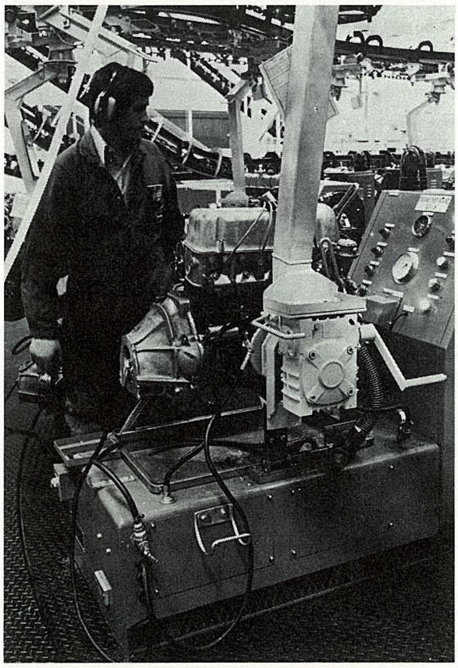
Noise pollution and the cost of hearing loss

The finding that continual exposure to noise can lead to hearing loss was first reported in 1831 by a Dr J. Fosbroke. Writing in *The Lancet*, he described an affliction called 'blacksmith's deafness'.

His suggestion for a cure is indicative of medical opinion at that time: 'I do for my own part believe firmly that if deafness were treated with decisive bleeding at its first coming on in plethoric subjects, it might be cured and prevented from establishing itself.'



Sometimes ear-muffs are the only answer.

Later reports by others described deafness in boilermakers, railway men, and rifle-bearing hunters, until by early this century there was general recognition of the damaging effect of prolonged exposure to loud noise. Physicians at that time used tuning forks to measure hearing loss, asking their patients to tell them how long a fork could be heard after it had been struck.

Nowadays, we can measure hearing loss with considerably greater precision. The International Standards Organization considers a person's hearing significantly impaired when his ability to hear tones at 500 hertz, 1000 Hz, and 2000 Hz — the crucial speech frequencies — is decreased by a factor of 18, or 25 decibels.

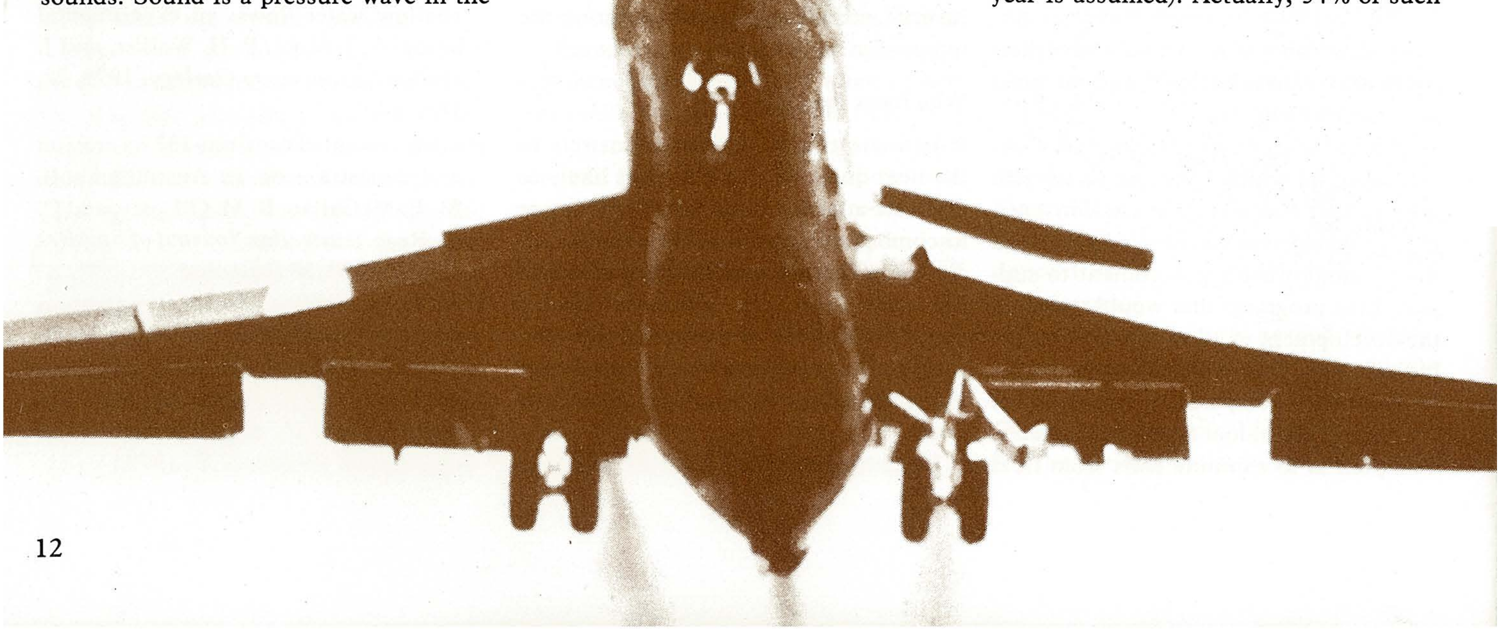
We know now that loud noise causes excessive vibration and fatigue of structures in the inner ear, particularly the delicate hair cells that convert physical movement into electrical impulses for transmission to the brain.

Our ears have a remarkable ability to respond to both very soft and very loud sounds. Sound is a pressure wave in the air: our ears can detect pressures as low as 20 micropascals and — although only momentarily without pain — can withstand pressures as high as 63 000 000 micropascals. On a logarithmic scale, that is a range from 0 decibels to 130 decibels — better than the dynamic range of most scientific measuring instruments. Sound levels are usually quoted in decibels (dB) and given a weighting according to their frequency so as to match more closely our perception of a sound's loudness. This measure — the dBA scale — also gives a good indication of the damage potential of sounds.

Although short bursts of loud noise are likely to lead to only a temporary loss in hearing sensitivity, scientists who study hearing have found that continual exposure to sound-pressure levels above 85 dBA may lead to permanent hearing loss. The degree of impairment depends on the noise level and its duration, as well as the susceptibility of the individual. Some people have what is known as 'hard ears' — a seeming immunity to hearing damage.

Nevertheless, considering the community at large, a table of risk can be drawn up showing the percentage of people expected to show deafness — defined as a hearing sensitivity decreased by 25 dB or more at speech frequencies. The table is reproduced on page 17.

It shows that 21% of people working in an environment where they are exposed continually to 90 dBA will show distinct deafness because of the noise after 40 years' exposure (a 40-hour week, 50-week year is assumed). Actually, 54% of such

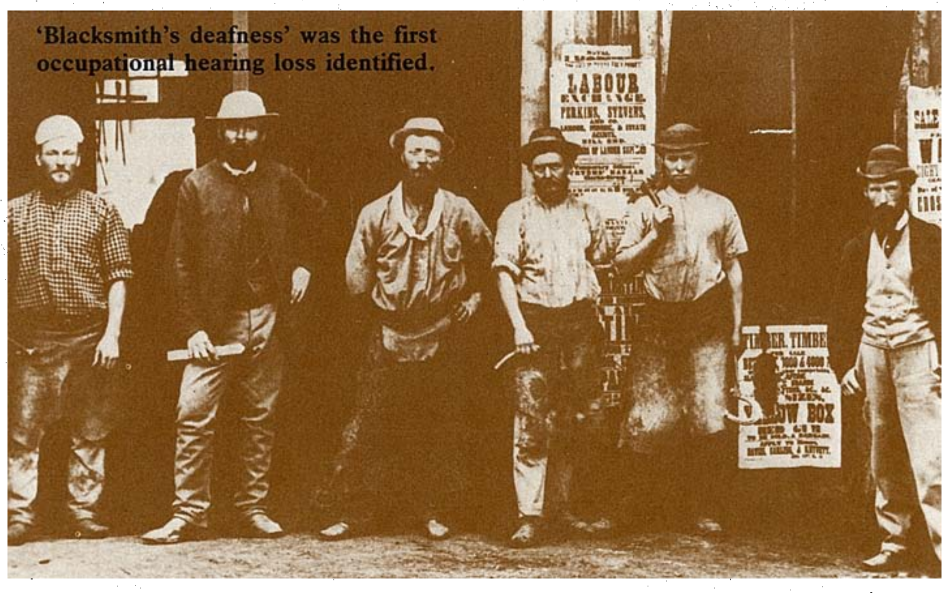


workers will be in the hearing-aid league because the effects of ageing must be added too. The bottom line of the table shows the effect of age only, and these base values must be added to those in the rest of table to get the total percentage of people with impaired hearing.

Concern about the damaging effect of noise has prompted a response at a number of levels. Some large industrial plants have instituted hearing-conservation programs designed to reduce hearing damage. Machine manufacturers have attempted to reduce the noise of the equipment they sell. Better, cheaper, and more comfortable ear protection has become available. Lastly, legislation has now made hearing conservation mandatory.

Daily noise dose

During the past few years, laws have been enacted in all Australian States to limit the level of noise permissible for workers in industry. The legislation is based on Australian Standard 1269, in which the concept of a 'daily noise dose' is defined.



'Blacksmith's deafness' was the first occupational hearing loss identified.

The maximum continuous noise level to which a worker can be exposed for an 8-hour day has been set at 90 dBA — a noise dose of 1.

Other ways of receiving a daily noise dose of 1 include exposure to 93 dBA (double the intensity of 90 dBA) for 4 hours, 96 dBA for 2 hours, and so on. The rationale behind the daily noise dose is that in all cases the amount of sound energy received per day remains constant.

Noise-dose meters available include types that a worker, exposed to any variety of loud sounds, can wear in his vest pocket. At the end of the day the unit gives a read-out of the integrated noise dose. If the reading exceeds 1·0, the legislation requires that action must be taken to reduce the noise dose. Such action can take three forms.

The first is engineering control, whereby machines are made quieter, either by redesign or by providing protective screens or boxes (see the box on page 15).

Administrative noise control is the second form. This calls for measures such as rostering workers between noisy and quiet locations or reduction of machine speeds.

As a last resort, personal hearing protection may be the only answer. This means the provision of ear-plugs or ear-muffs. These devices are often a nuisance, becoming uncomfortable to wear in many cases, especially in hot environments. Furthermore, some workers feel that they cannot communicate as well when wearing the units, or that they cannot as easily hear tell-tale noises from their machinery that would signify faulty operation and possible danger. (The box on page 14 discusses the principles of these devices.) Constant supervision and a regular testing of the workers' hearing by audiometrists are needed to ensure that the protection is effective.

The cost of protection

In a paper prepared for the Tenth International Congress on Acoustics in Sydney last month, Dr Don Gibson and Dr Michael Norton, of the CSIRO Division of Mechanical Engineering, presented estimates of the annual cost to Australian industry of undertaking personal hearing protection (issuing ear-muffs and so on) so that no worker would be exposed to a daily noise dose greater than 1.

They concluded that this protection would cost nearly as much annually as the workers' compensation payments for hearing damage that could result if it was not provided. Furthermore, they found that the cost of reducing machine noise to legal limits by engineering means (the alternative, and certainly the best long-term solution) would significantly exceed such payments.

Noise as a pollutant

All machines generate noise as an unwanted by-product, some more offensively than others. The problem for us at the moment is that noise wasn't considered in the design of most equipment presently installed. As a consequence, noise will bedevil us for at least the economic life of present machinery, say 20 years.

There is no financial incentive for most industry to reduce noise to 90 dBA.

Until these machines are replaced, we must resort to remedial measures like boxing-in a noisy machine. Considering noise as a pollutant, that's a rather extreme method of pollution control — it's far better to handle the pollution at its source. It has been estimated that the cost of incorporating noise-reduction techniques in new machines is about one-tenth that of present 'band-aid' practices.

But let us concentrate on the noise environment we have inherited. Very few published survey data are available in Australia on noise environments in industry, or on the loss of hearing and the amount of workers' compensation payments associated with noise. To get to grips with the problem, the research team therefore had to rely on a survey by the South Australian Department of Public Health on the noise level in that State's Government Workshops, together with the results of surveys conducted in the United States.

Noise wasn't considered in the design of most equipment presently installed.

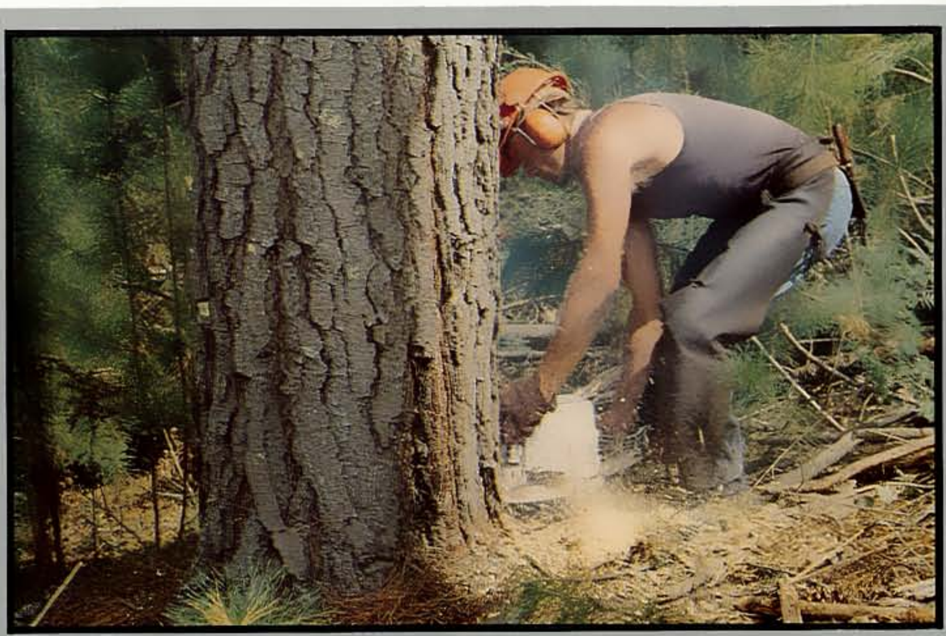
Communication in a noisy environment

In a particularly noisy work-place, it is necessary to raise one's voice, or even shout, to communicate with somebody else. In these situations, wearing ear-muffs or ear-plugs will still allow communication to take place: the voice and the surrounding noise are simply reduced by equal amounts. Indeed intelligibility of the speech may be improved because the ear isn't overloaded and responding in a distorted way. Similarly, the audibility of machinery and warning signals should remain when hearing protection is worn.

Mr Ted Lhuede of the Division of Building Research tested a variety of muffs for use by sawmillers. The workers greatly preferred one type of muff, which was light, didn't clamp too forcefully on the ears, yet provided a good 19 dB noise reduction. The only widespread complaint was that they were 'too hot'. Except for a few older sawmillers, none of them complained of any adverse effect on working ability or suggested that there was any problem because the saw couldn't be heard properly.

The older workers probably already suffered hearing impairment, so high-frequency sound was so attenuated that it became inaudible. In this case, ear protection should not be discarded; it is even more important that the residual hearing ability is not further impaired.

The answer lies in improving the audibility of the signal, or providing other means of warning. Alternatively, special communication equipment, consisting of noise-cancelling microphones and headsets equipped with earphones, can be used. Such equipment is commonly used in places where the noise level is too high to allow people to talk — or even think!



Hot work like this can make ear-muffs uncomfortable.

At the CSIRO National Measurement Laboratory, Mr Vic Burgess has developed a particularly suitable form of such a device. It uses radio links like other units, but the way the signal is transmitted allows workers to tune in to their fellows simply by coming into proximity to them. Although only one frequency is used, interference is avoided.

The trick is to use FM modulation in conjunction with induction field transmission. The former allows the 'capture effect' to take place, whereby only the strongest (closest) signal is heard; the latter means that the signal strength falls away very quickly, giving a limited range of about 10 metres.

Mr Burgess originally designed the system as a wireless hearing aid for use by deaf children in schools — the National Acoustic Laboratory is presently having 500 of the units manufactured for this purpose after successful trials with prototypes. Commercial manufacture of the unit is planned to begin later.

Placing the microphone of the hearing aid near the speaker's lips gives improved intelligibility of the voice above surrounding noise. Of course, what Mr Burgess' device does for deaf people (his wife was born deaf from German measles), it could also do for those with normal hearing in very noisy environments. A version suited to this purpose would need a noise-cancelling microphone and a suitable headset.

A frequency band has recently been allocated by the international body regulating radio channel allotments specifically for Mr Burgess' system (and similar ones that will no doubt follow).

This body of data was supplemented by information supplied directly to the researchers by governmental agencies, private industrial bodies, and acoustical consultants in New South Wales and Victoria.

Dr Gibson and Dr Norton first took the figure for the number of people currently employed in an industrial setting in Australia — 416 000 tradesmen, production workers, labourers, and the like. Then, using the American survey results as a guide, they estimated that 26% of our industrial work force — 108 000 people — are continuously exposed to noise levels greater than 90 dBA.

Assuming an age distribution for these workers identical to that of the Australian population at large, the research pair estimated the hearing damage that would result if they were exposed to 90 dBA, the legally allowable limit. Some 42 000, about 39% of the exposed workers, would be afflicted with impaired hearing. Some would be affected worse than others, but the research suggests that they would suffer an average hearing loss of 6%.

Of course the older workers, near retirement, are likely to be the most severely affected by noise exposure. The researchers calculated that, of those who had been at the work-place for 45 years, 93% would suffer hearing loss, with an average loss of 8%.

The effects of exposure to higher noise levels would obviously be greater. From the figures available to the research pair, it appears that the workers in some industries are exposed to noise levels averaging well above 90 dBA. Examples include the paper industry, at 98 dBA, and a number of industries at 94 dBA (textiles, timber, tobacco, and primary metal manufacture). At 94 dBA, 50% of varied-age workers would suffer an average hearing loss of about 8%; and at 98 dBA, 63% would suffer an average 10% hearing loss. In this way, the researchers went through each industry calculating the hearing impairment of its workers.

Next, they considered the lump-sum compensation figures paid to workers for loss of hearing. The awards made by various authorities vary considerably: however, the average sum paid for total loss of hearing in 1979 was $19 600, a 50% loss of hearing would bring $9800, and so on for other degrees of hearing loss. On that reckoning, the researchers estimate it would require $200m to compensate all the hearing damage present in the Australian work force (or a recurrent liability of $6m a year as unexposed workers enter the work force and others retire).

Even if all excessive noise were brought down to the 90-dBA limit, we saw, above, that 42 000 workers would still sustain

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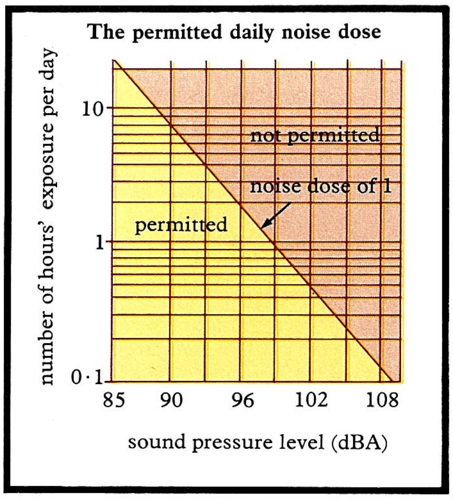
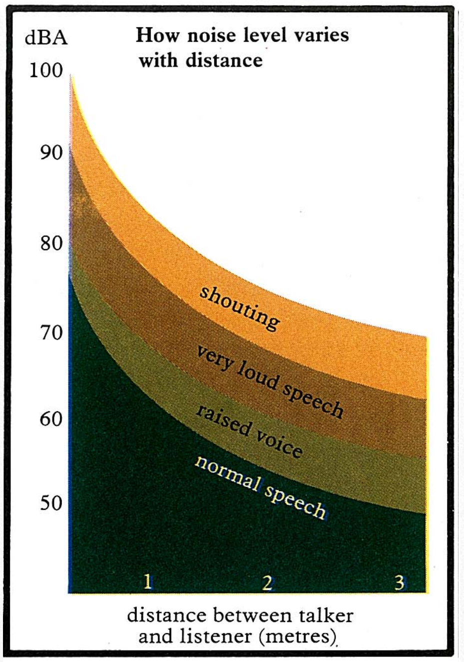


Legislation now requires that nobody should be exposed, unprotected, to more than a daily noise dose of 1, shown as the line on the graph. At 90 dBA, for example, exposure must not exceed 8 hours a day.



An engineering approach to lower industrial noise

Within a jet-engine test cell it is possible to have one of the largest engines operating at full power yet inaudible to people within 100 metres of the building. The idea behind the test cell, and the approach to most engineering remedies for excessive noise in industry, is to interpose a screen between the source and the receiver.

The simplest screen is air itself — that is, increased space between machine and operator. If there is no reflection, the sound-pressure level will decrease as the inverse square of the distance from a point source. That is, the level will fall by 6 dB for each doubling of distance. Unfortunately, if the operator is close to an extended source — a bottling line, for example — the level will decrease more slowly.

Consider too the effect of the sound reflected from walls — the reverberent sound field. This can be louder than the direct sound, particularly where a bank of machines is at work, since the operator will encounter both the direct and reverberent sound from all the machines. Generally, the noise level of a row of machines is 4–6 dBA higher than that of a single machine. However, if the room is highly reflective, then the level can be some 10 dBA higher.

In such situations, an acoustic ceiling, or treated walls, can reduce the sound level by more than 3 dBA.

However, in most situations, noise reductions between 15 and 25 dBA are usually sought. The engineering answer is to box-in the offending machine — or, alternatively, enclose the operator.

Noise in sawmills

Mr Ted Lhuede and Mr Bill Davern, of the CSIRO Division of Building Research, surveyed the noise levels in some 40 sawmills in Australia. They found that the average level of noise in sawmills at the operator's position ranged from 95 dBA to 105 dBA. Peak readings up to 119 dBA were recorded. Audiometry tests conducted on some of the workers confirmed the expected: the hearing of a number of them had been impaired.

As a measure to protect the hearing of the 3–4000 workers involved in the industry, Mr Lhuede and Mr Davern designed suitable enclosures — for machines and operators — to reduce noise levels. Some enclosures were complete boxes, others were partially open, and some comprised just a single panel. The first could give reduction up to 30 dBA, provided solid materials backed by porous linings were used; the simple screen could provide a quite worth-while reduction of about 5 dBA.

Of course, if the machine, or the operator, cannot be enclosed, the last resort (not an engineering solution) is to enclose the ear with ear-muffs or earplugs. At the start of their study, in 1974, Mr Lhuede found that only about 10% of workers used ear-muffs. But 4 years later the extent of use had changed markedly: in particular sawmills there is now a near complete acceptance of muffs.

The situation is not quite so satisfactory among timber-fallers, as a study by Mr Mel Henderson of the Division of Forest Research showed. As part of an investigation involving 31 fallers, he found none of them using ear-muffs, despite noise levels as high as 106 dBA and daily noise doses ranging from 2 to 14·5 — far above the limit of 1.

Even after conducting a seminar on noise-induced hearing damage and issuing muffs, he found that, 16 weeks later, only two fallers were wearing them for long enough to prevent permanent hearing damage.

Mr Henderson attributes the low level of use to the unpleasantness of ear-muffs under hot and arduous conditions.

Other aspects of ear-muff usage are discussed in the box 'Communication in a noisy environment'.

Noisy spinning frames

Spinning in textile mills is another process producing high noise levels. Typically, levels of 96 dBA are found, but Dr Dieter Plate of the Division of Textile Industry has measured levels as high as 102 dBA.

Experimenting with commercial spinning frames in his laboratory, Dr Plate and his colleagues have made modifications to them that reduce noise output by more than 5 dBA. Their results indicate that engineering modifications should enable a bank of machines to be run at 10 000 r.p.m. with noise levels below 90 dBA.

The same noise that causes hearing damage in industry is also likely to escape the factory and cause annoyance to surrounding residents. Since sound levels will drop by about 6 dB for each doubling of distance, they will certainly not be damaging, but could cause irritation for hundreds of metres round about.

At one of the timber mills surveyed by Mr Ted Lhuede of the Division of Building Research, noise levels at the perimeter could be expected to be 55–60 dBA, and in the early hours of the morning this could be unacceptable to a number of people, particularly in a country environment.

Australian Standard AS 1055 specifies that in the quietest neighbourhoods, 'areas with negligible transportation', you may expect 30 dBA outside your bedroom window. In the noisiest, 'areas in predominantly industrial districts or with extremely dense transportation', 55 dBA is a more realistic expectation.

The sound level inside a room with an open window is roughly 10 dBA less than that outside, so the noise level in your bedroom generally ranges from 20 to 45 dBA. The Standard indirectly implies that 30 dBA is the maximum level recommended for intruding noise in bedrooms.

Gauging from the 60–80 inquiries that Mr Paul Dubout of the Division receives each year from Melbourne householders who want to reduce noise in their homes, many people experience higher levels than that.

Surprisingly, industrial noise is rarely the problem; in about half the cases the noise was self-inflicted, arising from sources inside the home. Some 34% complained of the sound of others talking, or of noises from television, radio, or hi-fi.

Only 3% complained of noises emanating from the homes of neighbours.

Indoor building services such as heating, cooling, ventilation, and plumbing accounted for 12% of inquiries, three-quarters of them related to equipment in the inquirer's own home. Another 13% were caused by other domestic noise sources, about equally divided between the homes of the inquirer and his neighbours. In the last category, the noise of the neighbour's air-conditioner or pool filter pump can be especially distasteful.

Outdoor noise sources accounted for 41% of all household inquiries. Road traffic aroused 23%, aircraft 4%, and industry and building construction (and other noises) 14%.

As another pointer towards the level of unwanted noise in the home, we have the results of a survey conducted by Dr Maureen Worsley and Mr Rick Finighan, of the Division. In one Melbourne suburb, they found 30% of respondents volunteering complaints about noise when stating what 'privacy' meant to them. In this case the sources of noise mentioned were predominantly outside the home, including factory noise, lawn-mowers, traffic, and neighbours talking or arguing.

Ear-muffs in bed

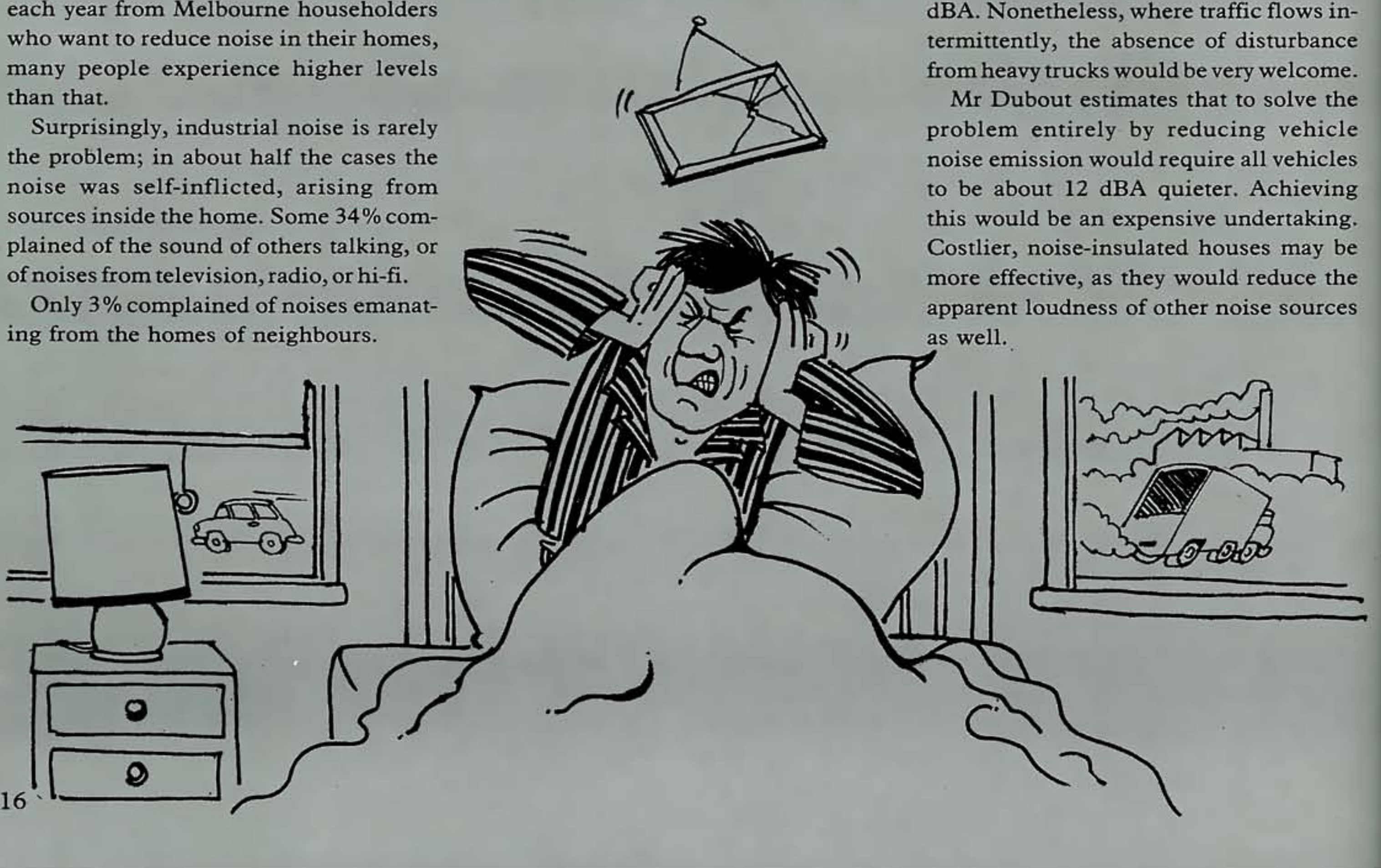
Of course, the hardest thing to do is to find a cheap and acceptable solution. Ear-muffs or ear-plugs work very well, but they are hardly an acceptable answer for most people. Tolerable levels of noise also vary among people. However, very few would not prefer a background level of traffic or other noise to be lower than 55 dBA.

Partitions and other building components of high sound insulation are costly, but they will do the job if wisely used. For a house under construction, 100-mm-thick thermal insulation batts placed in the walls will improve the acoustic performance by about 5 dBA.

The problem lies more with windows, particularly when the object is to exclude traffic noise, which contains predominantly low-frequency components. Good, high, solid fences or embankments are a start, but beyond installing tightly sealing windows with thick glass in them, little more can be done.

Of course, the obvious way to decrease traffic noise is to make quieter vehicles. Australian design rule 28 sets out to limit car noise to 84 dBA (measured at a distance of 7·5 m during acceleration); this would only require about 10% of recently produced cars to be modified. As for trucks and buses, the limits (85 to 92 dBA depending on mass and power) will reduce traffic noise only a little too, since heavy vehicles are only one-tenth as numerous in traffic streams. If all the trucks were battery-operated, the average level of traffic noise would drop by only 3 dBA. Nonetheless, where traffic flows intermittently, the absence of disturbance from heavy trucks would be very welcome.

Mr Dubout estimates that to solve the problem entirely by reducing vehicle noise emission would require all vehicles to be about 12 dBA quieter. Achieving this would be an expensive undertaking. Costlier, noise-insulated houses may be more effective, as they would reduce the apparent loudness of other noise sources as well.



How risk of hearing loss increases with noise level

Noise level	Percentage of people with impaired hearing after			
	10 years	20 years	30 years	40 years
85 dBA	3	6	8	10
90 dBA	10	16	18	21
95 dBA	17	28	31	29
100 dBA	29	42	44	41
effect of age	3	7	14	33

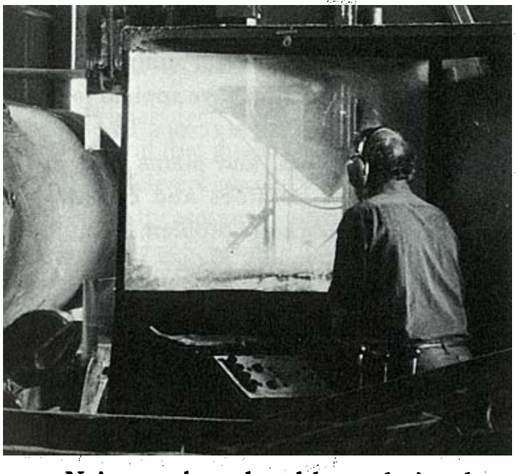
Risk of hearing loss increases rapidly as sound levels rise. The table refers to people exposed to noise for 40 hours a week in a 50-week working year.

hearing loss. The compensation payable to them in the long run would stand at about $50m, a saving of $150m from the unrestricted situation.

Figures obtained from the Annual Reports of the Commonwealth Commissioner for Employees' Compensation make an interesting comparison with the calculated ones. Those reports reveal that the average loss of hearing in cases actually receiving compensation is a relatively high 12%.

This may be because 60–70% of the claims reported by the Commissioner come from people in the Department of Defence, the majority of these being employees of the Department's Naval Dockyards, where noise levels are probably higher than the industry average. Another reason may be that only the older and more seriously affected workers seek compensation.

Be that as it may, the compensation authorities in New South Wales, Victoria, and Queensland, together with the Commonwealth board, paid out $5·54m in 1977–78, according to the CSIRO team's reckoning. (Figures for other States were not available.) This is quite close to the $6m that they calculated for all hearing damage.

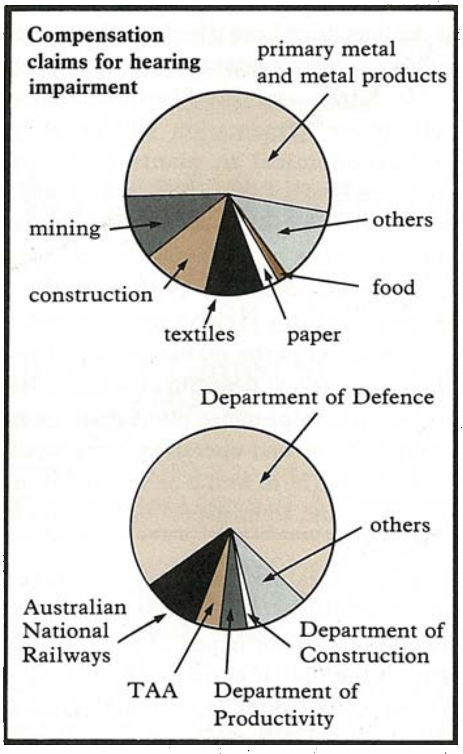


Noise can be reduced by enclosing the operator instead of the machine. This man is operating a band saw in a timber mill.

The repair bill

On the other side of the equation, the researchers estimate that, for all industry situations where workers experience daily noise doses greater than 1, noise monitoring would cost $16 per worker per year, audiometric testing about $27, and hearing protection such as ear-muffs about $3. Thus the recurring cost of protecting workers' hearing runs up to roughly $5m per year. Only in some industries would that cost be less than that of compensation payments. They are the food, chemical, and rubber and plastic industries, and the gas and electricity utilities. Here, the proportion of workers who need ear-muffs is much lower than in other industries.

The alternative approach is to box-in offending machinery. The researchers derived figures for the cost of this per worker, the amount depending on the particular industry involved. Once again, the American figures formed the basis of the calculation. The CSIRO team puts the cost of boxing-in all such machinery in Australian industry to reduce noise levels to 90 dBA or lower at $380m ($900 per worker, on average). The lost-opportunity value of this money might be some $30m (assuming we could earn 10% per year on it).



The chart at top shows the industry-by-industry breakdown of cases involving New South Wales employees in 1976. The other shows the breakdown for Commonwealth employees in 1977–78.

A scale of sound intensity

dBA	
130	painfully loud
120	jet take-off at 60 m
110	car horn at 1 m
100	shouting in ear
90	heavy truck at 15 m
80	pneumatic drill at 15 m
70	road traffic at 15 m
60	air-conditioning unit at 6 m
50	normal conversation at 3 m
30	soft whisper at 4 m
0	threshold of hearing

Zero dBA, the quietest sound audible to young, healthy people, is equivalent to a sound pressure of 20 micropascals (μPa), while 130 dBA is equivalent to 63 000 000 μPa.

Only in the paper and electrical industries, where noise-control costs per worker are low, would the cost of noise control be less than that of compensation. And compensation may still have to be paid to some workers exposed to noise levels at or below the legal limit.

On the basis of these figures, Dr Gibson and Dr Norton suggest that there is no financial incentive for most industry to reduce noise to 90 dBA (or below) and that the incentive to provide hearing protection is often marginal. However, force of legislation and community awareness will inevitably bring noise levels down — sooner, it is hoped, rather than later.

Andrew Bell

More about the topic

The economics of industrial noise control in Australia. D. C. Gibson and M. P. Norton. *Abstracts, Tenth International Congress on Acoustics, Sydney, July, 1980.*

'SAA Hearing Conservation Code: Australian Standard 1269 — 1979.' (Standards Association of Australia: Sydney 1979.)

'Seminar Papers on AS1269 — SAA Hearing Conservation Code.' (Standards Association of Australia: Sydney 1977.)