planes, HAVS, and the general noise of the schools.

The mean measured level in classrooms of quasi stationary noise was 44.6 dB(A), in rooms for the hearing impaired 48.4 dB(A). The short duration noise was 76 dB(A) and 76.5 dB(A); the non-stationary long duration noise was 59.6 dB(A) and 63 dB(A) respectively.

In more recent research the types of sound that he has divided into categories 1 and 2 really come together under the description of classroom generated noise. Presumably, for the measurement of short duration noise he requested that the students continue to work normally but refrain from talking. This is not normal observed classroom practice and therefore does not reflect accurately the normal pattern of noise. The quasi stationary noise can be directly compared to the ambient noise as stated in BB93, although he measured this at the end of lessons with the students sitting quietly at their desks rather than in empty classrooms as required in BB93.

In Sweden Lunquist[17] measured sound levels in 25 typical classrooms using a B & K 2237 sound level meter at ear height in asymmetrical positions. He recorded unoccupied levels for a 10-minute duration and then mid lesson occupied levels when the teacher was helping individual students and not teaching the whole class directly.

He was trying to find a link between students activity noise level and background noise. In analysing his results he feels that there is a statistical link between higher background noise levels and higher classroom activity noise levels. He then outlines many factors that can influence activity noise levels including low frequency sounds, type of activity and subject and ratio of girls to boys. He does not mention reverberation time.

In another study Lunquist [18] measured sound levels in 22 unoccupied classrooms in 3 schools in Sweden using the same method as above. He used both A weighting and C weighting and the difference between the two to analyse the results. Where the difference between the 2 readings was less than 15dB the noise was categorised as low levels of low frequency noise exposure and above 20dB became high levels of low frequency noise exposure. As a further part of this study he gave the students questionnaires to complete on the annoyance levels that they felt in the rooms. Eight classrooms were categorised as having low frequency levels of noise exposure and nine had high low frequency noise exposure. The students in their responses did not indicate that they felt any increased annoyance levels in the high low frequency levels existing in some rooms.

The relevant issue with this study is that the low frequency levels which were analysed as a result of the difference between the A and C weightings are such that they are not within the boundaries of human hearing and are therefore not being picked up by the students. He does not suggest what is the cause of the low frequency sounds either. An issue that should be researched is that of the masking effects of low frequency sounds that are within human hearing.

Yacullo and Hawkins [7] in their study looking at speech recognition in noise used multi talk babble as their noise stimulus. This noise stimulus was mixed with the speech stimulus and presented through one loudspeaker located in the corner of the test room. The signal to noise ratio was +6dB and +2dB, with the speech signal presented at 70dB representing normal conversational speech. There was no note made on the level of background noise.

Airey[5] measured background noise levels using $L_{aeq15\ mins}$ during a typical day in primary classrooms. She measured rooms that were occupied but the students were sitting in silence, when the students were working normally, and also when unoccupied. The measured noise levels ranged from 49dB(A) to 85dB(A). She cited many factors for these fluctuating sound levels including the environment immediately outside the classroom and indeed the location of the school as a whole; the age of the students

and capacity of the room; the construction of the room and quality of any sound insulation including any other sound sources like heating and ventilation systems.

The method of recording the background noise levels where the children are sitting in silence is open to question, if it is the ambient noise that is being measured then there is no need for the students to be present. Indeed can students of that age sit in silence for so long!

Crum and Matkin[19] measured 11 classrooms for hearing impaired students and found that only one was at an acceptable level in terms of the ambient noise levels. They used a portable sound level meter in two locations in unoccupied rooms, and also noted the sources of background noise. They also made a detailed analysis of each room. It is not known how the measurements were taken. Their conclusions looked particularly at the placement of the rooms within the school in general and the acoustic treatments or lack of, in each of the rooms specifically in relation to the hearing impaired students who used the rooms.

Recorded background noise levels should be analysed by frequency as well as just giving an average level so that it can be seen whether there is any predominantly low frequency noise present in the classrooms, as low frequency background noise is a more effective masker of speech than high frequency. Noise generated by a class is generally that of speech (multi-talk babble) and is more continuous in nature; this produces the greatest decrease in speech perception. Tests that use 'multi-babble talk' at a level of around 70dB(A) as background noise are more relevant and realistic as it is this type of noise that is the most prevalent noise in the classroom with which both students and teachers have to cope.

3.4 <u>Speaker to listener distance</u>

Peutz's[8] formula to calculate critical distance is

$CD = 0.2\sqrt{V/RT}$.

V = volume of room in m^3

RT = reverberation time

Crandell and Smaldino[4] use the following adapted formula to determine the critical distance.

$D_c = 0.20\sqrt{VQ/nRT}$

Critical distance =

V = volume of room in m^3,

Q = directivity factor, the voice is 2.5

n = number of sources

RT = reverberation time at 1400Hz.

They used the formula in classrooms where the reverberation time was to be measured to ensure that their recorded reverberation times were taken beyond the critical distance and therefore in the reverberant area of the classroom. Students seated beyond the critical distance, which in reality can be the majority of the class, receive the direct signal first but will receive the reflected signal marginally later as it has been reflected from ceiling, floors and walls on its way to the listener. Not only will this reflected signal arrive later but it will have been changed due to the reflections and absorptions of the materials on the surfaces of the room and will therefore have a different acoustic content.

Researchers in America have stated that speech perception scores will decrease until the critical distance is reached and then remain fairly constant. (Crandell 1991; Crandell & Bess 1986; Leavitt & Flexer 1991; Peutz 1971) There is little research that has been completed in a classroom with known reverberation time and signal to noise ratio to show that some seating positions beyond critical distance in classrooms are poorer for speech discrimination than others. This is of relevance to educators who recommend preferential seating positions for some students who require better speech perception conditions than others, for example hearing impaired students.

Finitzo-Hieber and Tillmann [9] in their experiments with 12 children in an anechoic chamber or a reverberation chamber with reverberation times of 0.4 seconds and 1.2 seconds, used a distance of 12 feet from the sound source. No reference is made to the critical distance.

Yacullo and Hawkins [7] used different speaker to listener distance in each of their test situations. They did consider the critical distance but their aim was to assess the greatest possible effect of reverberation on speech perception. They therefore chose 1.83m in the sound treated booth with an average reverberation time of 0.04 seconds, and 3.66m in the classroom, which had an average reverberation time of 0.82. This distance they felt represented that of the student position in an average classroom. They used Peutz's[8] formula to establish the critical distance in the rooms thereby making sure that their subjects were beyond this distance. In using different distances from the speech source they measured the sound level at the listener's ear to ensure a constant level. Although their results show a reduction in the scores correct at the different signal to noise ratios in the different reverberation times it does not show the benefit of being within the critical distance.

Nabelek and Robinson [10] used a formula, which took into account the directional source of the signal and receiver but went on to state that the precise distance could not be calculated due to the unknown directivity of the loudspeaker and receiver. They assumed that the reverberant sound field was predominant at a distance of 4m saying that Peutz demonstrated this procedure.

3.5 Signal to noise ratio

Many studies have looked at signal to noise ratios to establish a level at which students can easily hear the teacher's voice rather than having to strain to listen when there is competing background noise. Anderson[11] suggests that as the teacher raises her voice to combat background noise both her stress levels and those of the children are raised.
Voice intensity levels can be measured, and then compared to the level of background noise present.

3.5.1 Natural Classroom Background Noise

Airey [5] recommends a signal to noise ratio of +10dB(A) to +15dB(A) for comfortable and accurate listening in the classroom. In her research the loudspeaker level was set at 67.5dB(A) at 1 m distance with the background noise level, consisting of natural chatter from the class, was measured between 61-65dB(A) but it is not known whereabouts in the room this was measured. Thus giving a maximum of +6.5dB(A) and a minimum of +2.5dB(A) signal to noise ratio.
In a short pilot study by Smythe and Bamford [6] signal to noise ratios were found to be very different in different areas of a school. A library had the highest signal to noise ratio of +30dB(A), a classroom the lowest of -5dB(A). As the focus of this study were 4 hearing impaired primary

aged children, wearing a combination of hearing aids and FM systems and both with and without the aid of lip-reading, it is difficult to draw any conclusions other than the recommended levels of signal to noise were met in some areas but not in others.

3.5.2 Artificial Classroom Background Noise

Yacullo and Hawkins [7] in their study of speech recognition used a speech presentation level of 70dB. This level was used, they say, as it approximates average conversational speech. Babble was used as the background noise and adjusted to +2 and +6dB signal to noise. They also used two rooms with differing reverberation times 0.0 s and 0.8 s. The speech stimuli were sentence lists derived from Blair's materials. The signal and noise were attenuated, mixed and amplified through a loudspeaker located at a corner of the test room and at a height of 1 metre. Both signal and noise came from the one speaker. The normally hearing students listened monaurally with the other ear muffed. The argument for doing this was that binaural hearing enables the listener to suppress some of the masking effects of reverberation. Their results would surely then be relevant only for students with unilateral hearing losses. The results worsened with the lower signal to noise ratio and again with the longer reverberation time of 0.8 with a decreased signal to noise ratio.

Finitzo-Heiber and Tillmann [9] recorded four females and four males reading different prose passages. The recordings were remixed electrically then rerecorded. A 1KhZ pure tone signal was used to calibrate the intensity of the multi-talk babble. In their experiment they used signal to noise ratios (or message competition ratios) of 0dB, +6dB and +12dB and no noise competition (ie quiet). The speech stimuli were six consonant-vowel-consonant lists of monosyllabic words (from the revised Peterson-Lehiste lists 1962) recorded onto the first track of a dual track tape. They also changed the reverberation time by using an anechoic chamber and a reverberation chamber, which could be acoustically treated to alter the reverberation times.

These researchers used both normally hearing and hearing-impaired students. The signal intensity was individualised for each student to a level of 25dB above threshold level. The competition ratio was adjusted to +6 and +12 above the signal level for each student.

Signal and noise came from one speaker located at a distance of 12 ft from the listener. This was considered as being similar to that experienced by the distance a student would be from a teacher in a normal classroom. The students listened monaurally; students with a hearing loss used a hearing aid for one set of tests and the loudspeaker for the other. The results for both sets of students showed a decrease in the percentage scores gained as the signal to noise ratio worsened and also as reverberation time increased. The percentage scores for the hearing impaired were uniformly worse than their normally hearing peers. Again students listened monaurally to a signal that was individualised for each of them. The researchers do not say why they chose this method, nor do they say why they opted for monosyllabic word lists. They did not use ordinary classrooms but chose instead to use an unfamiliar small anechoic or reverberation chamber that could be easily modified to produce the required reverberation times.

The environment and method selected for this research is far removed from a normal classroom, where for example the signal and background noise would not come from the same pinpointed source of a loudspeaker.

To simulate a classroom it would require the background noise to be presented from other areas of the room or from external locations.
They also do not state how they decided to use signal to noise ratios from 0dB, +6dB, +12dB and quiet.
Johnson [13] chose a signal to noise ratio of +13dB(A) after looking at previous published work, particularly that of Nabelek and Robinson [11], which stated that young children needed 10-20dB 'greater relative presentation level'. Johnson's research looked at consonant and vowel identification within different variables those of noise; reverberation and noise with reverberation. She also used a different type of speech test. She therefore acknowledges that her results did not support those in other studies, because there were several differences in the methodology.
She found that consonant identification by children of different ages did not vary with sensation (intensity) level within the differing listening conditions.

3.5.3 <u>Teacher Voice Intensity</u>

Markides [16] measured teacher's voice levels using a B & K precision sound level meter type 2203 at a distance of 2 metres from the teacher's mouth. He dismissed the extremes of high and low intensity and took the most commonly occurring values. Average speech levels of the teachers were 57.5 dB(A), but ranged from 50 to 70 dB(A). Markides then related the teachers' voice levels to the background noise levels that he labelled as short duration noise, non-stationary noise and quasi stationary noise as outlined in the section on background noise levels. The differences in signal to noise were significant. In Markides study it is the short duration noise which produces the worst signal to noise ratio. He describes this short duration noise as mainly impulsive sounds such as footsteps, doors, desks, drawers etc banging which he states is controllable by the teacher. Markides measured each sound in the classroom independently and then compared one level against another to give the signal to noise ratios. He has stated that the short duration and non stationary sounds are controlled by the teacher so presumably the teacher can reduce the background noise levels of these two categories to the improve the signal to noise ratio. Interference from external sound sources is relatively minimal. The teachers' voice levels are at quite low intensities compared to other studies due to the fact that he was researching listening conditions for hearing impaired students where numbers are low and teacher to student ratio is high. Classrooms where all the students are hearing impaired tend to be quieter than normal mainstream classrooms.

3.5.4 Different background noise

Gengel [21] in a study examining speech to noise ratios with hearing impaired students classed noise in two ways, that of constant and fluctuating. A specially designed and constructed classroom was used with a reverberation time that could be adjusted. He used 0.7seconds.
The background ambient noise level was 20dB(A), which is very low and probably unrealistic in a real school. Constant and fluctuating noise recorded in real school buildings was used. The fluctuating noise was at a higher level in the lower frequencies than that of the constant noise, which peaked in the mid frequencies but was at a higher loudness level.
He used a monosyllabic word test using tape recorded lists of 50 monosyllabic words originally developed by Kreul et al in 1968. Each of the words used had 6 alternative responses differing by only the initial or final consonants. The speech was at a set loudness level of 70dBC. The

noise loudness varied from a ratio of +5dB to +30dB. The speech and noise source were acoustically mixed. All the students wore hearing aids set at a comfortable listening level. The data showed that a signal to noise level of below +15dB caused the students greater problems and that the constant noise was worse than fluctuating. This was to be expected as it was measured at about 8dB lower than the constant noise.
Gengel does not state the distance the listeners were from the sound source but we do know that both the speech and the noise emanated from the same speaker. Gengel goes on to examine ways of improving speech to noise ratio, which includes other researchers suggesting the teacher raising his/her voice 15-20dB above the level of the background noise. He feels this is not a practical solution. He does suggest sound barriers ie acoustic treatment and also changing the seating arrangement of the students so that they are not in the traditional rows but are in a semi circle around the teacher.
His work does not use a single methodology but seems to mix a lot of important factors together to support a view that +15-20dB is an adequate speech to noise ratio. He does not explain why he used a reverberation time of 0.7, nor the speaker to listener distance. The speech and noise are mixed; the classroom is specially constructed. He also does not adequately explain the background noise that is used.

3.5.4 <u>Summary</u>

Crandell and Smaldino [4] summarised other studies looking at signal to noise ratios and brought them together in the table below.

Table 3.1

Study	Signal to noise dB
Sanders (1965)	+1 to +5
Paul (1967)	+3
Blair (1977)	-7 to 0
Markides (1986)	+3
Finitzo-Hieber (1988)	+1 to +4

It is generally accepted that signal to noise ratio needs to be +15dB or above to give good listening conditions especially for immature listeners or those with learning difficulties or hearing impairment for example. The signal to noise ratios outlined in this chapter focus on levels that are well below this level and show that children do have significant problems as the signal to noise ratio worsens.

Consideration, however, is not given to distance from the speaker other than to say that the distance is comparable with where students would sit in their normal classroom. There is a significant drop in signal intensity the further away from the source the listener sits, combine this with noise that does not emanate from the same place as the signal as in normal classrooms, thus giving a very different picture to that given by most of this research reviewed in this chapter.

3.6 Speech Intelligibility

Speech intelligibility is being able to make sense of what is being said. Airey and Mackenzie[5] defined speech intelligibility as 'the process whereby a person can clearly hear what is being said and fully understand the context of the spoken word'.

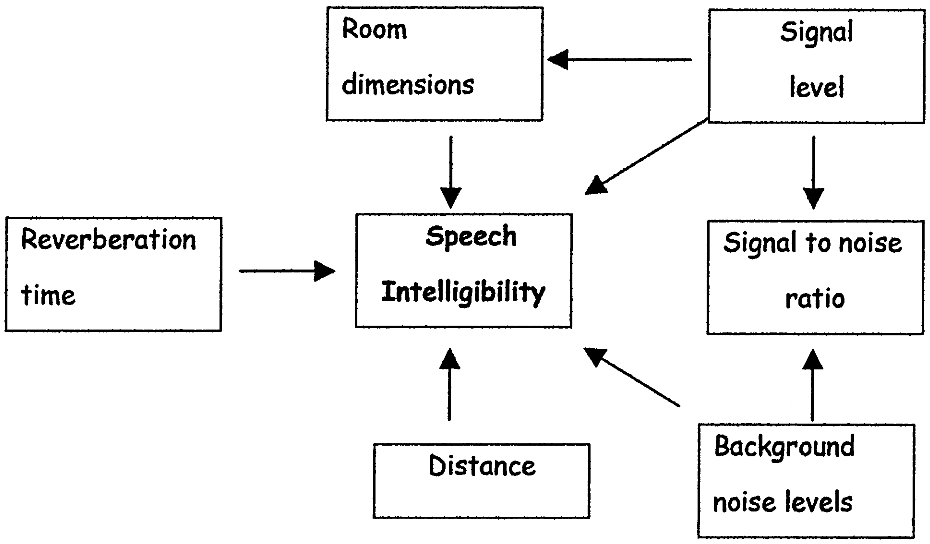


Figure 3.1 Adapted from Airey and Mackenzie[5]

BB93[1] states that ' The intelligibility of speech depends upon its audibility as well as clarity. Audibility is affected by the loudness of the speech relative to the background noise level. An increase in the background noise will cause greater masking of speech and hence will decrease intelligibility.'

It defines the following terms

- Clarity — the property of sound, which allows its information bearing components to be distinguished by the listener

- Audibility — the property of sound which allows it to be heard among other sounds

- Intelligibility this is the measure of the proportion of the content of a speech message that can be correctly understood

Clarity + Audibility = Intelligibility

Whether in quiet or in noise the spoken word has to be heard and interpreted for us to make sense of what is said. In quiet conditions a normal conversation is both audible and understandable. Introduce background noise and the intelligibility decreases. Different background noises and the intensity of the noise have differing effects on intelligibility, as does the ability of the person to hear. A mild hearing loss decreases a person's ability to hear and is worsened by any background noise. More severe hearing losses have more debilitating effects on speech intelligibility.

In classrooms speech is the main medium for delivering the curriculum, so it is imperative that the students in the class can hear the teacher.

The acoustics of the classroom have to, therefore, be good enough for a high level of intelligibility. The reverberation time should be short between 0.4-0.8 seconds, so that there is little masking of speech. Background noise levels should be low, at 35dB(A) or below. Thus giving good levels of speech intelligibility.

The speech transmission index and articulation index are methods of defining good or poor speech intelligibility levels using software and a sound level meter. These give ratings to areas of a room or auditorium. They do not use normal speech but electronically produced sounds containing all the sounds of speech, which are processed to give the ratings.

3.7 Discussion and Analysis

The issue that is raised throughout this review is that of what do students actually hear in the classroom when they are at the mercy of the acoustical characteristics of the rooms. An issue raised by many researchers is that of trying to assess the listening abilities of hearing impaired students with various methods of amplification within these acoustical variations. However the point must be made that if the acoustical environment is improved for normally hearing listeners then it will also improve for the hearing impaired. There are also so many methods of amplification available that to try to produce a comprehensive study of aided hearing-impaired students is almost impossible.

Conductive hearing losses and sensori neural hearing losses are very different and also do not bear easy comparison. People with sensori-neural hearing losses also can often suffer with sound distortion, therefore do not hear speech clearly and have to decipher what they do hear in order to make sense of what they hear. They also, if they wear hearing aids have to learn to filter out sounds that they do not need, for example background noise. Adult wearers of hearing aids are better able to do all this than more immature listeners. So putting students through such speech testing when the background babble is loud (70dB(A)) and constant over quite a long period of time is to be placing them in a very unpleasant environment.

There are, at last, new regulations for classroom acoustics in English schools, which should improve the acoustics in newly built schools, but there will still be many students trying to listen in poor acoustics. Reverberation time does affect the ability to pick up the sounds of speech as the reflected sounds mask the initial signal. When background noise is also present the speech perception is reduced still further as shown in these studies.

Critical distance is an important factor but only a few students, if any, actually are seated within this distance in a real classroom, as it is a comparatively short one in rooms with long reverberation times.

The use of real classrooms where there is the normal distribution of students seated around the room will therefore give a comparison of the different speech intelligibility abilities of the different seating positions. When using real classrooms the background noise level and signal to noise ratio can be set to reflect a normal classroom situation when classroom noise measurements have been completed beforehand.

The positioning of both the signal and the noise should reflect as close as possible the real classroom situation, the teacher at the front and the noise from other areas and not from the same source, as this noise can intrude from the corridor, adjacent classrooms, classrooms above and below and also from outside the school.

The issue of what speech intelligibility test material to use is a difficult one. Some researchers advocate the use of sentence materials with key words to be identified by the listeners, which more accurately reflects the language of the classroom. Using sentence lists produces a very long test, which must then include a discussion of the issue of boredom. Others use one-syllable words or nonsense words, creating a very difficult scenario, but much quicker in its application.

Ordinary classrooms need to have the acoustic conditions measured and the speech discrimination potentials of the students within them analysed in order to give teachers, educators, governors and the current government results that show that much of the aural content of lessons can be lost in the poor acoustical conditions that are present.

So the use of ordinary classrooms rather than specially built or adapted ones is, paramount.

These ordinary classrooms must be measured for unoccupied reverberation time and background noise levels.

Also normally hearing students using binaural listening skills and who have been tested for subjective language skills should form the research group.

The methods of testing of speech intelligibility that have been reviewed here do not give a easily completed or understood test for the classroom teacher. It is these front line educators who need to know whether their students can clearly access the spoken word. Students are not always quick to say if they cannot hear, many will just switch off rather than have to concentrate more to hear. Some who routinely sit at the back will never consider a move forward to enable them to access speech! Regardless of conditions some students will nevertheless access the lessons and progress academically; some will not, particularly those outlined in the introduction. Often these are also the ones who require additional educational support. Giving the teachers easily understood information about how much is heard in positions around the class and also advice about how best to improve the listening environment in classrooms is vital. There has been little research that has looked at the actual speech discrimination skills of students in various positions in a standard classroom.

If a classroom has acoustical conditions that are poor, whether it is a long reverberation time or intrusive and difficult to control background noise, the teachers that work in these conditions need to be given information to allow them to adapt their teaching methods to suit their environment. Explaining the effects of long reverberation time allows the teacher to change their style of teaching, so that the upward spread of masking of one sound into another is reduced. For example writing more key information on the board to reinforce the spoken word, and also using shorter spoken instructions with gaps between to allow the effect of the reverberation to fade.

Teachers need help to manage noise both in the classroom and from external sources. If a school is perceived as having a noise problem that can be directly related to the behaviour or management of the students then whole school policies can be encouraged. If the noise is from sources other than the students then investigation of these sources by using objective room measurements and subjective testing of students can be completed. Remedial treatment of the poor acoustic conditions should be explored and encouraged.

3.9 <u>Conclusion</u>

The researchers reviewed in this Chapter are experts in their field and have worked over many years in these areas of acoustics and speech intelligibility. Their research is not, however, within the knowledge boundaries of most teachers and educationalists. Most will take good room acoustics for granted but will very quickly feel that here is something wrong when they move into a classroom that has poor room acoustics but not be able to identify exact problem.

The following research looks at how room acoustics affects the speech discrimination abilities of students in their own classrooms, comparing different reverberation time profiles to how the student manage to discriminate speech. Teachers have identified that there are problems in some of these classrooms but do not have the knowledge of how room acoustics could be the problem. The teachers will receive feedback from this study to help them to understand the nature of the problem and what strategies could be used to reduce the problem of poor room acoustics.

3.10 References

(1) THE STATIONERY OFFICE Building Bulletin 93 Acoustic Design of Schools

(2) BRITISH ASSOCIATION OF TEACHERS OF THE DEAF

(3) ERCOLI L., AZZURRO A.P., MENDEZ A.M. STORNINI A.J. (2001) Case Study: The Acoustical Characteristics of Typical Argentinean Classrooms. *Building Acoustics,* 8, 301-310.

(4) CRANDELL C.C., SMALDINO J.J. (1994) An Update of Classroom Acoustics for Children with Hearing Impairment *Volta Review.* **96**, 291-306.

(5) AIREY S., MACKENZIE D., (1999) Classroom Acoustics; A research Project. Heriot-Watt University.

(6) SMYTHE R.L., BAMFORD J.M. (1997) Speech Perception of hearing-impaired children in mainstream acoustic environments: An exploratory study. *Deafness and Education (JBATOD)* 21/2, 26-31.

(7) YACULLO W.S., HAWKINS D.B. (1987) Speech recognition in noise and reverberation by school age children. *Audiology* 26, 235-246.

(8) PEUTZ U.M.A. Articulation loss of consonants as a criterion for speech transmission in a room. *Journal Audiological Engineering Society.* *19,* 915-919 (1971)

(9) FINITZO-HEIBER T., TILLMAN T.W., (1978) Room acoustics effects on monosyllabic word discrimination ability for normal and hearing impaired children. *Journal of Speech and Hearing Research* 21 440-458.

(10) NABELEK A.K., ROBINSON P.J.M. (1984) Monaural and binaural speech perception in reverberation for listeners of various ages. *Journal of Acoustical Society America.*

(11) ANDERSON K., 2001, Voicing concerns about noisy classrooms. *Educational Leadership, 58,* 77-79.

(12) NABELEK A.K., PICKETT J.M. (1974) Monaural and binaural speech perception through hearing aids under noise and reverberation with normal and hearing-impaired listeners. *Journal of Speech and Hearing Research,* 17, 724-739.

(13) ATAL, SHROEDER & SESSLER 1965, in BARRON M. *Auditorium Acoustics and Architectural Design* (1993) E & F.N. Spon. London

(14) JOHNSON C.E. (2000) Children's Phoneme Identification in Reverberation and Noise *Journal of Speech, Language and Hearing Research.* 43, 144-157.

(15) FINITZO T. (1988) Classroom Acoustics in Auditory Disorders in School children Roeser Downs. New York

(16) SHIELD B., DOCKRELL J., JEFFREY R., TACHMATZIDIS I. (2000) The Effects of Noise on the Attainments and Cognitive Performance of Primary School Children. South Bank University.

(17) MARKIDES A. (1986) Speech levels and speech to noise ratios. *British Journal of Audiology,* 20, 115-120.

(18) LUNQUIST P. (2002) The relationship between background noise levels and activity noise levels at school. ? 377-380.

(19) LUNQUIST P., HOLMBERG K., LANDSTROM U. (2002) Low frequency noise and annoyance in classroom. *Noise Notes* 1, No 4, 4-10.

(20) CRUM M.A., MATKIN N.D. (1976) Room Acoustics: The Forgotten Variable. *Language, Speech and Hearing Services in Schools.* 2, 106-110.

(21) GENGEL (1971) Acceptable speech-to-noise ratios for aided speech discrimination by the hearing impaired. *Journal of Auditory Research,* XI 219-222.

Chapter 4 Preliminary Experimental Investigation

4.1 Background

Teachers of the deaf in mainstream schools and units for the deaf, work in many different classroom environments with students who have varying degrees of deafness. Part of the work is to ensure that these students can access as much of the curriculum as possible. This involves, amongst many other strategies, assessing the students' speech discrimination abilities in the classroom.

Background noise is always an issue with deaf students. The effect of this on their speech discrimination is usually dramatic. Even slight background noise can interfere and prevent a student with a mild hearing loss from hearing the spoken word accurately. Hearing aids do not just amplify speech they also pick up and amplify background noise alongside the useful and necessary speech signals. Students with sensori-neural deafness may often hear sounds in a distorted manner so they have to learn to decipher many of the sounds they hear in order to make sense of and understand speech. Another part of the work of a teacher of the deaf involves talking with classroom teachers to try to reduce background noise to enable the deaf students to hear more clearly.

Other aspects of room acoustics, for example reverberation time, were not previously a significant issue in the work of a teacher of the deaf. More recently this became a concern in one new school building. The rooms used for speech testing echoed, with both student and teacher having difficulty discriminating each other's speech. On further investigation other classrooms in this new school appeared to have acoustic problems.

As a result of this, the Service for Hearing Impaired Children requested permission to do some speech discrimination assessments with students in this new secondary school, one of the six new schools all built to the same specifications at the same time in the city.

4.2 Aim of this work

The aim of this experimental work was to assess whether the speech discrimination abilities of normally hearing students and one hearing impaired student were being affected by the poor room acoustics found in these new classrooms. One hearing-impaired student was involved, as she was the only hearing-impaired student with hearing aids in the school at the time of the study.

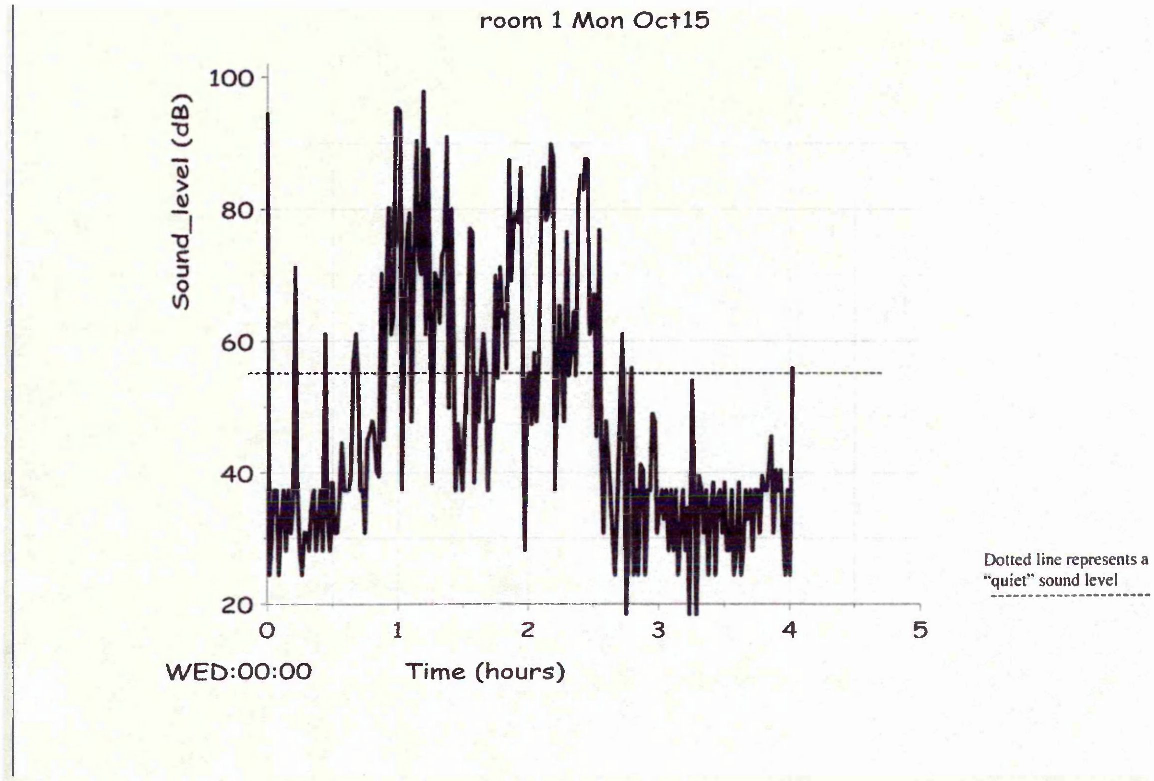
4.3 School Background

The school was one of six newly built in Sheffield as part of the first round of PFI funded school rebuilds. The new building houses the lower school site for students aged 11-14. The upper school site was not part of this new build. It is a mixed comprehensive school situated in a residential area of the city, away from busy main roads, railways and not under a flight path. It stands in landscaped grounds with sports pitches to the front and rear. There is little external environmental noise. Classrooms are built on three floors. A maths classroom on the first floor, a science laboratory also on the top floor and the drama studio, positioned at the far end of the school building away from the academic classrooms, were selected for the speech discrimination testing. The classroom and laboratory were felt to be poor acoustically with what subjectively felt to be quite long reverberation times. A physics teacher at the school had in fact carried out a basic reverberation test, using a laptop programme finding them to be about 1.6 and 1.8 seconds respectively. The guidelines for reverberation times, as recommended by the British Association of Teachers of the Deaf [1] and the DfES[2], were between 0.4 and 0.6 seconds (averaged across the speech frequencies). The drama studio, when first built, could not be used by drama groups, as the reverberation time was so long, at 3.4 seconds when tested, that it was an unbearable environment in which to work. It was subsequently treated with acoustic panelling and when re-tested was found to have a more acceptable reverberation time. When measured later by an acoustical engineer, with the same remedial treatment in place, the reverberation time was 0.44 seconds. It can therefore be stated that it would have been the same at the time of this testing.

4.4 Background Noise Levels

Basic background noise levels were measured during class observations, in the laboratory and classroom during the period of testing, using a basic type three sound level meter. This was to give an indication of background noise levels for the purpose of testing speech discrimination in the selected classrooms where the experiment was to be set up. It appeared, when observing these lessons, that the noise escalated quickly when the students were in groups particularly when working on an experiment in the laboratory. The teachers had great difficulty in getting the groups to quieten down. Peak noise levels occasionally reached almost 100dB. It felt like the signals were competing against each other so the students had to raise their voices in order to be heard against these competing signals. Figure 4.1 shows background noise levels measured by the physics teacher using laptop software. This was a very crude measurement but supports the levels measured on the type three sound level meter completed at a later time.

Figure 4.1 Background noise measures



4.5 <u>Outline of the Speech Discrimination Testing Procedure</u>

Seven normally hearing year seven students (11-12 years of age) were selected at random from one year seven tutor group. There was one condition, that they were not statemented for special educational needs. One hearing impaired, hearing aid wearer (14 years of age) was also tested, as she was the only hearing aid wearer in the school at that time. The Bamford Kowel Bench (BKB) test of speech discrimination was used. This consists of sets of 15 phonemically balanced sentences, with three or four key words in each sentence. These lists were recorded onto a video and presented to the students via video recorder and television. The students watched the video without lip-reading in quiet, with and without lip-reading in background noise. The background noise for the testing was provided by a babble tape played at a distance of 3m behind the student, measured at 70dB at the students' ear. The signal, from the television playing the BKB videotape, was 3m in front of the student and also set at a level of 70dB at the student's ear, thus giving a signal to noise ratio at the student's ear of 0dB. The students listened to each sentence and repeated what they heard; this was recorded to video and scored later. Target words that were correctly repeated were given a mark and then a percentage score was calculated.

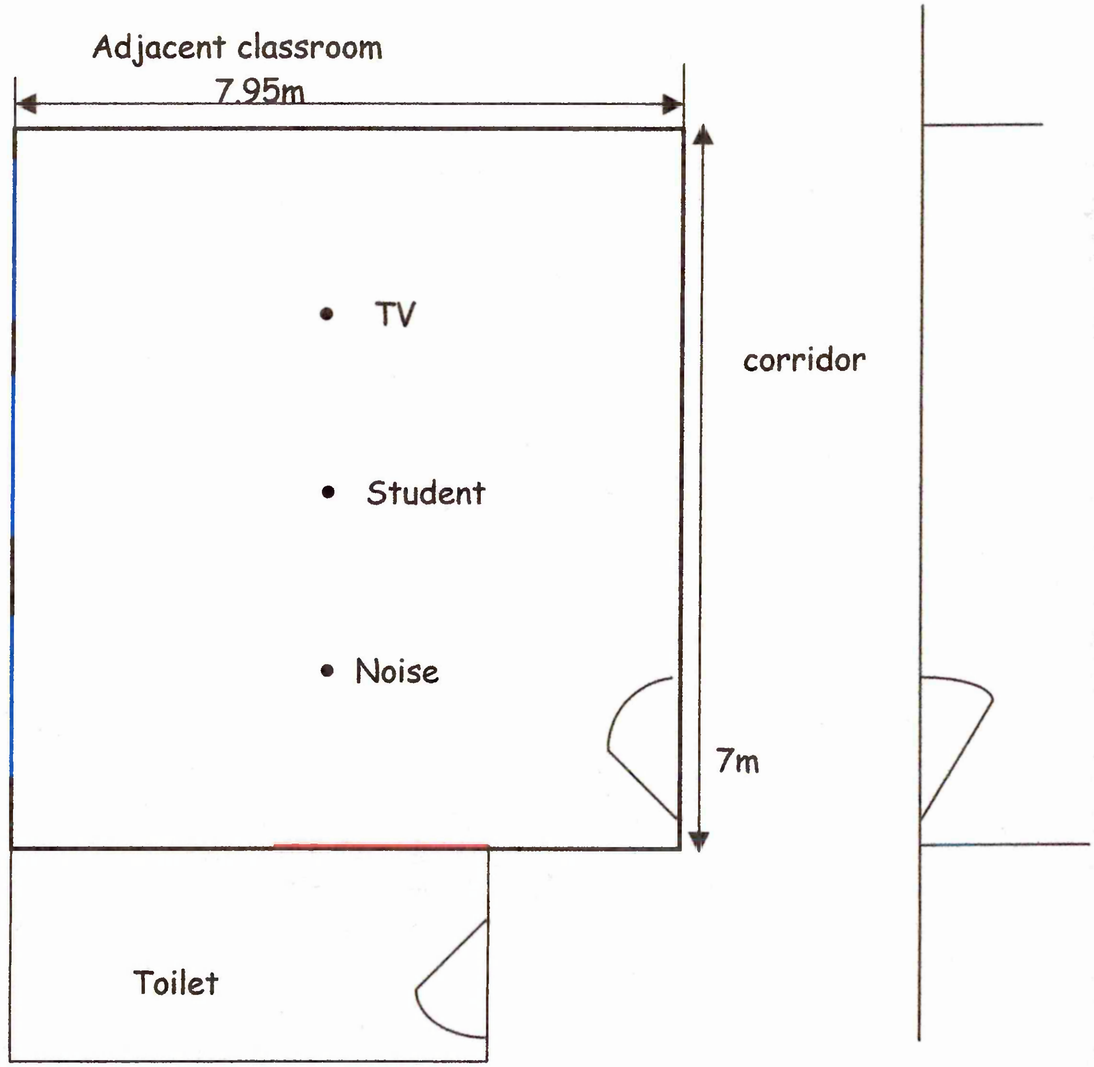
4.6 Room measurements

4.6.1 Introduction

Each classroom was accurately measured. The materials and surfaces were also noted. The layout plan shows the main features - doors and windows - of the classroom, and in the case of the science laboratory the layout of the workbenches are included.

The student was placed in the middle of the classroom with the TV/video in front of them and the background noise signal behind. The critical distance was calculated using www.mcsquared.com/criticaldistance.

4.6.2 Classroom 1



Windows | Height 2.93m

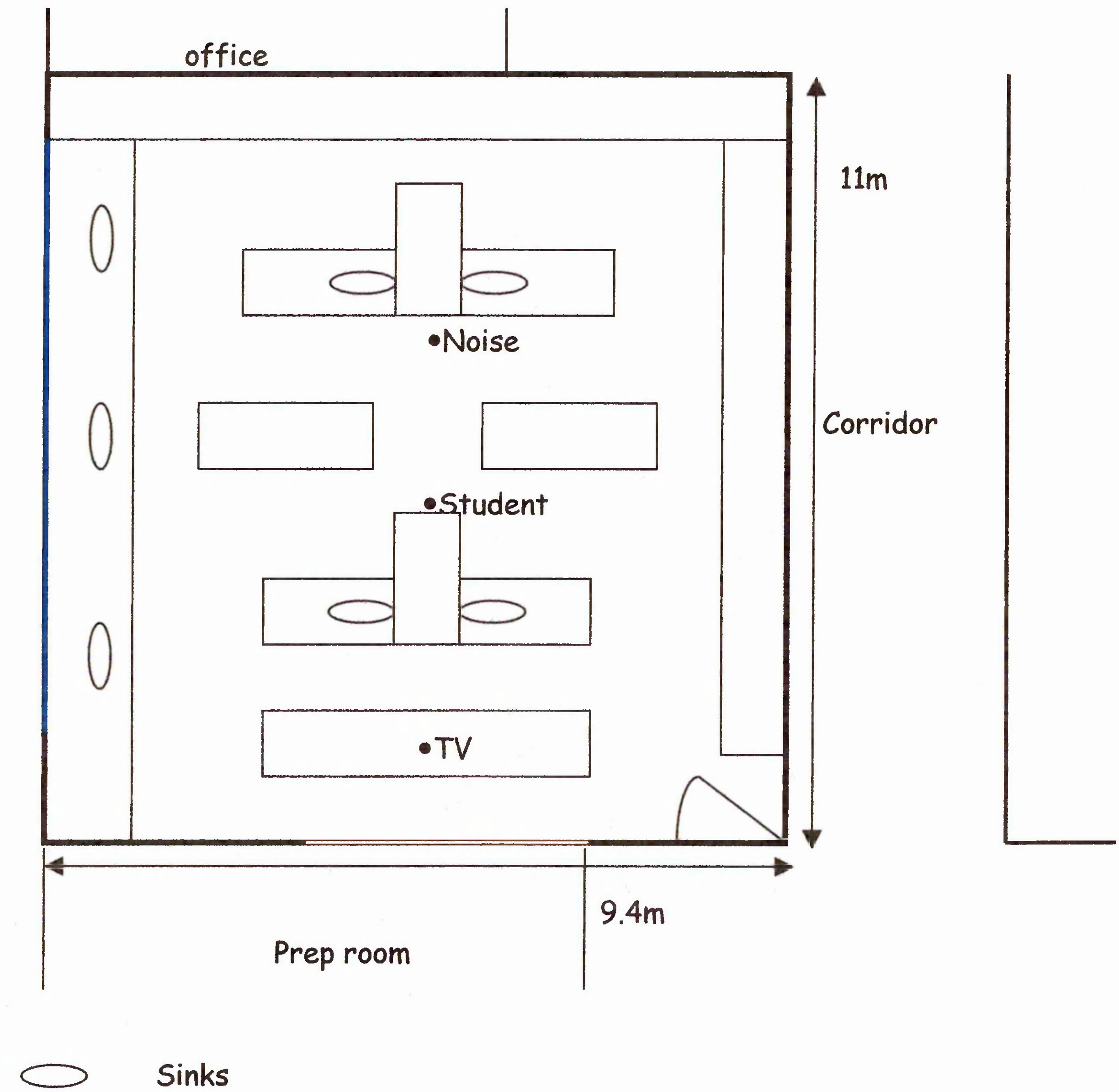
Whiteboard | -------- concrete joists

Critical distance - 0.8m. | Volume 163.1m^3

Figure 4.2 Layout Plan for classroom 1

This classroom is on the first floor. It is an academic room used mainly for Mathematics. It has a thin carpet, no underlay, attached to the concrete floor. There are vertical blinds to the windows. The classroom overlooks a play area, which is used at break and lunch times.

4.6.2 Science Laboratory

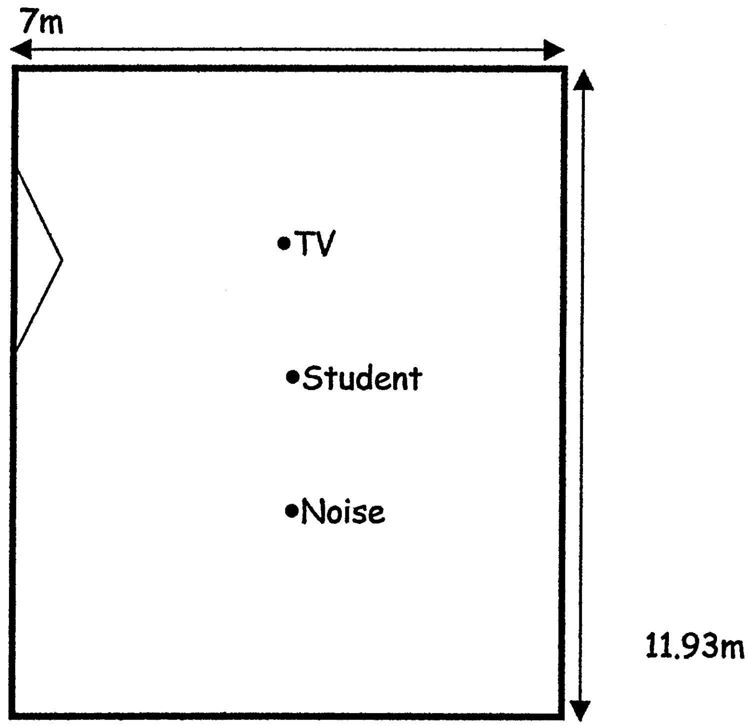


CD - 1.1m (taken with an average height) Volume 267.8m^3

Figure 4.3 Layout plan for science laboratory

The pitched metal roof height is from 3.3m to 4.2m. The concrete floor is covered in a non-slip finish. There are vertical blinds to the windows. The windows overlook a play area, which is used at break and lunchtimes.

4.6.3 Drama Studio



Height 5.2m
CD 2.5m Volume 434.3m^3

Figure 4.4 Layout plan for drama studio

The drama studio has no windows, a hard floor, some drapes around the walls and some baffle boards high up to the walls.

4.7 Results from this testing

These tables show the percentage correct as scored by the students in each condition in each room.

Table 4.1 Percentage scores of students in classroom

Room : classroom	RT:1.6s							
Student / Condition	A	B	C	D	E	F	G	Average
No background noise no lip-reading	100	98	98	100	98	92	88	96.2
With background noise no lip-reading	58	32	68	50	50	66	42	52
The effect of noise drop in discrimination	-42	-67	-30	-50	-49	-28	-52	-46
With noise with lip-reading	82	70	72	68	78%	78%	70	74
With lip-reading - improvement in discrimination	24	38	4	18	27	12	28	22

Subjectively, for the researcher, this room felt uncomfortable. When speaking it felt very echoic, creating a 'booming' sensation. The results from the testing confirm that listening in noise was very difficult.

Without lip-reading, students' scores did not rise above 68%, many scoring 50% or below.

In comparison, the test when done in quiet without lip-reading, the students all scored 88% or above.

It seems that that the effect of reverberation was to mask the speech sounds.

Table 4.2 Percentage scores of students in the science laboratory

Room: laboratory	RT:1.8s						
Student / Condition	A	B	C	D	E	F	Average
No background noise No lip-reading	88	98	100	90	92	100	95
With background noise No lip-reading	56	66	58	44	72	48	57
The effect of noise Drop in discrimination	-32	-32	-42	-46	-20	-52	-38
With background noise With lip-reading	50	94	78	74	90	78	77
With lip-reading Improvement in discrimination	-6	28	20	30	18	30	20

The results from the same speech discrimination test, with the same students but in a different room, were on average, better, yet, using a quite crude test of reverberation, the laboratory was measured as having a longer reverberation time by 0.2 of a second.

Subjectively, this room did not 'boom'. However the escalation of noise when a class was present and engaged in scientific experiments was dramatic, making it very uncomfortable for the class and very difficult for the teacher to bring under control.

Table 4.3 Percentage scores of students in the drama studio

Room: Drama studio			RT:0.44s					
Student / Condition	A	B	C	D	E	F	G	Average
No background noise No lip-reading	96	100	100	100	100	100	100	99
With background noise No lip-reading	74	98	88	82	92	92	94	88
The effect of noise drop in discrimination	-22	-2	-12	-18	-8	-8	-6	-11
With background noise With lip-reading	96	100	96	98	98	*	98	97
With lip-reading Improvement in discrimination	22	2	8	16	6	*	4	9

* TV broke down.

This studio had been acoustically treated to reduce the extremely long reverberation time that had rendered it unusable.

The results were distinctly better than the previous two classrooms even though the testing procedure and the students were the same.

4.8 Test of Speech Discrimination on a severely deaf student

The speech discrimination tests were repeated with a year 9 deaf student. She has a bilateral severe hearing loss and wears two hearing aids.

We completed the test with live voice rather than the television and video, using a sound level meter to monitor loudness of the live voice. The background noise was presented in the same way and at the same intensity. It was felt that to use the same method of speech testing on this deaf student as on the normally hearing would put her in a listening situation that was too difficult and therefore increase her stress levels, given the severity of her hearing impairment.

Table 4.4 Results of speech discrimination test with a severely deaf student using hearing aids.

	RT 1.6 Classroom	RT 1.8 Laboratory	Drama studio	Corridor
Quiet without lip-reading	88%	92%	80%	100%
Noise without lip-reading	24%	12%	30%	36%
Noise with Lip-reading	78%	78%	78%	80%

This student depends on lip-reading to give her additional vital clues to discriminate speech as can be seen by the results in noise with lip-reading. The additional test done in a corridor may seem a little bizarre but the corridors in the school were carpeted and had lowered ceilings with ceiling tiles and were a distinctly more pleasant listening environment than some of the other classrooms.

The table above illustrates how much a deaf student depends lip-reading. With the signal to noise ratio in this test being 0dB at the student's ear a comparison can be made with the scores gained below in Table 4.5 by Finitzo-Hieber[3], . This research, however, does not give an indication of the distance or the severity of the hearing loss, but a general comparison can be made.

Table 4.5 The percentage difference between hearing and hearing impaired in quiet and noise in rooms with different reverberation times.

	RT = 0.0 seconds		RT = 0.4 seconds		RT = 1.2 seconds	
Signal/ Noise Ratio	Normal Hearing	Hearing Impaired	Normal Hearing	Hearing Impaired	Normal Hearing	Hearing Impaired
Quiet	94.5	83.0	92.5	74.0	76.5	45.0
+12 dB	89.2	70.0	82.8	60.2	68.8	41.2
+6 dB	79.7	59.5	71.3	47.7	54.2	27.0
0 dB	60.2	39.0	47.7	27.8	29.7	11.2

4.9 <u>Discussion</u>

Students hear better when the classroom is quiet and when they can see the face of the speaker. Generally, normally hearing students can discriminate just as much speech when they cannot see the teachers face as long as they are focussed on listening, which these students were. For hearing impaired students this is different. Lip-reading gives them vital extra clues and improves their ability to discriminate speech. Noise can create a more difficult listening environment for everyone. When the students were tested in the drama studio which was known to have a shorter reverberation time than the other classrooms, the students were able to discriminate better with one only missing 2%, and others 6% or 8% with background babble noise but when unable to lip-read. The biggest drop in discrimination was 22%, but this was negated with the addition of lip-reading, restoring the figure to 96%, the same score for this student in quiet conditions without lip-reading. The scores, across all conditions, in the drama studio were much better than the other two classrooms.

These differing results gave an indication that there was a significant problem with the room acoustics in the two classrooms due to the poor levels of discrimination achieved by some students. It was felt that the long reverberation time caused some disturbance of the speech signal so much so that the listeners were encountering severe problems with understanding of speech. Subjectively, the classroom and the laboratory were different listening environments, so although the results indicated great difficulties with speech intelligibility, there was a need for more investigations on the acoustic characteristics of classrooms.

It is acknowledged that these initial measurements of reverberation time could not be said to be accurate ones, and therefore would not survive detailed scrutiny. However these rooms were tested, at a later date, by an acoustical engineer and found to have average reverberation times of 1.13s, 1.38s and 0.44s for the classroom, laboratory and drama studio respectively. These times are an average and therefore do not take account of differences between low, mid and high frequency reverberation that may be present in the rooms. The volumes of the rooms show that the largest of the three, the drama studio, actually gave the best student scores. The critical distance in this studio was also the longest of the three rooms. These two facts are due to the short reverberation time as recorded in the room by the acoustical engineer.

The BKB test is a useful tool to test the speech discrimination abilities of the students, however, it was a long test which demanded a level of concentration from the students, which some could not maintain. Using the test also put a strain on the facilities of the school as whole classrooms would be put out of use for a whole morning or afternoon meaning that classes had to be moved so there was a upheaval to the teachers and classes involved.

It also involved managing and moving a lot of equipment as it was felt that the same equipment should be used to prevent different sound qualities and as an experimental control.

Selecting students from the Y7 group was a good idea for various reasons, one being that they were new to the school so were not 'used' to the acoustics of the rooms. Another reason being that if any further research was needed in a primary school year 6 students could be used, as the age and ability levels between Y6 and Y7 students was very narrow allowing results to be comfortably compared. However it was felt that there should be some identification of the ability levels of the students selected so a suitable test of attainment needed to be used in any further research.

Although the results did indicate that there appeared to be problems with the classrooms, a different speech discrimination test that was shorter and easier to manage was felt necessary for any further testing in schools.

4.10 Conclusion

These findings led to further questions being asked about the acoustic characteristics of these newly built classrooms. A clearer and more accurate picture of the reverberation times was needed which may include a frequency analysis, so a comparison could be made between different reverberation time profiles and the results of speech discrimination testing.

The use of the BKB test needed to be examined to see whether a quicker but equally reliable test would be better. Also to be considered was whether to use normally hearing students or students with a hearing loss. The hearing impaired student who was involved in this study found the testing quite difficult, but the results did emphasise how much more difficult it was for hearing impaired students to function in this acoustically poor environment. However it would be very difficult to focus the study entirely on the hearing impaired as there are so few in mainstream schools, and the causes of deafness can be very different and the effects wide ranging that a comparative group of suitable numbers would be impossible to find within one school. It was felt, therefore that normally hearing students would be a more suitable group on which to focus with the emphasis then being on how much more difficult it is for the hearing impaired to function in these environments. Permission, therefore, was sought to complete this further research in another of these newly built schools using normally hearing year 7 students.

4.11 References

(1) British Association of Teachers Of the Deaf 2002 *BATOD Magazine* February, 23-24.

(2) Department of Education and Employment (UK) Building Bulletin 87 Guidelines for School Design 1997.

(3) FINITZO-HEIBER. TILMAN T. 1978, Room acoustics effects on monosyllabic word discrimination ability for normal and hearing impaired children. *Journal of Speech and Hearing Research* 21 440-458.

Chapter 5 Speech Intelligibility Testing Procedure

5.1 Introduction

This chapter details the method of school, classroom and student selection, and follows with the procedures for the administration of the speech intelligibility tests.

The previous study detailed in Chapter 4, was completed using normally hearing students and one severely deaf student, the results showing that the severely deaf student had more difficulty with speech discrimination than the normally hearing students. However it was also stated that as hearing impairment is a low incidence disability it would be very difficult to carry out research using just hearing impaired students attending one mainstream school. As hearing impairment consists of many different degrees and types of deafness such a study would not be comparing the speech discrimination abilities of like with like. For this current work students from the target school were required as they use the classrooms in the school everyday; one aim for this research being to provide teachers with information about the classrooms that they work in each day. Therefore hearing impaired students were not included in this research but it can be confidently stated that should the normally hearing students experience difficulty with speech discrimination tests then the hearing impaired will also have difficulty but to a greater degree.

5.2 School Selection and Background.

A total of six schools, four secondary and two primary schools, were built at the same time, to the same specifications and construction type, forming the first round of PFI funded schools in Sheffield.

The poor acoustics of the classrooms in one of these secondary schools was highlighted as a problem during routine speech discrimination testing as discussed in chapter 4.1 Following this, a study was carried out in this school to assess the impact of poor room acoustics on speech intelligibility, as previously discussed in Chapter 4.

The school selected for this current research project was the third of the secondary schools to be built as part of this programme.

It is an 11-18 mixed comprehensive school, situated in a residential area, away from main roads, railways and flight paths. It stands in landscaped grounds with sports pitches and courts around the buildings. There is little external environmental noise, although classrooms that face the sports Astroturf suffer from some noise disturbance especially during the summer when the windows are open.

The classrooms are on three floors. The performing arts department and sports hall is situated at one end of the new building in an adjoining block.

The school has a good academic record. It is one of the top five schools in Sheffield, according to the published league tables, for both GCSE and A level [1]. Many students stay on into the sixth form and progress to higher education.

It has a low proportion of students for whom English is a second language. There is a unit for visually impaired students based at the school all of whom are statemented for special educational needs. The percentage of students with a statement in 2003 was 1.3%, the percentage of pupils with special educational needs without a statement but on School Action or School Action Plus was 2.5% [1]. School Action means that the student receives help in the classroom that may include additional literacy or maths support with modified worksheets. A student on School Action Plus, will receive additional support from an outside agency for example educational psychologist, behavioural support, or support from sensory impairment services.

5.3 Room Selection

Teachers at this selected school had concerns about many classrooms. Amongst other problems they reported

- Generally there are high background noise levels in their classrooms
- Problems in keeping background noise levels in the classrooms to acceptable levels
- Difficulties in understanding speech from teacher to student and vice versa

A number of rooms having different acoustic characteristics was required for testing. Reverberation times were therefore measured in a selection of rooms. From these, four rooms with different reverberation time profiles were selected for the speech intelligibility research.
One humanities room on the middle floor (known as Room 1) and the English room directly above (Room 2) were selected. The room dimensions being exactly the same, however the ceiling/ roof was of a different construction and materials. The third is a top floor, food technology room (Room 3). The final one, is a specialist ICT room (Room 4) on the top floor.

5.4 **Student Selection**

Year seven students were felt to be the ideal group for this research. They are aged between 11 and 12 years; are new to the school in the September of year seven so have not 'got used' to the acoustics in the school. Another reason for selecting this age group is that if the testing were to be extended down into primary schools the best age group to work with would be year 6. Being the top year of primary, aged between 10 and 11 years this would make the age difference and ability range between year 6 and year 7 very close thereby giving credibility to results and enabling normative data to be produced for this age group.

A group of 16, year seven students from one tutor group were chosen. There were several stipulations on selection at this time. One was that no student with a statement for special education needs was included. The reason for this was to ensure both a level of understanding of spoken receptive language so that the students would be able to complete the test in a competent manner without anxiety. The second stipulation was that no student who had English as an additional language should be included in the selected group, again for reasons of understanding the spoken receptive language.

A third stipulation was required; that of normal hearing levels. Hearing impairment is difficult to quantify, sensori-neural loss is different to conductive loss; students with the same levels of hearing loss can perform very differently in speech discrimination assessments. Students with sensori-neural losses can suffer hearing distortions, which can affect their abilities to hear speech clearly. Also if students wear hearing aids this gives many more variables that would have to be considered. Overall it was felt that focussing on the normally hearing would produce a clearer picture of the effects of different acoustic characteristics of the chosen rooms and the different seating positions within the rooms on speech intelligibility.

Written permission was required from parents, which included a confirmation statement of no past or present hearing difficulties.

Once these students had been selected and permission gained from parents, the number reduced to 14.

On each day of the speech intelligibility testing, each student had their hearing tested to ensure that it was at normal levels. This was done through pure tone audiometric testing and tympanometry (a test of the flexibility of the eardrum, which indicates whether there is incidence of glue ear). Each student's hearing was required to be at normal levels on each occasion.

5.5 British Picture Vocabulary Scale

Each selected student completed the British Picture Vocabulary Scale, BPVS, prior to the speech intelligibility testing, to assess their level of receptive language to ensure that they would manage the selected speech discrimination test. The BPVS is a standardised test of English receptive vocabulary administered on an individual basis. The BPVS was chosen as it is a test that is used as a baseline assessment for many students, including hearing impaired, and it is readily accessible and quickly and easily administered.

Airey [2] selected to use Word Intelligibility by Picture Identification, WIPI, as a baseline assessment. This is a closed-set picture pointing word recognition test, consisting of 4 lists of 25 monosyllabic words. It is completed on an individual basis in the different conditions with and without lip-reading. The WIPI was not suitable for this research as it has an upper reading age limit of 11 years. The advantage of using the BPVS is that it is not age restricted and was therefore able to give an age equivalent of receptive language of the students which was above that of their chronological age.

In the BPVS the student is presented with four simple black and white illustrations on one page, from which he/she has to select the one that best matches the meaning of the target word. The target word is presented orally within a carrier sentence, for example *'Point to the........'*.

The testing continues until the subject reaches a ceiling level of understanding, that of 8 mistakes in a subsection of 12 pictures. From this level, subtracting the number of errors, a raw score, a standardised score, age equivalent and percentile rank can be calculated.

This test gives a reliable vocabulary age as related to the students' chronological age so, in this research, gave reassurance that the student could understand the words in the speech intelligibility test.

The Peabody Picture Vocabulary Test as used by Yacullo and Hawkins [3] is not a standard assessment in this country.

5.5.1 Results of the BPVS

The students' chronological ages, as can be seen from the table, range from 12 years 1 month to 12 years 11 months. Their vocabulary ages, according to the BPVS, range from 12 years to 17 years. Only 3 students resulted in having a vocabulary age below that of their chronological age.

Table 5.1 Student ages compared to the BPVS ages

	Chronological age	BPVS related age
A	12.09	12.05
B	12.09	12.01
C	12.04	15.02
D	12.05	13.00
E	12.09	14.10
F	12.11	12.0
G	12.08	14.10
H	12.02	13.10
I	12.09	17.00
J	12.01	14.10
K	12.05	15.0
L	12.10	14.05
M	12.05	16.0
N	12.07	15.06

The BPVS related ages that are above the chronological ages of the students have been highlighted in red.

5.5.2 <u>Discussion</u>

It is interesting to note that the oldest student has the lowest BPVS score. It is also interesting to note that of the fourteen students taking part in this study, eleven have a score higher than their chronological age. In fact ten have scores more than a year above their chronological ages, eight having a score of two years above, and two have a vocabulary age of three years or more above their chronological age.

This test was given to the students to assess their receptive language skills and it established that the words used in the AB word list were well within the language capabilities of all the students.

5.6 Student groups

The students were divided into two groups of 7. The two groups were tested separately.

Following hearing tests, the students were asked to sit in one of the positions A-G, as shown in Figure 5.2. After a brief introduction, instructions were given along the lines, '*You will hear a series of single words. There are 10 words in each list. Write down what you hear, the spelling does not matter as long as we can understand what you have written, if you only hear a bit of the word try to write that down. Please make your writing clear.*'

The first list, list 1, was always completed in quiet conditions. The second list was completed with the students sat in the same position as for word list 1. After this the students moved around the room alphabetically A-G, G-A, listening to a different list at each position. At no time was any feedback given to the students so they never knew if their responses were right or wrong. A complete cycle of testing took around 20 minutes. This was repeated in the four selected rooms at various time intervals over a period of several months. The fourth and final test was completed in the acoustically good room, Room 4.

5.7 Speech Test Selection

The selection of an appropriate speech test hinged around whether to use a sentence list or single word list. Previous researchers had supported the use of both types. Smyth and Bamford[4] in their work used the BKB sentence list, which was also used in previous research here as detailed in Chapter 4. Yacullo and Hawkins[3], Nabelek and Robinson[5] used modified rhyme sentence tests. Finitzo-Hieber and Tillmann[6], used monosyllabic word lists and Johnson[7] used nonsense word lists. So researchers are split as to the best method to use for speech intelligibility testing. Sentences are seen to be a more natural approach and more in keeping with how students receive the spoken information in class. Single words are a quicker and easier method to use but are criticised by some researchers as being unnatural. However there are several arguments that can be made to support the use of single word lists. One is that students are often expected to complete spelling tests of single words. A second is that a test of single words rules out the ability of students to use the contextual clues of sentence content to guess at any that they do not hear clearly.

In previous research detailed in Chapter 4, the BKB sentence lists were used. This was a very time consuming test and there was a high boredom factor involved for the students. One required result of this present research was to devise a quick but reliable test that could be easily adapted to different classrooms it was, therefore, not felt to be a good choice for this subsequent research.

For this current research the AB word list was selected. This consists of 8 different lists of phonetically balanced spoken words. There are 10 words in each list, spoken by a male voice, recorded on to CD and played back to the student through a CD player and speaker. There is no lip-reading. The AB word list was felt to be more appropriate than a nonsense word list as it uses familiar words. The AB word list is a test already used in the assessment of hearing impaired students so was felt to be an appropriate choice rather than using an unfamiliar and untried test. Use of the AB word lists gives the worst-case scenario that could be encountered by a student in a classroom that of one-word utterances, in background noise with no lip-reading.

5. 8 Test Methodology

5. 8.1 Seating position set up for Room 1

The room was accurately measured. The positional measurements were all started from the midpoint of the room as can be seen in Figure 5.2.

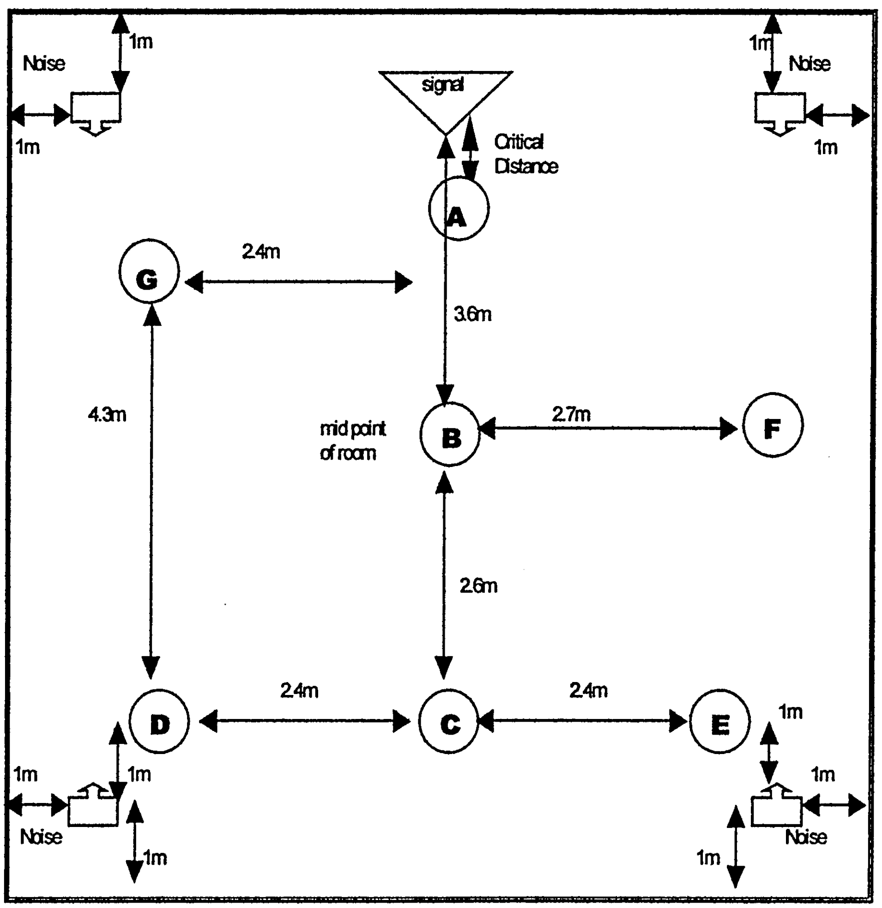


Figure 5.2 Plan of Room 1 for speech discrimination testing

The mid point of the room became position B. Position C was mid back, D and E towards the two back corners, F and G at the sides of the room with F near a window level with B, and G near the wall and almost level with position A. These points were chosen as being typical of seating positions for students within a classroom. Each position, C-G, was measured from the mid point of the room to ensure that each position was the same distance from the signal in each of the rooms used regardless of the actual size of the room. Positions B and G were equidistant from the signal with B being directly in front of the speaker and G to one side. Position A, within the critical distance for each room, as detailed in chapters 2.1.9 and 3.4, was calculated using an average reverberation time, detailed in chap 6, at 2kHz using a standard method using www.mcsquared.com/criticaldistance[8] .

It is acknowledged that this may not be completely accurate but it was felt that for the purpose of this research it was adequate as the student position was always within the maximum distance calculated.

This became position A as shown in Table 5.3. This position was the only one to be at a different distance in each room from Position B

Table 5.3 Critical distances in each room

Room 1	1.01m
Room 2	1.07m
Room 3	1.14m
Room 4	1.83m

A desk and a chair were placed at each position. The chair being at the measured position so that the students' were accurately placed.

5.8.2 **Signal and noise level set up**

The intensity level of background multi-talk babble was to be set at 70dB(A) at position B. This was felt to be an average level at which students worked in class when the background noise level measurements of students on task were analysed, as shown in Chapter 6.

The speech signal, the AB word list, was generated by playing the recorded list of words on a CD player and through a speaker. The speaker was set up at the teacher's position at the front of the room as if the teacher was seated at the desk.

To achieve a signal to noise ratio of 0dB(A), the signal output of the words in the lists, therefore, needed to be 70dB(A). The first AB word list was measured with the sound level meter at mid point B, at a height in line with the student's ears, whilst seated, with an aim to have an average intensity level of 70dB(A) for the whole list. Yacullo and Hawkins [3] also used 70dB in their research as being representative of normal conversational levels. Airey[2] used 67.5dB for her speaker level. The same list, list one, was then measured at each position, A, C-G to get an average signal level in dB(A).

To set up the background multi-talk babble, speakers were set up in each corner of the room. Continuous multi-talk babble (provided by the School of Physical Sciences at Manchester University) recorded on cassettes, was played through each speaker. Most of the reviewed researchers use multi-talk babble as the competing background noise, except for Airey[2] who used the class themselves chattering at a level of around 61-65dB. This is hard to maintain in such a contrived situation as conversations naturally ebb and flow all the time. Each speaker was set up at around 65-67dB(A), measured at point B. The background noise at position B was measured at 70dB(A) with all speakers in use. The use of four speakers in all four corners was to effectively produce a field of sound throughout the room rather than pockets of sound dotted around. The focus of this research was to examine how well students could discriminate speech in the most difficult of listening conditions, namely a very poor signal to noise ratio using multi-talk babble as the background noise, so a constant field of background noise was necessary. Also the classrooms observations showed that the main source of noise in the classrooms, generally, were the students themselves and not external noise intruding into the classroom space, which would give rise to more specific pockets of noise in certain areas of the room.

At each position A-G this background noise was measured. Thereby the signal, the noise and the signal to noise ratio for each position was gained. This is shown in Table 5.4.

The test methodology was the same in each of the four rooms. The measurements were always from the mid point of the room forming a template that could be used in any room.

5.8.3 Results

Once the tests were completed the students' answers for each position in each room were scored. Each word consisted of a consonant-vowel-consonant construction. If the student wrote the correct word a score of 10 was given. Two correct phonemes gave a score of 7 and one a score of 3. The scores were then added to give a score out of 100 and therefore a percentage correct.

The scores were then converted to graphical presentations through the use of Excel, these are given in Chapter 6 along with a discussion of the results.

Table 5.4 AB List One words with intensity levels in dB(A) recorded in all positions, showing average, range, noise and signal to noise ratios.

ROOM	POS	SHIP	RUG	FAN	CHEEK	HAZE	DICE	BOTH	WELL	JOT	MOVE	AVE	RANGE	NOISE	SNR
1	A	75	74	73	74	75	74	77	75	74	76	74.7	3	71	+3.7
2	A	77	74	73	75	75	74	77	75	75	76	75.1	4	70	+5.1
3	A	70	71	69	71	71	70	74	72	70	72	71	5	68	+3
4	A	71	75	77	68	72	75	75	75	74	72	73.4	9	71	+2.4
1	B	70	71	69	72	73	70	74	73	70	75	71.7	6	71	+0.7
2	B	70	72	68	70	73	69	74	73	72	73	71.4	5	68	-0.5
3	B	68	69	65	65	67	67	70	69	67	68	67.5	8	70	-0.5
4	B	71	75	72	67	71	73	74	74	73	72	72.1	6	70	+1.4
1	C	69	70	68	72	72	68	74	71	70	75	70.9	7	71	-0.1
2	C	68	70	67	69	70	69	70	70	69	74	69.6	7	70	-0.4
3	C	67	68	66	67	67	67	69	68	65	70	67.4	5	69	-1.6
4	C	68	71	70	69	70	72	74	71	71	73	70.9	6	69	+1.9
1	D	69	69	68	72	71	69	73	70	70	73	70.4	5	72	-1.8
2	D	67	70	66	69	69	69	70	71	69	70	69	5	70	-1
3	D	66	67	65	69	67	67	69	69	67	70	67.6	5	69	-1.4
4	D	69	72	69	65	73	71	75	74	74	70	71.2	10	70	+1.2
1	E	69	69	67	73	71	69	73	70	69	75	70.5	8	71	-0.5
2	E	68	69	66	68	69	69	73	70	69	69	69	5	69	0
3	E	66	67	65	69	68	66	70	69	67	70	67.7	5	67	+0.7
4	E	68	71	70	67	70	72	74	74	73	72	71.1	7	71	+0.1
1	F	70	70	68	72	72	69	73	71	70	73	70.8	5	71	+0.8
2	F	70	70	67	70	70	71	75	71	70	74	70.8	8	69	+1.8
3	F	68	68	65	65	67	67	72	70	67	69	67.8	7	68	-0.2
4	F	66	72	70	69	69	72	74	73	70	72	70.7	8	70	+0.7
1	G	69	69	69	74	72	68	72	70	68	75	70.6	7	70	+0.6
2	G	69	70	68	71	71	70	71	71	69	73	70.3	5	70	+0.3
3	G	68	70	67	68	68	68	71	70	68	69	68.7	3	67	+1.7
4	G	70	74	70	68	70	74	74	74	74	72	72	6	72	0

5.8.4 Discussion of Table 5.4

The data in Table 5.4 should not be analysed in isolation but alongside the reverberation time graphs, Figures 6.5-6.8, displayed in Chapter 6. Each of the four classrooms has different reverberation time profiles and it is these that affect the data both in this table and in the speech intelligibility results in Chapter 7.

There are several trends from Table 5.4 that can be highlighted.

Room 3 has lower intensity values than the other 3 rooms for the individual words in list one and for the average over all ten words. This room also has the lowest intensity level for the background multi-talk babble in six positions out of the seven across all rooms. Room 3 is the largest of the rooms although the measurements for the positions are all the same from mid point of the room, position B. The speaker used for the signal was at its maximum intensity without producing a distorted signal, the size of the room creating this difficulty. The decision was taken to keep the background multi-talk babble at the same intensity level as in the other rooms, that of 70dB(A) and then compare the signal to noise ratio across the positions with the other 3 rooms with the students results. In fact on only three occasions are the signal to noise ratios in Room 3 shown to be the worst, once in position B, again in positions C and F. In position F it is the only signal to noise ratio that is negative. In positions E and G the signal to noise ratio are the highest values. The signal to noise ratio in Room 4 is always a positive figure.

The loudest intensity of the background babble noise is in Room 1, 6 times out of the 7 positions.

The widest range of intensities of the signal strength is in Room 4 in position D showing a range of 10dB(A), as is the second 9dBA widest ranges.
The position showing the narrowest range of intensities of the words is position C, the mid position at the back of the room. Interestingly this position also shows the widest range in the signal to noise ratio, from -1.6 to +1.9 (ignoring position A which is within the critical distance).
The position showing the widest range of intensities of the individual words is position A, within the critical distance of each room. The signal to noise ratios in this position are all positive figures ranging from +2.4 to +5.1dB(A).
The word 'fan' has a dB(A) range of 8, from 69-77dB(A) across all the rooms. This is the widest range of any word in any position in any room.
The narrowest range is that of 'cheek', across all rooms and positions there is only a 2dB(A) difference, as is that of 'well' again only a 2dB(A) range.

Figure 5.5 AB Word Lists

List 1	List 2	List 3	List 4
Ship	Fish	thud	Fun
Rug	Duck	Witch	will
Fan	Gap	Wrap	Vat
Cheek	Cheese	Jail	Shape
Haze	Rail	Keys	Wreath
Dice	Hive	Vice	Hide
Both	Bone	Get	Guess
Well	Wedge	Shown	Comb
Jot	Moss	Hoof	Choose
Move	Tooth	Bomb	Job

List 5	List 6	List 7	List 8
Fib	fill	badge	bath
Thatch	catch	hutch	hum
Some	thumb	kill	dip
Heel	heap	thighs	five
Wide	wise	wave	ways
Rake	rave	reap	reach
goes	goat	foam	joke
Shop	shone	goose	noose
Vet	bed	not	got
June	juice	Shed	shell

5.9 Conclusion

Once all the speech discrimination tests had been completed the scores of the individual students in all the positions in the four rooms were totalled. These are detailed in Chapter 6. These scores need to be analysed alongside the reverberation time and background noise level graphs in Chapter 7.

5.10 **References**

(1) www.dfes.gov.uk/cgi-bin/performance tables

(2) AIREY S., MACKENZIE D., (1999) Classroom Acoustics; A research Project. Heriot-Watt University.

(3) YACULLO W.S., HAWKINS D.B. (1987) Speech recognition in noise and reverberation by school age children. *Audiology* 26, 235-246.

(4) SMYTHE R.L., BAMFORD J.M. (1997) Speech Perception of hearing-impaired children in mainstream acoustic environments: An exploratory study. *Deafness and Education (JBA TOD)* 21/2, 26-31.

(5) NABELEK A.K., ROBINSON P.J.M. (1984) Monaural and binaural speech perception in reverberation for listeners of various ages. *Journal of Acoustical Society America*

(6) FINITZO-HEIBER T., TILLMAN T.W., (1978) Room acoustics effects on monosyllabic word discrimination ability for normal and hearing impaired children. *Journal of Speech and Hearing Research* 21 440-458.

(7) JOHNSON C.E. (2000) Children's Phoneme Identification in Reverberation and Noise *Journal of Speech, Language and Hearing Research.* 43, 144-157.

(8) www.mcsquared.com/criticaldistance

6.1 Room Measurements

Detailed measurements were taken of Rooms 1-4 along with information, of materials, where possible, used in their construction and the fixtures and fittings. Photographs were also taken for visual references. Reverberation time measurements were taken as detailed later in this Chapter.

6.2 Measuring Procedure for Reverberation Time

BB93 [1] regulations stipulate that the three frequencies that must be used for testing reverberation time in classrooms are 500Hz, 1KHz and 2KHz as these are the main speech frequencies. Crandell [2] advocates measuring from 125 to 8KHz as there may be distortion of speech due to excessive low frequency reverberation.
A summary of 5 studies is given in Table 6.1. These do not specify which frequencies have been used.

Table 6.1 Summary of average reverberation times cited from Crandell [2]

Study	Reverberation time
Koderas	0.4-1.1
Nabelek & Picket	0.5-1.0
McCrosky & Devens	0.6-1.0
Bradley	0.39-1.2
Crandell & Smaldino	0.35-1.2

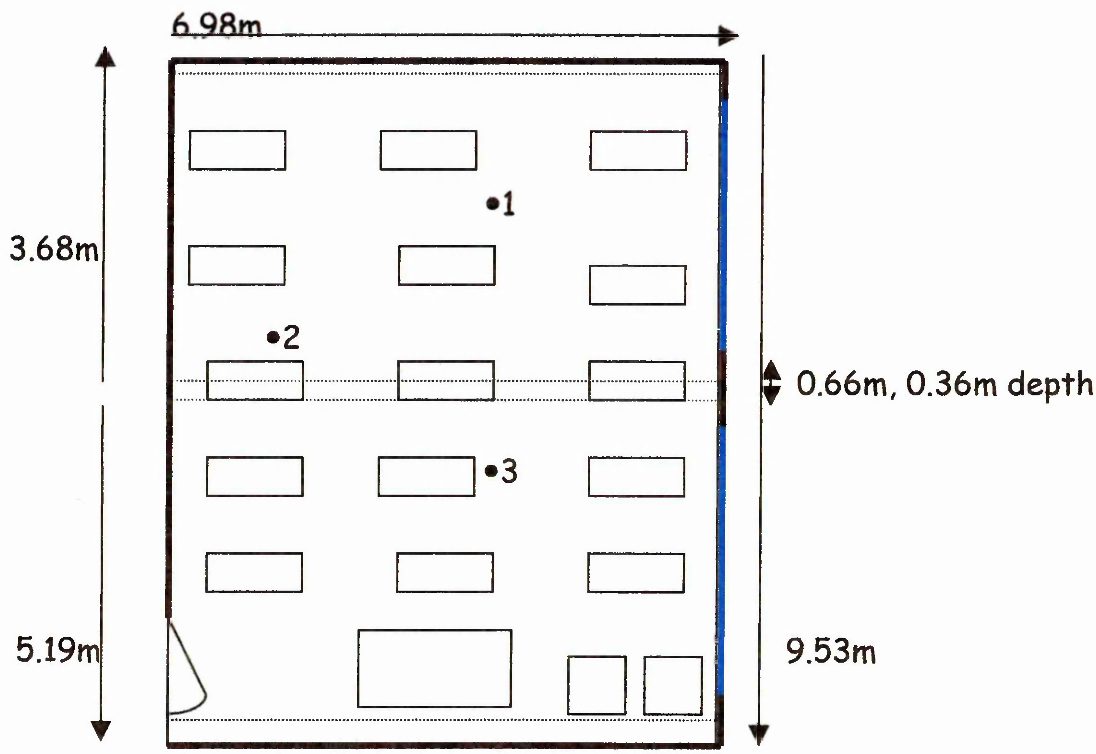
The reverberation times in this table range from the lowest of 0.35 seconds to the longest of 1.2 seconds but it is not clear whether the frequencies measured were the ones he advocates. Crandell did think that this range was typical across classrooms in America. Airey[3] measured reverberation in 1/3 octave bands between 63 and 4KHz, using 6 different positions. However she then only selected 500Hz as the averaged representative figure in each room.

One of the selected rooms in this study was felt to have long reverberation in the low frequencies, as it was a very uncomfortable space in which to talk. This is due to the Early Decay Time (Chapter 3.2.1) which is picked up as a subjective judgement of a room by a listener, describing it as 'booming'. If only 500Hz was taken as the representative frequency then the low frequency reverberation time would not have been highlighted. As low frequency reverberation prolongs the spectral energy of vowel sounds thereby masking succeeding consonant sounds the low frequencies may be important in determining the speech intelligibility abilities of students. So it was decided that for this study reverberation time measurements would extend from 63Hz to 8KHz. Reverberation time measurements in this research were taken at three positions in each room as stipulated in BB93[1]. These positions are marked 1, 2 and 3 on the plans shown in Figures 6.1, 6.2 and 6.3. These positions were at least a meter from the walls or windows. These measurements were taken with a Norsonic 118 type one sound level meter, calibrated both before and after testing. An average of the three measurements was taken as the reverberation time for each room. The results were recorded then converted into Excel spreadsheets.

6.3 Room Dimensions

Each of the four selected classrooms was accurately measured. The materials, fixtures and fittings all noted. The positions marked 1, 2 and 3 on the layout plan show the positions of the sound level meter for the reverberation time measurements.

6.3.1 <u>Room 1</u>



Height 2.9m Volume 193m^3

• 1 position of reverberation time measurement

windows

filing cabinets

desks

concrete joists

Figure 6.1 Plan of room 1

6.3.1.1 <u>Room Description</u>

This is a first floor English teaching room.

The Photographs, 6.1 and 6.2, show the concrete ceiling with the concrete joist running across the width of the room.

At the front and back of the room are half exposed concrete beams with the dividing walls of the two adjacent classrooms built up to them.

The walls are painted plaster on masonry blocks, with pin-board screwed directly on to the walls with no batons. The pin-board itself is 10mm thick and covered with examples of students work.

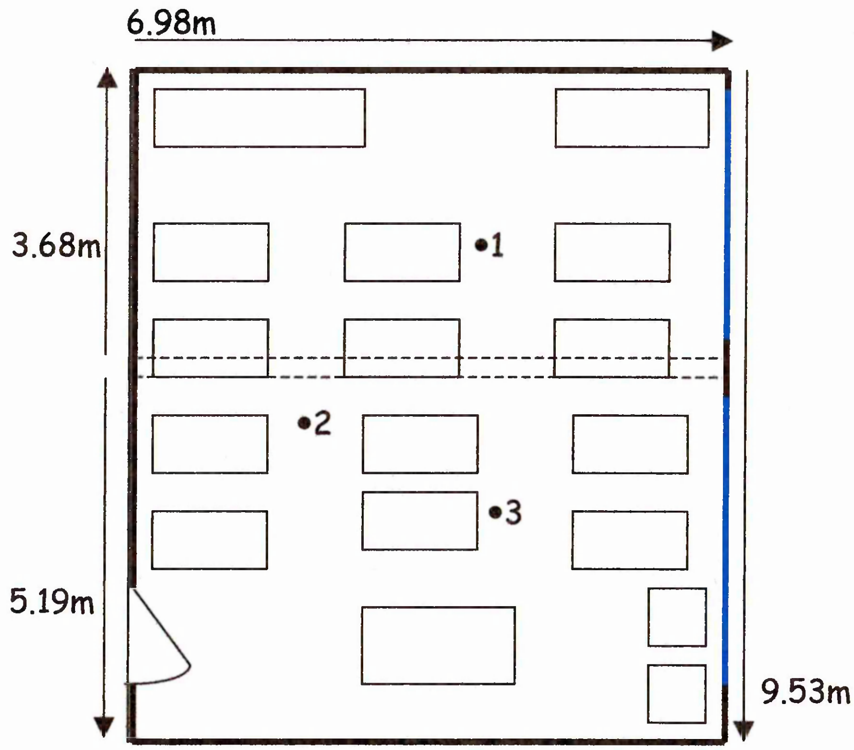
The room is carpeted, but it is a thin carpet laid directly on the hard concrete. There are three rows of strip lighting suspended 43cm down from the ceiling. The windows are double glazed with a 10mm gap between the panes. They are recessed 20cm into the wall. The windows look out on to a driveway that is rarely used, and from that to a grassy bank and trees. There are no blinds or curtains.

At the time of testing there were no computers in the room. It was set out as a standard teaching room with all the desks facing the front. The desks have hard laminated tops and metal frames. The seats were hard plastic on metal frames. There are several metal filing cabinets at the front corner of the room. Behind the teaching position are a whiteboard and an interactive whiteboard. The door is located to the front corner of the room opposite the windows. It is wood with toughened glass sections. It is set in a further area of wood with a section of toughened glass running from top to bottom. This area measures in total 1.708m (1.43m x1.22m). There are no door closing mechanisms, nor insulating tape down the doorframes. The door leads out on to the corridor that runs through the centre of the school building with classrooms and offices to each side down the entire length. The corridors are carpeted and the ceilings are tiled.

Photograph 6.1 Room 1 View of the back wall

Photograph 6.2 View of side wall and ceiling

6.3.2 Room 2



Height 4.2m to 3.3m   Volume 249.5m^3

• 1   position of reverberation time measurement

filing cabinets

desks

window

metal girder

Figure 6.2 Plan of Room 2

6.3.2.1 Room Description

This is a second floor humanities teaching room.

The room is exactly the same width and depth as Room 1 directly below.

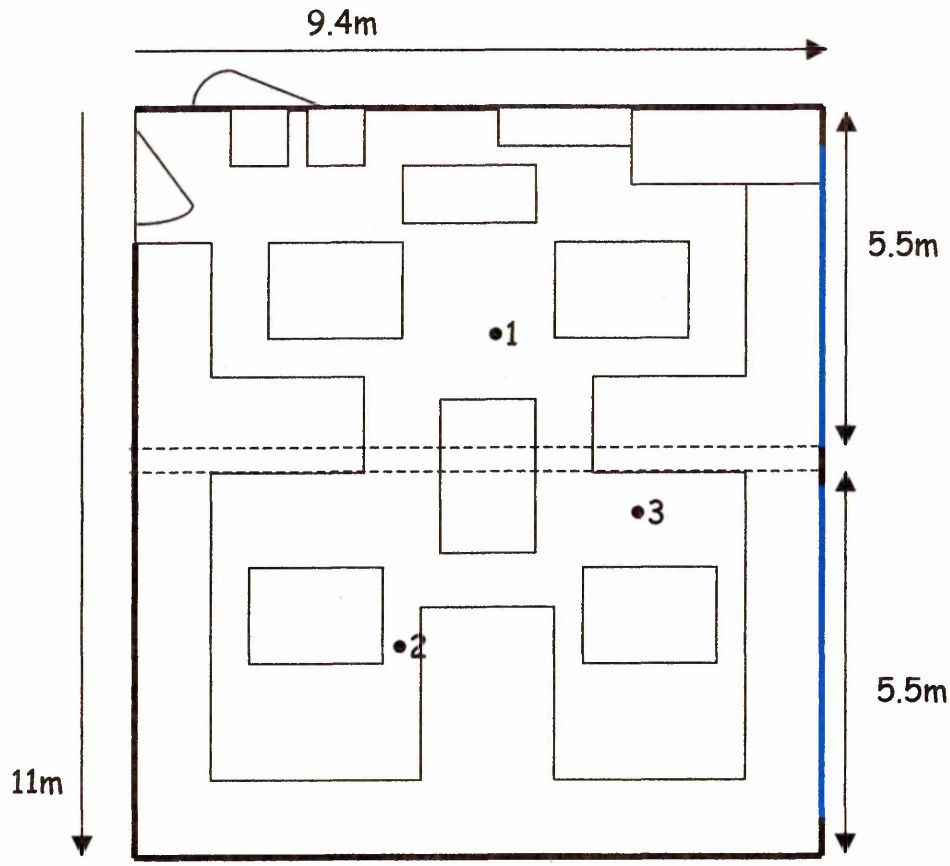
There are three rows of lights suspended from the roof, which is of a metal construction and pitched. There is a metal girder running across the width of the room as can be seen in Photograph 6.3.

There appears to be little in the way of efficient insulation between the outer and inner layers of this metal roof as rain noise is a reported problem. The walls, carpet, windows and door are all of the same dimensions and positions as in room 1 below.

The room is set out in the traditional manner of an academic classroom with all the desks facing the teaching position at the front. The desks have hard laminated tops and metal frames. The chairs are hard plastic. There are several metal filing cabinets in the front corner of the room next to the window. Behind the teacher's desk are a white board and an interactive board. The door opens to the main central corridor of the school.

Photograph 6.3 Room 2 showing detail of roof structure

6.3.3 <u>Room 3</u>



Height 4.2m to3.3m.   Volume 387.8m^3

• 1   positions of reverberation time measurements

groups of desks

filing cabinets

window

metal girder

Figure 6.3 Plan of Room 3

6.3.3.1 **Room Description**

This is a top floor food technology room.

Photograph 6.4 shows the pitched metal roof. Again rain noise has been reported as a problem so there would appear to be inefficient insulation in the gap between the inner and outer layers. Again there is a metal girder running across the width of the room. There are three rows of suspended lights from the roof. The walls, windows and entrance door are all the same construction as in the other rooms, but the window area is larger. There are areas of pin-board, again screwed directly on to the walls, around the room split to accommodate pipe work and tiled areas. There are exposed pipes and ducts around the room. There is an extractor fan unit positioned in the back corner of the room.

The windows overlook a hard play area used for PE lessons and break times so there is external noise coming into the room when this area is used and the windows are open. The floor is vinyl directly on to concrete. The room is divided into work bays, each having a sink, work surfaces, cookers and appliances. There are splash back tiles behind each sink. Cupboards are situated below the work surfaces.

There are the same type of desks and chairs as before in each of these work bays. All the surfaces are hard, flat and shiny.

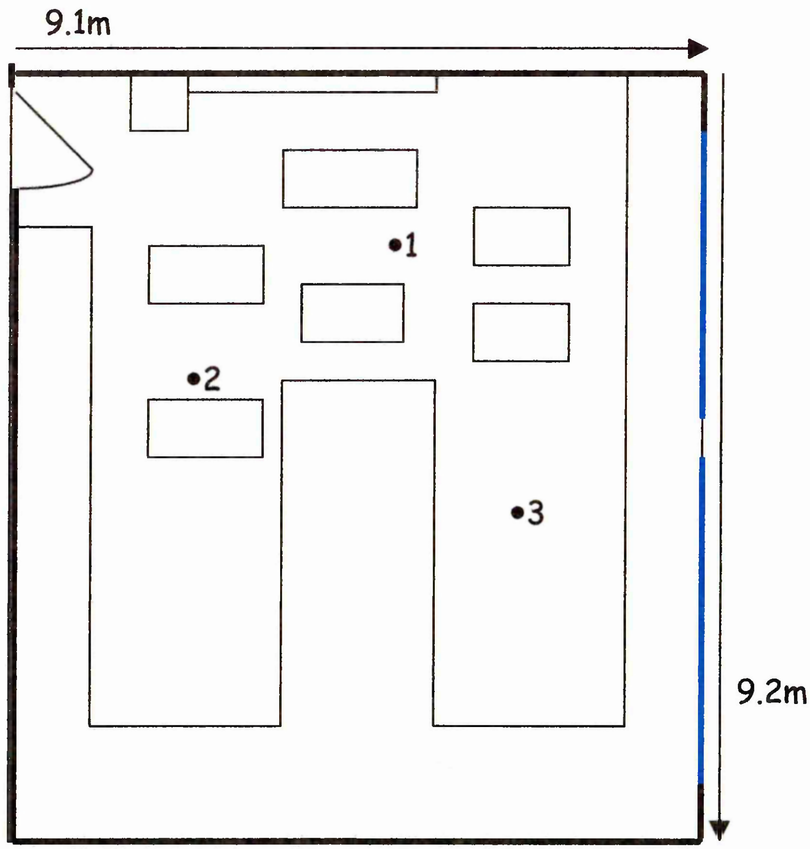
There are several metal filing cabinets at the front of the room and also desks with computers on and a couple of book shelves.

Behind the teaching position at the front is a whiteboard.

One door leads into an office/preparation room, which divides the two food technology rooms, the other, leads into the corridor. This is not the main corridor of the school, but a branch off it, which leads only to this and the other food technology room.

Photograph 6.4 Room 3 View of the back wall and roof structure

6.3.4 Room 4



Height 2.4m Volume 201m^3

• 1 position of reverberation time measurements

desks

window

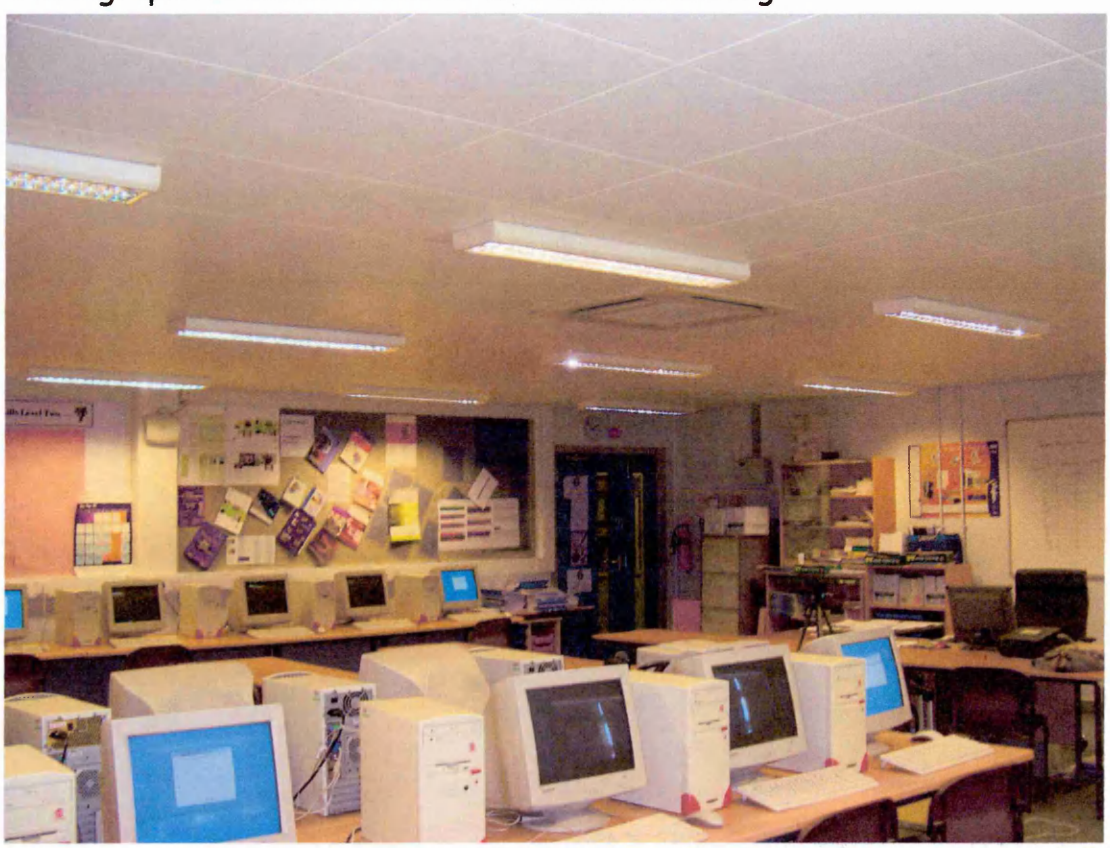
Figure 6.4 Plan of Room 4

6.3.4.1 Room Description

This is a top floor computer room. The room dimensions show that it is almost square. Photograph 6.5 shows the lowered tiled ceiling (below the original pitched metal roof) with the air-conditioning unit.

The walls, windows, door, pin board and carpet are the same as in the other rooms. There are vertical blinds along the entire length of the windows. The windows look out on a play area used mainly at breaks and lunchtime. The desks and chairs are common to the rest of the school.
The computer worktops are set out in an E shape. This means that none of the students are automatically facing the teacher but are sideways on or with their back to the teaching position.
The door is located to the front corner facing the windows and opens into a short corridor, off the main corridor of the school, giving access to 3 classrooms and 1 preparation room/office, on each side of the corridor.
At the time of testing the computers and the air conditioning were turned off.

Photograph 6.5 Room 4 View of side wall and ceiling



6.4 Analysis of classrooms

The classrooms selected for this study and described in this Chapter have many commonalities of structure, design and furnishing, whilst having some differences required by their allocated subjects.

The greatest structural difference between them is the roof/ceiling construction. Two of the classrooms, Rooms 2 and 3 have the pitched metal roof; in Room 4 the pitched metal roof is hidden behind the tiled ceiling. The fourth room appears to have concrete girders as the ceiling structure with the joist running at 90^0 across the width as a support. Windows, walls, lighting, doors, desks and chairs are all the same in both size and materials. Pin-boards are all of the same thickness being attached directly to the walls, but the areas covered by the pinboard vary in each of the rooms. The doors are all located at the front corners of the room opposite the windows.

The layout of the rooms vary, particularly in Room 3, with the others having some similarities in that they are for non-practical subjects, therefore having the desks and chairs in positions as required by the subject areas, for example in Room 4 the layout provides for easy individual access to the PCs and less whole class interaction; in Rooms 1 and 2 the layout is typical of academic classrooms.

The Room 3 has the largest area and volume. Room 1 has the smallest area and volume. Room 4 is almost the same in length and width.

6.5 Reverberation Time Results

6.5.1 Room 1

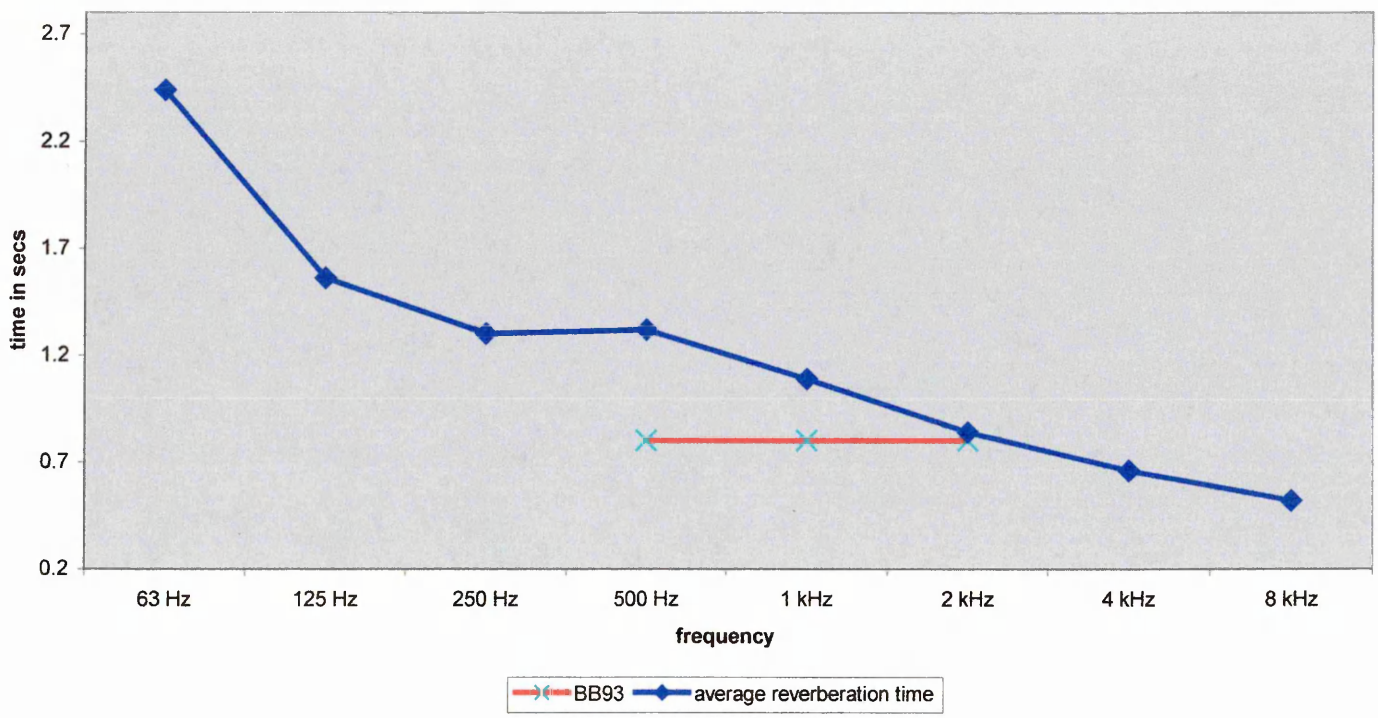


Figure 6.5 Average Reverberation Time

Figure 6.5 shows that the reverberation time is very long in the low frequencies particularly at 63Hz where it was measured as an average of 2.44 seconds, from 2.2-2.72 seconds the actual times measured. The 0.5 second difference at this low frequency may be due to the position of the sound level meter related to the length of the sound waves.

The reverberation time decreases through the frequencies but only comes close to the BB93 regulations for normally hearing students at 2kHz, measuring an average of 0.84 seconds then dips below the critical point of 0.8 seconds in the higher frequencies of 4KHz and 8KHz.

6.5.2 Reverberation Time Room 2

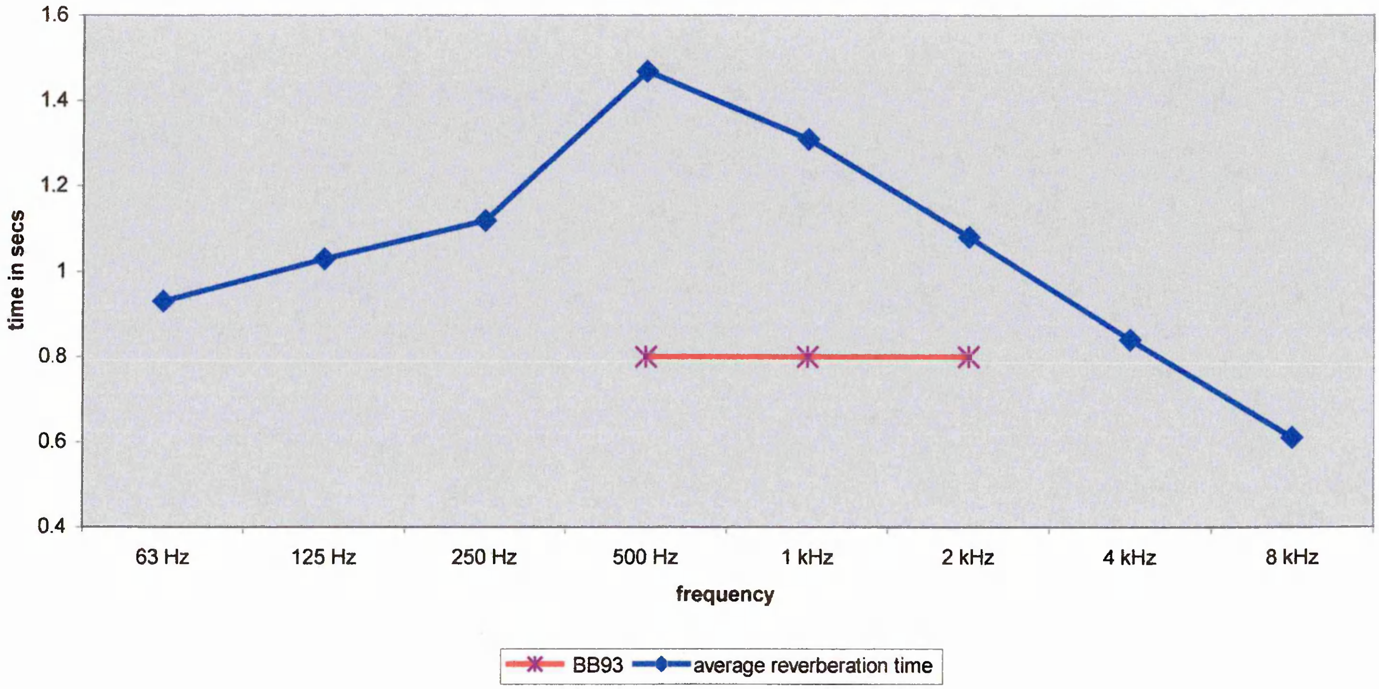


Figure 6.6 Average Reverberation Time

Figure 6.6 shows reverberation time peaking in the mid frequency of 500Hz, at 1.47 seconds. This is very different to Room 1 directly below. This may be accounted for by the different ceiling construction, as detailed earlier in this Chapter.

6.5.3 Reverberation Time Room 3

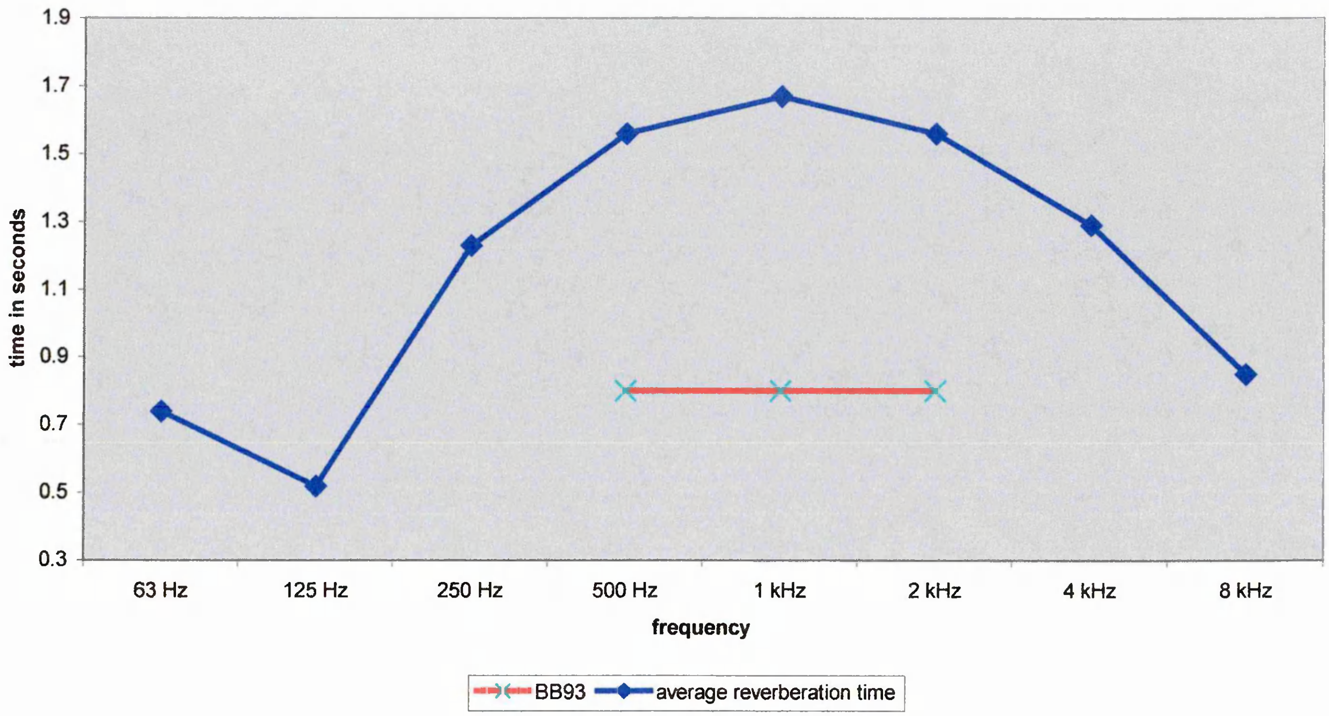


Figure 6.7 Average Reverberation Time

This graph shows the reverberation time peaking from 500Hz to 2KHz, being much higher than the BB93 regulations shown in red. The dip at 125Hz may be accountable to the metal roof construction.

Subjectively this room does not boom but teachers and students working in it report that it becomes exceptionally noisy and therefore difficult to hear and to be heard without having to raise their voices to an uncomfortable level. With it being a practical room this was a real concern expressed by teachers as they felt that noise levels escalated really quickly and it was very difficult to quieten the classes.

6.5.4 Results Room 4

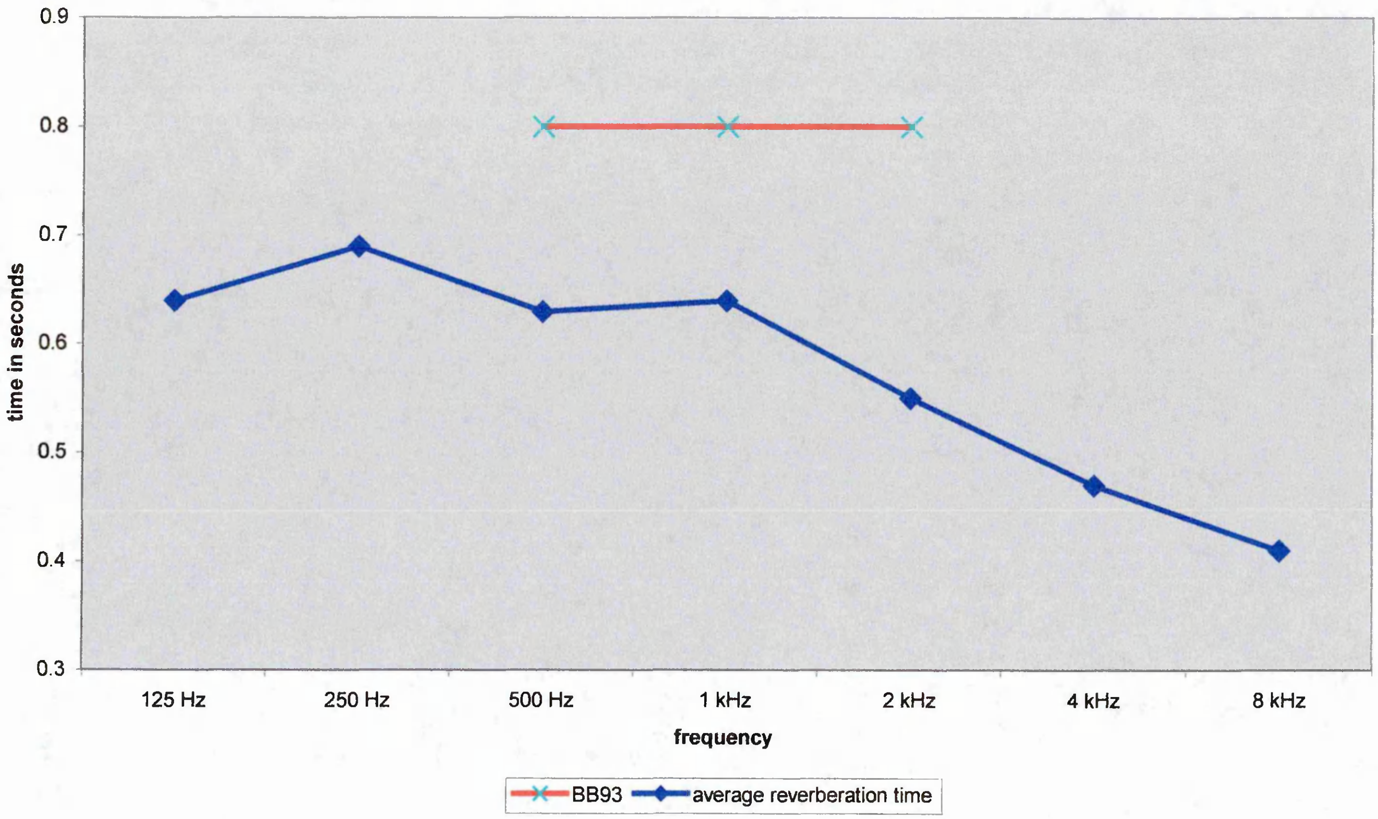


Figure 6.8 Average Reverberation Time

This classroom, being a specialist computer suite, has to have appropriate lighting, air-conditioning and, therefore, a lowered tiled ceiling. The reverberation time, as can be seen in the graph above, is markedly different to the other rooms that have been measured. The reverberation time is below BB93 regulations, in fact it is below the 0.8 seconds across the range from 63Hz to 4KHz.

This room feels, subjectively, a very comfortable room for teaching.

6.5.5 Analysis of reverberation time measurements

The four rooms have produced four different reverberation time profiles. However within the individual rooms the three positions used in the reverberation time measurements give very similar reverberation time graphs.

Rooms 2,3 and 4 are all situated on the top floor; Rooms 2 and 3 have pitched metal roofs, and produced similar reverberation time patterns that peaked in the mid frequencies. Room 4 has a flat tiled ceiling which made a difference to the reverberation time by reducing it significantly in the mid to high frequencies, making it the only room to comply with BB93.

Room 1, although having the same dimensions of width and depth to Room 2 directly above, produced a significantly different reverberation time that was very long in the low frequencies. This is probably caused by the different ceiling construction creating different patterns of sound reflections around the room with further reflections coming off the concrete joist. Previous research has seldom looked at the low frequency reverberation so it is difficult to make a comparison, and no research could be found that indicated such a long reverberation time was present in any of the classrooms that have been studied previously.

The subjective effect of this long reverberation time in this classroom is that the room 'booms', in other words when someone speaks the low frequency reverberation creates a booming effect that distorts the sounds of speech making them indistinct. If only a few people are in this room it becomes quite uncomfortable after a short amount of time. If there is a larger group of people or a full class then this effect is less pronounced as the number of bodies present will absorb some of the sound, thereby slightly reducing the reverberation time, however it is still present and will affect the speech intelligibility. BB93[1] stipulates that classrooms must be tested when they are unoccupied. This is important as small groups of students or 1-1 tuition occurs quite often in classrooms and therefore the acoustics need to be good for these situations.

6.6 **Background noise level measurements**

6.6.1 Background to measurements.

A series of noise level measurements, L_{Apeak} and $L_{Aeq2mins}$ and $L_{feq2mins}$, detailed in Chapter 2, were taken alongside lesson observations, were completed in various classrooms within the school to gain an indication of the levels of internal background noise generated in classrooms.

Only year seven classes were involved to relate to the group of students who were completing the speech intelligibility tests.

The data from these measurements would be used in the later testing to set the levels for the background multi-talk babble noise.

Observing year seven classes in Rooms 1-4 was not always manageable due to the timetable and other administrative constraints but this was not felt to be an insurmountable problem as alternate rooms with similar dimensions and acoustic characteristics were available.

The time span of a lesson is one hour. There is usually more noise at the start and end of lessons as classes change over, however it is the noise in the lessons between these two points that is important.

The frequency analysis tables are included for comparison of different frequencies of sound present in the classroom and can then be related to the subjective observations.

6.6.1 Background noise levels in a top floor classroom

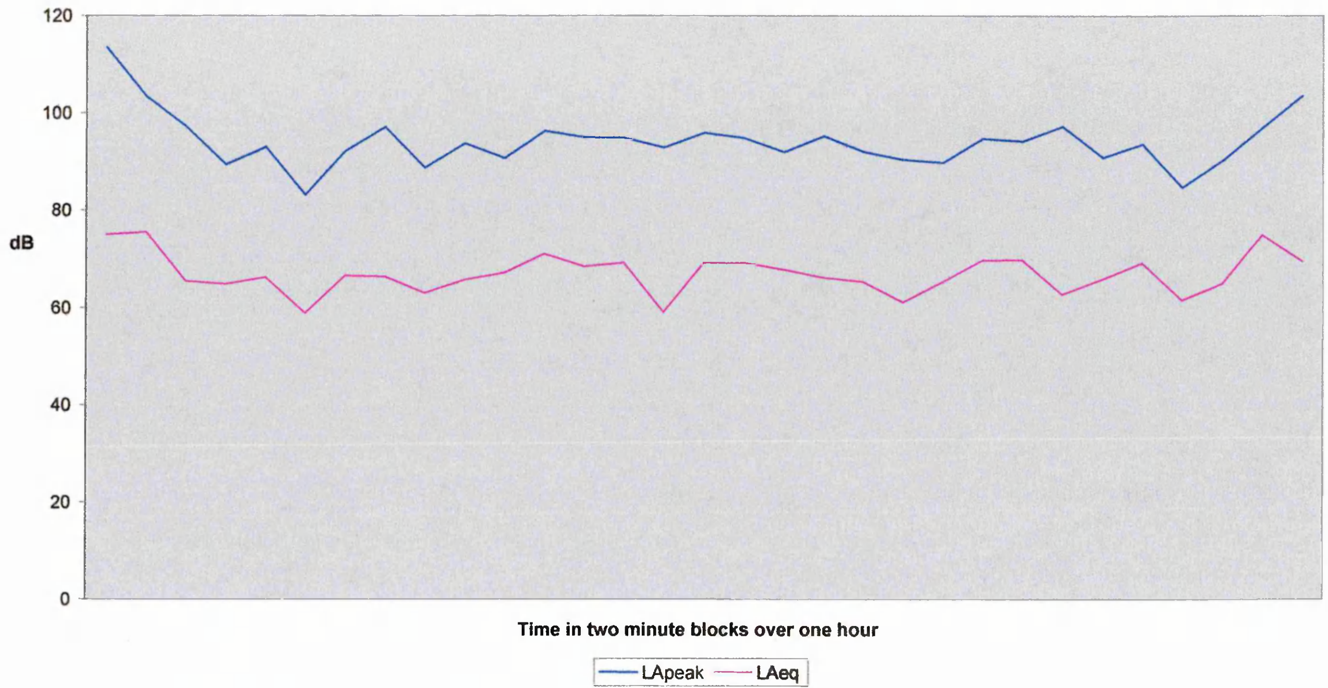


Figure 6.9 Background noise measurements

These measurements were taken in a classroom adjacent to Room 2. It is exactly the same size and construction common to the top floor rooms. It is an RE lesson with the selected year seven class. It is a female teacher.

There is no noise from heating, air conditioning or ventilation systems. It is the summer and the windows are open, and overlook a grassy bank with trees and a rarely used service road. There was no evidence of noise from external sources intruding into the classroom during this period of testing. The lines show the troughs where the class is working fairly quietly. These troughs however are short lived as the noise, which is no more than general chatter between the students, starts to rise. The quietest recorded $L_{Aeq2mins}$ is 58.8dBA, and the loudest, ignoring the noise at the start and the end of the lessons, is 69.8dBA. The remainder of the graph shows the class working at a level of around 65-70dBA. This class was one of the quietest observed and were well on task throughout the lesson.

When the frequencies, in Figure 6.10, are analysed, 500Hz is the predominant frequency, signifying that speech is the main sound in the room.

When the blue line, the L_{Apeak}, is taken into account it should be noted that the line is at a considerably higher level, the quietest being 83.2dBA, the loudest 97.2dBA. These are sudden loud, impact sounds such as the teacher or students shouting or doors slamming shut in adjacent rooms.

Table 6.10 Frequency Analysis of Figure 6.9

8.0 Hz	16 Hz	31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1.0 k	2.0 k	4.0 k	8.0 k	16.0 k
66.8	63.2	66.6	60.1	62.1	67.4	71.8	71.9	66.8	61.2	51.9	42.3
76.2	74.5	72	63.9	60.9	66.9	72.4	72.5	67.5	60.2	50.2	39.8
65.2	63.9	64.1	52.6	49.4	60.8	61.8	62.5	56.5	50.3	43.3	32.5
70.7	66.3	65.4	56.5	53.3	60.9	63.8	61.2	54.8	47.6	41.8	32.8
57.8	53.9	57	49.4	50.6	60.4	63.3	63.6	55.9	49.7	42.3	32.1
58.5	54.2	56.5	48.7	52.4	55.3	58.3	54.1	49.2	43.4	36.1	27.4
54.8	52.5	56.4	49.4	49.7	60.2	63.7	63.8	57.5	51.7	43.3	34.3
56.1	55.5	58.6	50.1	49.8	62.1	64.6	62.4	57.1	52.4	44.5	34.9
54.9	54	56.8	48	48.1	60.4	61.9	58.8	53	47.6	40.4	33.5
55.2	53.3	56.6	52.6	50.5	62	64.5	62.1	55	48.5	40.6	30.3
62.9	59.2	59.6	52.7	53.7	63.6	66.6	63.3	56.7	50.1	41.3	31.1
58.3	56.2	60.2	55.6	55.4	65	68.8	67.8	61.2	55.1	45.8	36.1
57.2	55.4	57.9	52.1	55.1	64	67.2	64.8	58.6	52.3	43.5	34.5
52.4	54.2	57.7	51.4	52.4	63.7	66.8	66.5	59.6	52.1	43.3	32.7
56.7	53.4	56.6	51.4	55.6	56.6	57.8	54.6	48.9	45.6	39.2	30.5
58.2	54.8	58.1	51	50.9	63.7	67.7	66	59.3	52.3	43	33.6
55.4	54.3	57.1	53.8	53.5	61.9	67	66.2	60.6	52.4	44.4	33.8
56.7	55.1	57.8	51.5	52	62.9	65.5	64.4	58.4	54.8	49.2	35.2
59	54.2	58	50.3	50.1	62.7	65.3	61.8	56.1	49.7	41.5	31.7
53.2	54.6	58.2	50.1	48.6	61.7	64.7	61.1	54.7	48.1	40.8	31.6
54.8	53	56	49.1	48.6	58.3	59.9	57.2	50.9	44.4	37.7	28.8
53.7	54.5	58.6	50.1	49.1	61.9	64.1	61.4	55.4	48.5	41.4	32.1
63	60.7	62.5	53.2	54.5	64.5	68.7	65.4	60.3	55	46.9	38.5
63	59.9	62.6	58.9	57.9	64.8	68.4	66.3	59.6	53.6	45.6	38.2
54.9	56.4	58.5	51.7	53.6	60.4	62.3	57.4	52.9	48.6	41.7	33.6
54	54	57.4	49.5	49.6	61.3	64.9	61.9	55.6	50.3	42.1	31.7
55.6	57	59.9	53.6	55.4	63	67.5	65.7	59.6	55.4	47.9	38.3
59.5	58.4	60	50.8	50	56.7	60.6	57.1	52.2	46.5	43.2	33.4
61	57.6	59.7	51.8	52.9	60.7	63.8	60.4	55.6	50.2	42.8	33.7
66	63.8	67.5	63.2	64.1	68.4	72.9	71.5	66.1	60	49.9	42.9
69.1	63	66.8	56.8	55.8	66.2	67.6	63.8	61.9	57	53.7	41.6

Numbers in red in all of these tables show the most intense sound at that time snap.

6.6.2 **Background noise level in Room 3**

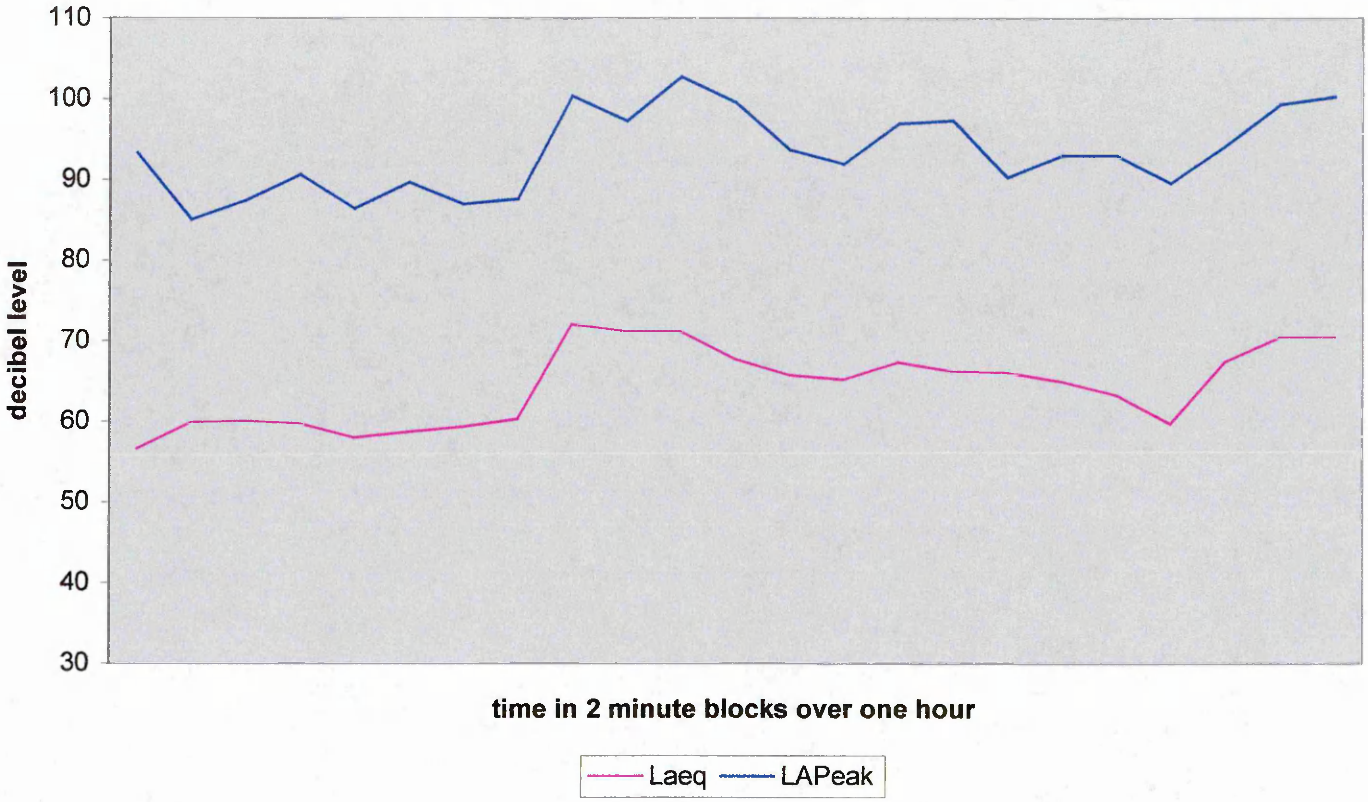


Figure 6.11 Background noise level

This graph shows the recorded noise levels in Room 3 during a year seven food technology lesson.

The room was empty prior to this lesson, however there was noise from the adjacent class when the class left at the end of the previous lesson. As the class come into the room they brought their stools to the demonstration area, the register was taken and there was very little chatter from the class. The class then quietly watched a demonstration, The point at which this session finished, the whole class moved from demonstration area to their positions around the room. This can be seen clearly with the subsequent higher noise levels as stools were scraped on the floor and moved around. When the frequencies are analysed in Table 6..12 there is a significant shift at this point, 500Hz becoming the predominant frequency rather than 16Hz. This low frequency noise may be that of the air-conditioning unit which was switched on. This is relevant as it presents in the room as a low hum that may disrupt the speech signal.

Following the demonstration the class then made their own scones, but were chattering amongst themselves.

The general noise level is again around 65-79dBA.

Table 6.12 Frequency Analysis of Figure 6.11

8.0 Hz	16 Hz	31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1.0 k	2.0 k	4.0 k	8.0 k	16.0 k
60.4	63.9	57.4	48.8	51.1	54.3	53.2	51.9	49.5	46	40.4	33.5
53.4	59	54.6	44.6	44.2	54.5	56.7	56.8	51.3	44.5	40.7	29.7
56.9	60.9	54.6	45.8	45.3	55.2	58.1	56.7	50.3	44.8	41.5	32.1
54.2	59.8	52.9	48.6	47.2	53.2	57.2	57.1	49.5	44.3	40.7	30.6
54.4	60.1	51.6	42.8	43.5	53.3	55.9	54.3	48.7	43.3	38.3	27
53.1	57.7	53.3	49.5	54.8	54.9	56.6	54.4	50.6	44.7	40	29.4
54.5	59.8	53	44.6	46.3	55.1	56.8	55.7	51	45.6	40.5	31.5
53.5	59.8	53.9	48.5	47.4	56.7	57.6	57	51	44.8	41.8	32.7
61.2	67.3	60.6	51.9	59.1	71.1	70.6	66.9	63.3	58.7	50	40.3
62.7	68.4	62	53.4	58.2	66.6	69.8	66.9	62	56.7	48.4	39.6
61.5	65.4	58.1	54.3	58.5	64.3	68.7	67.1	63.3	58.8	51.4	42.7
59.2	64.8	56.6	47.9	52.7	63.5	65.9	63.7	59.3	53.3	45.3	36
59.1	64.2	56.4	46.6	50.2	60.6	63.3	60.7	58.4	55.7	49.3	41.4
57.6	60.6	55.3	47.2	51.6	60.2	63.1	61	57.1	52.1	44.7	35
59	63.3	56.9	49.9	59	62.1	64.9	63.9	58.9	53.8	44.9	34.9
59.7	63.7	55.7	44.8	49.5	60.7	63.7	62.4	58	54.3	48.3	38.2
58.1	62.3	56.1	43.8	48.6	59.4	62.8	62.2	58.7	53.4	45.3	35.9
58.9	64.2	55.4	44.5	49.7	59.8	62	60.8	57.6	51.7	44.6	35.7
57	59.9	53.5	43.4	49.4	58.2	61.2	58.8	55.5	49.4	43.6	34
57.7	62.3	54.9	45.5	50.2	58	59	53.9	50.7	46.5	40.8	31.6
58.5	64.6	58.8	49.1	56.5	62.9	65.8	63.5	58.2	53.4	46.9	40.9
60.5	65.7	58.5	50.7	56.4	65.5	68.8	66.4	61.9	56.7	50.1	40.9
66.6	70.7	62.6	51.8	57.4	66.8	68.7	66.2	61.8	56.6	48.6	40.6

6.6.3 Background noise levels of an Empty Ground Floor Room

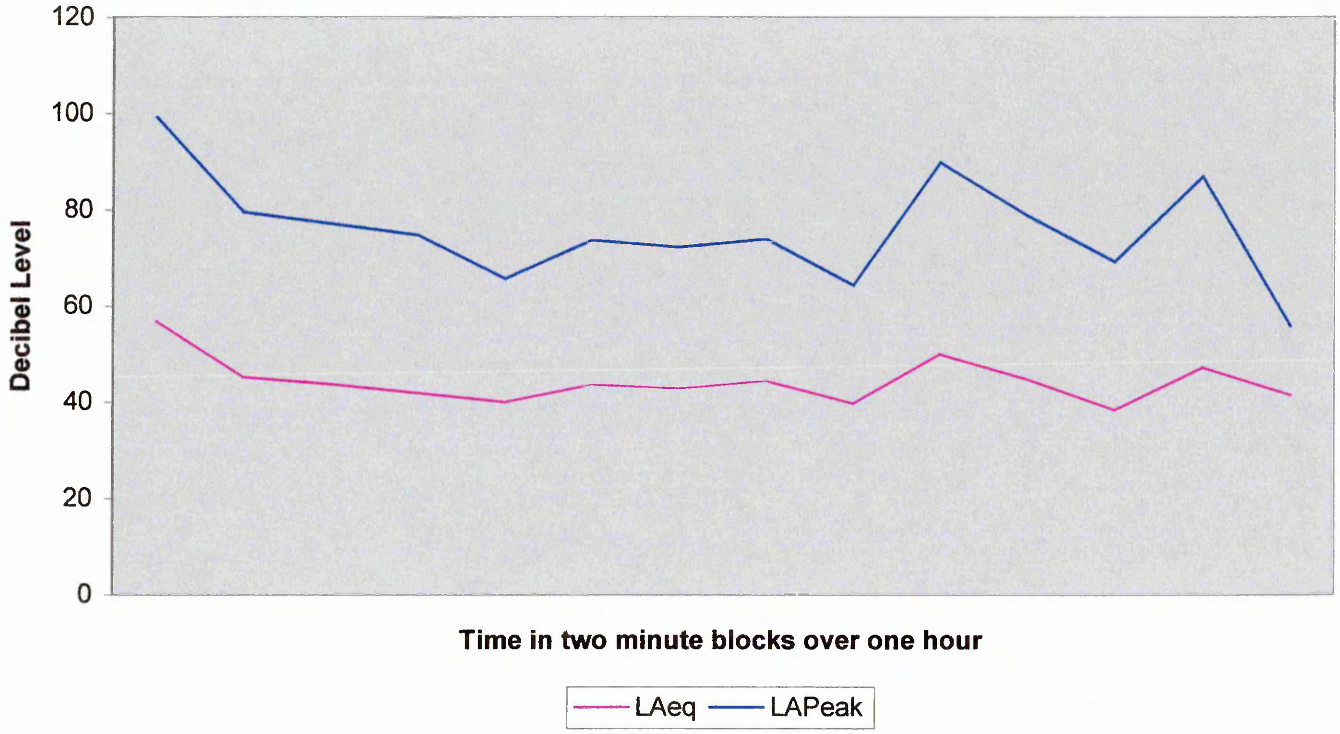


Figure 6.13 Background noise levels

The inclusion of a graph showing the noise levels within an empty room when adjacent classrooms are occupied is to give an indication of the ambient internal noise levels within the school.

The time span of this measurement is shorter. It does not record the start of the lesson, but starts some 30 minutes into the lesson, and finishes some 6 minutes after the end of the school day.

The $L_{Aeq2mins}$ levels are lower at 40-45dBA, rather than the 65-70dBA as seen in the previous graphs. This indicates that the class generates an additional 25 to 30dBA noise.

Table 6.14 Frequency analysis of figure 6.13

8.0 Hz	16 Hz	31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1.0 k	2.0 k	4.0 k	8.0 k	16.0 k
71.1	69	63.1	59.7	56.5	53.5	53.9	52.8	48.2	43.6	38.5	30.9
65.7	60.2	59.1	54.4	48	44.5	41.4	40.5	36.5	34.6	25.6	20
65.6	59	57.7	51.6	44.6	43.3	40.5	36.3	34.4	37.1	24.4	17.9
65.6	60.6	59.9	52	44.7	41.7	41.1	36.1	30.5	27.2	20.3	12.7
58.8	55.5	54.9	52.3	42.7	39.6	38.1	34.3	29.2	31.2	17.1	12.5
65	57.7	56.2	52.8	43.3	42.2	42.5	38.1	32.1	34.3	22.9	14.8
69.5	63.7	59.1	51.7	45	43	42.1	37.7	29.7	26.4	20.7	16.3
66.4	60.8	54.3	49.6	42.1	41.7	43.2	40.1	34.4	30.4	21.6	15.8
59.3	52.5	51.2	47.5	38.3	38.9	40.9	32.9	25.7	20.6	16.9	12.3
69	67.4	63.5	54.8	49.6	49.8	48.4	44.5	40.8	37.1	31.5	22.6
59.9	60.7	58.3	51.8	48.8	46.2	44.2	37.8	33.6	28.3	23.1	16.6
55.5	56.3	54.4	49.7	44	41.2	37.6	31.4	24.1	20.5	15.9	12.1
59.2	59.4	57.8	51.1	44.3	42.7	46.4	43	36.9	34.7	29.1	20.1
49.2	53.5	53.1	46.8	43.1	38.9	41.6	34.9	29.7	28.2	26	19.9

The frequency analysis of Figure 6.18 shows a significant change to the predominantly most intense frequency. Here it is the very low frequencies of 8Hz and 16Hz. There are no heating or ventilation systems operating and the although the windows were open there was no external noise intruding into the classroom so this frequency analysis suggests that the noise measurements from this room consist of the low frequency 'hum' of many sounds transmitted through the concrete structure of the school. There is a change in the most intense frequency, to 16Hz, 2 minutes before the bell goes signifying the end of the school day, which continues to the end of the measurement time. This may be the noise of the mass movement of students.

6.6.4 Discussion of background noise levels

The background noise used in the speech intelligibility assessments was that of multi-talk babble, the most distracting noise that students complain of in the classroom and it is this noise that is predominant in the $Laeq_{2mins}$ frequency analyses. However the presence of a low frequency noise is worrying as this may be an inherent characteristic of this building and therefore exceptionally difficult to remove.

6.7 Conclusion

The four rooms that were chosen for this study have presented with very different acoustic characteristics with regard to the reverberation times. One having a short reverberation time bringing it within the BB93 regulations (although the school was built to BB87 guidelines, and as such does not have to comply with these regulations. The BB93 regulations are used here as a benchmark of good practice.) It is worth emphasising here that all of these rooms are normal school classrooms, used by the students during their normal week at school. They are not artificially created for this project.

Chapter 7 details the results of the speech intelligibility tests performed in these rooms. The procedure for the speech intelligibility tests is the same in each of the rooms using the same students.

6.8 References

[1] The Stationery Office Building Bulletin 93 Acoustic Design of Schools

[2] CRANDELL C.C., SMALDINO J.J. (2000) Classroom Acoustics for Children with Normal Hearing and with Hearing Impairment *Language, Speech and Hearing Services in Schools.* **31**, 362-370.

[3] AIREY S.,(1998) A survey of acoustical standards in UK classrooms and their effects on pupils and teachers. *Proceedings of the Institute of Acoustics* 20, 14-21.

Chapter 7 Results of the Student Speech Intelligibility Tests

7.1 Speech intelligibility scores

The aim of this research was to evaluate speech intelligibility skills of the same students under the same conditions of distance and background noise, and using the same word lists. The classrooms that were selected were shown to have different reverberation time profiles.

The results are presented in different formats- tables of scores by room, and graphs of student scores. The results are discussed and then analysed. There was one student absent for the testing in Room 1 and Room 4. The classroom layout plan in Figure 7.1 shows the student positions *A-G*. background noise speakers and signal positions

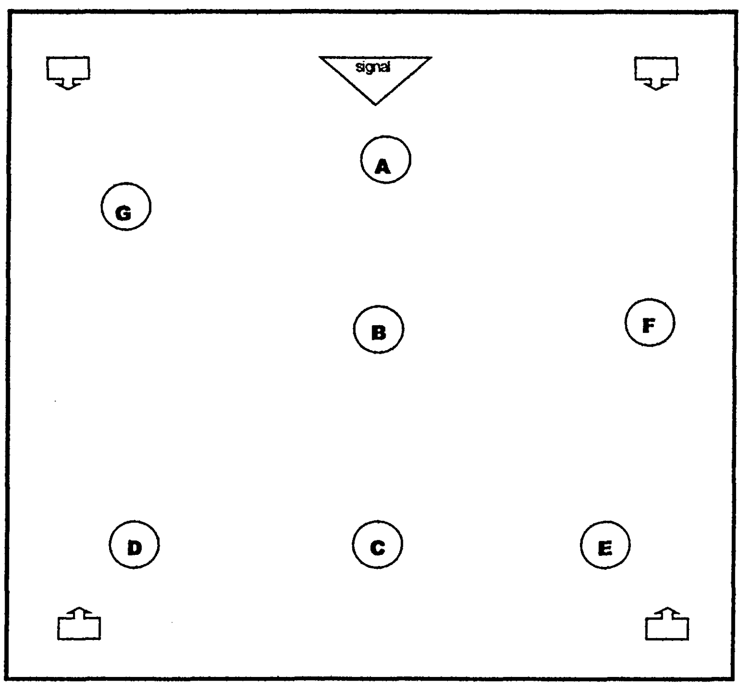


Figure 7.1 General layout of each of the rooms

The more detailed plan is shown in Figure 5.2 in Chapter 5.

This is a very basic outline of the room layout showing the student positions relating to each other and to the signal and noise.

7.2 Results of the Speech intelligibility tests by room

These tables show each student's percentage score by room. There is one student absent for the test in Rooms 1 and 4.

Table 7.1 Student percentage scores for Room 1

		Student positions						
student	**quiet**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
2	70	70	53	51	39	20	57	45
3	83	59	53	54	26	29	47	63
4	80	66	35	29	39	39	63	47
5	66	64	46	57	42	49	53	50
6	100	66	64	42	26	31	58	61
7	71	43	46	40	**16**	47	43	44
8	87	71	23	49	50	43	42	63
9	87	77	41	47	46	50	36	53
10	84	70	45	39	32	53	51	46
11	66	70	45	43	53	50	39	50
12	90	70	30	49	42	33	40	36
13	83	78	39	39	39	42	57	46
14	80	78	42	47	72	30	49	60
average	80.5	67.8	43.2	45.1	40.2	39.7	48.8	51.1
rating	1	2	6	5	7	8	4	3

		Student positions						
student	quiet	A	B	C	D	E	F	G
1	90	56	46	56	47	23	35	36
2	69	71	46	41	42	62	61	41
3	90	87	42	39	39	49	45	43
4	83	70	57	53	45	43	45	67
5	90	77	57	25	48	39	60	50
6	100	84	43	36	43	57	57	47
7	80	60	41	53	40	41	49	57
8	90	78	56	60	32	46	53	66
9	80	81	54	47	48	50	59	48
10	90	86	39	46	45	29	63	60
11	80	83	50	50	43	57	60	33
12	87	80	42	47	43	46	36	47
13	90	74	57	36	40	46	43	32
14	86	67	64	53	46	53	46	60
average	86.1	75.3	49.6	45.9	42.9	50.1	50.8	49.1
rating	1	2	5	7	8	4	3	6

Table 7.2 Students percentage scores for Room 2

		Student positions						
student	quiet	A	B	C	D	E	F	G
1	97	91	70	52	67	40	54	57
2	76	97	54	64	43	64	64	67
3	83	84	69	70	60	71	59	65
4	90	84	70	50	57	55	67	61
5	90	93	56	77	47	73	57	63
6	100	90	54	57	66	71	69	52
7	97	80	43	46	39	46	57	67
8	97	83	49	80	61	59	77	57
9	97	80	50	78	46	53	60	54
10	100	97	64	64	67	49	60	49
11	90	80	53	65	67	74	56	80
12	97	94	53	83	54	47	75	60
13	94	91	54	56	43	70	54	63
14	97	81	73	61	77	59	59	60
average	93.2	87.5	58	64.5	56.7	56.7	62	61.1
rating	1	2	6	3	=7	=7	4	5

Table 7.3 Students percentage scores for Room 3

		Student positions						
student	**quiet**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
1	100	87	81	70	68	64	77	70
2	100	100	77	73	79	65	81	84
3	97	90	97	81	60	67	88	91
4	100	87	79	77	49	84	87	63
5	100	80	84	71	68	87	66	87
6	97	94	81	70	74	64	60	80
7	100	94	74	77	70	20	64	81
8	90	94	73	67	90	53	67	84
9	100	87	71	70	68	63	67	77
10	84	94	80	81	80	78	70	71
11	83	94	80	81	70	68	74	87
12	100	97	74	80	77	70	81	74
13	86	97	84	76	62	26	68	78
average	95.2	91.9	79.6	74.9	70.4	62.2	73.1	79
rating	1	2	3	5	7	8	6	4

Table 7.4 Student percentage scores for Room 4

What is noticeable about the scores in Room 4 is that they are significantly higher than in the other rooms tested. This is highlighted in Table 7.5.

		Student positions						
position	**quiet**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Average room 1	80.5	67.8	43.2	45.1	40.2	39.7	48.8	51.1
Average room 2	86.1	75.3	49.6	45.9	42.9	50.1	50.8	49.1
Average room 3	93.2	87.5	58	64.5	56.7	56.7	62	61.1
Average room 4	95.2	91.9	79.6	74.9	70.4	62.2	73.1	79

Table 7.5 Average percentage scores by position

7.3 Results of the speech intelligibility tests by student.

These graphs show the results by student.

They do not indicate in which positions the students are seated, although this information can be determined by examining other data.

7.3.1 Results of students in Quiet

In quiet within the critical distance of the rooms, these conditions are the best possible that could be available to the students.

Therefore it is surprising that so many scores are below 90%. However the students were presented with only one word which was not repeated, so this should be taken into account with these scores and all of the tests completed in noise. It is the worst case scenario that is used.

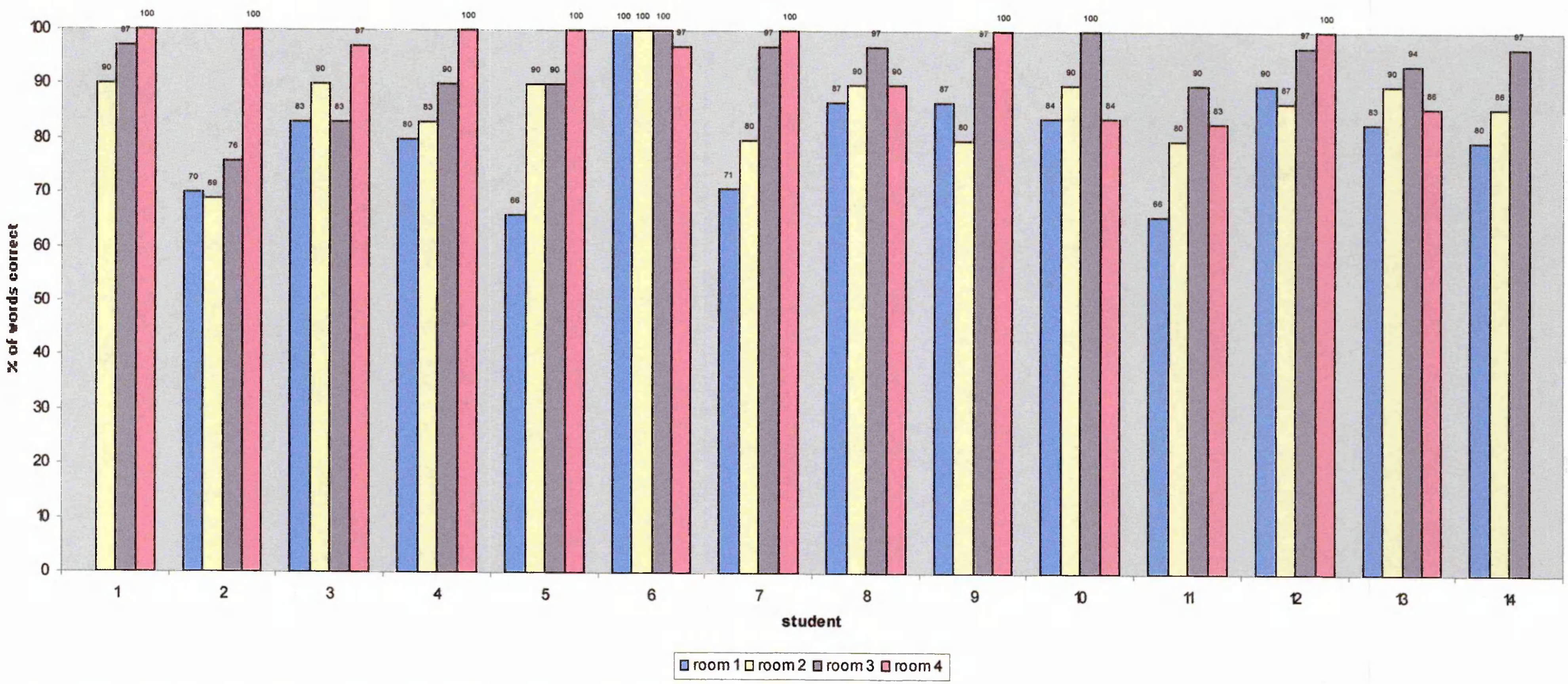


Figure 7.2 Test scores for all subjects in quiet conditions

7.3.2 Results of students in background babble noise

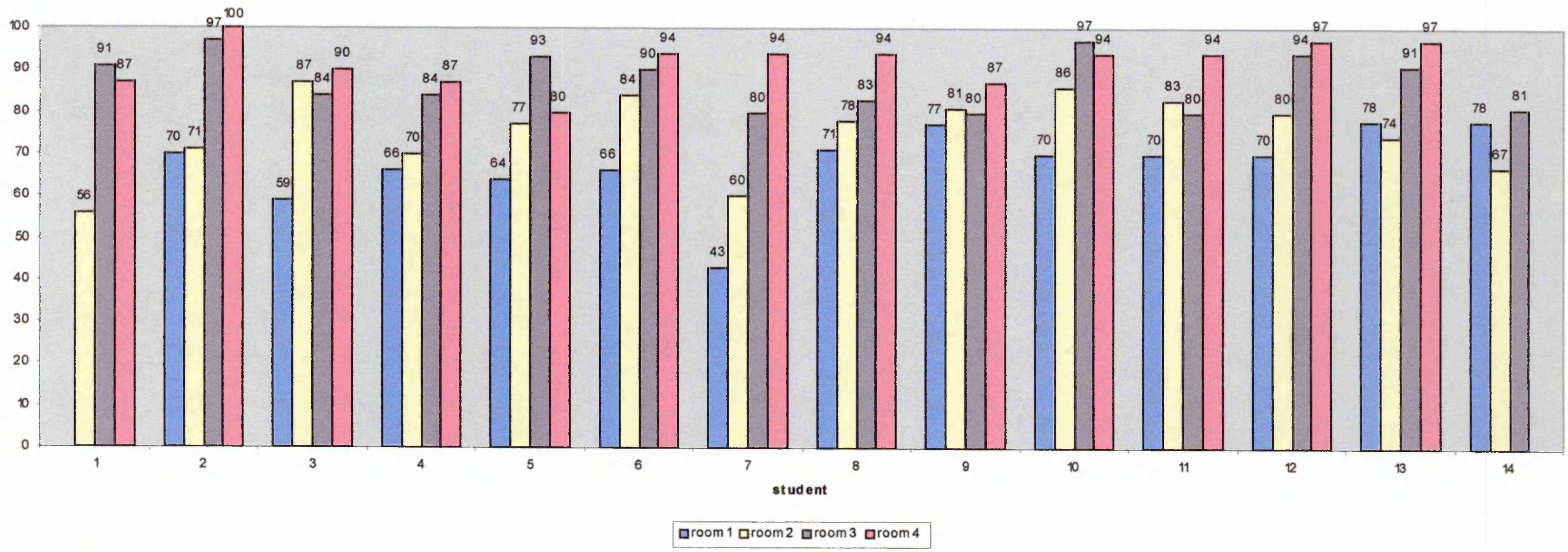
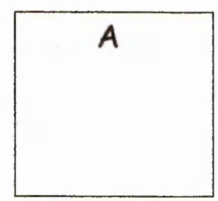


Figure 7.3 Results in position A



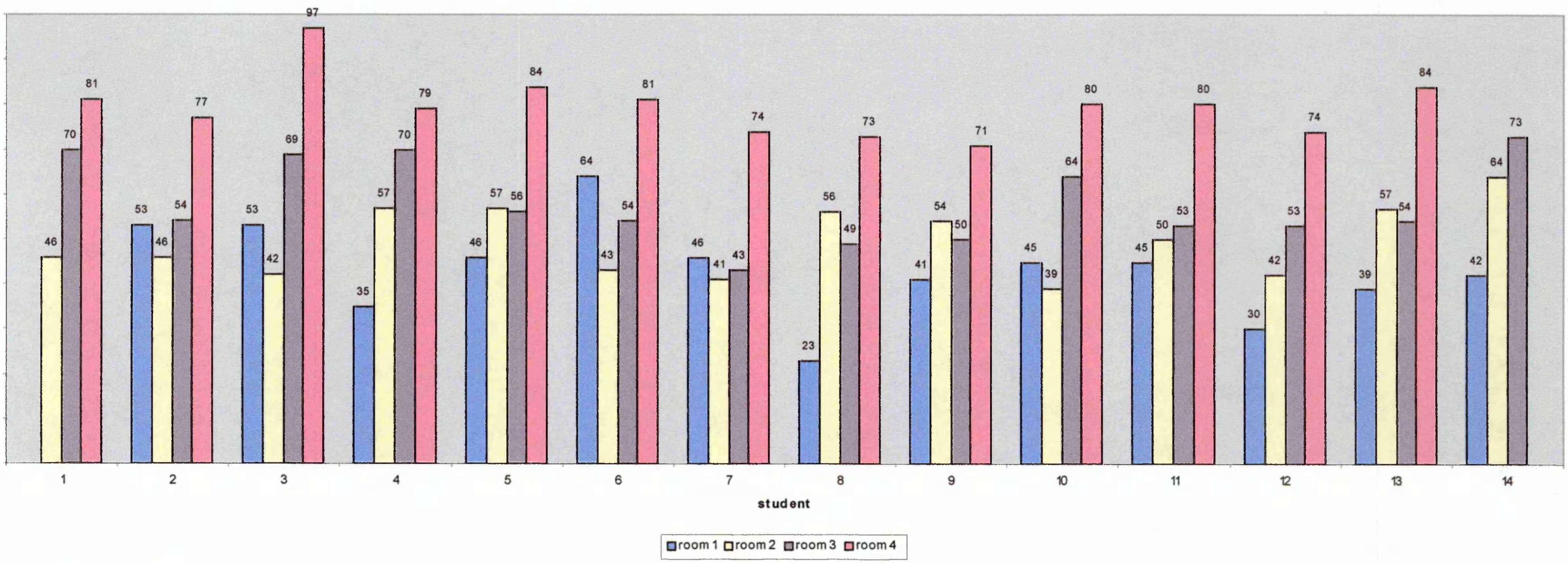


Figure 7.4 Results in position B

B

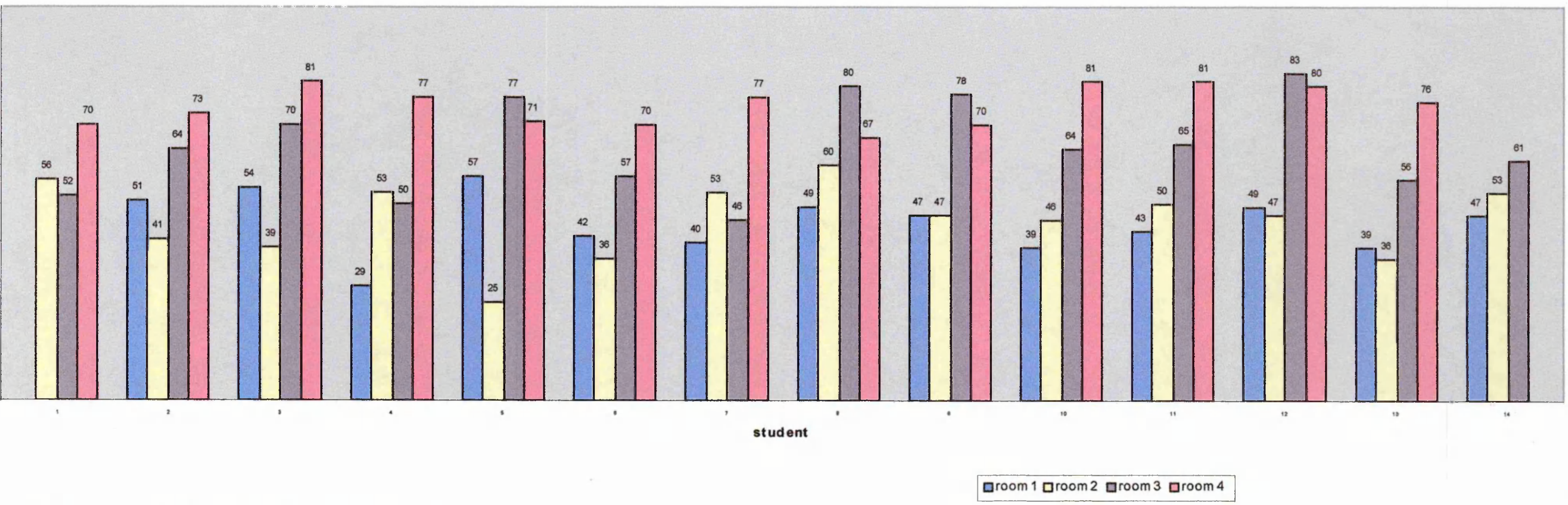
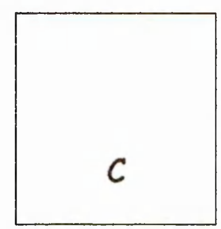


Figure 7.5 Results in position C



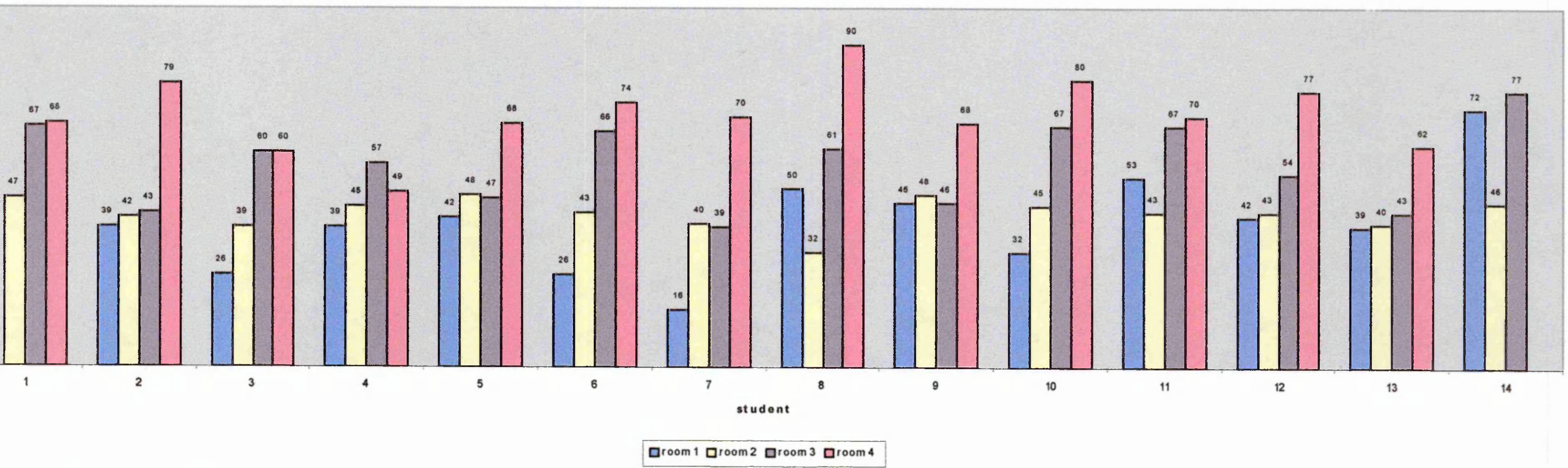
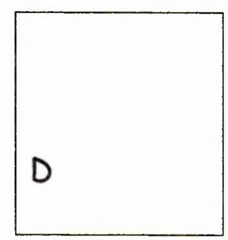


Figure 7.6 Results in Position D



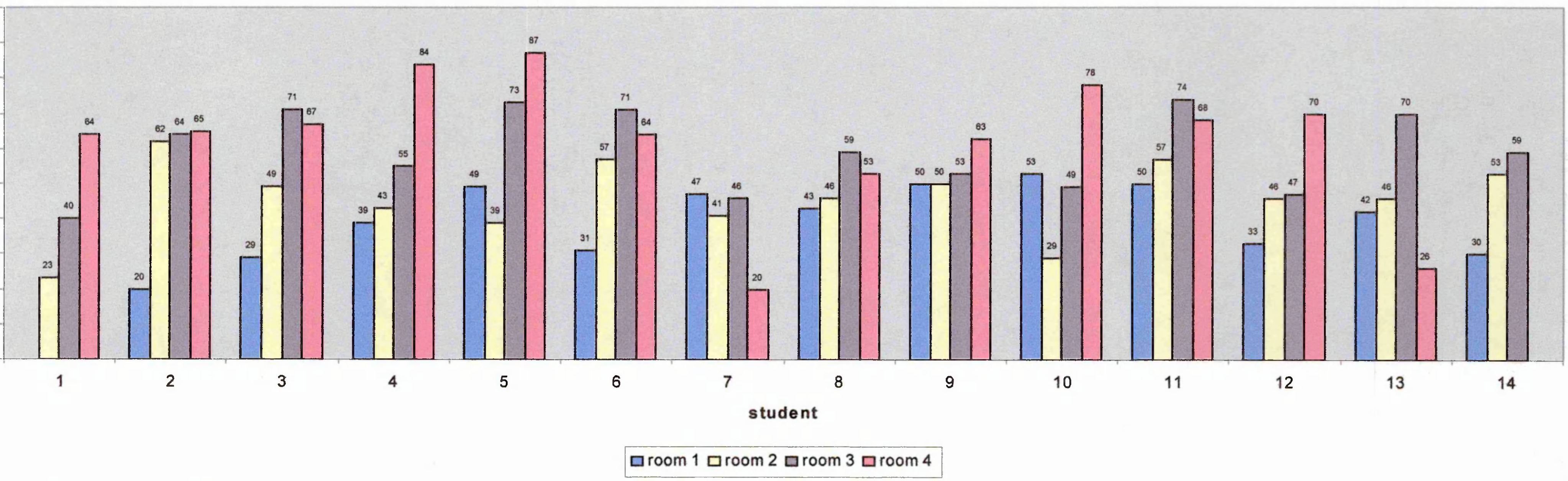
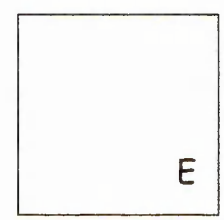


Figure 7.7 Results in position E



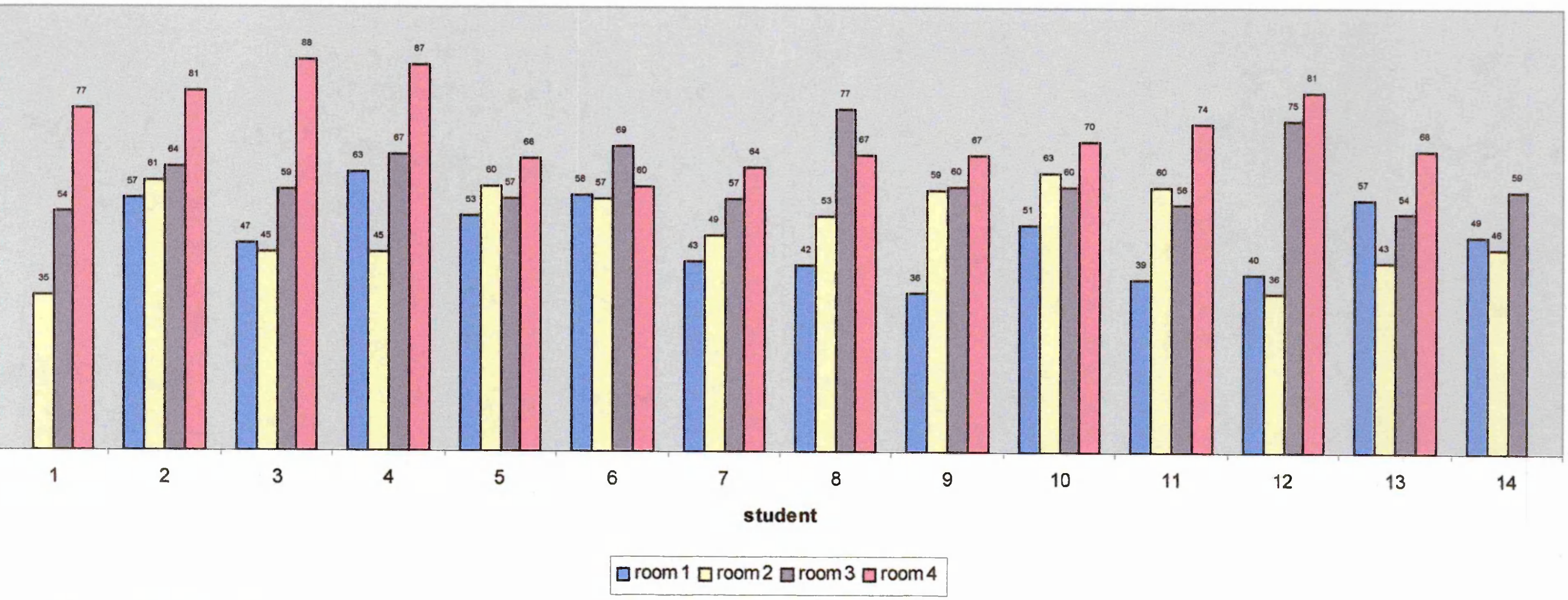
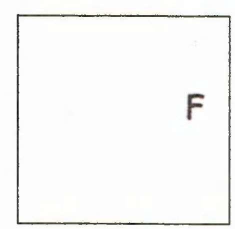


Figure 7.8 Results in position F



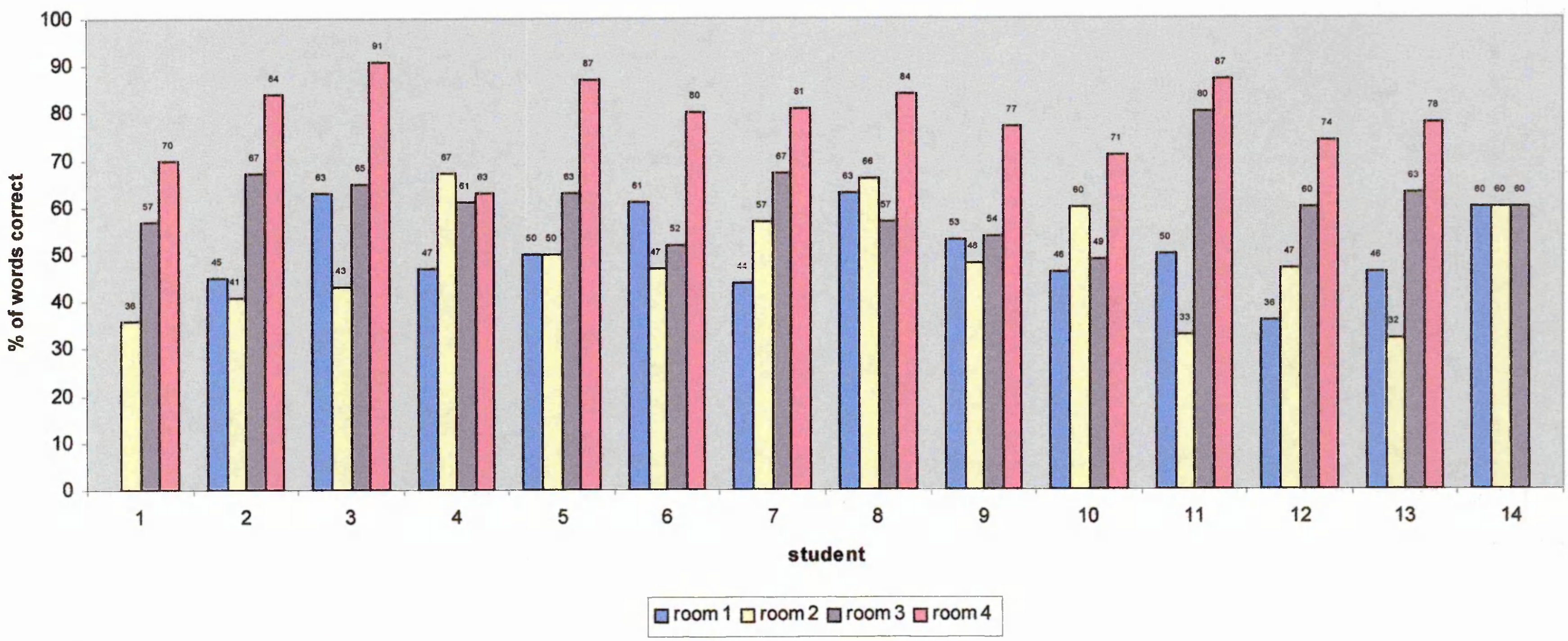
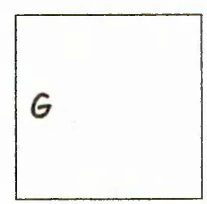


Figure 7.9 Results in position G



7.4 Discussion and analysis

It is necessary to have the reverberation time graphs, and the different room volumes, all detailed in Chapter 6, to hand when discussing these results as the acoustic characteristics of the rooms are different and therefore may have influenced the speech intelligibility of the students.

7.4.1 In quiet and noise in position A

Other researchers have found that in quiet, in any of the rooms, students achieve higher scores than in conditions of background noise. In Finitzo-Hieber and Tilman's[1] as detailed in Chapter 3.2, the mean recognition scores (12 normally hearing students) for monosyllabic words in a given reverberation time of 0.4 seconds was 92.5%. In this study the scores in Room 3, 93.2% and in Room 4, 95.2% are very similar. The reverberation time in Room 4 is the lowest recorded in this study but is not a flat 0.4s as in Finitzo-Hieber's study.

Again in Finitzo-Hieber's work, in a room with a higher reverberation time of 1.2 seconds the scores drop to 76%. In Room 1 in position A in quiet the students' average score was 80.5%, in Room 2 the average was 86.1%. It is not known at what distance the students are sat from the signal source in Finitzo-Hieber's study.

It was expected that the scores in quiet, in any position, would be the highest both in the individual scores of the students and in the average scores. Generally this was the case, with 11 students gaining 100% in quiet. The one student in Room 1 who scored 100% in quiet was seated in position A.

In all of the rooms there were some students from who did better in the background babble noise than in quiet, although very few. Looking at Table 5.3, this shows that the signal to noise ratios in position A are all positive, but not high figures, the highest is +5.1dB(A) in Room 2. Therefore the effect of the background babble is not as evident as in the other positions.

The recorded decibel range of the individual words in list one in position A in Room 4 was much wider than in the other rooms, with a range of 9dB(A). This is probably because the sound level meter was able to measure the quieter high frequency sounds that could not be picked up in the other rooms in this position.

Position A is within the critical distance so the students have the benefit of the reinforcement of the original signal by the reflected signal arriving at around the same time.

In background noise the averages in position A in Room 1 was 67.8%; in Room 2 was 75.3%; in Room 3 87.5%; in Room 4 91.9%.

Room 1 has the lowest percentage scores in these two conditions. 2 students scored only 66%, another 70%. The score in quiet in position A in Room 1 should be noted as these are the best possible listening conditions and within the critical distance of the room.

In background noise no student in Room 1 in position A scored above 77%, the lowest was 43%.

The lowest score in quiet in any room in this position is 66% in Room 1.

The highest scores in both quiet and noise were in Room 4; one student scored 100% in background babble noise.

7.4.2 Position B

Position B is the mid point of the room. Traditionally this is seen as being a good place to sit to be able to hear the teacher as it is directly in front of the teaching position. Table 7.4 shows that position B was the next highest percentage score after A in Room 4 but this is the only room where that is the case. Table 7.5 shows that other seating positions have higher intelligibility ratings, for example rooms 1 and 3 show that position C is better. This cannot be easily explained as C is directly behind position B.

The average percentage score in position B in Room 1 is only 43.2%, with the lowest individual student score being 23% and the highest 64%, this is the widest range of scores in this position. The signal to noise ratio in this room was just a positive one, measured at +0.7dB(A), whereas in Rooms 2 and 3 the figure was just a negative at -0.5dB(A). This is not a significant figure; just over 1dBA is not a perceptible difference.

In Room 4 every student has a higher score in this position than in any of the other 3 rooms. The difference in these scores and the next best scores by each student range from between 9% and 28%.

Room 1 has the worst score 8 times out of 14.

7.4.3 Position C

The lowest score by any individual student in Room 2, is student 5, that of only 25%. Room 3 has 6 of the lowest percentage scores but also the highest across all rooms of 83%.

However in Room 4 all students score 67% or above. Room 4 has the highest percentage scores in position C by 8 students.

In Room 1 no student scores above 57%, it has the lowest scores from 6 students.

7.4.4 Position D

This is, with position E, the furthest position from the signal source and one of the two closest to the background babble sound source as can be seen from the detailed diagram in Chapter 5. This sound source is only one meter back from the seating position and may be a greater irritation to the students than in other positions even though the measured levels are similar to other positions.

In Room 4 the sound level meter was able to pick up the quieter sounds of the individual words of list one, the range being 10dB(A). 12 students recorded their highest percentage scores in this position.

The worst score of any position in any room was recorded, that of 16% in Room 1.

7.4.5 Position E

In Room 4 in this position two students scored only 20% and 26%. These scores were significantly lower than the others in Room 4 with the next highest being 53% then 63%. Other comparable scores in this position were in Room 2 where one student scored 23% and in Room 1 where 20% and 29% were scored. This may be due to the layout of the room as it is a computer suite, and as can be seen on the layout plan in Chapter 6, there are banks of computers occupying the central area of the room. Position E was situated to the left of this bank as you look towards the back of the room from the signal position at the front. The source signal would not have gone directly to the listener sat at E but was more likely to be reflected from and around the computer terminals. This may have given some of the students more difficulty in listening. Another factor giving rise to these two low scores may be that the word list is the common factor linking the two poorest scores, in other words one list may be more

difficult to hear than another even though they are phonetically balanced. However the two were different lists, one was list 3 the other list 4.
The range of scores in Room 4 go from 20% to 87% giving a range of 67%. This is much wider than in the other positions in the same room. (A 80-97%; B 71-97%; C 67-81%; D 49-90%; F 60-88%; G 63-91%)
The fact that these two scores are so low and that generally the scores are much lower and the range is much wider than in other positions suggest greater fluctuations in the speech signal and therefore with the speech intelligibility in this position in this room.

7.4.6 Position F

As seen in Figure 5.2 position F, is to one side of the classroom. It is closer to the signal source than the two corner positions of D and E. However the seating position of the student is close to the window. This was to show if there was any discernible effect on speech intelligibility from reflections from the glass.
In Room 4, 11 students gained the best scores in this position. Room 1 has 7 of the lowest scores.
In Room 1 this position ranked 4th, coming before C, D and E. The average score was 48.4%.
In Room 2 it was ranked as the third best position behind position A (in both quiet and background babble). The average was 50.8%
In Room 3 this position was again ranked 4th but this time D and E were ranked behind it at equal 7th, with A and C in front. The average score was 62%.
In Room 4, F was ranked 6th with only positions D and E behind it. The average was 73%.

The average score of position E in Room 4 is well below the other averages in the same room with an 8.2% difference from position D. These figures suggest that there are difficulties with speech intelligibility in this position in this room.

7.4.7 Position G

Room 4 has the highest scores from all the students, the lowest of these being 63%; this matches the highest score in Room 1. The two lowest scores are in Room 2, those of 32% and 33%.

This position although to one side was not positioned close to the wall but more towards the main body of the classroom. The distance from the signal is closer than positions C, D E and F, so this is to be expected, although the directivity of the signal toward the centre of the room may have an impact. The rankings, shown in Table 7.6, from the 4 rooms were 3rd, 5th, 5th and 4th respectively. The average percentage scores were very different being 51.1%, 49.1%, 61.1% and 79%, the highest of these being in Room 4, having the shortest reverberation time.

7.4.8 Further discussion by position

Table 7.6 Position ranking. (Q=quiet)

Positions	Q	A	B	C	D	E	F	G
Room 1	1	2	6	5	7	8	4	3
Room 2	1	2	6	3	7	8	4	5
Room 3	1	2	6	7	8	5	3	4
Room 4	1	2	3	5	7	8	6	4

This table ranks each position in each room by average scores. As expected list number one completed in quiet, without the background babble noise, rates first every time regardless of the position in which the students are seated. Position A, within the critical distance, is ranked second every time. This was also expected as the direct signal is reinforced by the reflected signal arriving at the listeners' ears at the same time. It was then expected that position B, in the mid point of the room would be ranked at third. However, this was not the case in three of the four rooms. In fact position B was rated at sixth in these three rooms. This was very unexpected as teachers traditionally think that the mid point of a room is a good seating position. Many students with hearing problems, attention difficulties or behavioural difficulties are placed in the middle so that they can hear all that is going on around them as well as hearing the teacher.

The reason for these results may be found in the acoustic characteristics of these classrooms, namely the reverberation times related to the room geometry.

In Room 1 and 2, positions D and E ranked as the two worst listening positions. In fact E is ranked the worst position 3 times out of 4.These are in the two back corners and this was an expected outcome. However in Room 3 position E rated 5th, coming before B, C and D.

The ratings of positions F and G were not really predicted prior to the work as it was not known what effect directionality of the signal source and any reflections of sound energy would have on the students.

It was stated in Chapter 3 that researchers in the States, including Crandell, [2] found that once the critical distance was reached then speech intelligibility scores beyond this distance remained fairly constant.

7.5 Analysis of Word Lists

The analysis of the scores of each word list can be seen in the Table 7.7 below. This does not include the list completed in quiet. List 3 has the greatest number of lowest scores recorded by students. The lists are given in Figure 5.5. This may be significant. List 3 may contain words that are not commonly used, but equally there are words in other lists that may be equally uncommon or outdated. Another reason may be that although the lists are phonemically balanced, the order in which the phonemes appear in a word may make the word easier or harder to hear. For example a high frequency phoneme at the beginning of a word may be more difficult to hear in certain acoustic conditions, with long reverberation time in the high frequencies, than in others. This is not an area within the parameters of this study.

List number 2 never records the worst score. This may be due to the fact that it is always the first list played after list number 1, therefore the students are fresh, ready for the task, not bored etc. However if these reasons are followed logically list number 8, always the last to be played, should score the worst but it does not.

All phonetic spellings of the words were acceptable, for example which or witch.

Table 7.7 The worst scores by word list

List number	2	3	4	5	6	7	8
No. of times worst score	0	9	5	4	4	5	4

Researchers in both the US and New Zealand are looking at updating these lists to make them more 'user-friendly' and therefore acceptable for such studies as this. Arthur Boothroyd[3] is also updating his lists to create a interactive, computerised version. But prototypes so far suggest included words are very particular to these countries and therefore not universally acceptable. As yet there are no researchers in Britain, to my knowledge, working to update these lists.

7.6 Discussion by student

Another factor to analyse is that of whether some students tend to have greater difficulties with this test than others. Other research may discard students who attain such scores, but as this study focuses on real school students in real classrooms during the actual school day it was appropriate to include them here.

Table 7.8 Number of times a student has recorded the worst score

Student	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Number of times gives worst score	5	1	0	3	2	2	7	2	2	1	2	2	1	0

Remembering that all the students had their hearing checked prior to each test, it could be confidently stated that their hearing was normal. Looking at Table 7.8 above, it is striking that student 7 recorded the worst scores on 7 separate tests, 4 of these were in the same room, Room 2. Student 1 recorded the worst scores on 5 occasions, twice in room 2 and three times in room 3. There may be many reasons for these.

These students may not have been feeling well, may have had a bad lesson previously, may be pre-occupied with other work, all sorts of reasons. All of these reasons are valid and any or all of them may impinge on that particular student's ability to discriminate speech in that classroom on that occasion. This is common to all students in the classroom not just to this particular test.

7.7 Discussion by room

7.7.1 Room 1

Room 1 has consistently lower average scores than any other room. There is only one exception to this; position G has a higher average score than the same position in Room 2.

A previous study by Finitzo-Hieber[1] (detailed in Chapter 3), in a room with a flat reverberation time of 1.2 seconds, the mean scores of the students in a signal to noise ratio of 0dB was 29.7%. In Room 1 where there is a recorded reverberation time of about 1.2 seconds at 250 and 500Hz, but a steep increase in the lower frequencies to over 2.2 seconds, the average score in position B was 43.2%. The noticeable difference between the 2 studies was that in Finitzo-Hieber's the students listened monaurally. Also the study was not conducted in a normal classroom and the students were not listening in what was a normal situation. So it is difficult to make a comparison other than to say that in both studies the room with the highest reverberation time produced the worst scores in a signal to noise ratio of 0dB.

The researcher noted that this room, subjectively, 'boomed'. This is a valid judgement based on the Early Decay Time of this room and was accounted for by the objective measurements of long reverberation time.

Room 1 has the smallest volume of the 4 rooms used in this testing, with similar materials, fixtures and fittings. Room 4 is slightly larger in volume but has the lowered ceiling in place which provides greater absorption of sound and less reflections.

7.7.2 Room 2

The inverse square law states that with each doubling of the distance from signal source intensity decreases by 6dB. (detailed in Chapter 2). The difference in signal strength from source to each student position show that there is a greater decrease here than in the other rooms, as shown in Table 7.9. Room 2 is highlighted as having the highest decrease in signal intensity levels.

Table 7.9 Decrease in sound pressure levels in dB(A) from source to each receiver position.

	signal-B	signal-C	signal-D	signal-E	signal-F	signal-G
Room1	3	3.8	4.3	4.2	3.9	4.1
Room 2	3.7	5.5	6.1	6.1	4.3	4.8
Room 3	3.5	3.6	3.4	3.3	3.2	2.3
Room 4	1.3	2.5	2.2	2.3	2.6	1.4

The decrease is particularly apparent from signal to position C, a distance of 4.9m; and signal to positions D and E, a distance of 5.4m. These distances are exactly the same in the other rooms but the signal decrease is less.

This decrease must be due to the acoustic characteristics of the classroom. It is the same dimensions as Room 1 but has a different roof -

a pitched metal roof, giving a larger room volume and different reverberation time profile. However Room 3, although a larger room, also has the pitched metal roof and has a long reverberation time in the mid frequencies similar to Room 2.

The speech intelligibility test scores do show that the students did find the listening conditions difficult. The averages show that only Room 1 gave worse scores.

7.7.3 Room 3

It should be noted that the intensity level of the background babble noise in Room 3 was the lowest in all positions except B, shown in Table 5.4. The average signal intensity of list 1 was also the lowest in each position. This was probably due to the size of the room. However the drop in signal intensity to each position was not as great as that in Room 2. The signal to noise ratios were the worst in 3 positions, B, C and F, but the student average scores in these positions were better than in Rooms 1 and 2. This indicates that the students did not find the conditions as difficult as those in Rooms 1 and 2.

The volume of this room was the greatest of the four rooms. There was little in the way of absorptive materials as it is a food technology room with greater shiny, reflective and hard surfaces that in the other rooms.

7.7.4 Room 4

The rankings in this room, it could be argued, restore the natural expectations of listening conditions in a classroom, the seating positions closer to the signal source showing the higher average scores.

Room 4 had the highest signal to noise ratio at +1.5dBA at position B. The background noise was 70dBA as expected but the average signal strength was higher with some of the words in List One being recorded at 3-5dBA higher than in other rooms. This is probably due to the shorter reverberation time, as shown in the reverberation graph in Chapter 6, allowing a clearer signal to be heard without the effects of reverberation being felt. The room itself was the second smallest in volume to Room 1, but had the lowered ceiling that absorbs sound rather than reflecting sounds back into the room.

The drop off in signal intensity, Table 7.9, was also the lowest of the 4 rooms. This is particularly so at position A, within the critical distance, which was the longest of the 4 rooms at 1.83m. The signal decrease was only 1.3dBA compared to 3+dBA in the other rooms.

7.8 Reverberation Times Conclusions

Reverberation time measurements showed that the four selected rooms had different reverberation time profiles.

The listening conditions imported into each room were exactly the same.

The students used for testing were the same and were tested to check that their hearing was normal on each occasion. Their subjective vocabulary levels were tested and all found to be at their chronological age or above.

The percentage correct scores were found to be very different.

The same list was always the one presented in quiet. The room with the shortest reverberation time and therefore, thought to be the best room for listening, was tested last. What turned out to be the worst room for listening was tested first. Therefore the argument for the students learning the words is not substantial and is also supported by the fact that they were never given feedback as to whether their responses were correct.

Room 1 consistently was the worse for listening. The reverberation time was distinctive in that it predominated in the low frequencies.

7.9 References

(1) FINITZO-HEIBER. TILMAN T. (1978) Room acoustics effects on monosyllabic word discrimination ability for normal and hearing impaired children. *Journal of Speech and Hearing Research* 21 440-458.

(2) CRANDELL C.C., SMALDINO J.J., ANDERSON K. Classroom Acoustics. Alexander Graham Bell Association for the Deaf and Hard of Hearing: *Periodicals*. Accessed online http://www.209.41.163.85/periodicals/acoustics.cfm on 30.10.2001

(3) BOOTHROYD A. CASPA available from www.arthurboothroyd.com

Chapter 8 Conclusions

8.1 Background

Previous researchers, as reviewed in Chapter 3, have used many different methods to show the effect that noise and reverberation have on students' ability to discriminate speech. However few of the reviewed researchers used students in their own classrooms. Many used adapted anechoic/echoic chambers, or recorded the speech signal in different acoustic environments then played the resultant signal via headphones to the student. Some used students with a hearing impairment whilst others only allowed students to listen monaurally.

Airey and Mackenzie[1] , in their study did use primary children in their own classrooms as a way of assessing pre and post remedial acoustic treatment to the classrooms.

The purpose of this research was to select and implement a test of speech intelligibility in four classrooms with different reverberation time profiles in order to examine whether the different reverberation times affected the students' speech discrimination abilities.

This testing was initiated through concerns that were expressed by teachers that there were poor listening conditions in their classrooms within this newly built school. The research was developed to assess how students hear in their everyday classroom environments as so much of the school curriculum is presented through the spoken word.

So this project was completed in real school classrooms using students from the school.

8.2 Student Preparation

The results from the speech intelligibility testing as detailed in Chapter 7, show that although the test procedure, layout and students were the same in all of the different rooms, the results gained by the students are very different. It could be argued that the students themselves came to each of the tests from different school situations that may influence their abilities on the day. For example they may have come from a test situation in the previous lesson; from PE making them tired; from break or lunch; or from a preferred lesson rather than this testing. However the tests show trends that cannot be explained by such suggestions. The evidence here suggests that the room acoustics have an impact on the speech discrimination ability of the students.

8.3 Factors affecting speech intelligibility

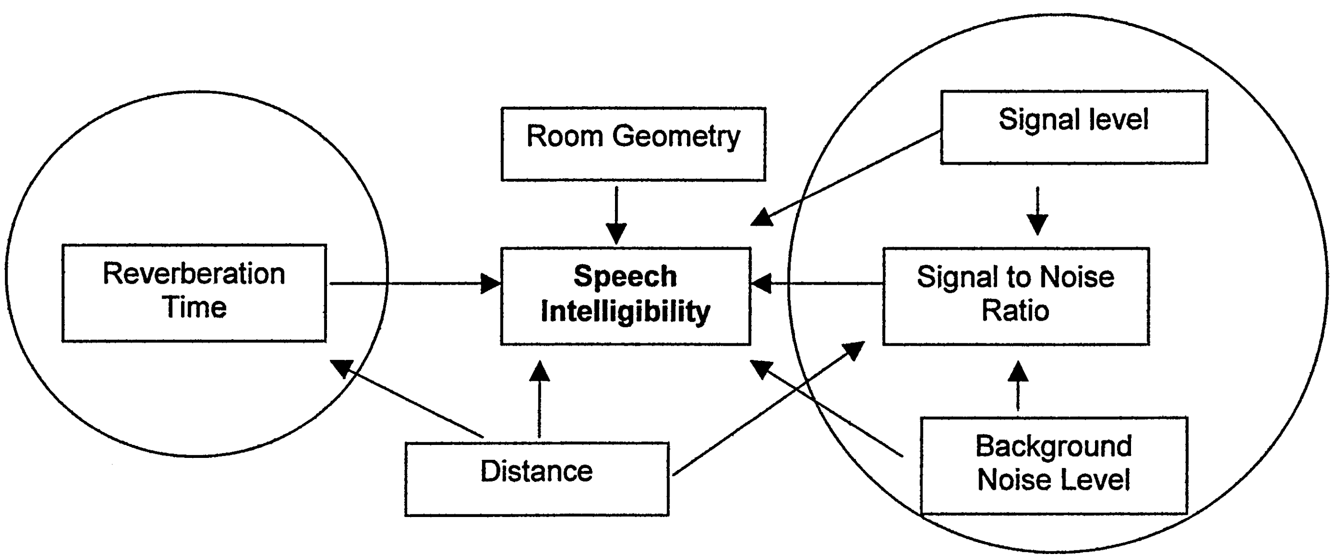


Figure 8.1 Factors affecting speech intelligibility

Adapted From Airey and Mackenzie [1]

It is worth showing this graphical representation again. Reverberation Time and Signal to Noise have been circled as being the most important factors.

In any room the factors in Figure 8.1 can be objectively measured.

Once a building has been completed the geometry of a room cannot be changed though it can easily be measured objectively. The construction materials can be detailed and then the rooms can be tested for impact noise from above, and intrusion noise from adjacent rooms, and from corridors. Ambient noise levels can be measured as can background noise levels when students are present in school. The voice intensity of the teacher can be recorded and therefore the signal to noise ratio can be calculated at different distances from the speaker so in a classroom a complete map of signal, noise and signal to noise ratio can be mapped out. This can give valuable information to teachers about any positions in class where a student may not be able to receive a clear voice signal due to a dead spot (due to the room geometry and reverberation time) or where intrusive background can cause a decrease in speech intelligibility.

8.3.1 Reverberation Time

Reverberation time is dependent on the room geometry and construction, although the materials, fixtures and fittings present can alter the reverberation time to a degree, as is shown in the Sabine method of calculating the reverberation time. The room volumes form part of the room geometry along with the shape.

In Room 1 the long low frequency reverberation as shown in the Figure 6.5.1 in Chapter 6 is probably due to the size, volume, shape and ceiling construction of the classroom, also detailed in Chapter 6.

The students' scores in the AB word list when presented in Room 1 are consistently lower, as shown in the tables in Chapter 7, in all positions than in the other 3 rooms, even in quiet. This suggests that even without background noise as a distraction there is a problem with the acoustics of the room. Room was subjectively described as 'booming' by several people, including the researcher. It was the only room in this school to be described in this way, although other classrooms in another recently built school were similarly described. These rooms were found to have similar reverberation time profiles when objectively measured using a sound level meter. An Early Decay Time profile of the room would support these findings.

8.3.2 <u>Distance</u>

As detailed in Chapter 2, the inverse square law says that signal intensity decreases over distance. This sort of word list in this sort of test situation should prove this. However reverberation muddies the water of this theory as the room geometry and reflections can create problems for listeners.

Position A, being within the critical distance, is the best position in the room as the reflected sounds arrive almost at the same time as the direct signal thereby supporting and enhancing it. Table 5.2 in Chapter 5 shows the maximum critical distance in each room.

Further away the reflected sounds arrive later than the direct signal so have the effect of smearing the direct signal. Position B is 3.6m from the signal source, position C an additional 2.6m from the signal source (6.2m total). So in looking at the inverse square law the 3 positions of A, B and C are selected as they are in line one behind the other through the length of the classroom. The student scores in the AB word list should decrease

with the distance from the signal through the positions A, B and C. In Room 4 this is generally the case. There are 4 students in this room who score better at position C than in position B. However the average scores show that the students' score better in position B than C by 4.7%.
In Room 2 again the average scores show that the students score better in position B than position C by 3.7%, with 4 students scoring better in position C than B (by 8%, 4%, 5% and 5%). However in the other two rooms, 1 and 3, the average scores are better in position C than B. In Room 1 the average is 43.2 at position B and 45.1 in C. In Room 3, the students score an average of 58% in B and 64.5% in C; there are 10 out of the 14 students who score better at position C than B.
As the test situation is exactly the same in the 4 rooms it can be suggested that these results show that reflections from the steel girder in Room 3 and the concrete beam in Room 1, have an effect on the speech intelligibility of position B that is situated below these structures in the centre of the room. This may be further affected by the reverberation and the size of the room particularly that of Room 3. The strength of the speech signal measured at position B and C differs by only 0.1dB(A) and the background babble noise is 1dB(A) louder at position B. (Shown in Table 5.3.) This gives a difference in the signal to noise ratio of 0.9dB(A) between the two positions, which is not a perceivable difference to a listener. The reason for this anomaly may be the geometry of the room, the size, the pitched roof and the steel girder that spans the width of the room above position B.

The point that needs to be raised here is that position B is recognized by teachers as being a good seating position for many students who may experience difficulties with learning in the classroom. Teachers would not be expecting a student seated here to have difficulty with speech intelligibility. In fact teachers of the deaf often request that hearing impaired students are seated in the middle as it places them in a very good position to hear all that is going on in the classroom. In Room 3 it would be a particularly inappropriate place for such a student to sit. Therefore advice to students and teachers who use Rooms 1 and 3 can be revised following the results of this research.

Looking at positions D and E, being in the corners of the rooms, it was expected that these two positions would probably give the worst scores in the speech intelligibility test. The distance from the signal source and the directivity of the signal being two reasons why this was expected. When the data in Table 5.4 is scrutinised it can be seen that the intensity of the signal at these two positions is not that much lower than in the other positions in the rooms. (The signal intensity in Room 3 is 1-2dB(A) lower than in the other rooms across most of the positions, this is probably due to the fact that this room has the largest volume of the 4 rooms that were used.)

Another possible reason could be that these positions suffered from more reflections coming from the corners of the rooms. In Room 4, where the reverberation time was below the recommended level within BB93[2] the students' scores for the AB word list in position D was between 14 - 30% better than in the other 3 rooms. In position E the improvement in scores was between 9- 22%. However this difference is no better or worse than the differences in the other positions in the room so it can not be stated that the reflections in the corners of the rooms have an impact on speech intelligibility.

8.3.4 Background Noise and Signal Levels

The measurements of background noise levels in occupied classrooms, particularly in Room 3, as shown in Chapter 6, and in a science room measured during preliminary work outlined in Chapter 4, support the suggestion that noise levels in classrooms increase as students and teachers raise their voices to combat the effects of long reverberation time.

Using the AB word list in noise is a difficult test for students as described in previous chapters, but it is a quick and easy method to illustrate difficulties that students do encounter in their classrooms. Just using the test in background babble noise in a good acoustic environment, for example in Room 4, showed that students in some positions in the room can miss spoken information. In position A in background babble the average score was around 92%, in position B this score dropped to 80%. In Room 3 these scores had dropped to 86% and 58% respectively; in Room 2, 75% and 50%; Room 1, 68% and 43%. The only factor that has changed is the acoustic environment, specifically that of the reverberation time profile. It could be stated that the actual room sizes are different, but the room with the smallest volume is in fact the worst room for speech intelligibility, that of Room 1. It is precisely these room dimensions and the construction materials that are causing this problem with speech intelligibility.

8.4 Conclusions

The conclusions that can be reached from the results of this research show that reverberation time does influence and affect a student's ability to hear the spoken word.

8.5 References

(1) AIREY S., MACKENZIE D. (1999) Classroom Acoustics; A Research Project

(2) THE STATIONERY OFFICE Building Bulletin 93 Acoustic Design of Schools

Chapter 9 Future Developments

9.1 Speech test developments

One issue raised by this research and the preliminary work is that of the material to use in the test. A speech intelligibility test requires the spoken word to be played to listeners in the test situation. Previous work used the BKB sentence list. This sentence list has key words embedded within a carrier sentence which have to be correctly repeated. There are no contextual clues to aid the listeners. Discussion in Chapter 4 related to the length of time taken to complete the test and the boredom factor experienced by the students.

This research used single words for the speech discrimination test. It can be argued that this is unrealistic in the classroom and a very hard test. For the purposes of this research it was seen to be easy to set up, quick to complete and simple to mark. The AB word list suited this project but future projects would require development of the single word list to be wrapped into a carrier sentence. The reason being that in background babble noise so effectively masks the speech signal, particularly in rooms with long reverberation times, that students find it difficult to pick out and may miss the word entirely. While the purpose of the research was to investigate the listening conditions in rooms with long reverberation times, it is recognised that students can become very disenchanted and could switch off completely if they do not have a realistic chance of hearing the word.

If the word was wrapped in a carrier sentence, for example *'write the word ship'* the students would be cued in to listen for the word whilst being given no contextual clues to the word itself.

Another issue with the AB word lists is the actual words that are used. Some, it could be argued, are quite dated and not within the normal vocabulary of the 11-12 year old students. For example wreath, jot, haze, rake, thatch and vice.

Future research will look at developing this type of test using carrier sentence and also updating the actual words. Development has already been started by Arthur Boothroyd[1], the original designer of the AB word lists, to encompass the original words in a carrier sentence, and also to look at the relevance of the words themselves to match the English needs of the test. Researchers in New Zealand have already adapted the word lists but these contain unsuitable words for the English test situation.

9.2 Building Regulations

Building Bulletin 93[2] is a welcome start to standards of new buildings for schools. The regulatory nature of it should make acoustics in classrooms much better.

However the results of this research suggest that the regulations regarding the reverberation time in classrooms may not be stringent enough to bring overall improved standards in classroom acoustics. The issue is that of the frequencies covered by the reverberation time testing. Is 500Hz, 1KHz and 2KHz a good enough standard at 0.8 and 0.4 seconds for normally hearing and hearing impaired students in secondary school classrooms? According to this research the answer is no. The low frequency reverberation that was present in Room 1 created the worst listening conditions of all the tested classrooms. The upward spread of masking caused huge problems with speech discrimination for the students.

The speech transmission index is also recommended, within BB93, for assessing listening conditions of open plan rooms in schools. This can be used in addition to live speech testing in other cellular classrooms. Using it alongside live tests would give a very good representation of how the room performed. In using the two tests together it can be seen whether there is a correlation between the two sets of results. If so then the sole use of the speech transmission index could be recommended. There is no reason to limit the use of the speech transmission index to just open plan rooms.

9.3 Sound Field Systems

The method of speech intelligibility testing as detailed in this study has also been used in other research work. Sound field systems have been installed in some primary school classrooms in the city. The speech intelligibility test has been used to assess the impact of these sound field systems on the listening conditions in classrooms. The speech discrimination test is completed in a variety of situations with and without the sound field in use.

The reason for fitting a sound field system is to give an even spread of the teachers voice into all areas of the room so that students sitting in any position receive an equal intensity of the signal. This allows the teachers to reduce their voice intensity as they do not have to shout to make themselves heard or to maintain discipline. It also should allow all students to hear more clearly and therefore help those who have a hearing loss.

However sound field systems need to be installed correctly and maintained well for them to remain effective tools in the classroom. Sadly this is not always the case. Using the AB word list in the same way that has been detailed in this study has helped to indicate inadequate installation and inappropriate use. For example, some speakers have not been installed correctly, some have been pointing upwards towards the ceiling, others have been placed in the wrong position on the walls, thereby creating areas of the classroom where students cannot hear well. Other systems have been found to be set at the incorrect volume, making the sound field either not loud enough, or too loud.

9.4 Test development

The experimental procedure has now been adapted from the initial method as outlined in Chapter 5. A portable sound field system is now available, rather than the four tape players, linked to a CD playing background multi-talk babble, and has been used to great success. It takes more time to set up but a more even spread of the background babble noise and better sound quality is experienced throughout the room.

It is hoped that alongside this updated method of the speech discrimination test, an updated and more relevant set of AB word lists, and the Speech Transmission Index, that a new procedure will soon be available to use in future classroom assessment of room acoustics.

9.5 Remedial treatment to existing classrooms

This test can be developed as detailed in the above sections and can then be used to re-assess the four rooms used in the study to assess the impact on student speech discrimination ability following any remedial acoustic treatment that may be installed as a consequence of this research.

9.6 References

(1) BOOTHROYD A. www.arthurboothroyd.com

(2) THE STATIONERY OFFICE Building Bulletin 93 Acoustic Design of Schools

AIREY S. (1998). A Survey of Acoustical Standards In UK Classrooms and their Effect on Pupils and Teachers. *Proceedings of the Institute of Acoustics* **20** Part 4, 14-21.

AIREY S., MACKENZIE D., (1999) Classroom Acoustics; A research Project. Heriot-Watt University.

AIREY S., MACKENZIE D., CRAIK R.J.M. (1997) The effect of Room Acoustics on the Intelligibility of Speech in School Classrooms. *Proceedings of Internoise.* Heriot-Watt University.

AIREY S., MACKENZIE D., CRAIK R.J.M. (1998) "Can you hear me at the back?" Effective Communication in Classrooms. *Noise Effects* **1**, 195-198

ARNOLD P., CANNING D., (1999) Does Classroom Amplification aid Comprehension *British Journal of Audiology* **33** 171-178.

ASSMANN, SUMMERFIELD Q., The Perception of Speech under Adverse Acoustic Conditions in Speech Processing in the Auditory System, in Springer Handbook of Auditory Research, (eds) Greenberg S. Ainsworth W. Popper A. Fay R.

BERG F.S. (1993) Acoustics & Sound Field Systems in Schools. Singular Publishing Inc. San Diego California.

BERG F.S. (1997), Optimum Listening and Learning Environments in *Audiology in Education,* McCracken, Laoide-Kemp. Whurr, London

BLAKE P., BUSBY S. (1994) Noise levels in New Zealand Junior Classrooms: Their impact on hearing and teaching. *New Zealand Medical Journal.*

BROUGHTON A. (2001). Classroom Acoustics: Perception and Reality A report on the implications for inclusion of a Survey into the acoustic environments in which three year 9 profoundly deaf students learn. Shropshire Sensory Inclusion Service.

CEPEDA RIANO J., GARCIA ORTIZ E., MELCON OTERO B., VIDAL GONZALEZ M.I., Intelligibilty in a School in Leon, Spain. *Internoise.*

CRANDELL C.C., SMALDINO J.J., ANDERSON K. Classroom Acoustics. Alexander Graham Bell Association for the Deaf and Hard of Hearing: *Periodicals.* Accessed online http://www.209.41.163.85/periodicals/acoustics.cfm on 30.10.2001

CRANDELL C.C., SMALDINO J.J. (1994) An Update of Classroom Acoustics for Children with Hearing Impairment, *Volta Review* 96, 291-306.

CRANDELL C.C., SMALDINO J.J. (2000) Classroom Acoustics for Children with Normal Hearing and with Hearing Impairment *Language, Speech and Hearing Services in Schools.* **31**, 362-370.

FINITZO-HEIBER. TILMAN T. (1978) Room acoustics effects on monosyllabic word discrimination ability for normal and hearing impaired children. *Journal of Speech and Hearing Research* 21 440-458.

HEERWAGEN D., ANDERSON K. LANG D., TOWNE R. (1997)_Measuring Speech Intelligibility in Kindergarten through fifth grade in a Seattle Public School. *Acoustical Society of America* 134th Meeting Lay Language Papers

HERBERT R.K. (2001)_Poor Marks for Classroom Acoustics Ostergard Acoustical Associates, USA www.facilitiesnet.com

HODGSON M. NASAL E-M. (2002) Effect of Noise and Occupancy on Optimal Reverberation Times for Speech Intelligibility in classrooms *Journal of Acoustical Society of America* **111** (2)

KRING H.R. Poor Marks for Classroom Acoustics. Building Operating Management Online. http://www.facilitiesnet.com accessed on 30.10.2001.

LUMQUIST P. The Relationship between Background Noise Levels and Activity Noise Levels At School. *Internoise.*

MACKENZIE D., AIREY S.,(1999)_Classroom Acoustics: A Research Project Report Heriot-Watt University Press, Edinburgh

NABELEK A.K., ROBINSON PJ.M. (1984) Monaural and binaural speech perception in reverberation for listeners of various ages. *Journal of Acoustical Society America.*

NELSON P.B., SOLI S. (2000) Acoustical barriers to learning: Children at risk in every classroom.*Language,Speech and Hearing Services in Schools.* Washington.

SCHICK A., KLATTE M., MEIS M. Noise Stress in Classrooms Contributions to Psychological Acoustics: In A. Schick, M. Meis & C. Reckhardt (2000) *Results of the 8th Oldenburg Symposium on Psychological Acoustics.* 533-569.

SEEP B., GLOSEMEYER R., HULCE E., LINN M., AYTAR P., Classroom Acoustics. Prepared for the Technical Committee on Architectural Acoustics of the Acoustical Society of America. 2000.

SHIELD B., DOCKRELL J., JEFFREY R., TACHMATZIDIS I. (2000) The Effects of Noise on the Attainments and Cognitive Performance of Primary School Children. South Bank University.

SMYTHE R.L., BAMFORD J.M. (1997) Speech Perception of hearing-impaired children in mainstream acoustic environments: An exploratory study. *Deafness and Education (JBATOD)* 21/2, 26-31.

SUTHERLAND L., LUBMAN D. (2001) The Impact of Classroom Acoustics on Scholastic Achievement. 17th Meeting of the International Commission for Acoustics. Rome September 2-7th. Accessed online http://www.nonoise.org/quietnet/qc/ICA2001.htm on 24.02.03

THE STATIONERY OFFICE Building Bulletin 93 Acoustic Design of Schools

WATERHOUSE R., HARRIS C. (1979) Sound in enclosed spaces. In Harris C. (ed) Handbook of noise control. New York. McGraw Hill pp 4-9.

YACULLO W.S., HAWKINS D.B. (1987) Speech Recognition in Noise and Reverberation by School Age Children. *Audiology* 26, 235-246.