Proceedings of the Institute of Acoustics

NOISE AND HEALTH – METHODOLOGICAL ISSUES IN THE ASSESSMENT OF NOISE EXPOSURE

G.Kerry University of Salford, Salford M5 4WT
P.D.Wheeler University of Salford, Salford M5 4WT

1 INTRODUCTION

There is considerable interest in the potentially adverse effects of chronic noise exposure of populations living close to major civil airports. In particular there is deep concern that children attending schools located in these areas might suffer reduced cognitive performance. However differential cognitive performance outcomes between nominally "noise-exposed" and "non noise-exposed" groups are not always identifiable[1].

Generally the mechanisms involved in the influence of environmental noise on cognitive performance are not fully understood and we would argue that a knowledge of the auditory environment is an important aspect of any analysis of possible mechanisms.

Conventionally the effects of environmental noise on people are usually assessed in terms of the average daily exposure, measured in terms of the daytime or night-time A–weighted Leq outdoor noise level. The noise level inside dwellings, workplaces and schools from external noise sources such as road traffic or civil aviation is often not monitored in studies on environmental noise effects.

The use of a general descriptor such as a 16hr L_{Aeq} measure of the external noise environment is of little value when seeking to identify and quantify the influence in the classroom of external noise from aircraft fly-overs. What matters, in the case of school studies, is the level and duration of the noise reaching inside the classroom during school hours. This is a function of both the temporal pattern of the external noise, as defined by the maximum level, intermittency and duration, and the amount of sound insulation provided by the school building fabric.

An alternative and relatively simple analysis of the key acoustical factors for describing the classroom noise environment and the influence of external noise sources on the teaching and learning environment is presented below.

2 CONVENTIONAL ENVIRONMENTAL NOISE CRITERIA

Environmental noise criteria are increasingly being stated in terms of the daily equivalent A-weighted sound level (L_{Aeq16}), or its derivative L_{DEN}, the equivalent sound level during the day, evening and night, the evening level having a weighting of +5 dB and the night-time level a weighting of +10 dB.

The European Commission has recently proposed the adoption of L_{DEN} for its Framework Directive on the Assessment and Management of Environmental Noise[2].

L_{Aeq16} and its derivatives, L_{DN} or L_{DEN}, are proposed as the appropriate indices for the assessment of community response to environmental noise by the European Commission's expert Working Group on Dose Effect Relationships for environmental noise from transportation sources. Their Position

Paper[3] proposes three different polynomial relationships for calculating the percentage of people "annoyed" or "highly annoyed" (%HA) in community surveys of the effect of noise from civil aircraft movements around airports, from road traffic and from railways.

Thus, as derived from this proposal, a daytime external L_{Aeq} of 50 dBA is predicted to result in 6%HA for aircraft noise, 3%HA for road traffic noise and 1%HA for railway noise, and a daytime external L_{Aeq} of 70 dBA is predicted to result in 35%HA for aircraft noise, 26%HA for road traffic noise and 15%HA for railway noise. Confidence intervals (95%) are typically quoted as 3- 5 %HA. The Position Paper excludes certain specific types of noise source from this global characterisation, such as helicopters, military low-flying, train shunting and shipping noise. The noise exposure is defined in terms of the façade level at the most exposed side of the dwelling.

Using simply a L_{Aeq} based descriptor of environmental noise; it is almost universally argued that, in some way, aircraft noise is more annoying than road traffic and rail noise. Researchers examining the effects of environmental noise on children's learning also argue that aircraft noise has a greater effect, as observed both in field and in laboratory studies. It is seen as "more harmful" by its nature.

Such views are frequently presented at international conferences and at gatherings of specialists, but no attempt has seemingly been made to investigate why civil aviation noise is seen as more of a problem than road or rail noise.

3 AN ALTERNATIVE APPROACH

Our analysis is based upon a very simple "single-number" quantification of the performance of the various components in the auditory pathway from environmental noise source to listener, leading to an estimate of the relative audibility of the noise in the dwelling, office or school in terms of the "signal-to-noise ratio" of the event.

It clearly shows that, for the same external L_{Aeq}, airport noise and road traffic noise can be expected to produce entirely different auditory environments in the dwelling. It also shows that there is a threshold for such adverse effects, which is quite different for each type of noise source.

The current problems in linking environmental noise levels to community effects are believed by the authors to be largely associated with the widespread use of L_{Aeq} based indices, without any thought being given to the underlying acoustical analysis issues.

The key points of our argument are presented below in summary form:

The analysis must take account of:

- Sound insulation of the building structure
- Internal ventilation noise
- Availability of air conditioning
- Use of open windows during summer months
- Internal noise generated by the activity of the children at the time of the external event
- Acoustic characteristics of the classroom

The exemption of LEA maintained schools from the Building Regulations ended in April 2001 and all school buildings are now subject to detailed design checks and on-site inspections by Building Control Officers. The DfES is in the process of producing new guidance on the acoustic design of school buildings[4] which will satisfy both requirement E4 from Part E of schedule 1 to the Building Regulations 2000[5] which covers new buildings and The Education (School Premises) Regulations 1999, SI1999 No.2[6] which applies to both new and existing buildings. The introduction of these guidelines and the inclusion of schools under the Building Regulations should result eventually in a better internal noise climate in most schools even those near major sources of noise. However it is unlikely that existing schools will be improved significantly unless there is a clear indication of adverse effects of noise. The sound insulation of a schools building structure, a vital constituent of the analysis, can vary from very poor, say 10dBA to very good approaching 40 dBA, (in terms of the level difference – free field external noise to inside classroom). In many existing schools the range is more likely to be from 10 to 30dBA. With brick built construction, the insulation is usually governed by the area and quality of the glazing and in particular whether windows are open for ventilation or not. With typical 1960s constructions façade inter-glazing panels may also be weak. “Temporary” modular units and single story flat roof constructions often provide little insulation. Figure 1 illustrates the typical external sound insulation that can be expected in many schools today.

In some schools considerable efforts have been made to provide high quality insulation and to maintain it, and some form of ventilation or air condition may be provided. Noise from these systems or from other mechanical devices (such as fume cupboards) can influence the noise in the classroom unless properly designed. In other situations we may find that during winter external noise levels may be adequately reduced by well sealed windows but in summer additional ventilation is required and what was in one instance an acceptable situation can suddenly become a totally unacceptable one.

The internal classroom noise is not only a function of the external level and the sound insulation but also the class activity noise. Both will be influenced by the internal classroom acoustics. Guidelines for acceptable reverberation times, inter-classroom insulation and isolation of noisy activities are contained in the aforesaid DfES Building Bulletins. But in any given situation there is considerable leeway and the uncertainty in internal levels may easily be +/-5dBA to +/-10dBA. Class activity levels also vary enormously and are often influenced not only by the internal acoustics but also the level of intrusive noise. Figure 2 illustrates the sort of change that can occur when the schoolchildren take part in “quiet” activities to “noisy” activities.

4 A SIMPLE CASE STUDY

Consider a 16-hour $L_{Aeq\ noise}$ environment of 70 dBA for a school near a busy motorway where the external noise is constant all day, or for a school under the landing path of a busy airport.

In the motorway case the noise level varies very little, within $\pm$ 3 dBA all the time, since the road traffic flow is more or less constant over the day.

In the airport case, we can expect to see individual events giving maxima of 75 to 85 dBA (I second Leq) for aircraft overflights (on approach), and an ambient noise level of 50 – 55 dBA. The interval between events is typically 60 to 90 seconds and the duration of event (-10 dB) is around 20 seconds. The L_{Aeq} of such a noise pattern is some 15 - 20 dBA less than the individual maximum noise levels.

Figure 3 illustrates such an environment, recorded outside a school under the eastern inbound flight path at Heathrow during one autumn morning in 2000.

To understand the importance of the event noise level and the frequency of occurrence of the noise events versus the longer term $L_{Aeq,16hr}$, let us put some numbers to the analysis.

Let us say that the overall effective sound insulation of the school building is in the range 15 to 25 dBA, that the interior noise level from H&V (heating and ventilating) is 35 to 45 dBA, that the activity noise level for quiet work is 45 to 50 dBA L_{90} [1] and for busy times is 55 to 60 dBA L_{90} (L_{10} [2] levels in the classroom may be 65 to 75 dBA).

[1] L_{90} – the level exceeded for 90% of the time (a measure of the background noise level)

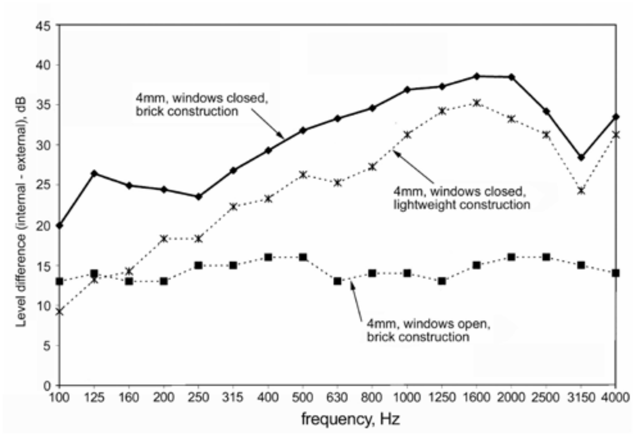

Figure 1 *- Typical external façade sound insulation that can be expected in many schools*

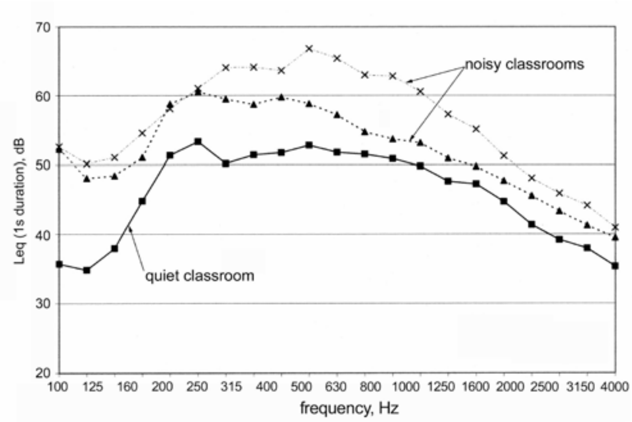

Figure 2 *– The change that can occur in the noise level in a classroom when schoolchildren take part in "quiet" activities to "noisy" activities.*

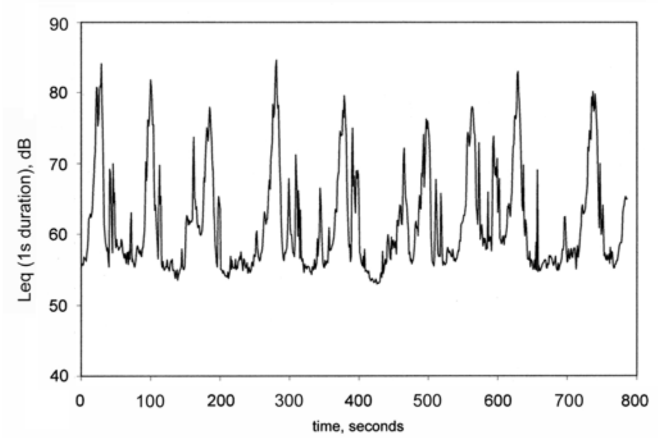

Figure 3 *- Noise environment, recorded outside a school under the eastern inbound flight path at Heathrow during one autumn morning in 2000.*

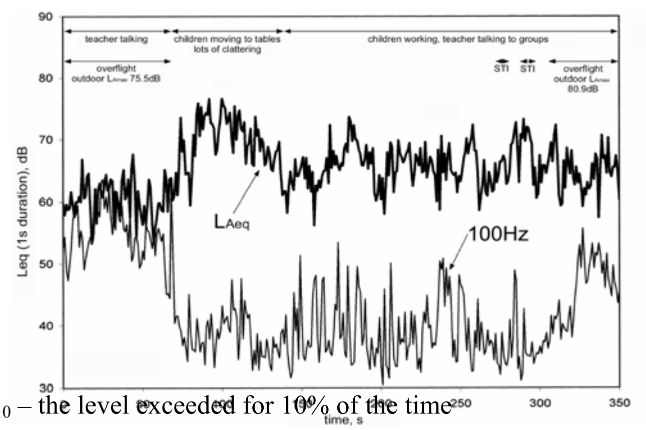

Figure 4 *- Typical levels inside a classroom. Aircraft event is shown clearly in 100Hz plot but is hidden by the noise in the classroom in the A-weighted plot.*

[2] L_{10} – the level exceeded for 10% of the time

We know that aircraft flyover noise has a considerable low frequency component and the sound insulation of the school building is lowest at low frequencies, and therefore that the noise of the aircraft heard indoors is dominated by components at 250 Hz or lower. The noise from children talking is predominantly middle and high frequency noise and intelligibility is chiefly controlled by high frequency components.

If we make a very simplistic analysis:

Case 1 - During an aircraft flyover in classroom 1 (relatively good insulation – high classroom activity)

If the external noise of a particular flyover is 90 dBA , the internal noise level from the flyover (in a classroom of moderately good insulation – level difference 25dBA) will be 65 dBA. If the activity noise level (busy time) is 60 dBA, the effective “signal to noise ratio” (SNR) of the overflight will be 5 dBA. A simple auditory assessment suggests that the aircraft event, because it is predominantly low frequency in content, will certainly be noticeable in the classroom, but will not unduly affect speech reception - a minor effect only.

Case 2 - During an aircraft flyover in classroom 2 (relatively poor insulation – low classroom activity noise)

If the external noise level for the second classroom is also 90 dBA, the internal noise level from the flyover (this classroom has relatively poor insulation because, say, the windows are open - level difference 15dBA) could be 75 dBA. If the activity noise level (quiet study) is 45 dBA, the aircraft overflight “SNR” will be 30 dBA and the auditory assessment suggests a major disruption.

Case 3 - During an aircraft flyover 2 in classroom 3 (moderate insulation - moderate classroom activity noise)

With the external noise level still 90 dBA, in a classroom with medium insulation (level difference 20dBA) the internal noise level from the flyover will be 70 dBA. If the activity noise level is 55 dBA, the overflight “SNR” is 15 dBA – a middle category condition. The auditory assessment suggests impaired activity.

Let us take a comparison with a road traffic noise source.

Case 4 - Motorway noise at 70 dBA in classroom 3 (moderate insulation – moderate classroom activity noise)

The external noise level is a constant 70 dBA. For medium insulation – level difference 20dBA, the internal noise level in the classroom from vehicles will be 50 dBA (constant). If the activity noise level is 55 dBA, the road traffic noise “SNR” is -5 dBA. Auditory assessment suggests minimal effect.

Case 5 – Effect of aircraft flyover temporal pattern

Let us assume that the last aircraft noise category (Case 3) is most typical of the classroom noise environment under the civil airport flightpath and that the teacher seeks to maintain normal classroom activity during the overflights, which last around 20 seconds and occur every 80 seconds. This constitutes a 25% interruption rate for the lesson.

What if the noise environment changes? This analysis was made for a 90 dBA aircraft event noise level, 70 dBA 16 hour $L_{Aeq,}$ noise environment.

What if we chose a school with a 75 dBA 16 hour L_{Aeq} noise environment? This could be a site where the average overflight noise level is higher or the event duration longer or number of events greater or any combination.

Our auditory model suggests that ± 5 dBA for the aircraft noise heard in the classroom is unlikely to have a major effect on the teaching and learning environment (provided we are still in this middle auditory environment range).

But if the events are longer or there are now more overflights, the time for which work is disrupted is greatly increased.

On the other hand, a noise environment of, say, 65 dBA 16 hour L_{Aeq} may mean one flight every 240 seconds or a quieter flight every 80 seconds.

These different circumstances are likely to have quite different effects in the classroom.

Our analysis suggests that within the medium auditory classroom condition (Case 3), where there is a noticeable but not overwhelming noise intrusion, the frequency and duration of overflights matters much more than the actual noise level and that, typically, it is this medium category condition that exists in schools under the flightpath at Heathrow, for example.

Within this medium category condition, how should we compare the effect in the classroom of one 20 second duration overflight every 80 seconds or one overflight, 10dB louder, every 800 seconds? Both patterns have the same external L_{Aeq} level.

We conclude that when comparing the external noise environment of schools, it is necessary to know the interior noise level during and between overflights and the frequency and duration of overflights - not just the 16 hour $L_{Aeq\,,}$ which will not give a reliable basis for comparison.

In addition, we see that the type of classroom activity is an important factor; hence, the possibility that aircraft noise may influence some learning processes more than others do.

5 THE ROLE OF OBJECTIVE SPEECH INTELLIGIBILITY MEASUREMENTS

The interaction between the noise environment and the learning process is generally regarded as being a complex subject, with habituation being just one element. It would be naïve to suggest that traditional measures of the auditory environment could provide all the answers. However, we believe that a knowledge of the auditory environment assists in the assessment and interpretation of noise effects studies. It is therefore necessary to determine how the auditory environment in the classroom can be measured objectively and simply. The term auditory environment covers both the noise environment in the classroom, caused by internal noise from mechanical services and other activities elsewhere in the school, and noise from outside together with the speech environment, i.e. the speech of the teacher, the effect of the classroom acoustic conditions on the speech heard by the children and the interfering effect of the background noise (from any source). It is generally accepted by both acousticians and educationalists that a satisfactory classroom auditory environment is necessary for effective teaching and learning. To achieve this speech intelligibility must be adequate and the noise environment must not be excessive.

There are many ways of assessing the auditory environment in terms of speech intelligibility. One way is to use the objective Speech Transmission Index (STI) and couple this with subjective quality judgements made at the time of the measurements.

The STI system was first developed in the 1970s and uses a time-varying signal having similar frequency characteristics to human speech, which is generated and transmitted through the "system" under test. The system could be a telephone line or radio link, the prime reason for the techniques development, or a room. The signal has time-varying components over a range of repetition rates representative of speech, and the degree of smearing over time, in each frequency band, from 125Hz to 8kHz, is measured. It has shown to be a repeatable and reliable indicator of speech intelligibility by many researchers working in the fields of architectural acoustics and in speech communications[7].

The STI technique has now been incorporated into automated PC-based systems. For architectural acoustics purposes, a sound impulse is used to excite the space and a microphone and data acquisition channel to capture the impulse response of the space. This signal is then processed and the sound quality criteria and indices derived. For the assessment of speech intelligibility in a classroom, it is important to use a source that can replicate the frequency spectrum, sound level and directivity of the human voice. A suitable source is the Bruel & Kjaer mouth simulator which can be readily placed at any suitable location, normally occupied by the teacher. The signal from the simulator and the background noise can then be picked up in turn at a range of monitoring positions using microphones located where the children work.

The human voice will generate a long term RMS sound level of around 67dBA, as measured 1 metre in front of the speaker, at mouth level, for conversational level continuous speech. Slightly raised vocal levels might be delivered by a teacher under quiet classroom conditions, since the teacher expects children throughout the classroom to here their voice and so an appropriate normal level would be 70dBA at I metre. Raised voice conditions, which might be difficult for an untrained speaker to maintain for any length of time, can be represented by a vocal level some 6 dB higher, and a shout having an even higher level. Therefore for a full assessment to be completed a variety of source levels must be used under a variety of listening conditions.

STI values are quoted as three digit decimals in the range o to 0.999 based upon the sum of a matrix of individual component values at both intermodulation frequencies and the seven octave bands. For each of the latter an average octave modulation transfer index is produced. A high value is an indication that, in the frequency range concerned, the speech-like test signal fidelity is maintained. STI values in the range up to 0.300 are rated as "bad", 0.3 to 0.6 as "poor", 0.6 to 0.75 as "good" and greater than 0.75 as "excellent".

High levels of low frequency sound from aircraft overflights will reduce the modulation index at the lower frequencies of 125Hz and 250Hz and may thus reduce the overall STI value. However this will depend on the quality of sound transmission at high frequencies. Excessive reverberation in the classroom will have an adverse effect on rapidly changing high frequency speech signals and this will also reduce the modulation index and overall STI value.

The noise generated by children chatting or working is mainly high frequency in content and will consequently affect the high frequency, intelligibility-bearing, components of speech. The modulation index in the frequency range 500Hz to 4kHz is mainly affected. The knocking of chairs, scrapping of desks and other transient noises will generally affect the lower frequencies.

Examples of some STI values obtained on a recent exercise in a classroom near an airfield are given in table 1 together with some comments on the activities at the time.

Table 1 *- Examples of STI values obtained in a classroom*

Reference	Time	Mic/Voice Pos	Voice level	STI value	Rating	Comment
026	10.54	3/1	2	.675	Good	Quiet class
028	10.56	1/1	2	.756	Excell	Quiet class with aircraft
032	11.27	3/1	1	.629	Good	Quiet class, aircraft take-off
038	13.20	3/1	1	.186	Bad	Children talking
039	13.24	3/1	1	.076	Bad	Noisy children, aircraft flyby
040	13.26	4/1	1	.085	Bad	Noisy children only
051	14.53	4/1	1	.601	Good	Empty classroom, aircraft flyby

6 CONCLUSIONS

The effects of environmental noise on people are usually assessed in terms of the average daily exposure, measured in terms of the Leq outdoor noise level adjusted for evening or night-time periods if appropriate. In the case of school children where studies seek to identify and quantify the influence of noise from flyovers on cognitive performance it is suggested that such a measure is totally inadequate. Of importance is the total auditory environment within the classroom. This is a function of the level, duration and temporal pattern of noise from an external source reaching inside the classroom as well as noise generated within the classroom from teaching activities as well as other internal noise sources. Therefore both the performance of the building fabric and the internal acoustics of the classroom must be taken into account.

A simple alternative approach based upon a simple single number assessment of the "signal to noise ratio" of an event has been used to assess the audibility of noise in the classroom. This shows that the type of overall activity in the classroom is an important factor and suggests that aircraft noise may influence some learning processes more than others.

To assist the interpretation of classroom studies, it is suggested that the speech transmission Index (STI) method is now sufficiently developed to be used to monitor the auditory environment during class activity. Modern computer based systems provide a ready means of carrying this out in the classroom.

7 REFERENCES

1. The West London Schools Study: The effects of chronic aircraft noise exposure on child health. M.Haines et al. Proc 17th ICA Rome 2001
2. Framework Directive on the Assessment and Management of Environmental Noise, European Union Directive 2002/49/EC
3. Interim position paper on Dose Response Relationships between Transportation Noise & Annoyance WG2, EU Commission.
4. Draft Building Bulletin 93, section 1, DfES website, September 2002
5. Part E of schedule 1 to the Building Regulations 2000, HMSO
6. The Education (School Premises) Regulations 1999, SI 1999 No.2, HMSO
7. The Measurement of Speech Intelligibility, H.M.Steeneken, Proc. IOA Volume 23, Part 8, 2001.