Section of Otology

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Papers

Acoustic Trauma – Clinical Presentation

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Noise and its harmful effects on hearing are attracting increasing attention. This communication, based on a study of 160 patients who attended with symptoms attributable to acoustic trauma, attempts to indicate the degree to which the disabilities caused by noise are permeating the everyday life of the individual.

This review was largely prompted by a consideration of some of the recommendations in the final report (1963) of the Committee on the Problem of Noise (Wilson committee), which was appointed by the Government to examine the nature, sources and effects of noise and to advise what further measures could be taken to mitigate the problem. It surveyed many aspects of noise; of particular interest to the otologist are the sections dealing with industrial noise and occupational exposure to high levels of noise. Professor W Burns, Dr T S Littler and Air Vice-Marshal E D D Dickson were among those who gave evidence. One important conclusion of the committee was that industrial research should be undertaken, and the lines of the Government research programme were indicated in some detail.

The Wilson committee has been criticized for failing to lay sufficient emphasis on the causal relationship between noise and deafness, notably by Philip Beales (1965) who strongly attacks the suggestion, made in the report, that the effects of noise may be more psychological than physical. Feeling on this subject was summed up admirably by a comment in the *Sunday Times* in 1963: 'There is mounting evidence that one person in ten becomes deaf or partly deaf as a result of working in noisy surroundings. This is an aspect of noise which the Wilson committee hardly touched upon.' It is also a pity the committee considered that the present knowledge of this complex problem did not provide a sufficient basis for legislation. Noise-induced hearing loss is not a prescribed disease under the provisions of the National Insurance (Industrial Injuries) Act, 1946. It is a sad reflection on the state of our national legislative conscience that the United Kingdom is one of the few remaining countries which still do not recognize noise deafness as a disabling occupational disease. The fact that the author has seen an average of one new patient each week complaining of symptoms directly arising from acoustic trauma surely underlines the magnitude of the problem and stresses the vast amount of damage to hearing which must be taking place in industry each year.

There have been many audiometric surveys on people employed in selected noisy industries. The early occurrence of an 'acoustic dip' in the region of 4,000 cycles per second has long been recognized; downward spread of this noise-induced damage to involve the conversational speech frequency range may appear later; an impression often given is that this occurs only rarely and does not necessarily cause any notable disability. The thesis of this report is that noise-induced damage to the inner ear is commoner than is generally supposed and that symptoms produced by it are more frequent than is thought.

It seemed pertinent to approach this problem from the clinical aspect. An analysis has been made of a series of patients with symptoms associated either with the effects of industrial noise or more rarely with acute acoustic trauma.

Definition of Terms

In this context the description 'acoustic trauma' is used to cover both the acute (explosive) variety, and the chronic (noise-induced) form. Temporary threshold shift (TTS) is the extent to which the threshold of hearing is raised as a result of noise exposure and is reversible. The length of time during which recovery can continue to take place is still in doubt; for practical purposes it is frequently assumed that complete recovery occurs within forty-eight hours. Most determinations of TTS have been made by a comparison of audiograms at the beginning and end of a working week. The work of Atherley (1964) on a group of weavers in whom he compared the 'Monday morning thresholds' with the thresholds after a sixteen-day holiday indicates that the process of complete recovery may occur over a much longer period. It is considered probable that the degree of TTS is an indication of the eventual extent of any permanent threshold shift which will occur after prolonged or repeated noise exposure.

Permanent threshold shift (PTS) may be so slight that no subjective symptoms are produced but, with excessive noise exposure, noise-induced deafness known also as chronic acoustic trauma becomes apparent.

Sudden bursts of abnormally intense sound or single explosive incidents may cause permanent inner ear damage and constitute acute acoustic trauma.

Mixed acoustic trauma occurs when the working noise environment contains intense steady state noise interspersed with impulsive peaks of even greater intensity, the jet engine being the most notorious offender in this respect.

In the cases under review, the effect of temporary threshold shift was minimized as far as was practicable, the majority of audiograms being carried out on a Monday morning before the start of the week's work.

The commonest complaint was deafness. Almost 90% showed a hearing loss of 30 decibels or more at or below 2,000 cycles per second.

Sex Incidence

As expected, there was a marked preponderance of men: of the 160 patients, 136 were men and 24 were women (a ratio of almost 6:1), since more men than women are employed in the noisier industries. The investigations of Ward *et al.* (1959) into susceptibility and sex support the view that differential exposure, not differential susceptibility, accounts for the observed differences. Certain investigations, however, seem to show that women are more resistant to the effects of acoustic trauma than men; and Rosen *et al.* (1962) in studies of a noise-free population found that the hearing of men deteriorated more with age than did that of women.

Age at Presentation

The age at which patients first came for examination is shown in Fig 1. The two children aged under 10 years were both involved in acute explosive episodes. The proportion of cases associated with service in the armed forces is indicated. Ten patients became aware of deafness in their

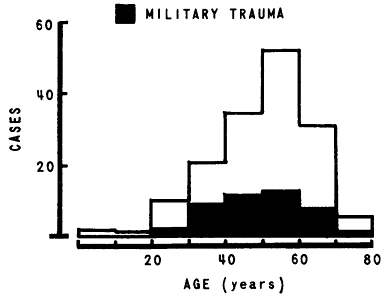

Fig 1 *Acoustic trauma, 160 cases*

20s; there was an appreciable increase in the 30s (21 cases) and 40s (35 cases) to a maximum of 53 cases in the 50s, with a decline to 31 cases in the 60s and only 7 in their 70s.

In this series deafness began at an earlier age than would have been seen in a comparable study of presbycusis. Particular attention was paid to the hearing losses over the generally accepted speech range of 512, 1,024 and 2,048 cycles per second. Hinchcliffe (1958) obtained smoothed presbycusis curves derived from the data of a random sample population. These demonstrated an average loss of less than 15 dB at 2,000 c/s at the age of 70. Littler (1962) considered that, since the exact mechanism of presbycusis loss is still undecided, presbycusis corrections should not yet be introduced: no such corrections have therefore been applied to the present series.

Symptoms

The frequency with which the various symptoms occurred and the multiple combinations in which they presented are shown in Table 1. By far the greatest number complained only of deafness; in association with other symptoms, deafness was reported in almost 90% of all cases. Tinnitus was present in some 30% and disturbances of balance in about 20%.

Deafness: The majority of cases seen were of the noise-induced type (122 patients); acute acoustic trauma accounted for a further 13 and the remaining 25 showed associated ear pathology in

Table 1
Symptoms

	No. of cases
Deafness	86
Deafness + tinnitus	21
Tinnitus	15
Deafness, tinnitus, unsteadiness	13
Deafness + unsteadiness	11
Unsteadiness	4
Tinnitus + unsteadiness	2
Deafness + distortion	2
Deafness + irritation	2
Numbness: stuffiness	2
Pressure + irritation	1
Earache	1

addition to the effects of noise: the one person with a history of prolonged exposure to jet engine noise, with its risk of mixed acoustic trauma, came into this last category but several subjects detailed both explosive incidents and many years' continuous work in noisy industry.

A leading article in the *Lancet* (1960) stated: 'It is surprising how indifferent a man will be to the incessant rattle of machinery, to the high-pitched whine of a saw, or to the affront from a nearby pneumatic tool or panel-beater.' This was evident in the present survey: only 4 of the 122 patients with noise-induced deafness said they considered noise to be responsible. The *Lancet* further remarked that 'only by direct inquiry is the physician who suspects early deafness likely to learn that the patient is subjected to intense noise at work'.

'Dizziness': This symptom was often described vaguely: 'slightly off balance', 'maziness', 'dizzy do's' and 'unsteadiness', as opposed to anything approaching true rotatory vertigo, were the terms commonly used. It is interesting to note that John Fosbroke's classical description of blacksmith's deafness in 1831 included 'slight vertigo' as a symptom once deafness became established.

In 4 cases dizziness was the only symptom complained of. Two of these patients gave very accurate descriptions of the Tullio phenomenon. One was a vertical borer, 57 years of age, who stated that high-pitched noises made him dizzy; he was one of the few who did not complain of clinical deafness but his audiogram showed a bilateral acoustic dip of 55 dB at 4,000 c/s. The other was a man of 46 who had been staying at a house in France alongside a fast stretch of railway line: dizziness had been provoked by the screech of whistles as trains speeded past his bedroom; he too was unaware of deafness but audiograms showed an acoustic dip of 25 dB at 4,000 c/s.

A third man, aged 38, gave a vague history of unsteadiness and at times felt as though he were veering to one side or the other; he had worked in railway engineering shops since leaving school and for the last fourteen years was employed in a riveting shed; while his Hallpike caloric responses were normal, his audiogram showed a dip at 4,000 c/s of 45 and 40 dB respectively in the right and left ears.

Occupation

The main occupations involved were as shown in Table 2. Among less frequent sources of occupational noise were pneumatic drills, an air compressor, a dental surgeon's ultrasonic drill and a blacksmith's forge.

The high proportion of occupations in which impact noises such as hammering or riveting are produced, compared with those producing intense

Table 2
Occupations

	No. of cases		*No. of cases*
Engineering	32	Weavers	10
Armed forces	22	Printers	6
Diesel engine workers	17	Machinists	6
Spinners	15	Sheet metal workers	5
Boiler-makers	14	Riveters	4
		Circular saw workers	4

pure tones in narrow bands such as the whine of a circular saw, is especially to be noted: as HM Factory Inspectorate points out (Ministry of Labour 1963), noises emitted from such sources may be damaging to hearing at levels 10 dB lower than steady state industrial noises.

Diesel engine noise: The large number of cases (17) in this category was surprising; it was third in the list of individual noisy occupations and came before the traditionally better known deafening industries of boiler-making, weaving and riveting. It included men engaged in the manufacture, testing, maintenance and operation of both commercial diesel vehicles and diesel locomotives. In a table of noise levels of some typical sounds in the Wilson committee's report, levels of 92 dBA[1] were recorded at a distance of 25 feet from a heavy diesel propelled vehicle. Several authors in the National Physical Laboratory's Symposium on the Control of Noise (1962) drew specific attention to diesel engines. T Priede stated (p 97) that 'one of the major objections to diesel engines which tends to prevent their wider use is that they are noisier', having found that their noise spectra showed a broad peak in the frequency range from 800–2,000 c/s, i.e. in the frequency range to which the ear is most sensitive. Coles & Knight (1965) noted overall sound levels in the region of 120 decibels in diesel propelled ships and although continuous in character the noise had impulsive components.

Occupational History

The importance of taking a complete history of all occupations followed since leaving school was very evident. For instance, one man, aged 52, gave his occupation as a joiner, a pursuit which one might consider comparatively innocuous as regards noise: on being questioned about the details of his job, however, he said that he worked continuously with extremely noisy circular saws and, perhaps even more significant, that ten years previously he had been engaged in a curious process involving the use of a pneumatic hammer for firing nails into concrete walls; he 'felt his ears sting' was how he described the sensation at that time. Another man, aged 39, gave his occupation

[1]dBA is a specific unit measuring sound level, using frequency network A incorporated in the amplifying circuit of the sound level meter. Three such networks, A, B and C, are now commonly used

as painter and decorator; referred on account of 'defective hearing' he had a bilateral high-tone deafness. Inquiry into previous occupations revealed that for 14 years he had been firing harpoons with an Antarctic whaling fleet. A 'kennel man' had been a boiler-maker for six years; a gardener had been a diesel-engine fitter for thirty-five years.

Some complexities involved in unravelling a history of previous noise exposure are demonstrated by the following case, a man of 43 presenting with 'deafness': from the age of 14 until he was 20 he had worked in a noisy cotton mill; he had then entered the army where he was exposed to a good deal of gunfire and exploding mortar bombs; on demobilization he returned to cotton spinning which he then found very noisy; following this he had a spell as a sheet metal worker and, for the last six years, had been engaged as a fitter in what he considered his noisiest job to date, working on heavy castings. In addition there was evidence of past middle ear disease. He had a 55 to 60 dB air conduction loss over the speech frequencies, with correspondingly poor bone conduction. Another man, aged 50, described himself as an electrical fitter's mate but, at his place of employment, his actual working space was bounded on one side by a bank of printing machines and on the other by a circular saw; audiograms showed a bilateral perceptive hearing loss.

It was interesting to note how frequently patients seemed to become aware of their deafness only when changing from one noisy occupation to another: for example a boilermaker for thirty years changed to work with power station turbine generators and found this new noise environment upsetting.

Noisy Pastimes

Careful inquiry should be made into any hobbies of a noisy nature: 4 cases in this series had symptoms related entirely to spare time pursuits. Two of them were associated with game shooting, one with clay-pigeon shooting, all these using 12-bore shot guns. The fourth fired small arms with a rifle club two nights a week.

The clay-pigeon shot was a man aged 54 who presented within a few months of taking up his hobby, giving no history of any previous noise exposure; he complained only of a feeling of slight stuffiness in his ears. He showed a bilateral acoustic dip of 55 dB at 4,000 c/s. Suitable ear defenders were fitted and have been worn conscientiously ever since. Audiograms have been repeated annually during the past four years. The dip in the left ear has remained stationary at 55 dB but that in the right has improved to 25 dB. An audiogram of the right ear showed a dip at 4,000 c/s when he was first seen and an improvement after wearing ear muffs. It also illustrates the fact that most ear protectors give better attenuation for high frequencies than low; there is slight deterioration in hearing at the lower end of the frequency scale.

In the other 3 cases the hearing in the right ear was affected more than in the left. This finding is particularly interesting since usually, as Ballantyne (1960) has noted, 'the deafness of rifle shooting is more marked in the left ear in the right shouldered shot' (as these men were), 'since the butt of the rifle is nearer to this ear.' The rifle shot was only 25 years old and showed a dip beginning with a loss of 15 dB at 1,000 c/s, dropping sharply to 65 dB at 2,000 and a maximum of 75 dB at 4,000 c/s.

Motor cycles and mini-sports cars are particularly offensive noise weapons when it is considered that they can emit sound pressure levels of over 100 dB. It is particularly disquieting to read in the Wilson committee's report 'that for motor cycles a limit of 90 dB was the lowest that could be achieved at present.'

Acute Acoustic Trauma

There were 13 cases of acute acoustic trauma, 2 children and 11 men. In only 4 patients was there evidence of healed perforations, 2 bilateral, making a total of only 6 perforations in 26 drums: 4 of them were typically in the posterior segment of the drumheads; in the youngest, a girl aged 7, there were bilateral healed anterior perforations, with no past history of ear disease, but bleeding occurred at the time of the explosion.

Of the 11 adults, only 4 gave a clear-cut history of acute acoustic trauma alone. In 6 of the 7 other cases the acute acoustic trauma was complicated by a history of many years working in high intensity noise. Their individual case histories all demonstrated the complexities which beset attempts to introduce satisfactory legislation and workman's compensation for noise induced hearing loss. To quote just one illustrative example, a 57-year-old fitter currently employed in a forge: on leaving school he had worked for seven years as a boiler-maker's apprentice; for the next thirteen years he had been a steel plater; during the war he had served in the Home Guard and had experienced increased deafness and distortion of hearing when on the firing range. His reason for attending hospital was that these symptoms had again been precipitated, with increased intensity, four months earlier and had shown no signs of abating: the incident which provoked them had occurred whilst he was watching a yacht race; he was standing four feet from two starting cannons and as soon as they fired he experienced deafness and distortion. His audiogram showed a sudden drop in hearing in the right ear of 45 dB at 1,000 c/s and of 65 dB in the left ear at 2,000 c/s.

Of the children, one had been sitting in front of the fire when an explosive mixed with the coal blew the fireguard, the fire and the fire grate out into the room.

The other, a healthy boy aged 9 with a completely negative medical and family history, who had even escaped mumps, had been discovered to have a severe unilateral perceptive deafness on routine school audiometric testing. Having exhausted all other likely possibilities and having recently read Glorig & Ward's (1961) report of a case of fire-cracker-induced hearing loss, I inquired whether this child had ever been involved in a firework explosion. The parents were astonished at this question; at the age of 5 the boy had dashed to the front door in answer to a loud knock, a lighted firework of the 'banger' variety had been thrust through the letter box and exploded in his face; he had complained of deafness for some time afterwards but both he and his parents had since completely forgotten this incident.

Cases with Associated Ear Disease

Otitis media: 16 patients (10% of all the cases) showed evidence of otitis media; 10 cases were bilateral, 6 unilateral, making 26 ears out of a total of 320 ears (just over 8%). Twenty-one of the perforations were healed, 5 were patent, 3 of these showing active suppuration. No cases of cholesteatoma, polyposis or granulations were seen.

There was a much higher incidence in this group of subjective vertiginous symptoms: almost half, 7 out of the 16, described such symptoms, whereas of all those without evidence of otitis media at any time only 21, about 1 in 7, described some disturbance of balance.

The 4 patients who sustained acute acoustic trauma and showed healed traumatic perforations did not complain of any balance disturbance nor did the 7 patients with otosclerosis.

It has been suggested by Glorig (1958) that scarring from otitis media may protect the inner ear from the effects of noise by acting as a built in ear plug. This was not evident in the present series, 6 cases showing perceptive losses between 85 and 100 dB. The protective effect of the stapedius muscle reflex may be less as a result of middle ear suppuration and the effects of acoustic trauma greater.

Otosclerosis: 7 patients had otosclerosis, 4 male and 3 female; the women all in their 40s and all cotton mill workers. One of them had worked from 14 only until 21; soon after this she first became aware of deafness. Her audiograms showed considerable impairment of bone conducted hearing, 40 dB loss at 500 c/s and 55 dB at 1,000 c/s but with an air-bone gap of 35 dB. A similar picture was seen in one of the other women who had been a ring spinner since the age of 14.

Were the bone conduction losses those frequently encountered in otosclerosis or was cochlear damage induced by noise before the stapes became fixed? Steffen *et al.* (1963), dealing with stapedectomy and noise, noted the difficulty of separating the labyrinthine element in otosclerosis from the effects of noise and presbycusis.

Of the 4 men 3 had been accepted for and served their full time during World War II in the armed forces; presumably their hearing had been sufficiently acute on entry to pass normal routine hearing tests. One of them had in fact worked for seven years in a cotton mill before being enlisted and returned to even noisier industrial activities when demobilized. The fourth man had worked as an engineer in a noisy machine shop all his life.

In only 1 of these 7 cases was bone conduction normal in the speech frequencies – surely a much higher proportion of perceptive hearing loss than would be encountered in a group of non-noise-exposed otosclerotics. The average age of this group was 44.

What advice should these patients be given? If surgical correction of their otosclerotic deafness is contemplated it seems clear that they should be warned of the subsequent increased risk of noise-induced hearing loss should they continue to work in noise. Either they should be encouraged to change to a quiet occupation or the operative technique of any surgical procedure should ensure preservation of function of the stapedius muscle and its protective reflex.

This problem was considered by Sagardia (1963) who studied patients, who had undergone stapedectomy, working in noisy surroundings not exceeding 85 dB, that is, within the limits of the damage risk criteria suggested by Burns and Littler for people with normal ears. These ears, deprived of their stapedius muscle reflex showed irreversible deterioration from 1,000 to 6,000 c/s. A similar series not exposed to noise showed no such deterioration, neither did noise affect other operated cases in which the ossicles and the stapedius muscle were preserved.

Kos (1962) described severe inner ear changes following stapedectomy in ears subsequently exposed to intense noise.

Streptomycin deafness: A severely deaf man aged 32 had been treated with very large doses of streptomycin for tuberculous meningitis ten years previously; during the past 18 months he had been working about twenty yards from jet-engine test beds which operated for about three hours daily. He had experienced a considerable increase in his deafness during this period: his audiograms taken before exposure to jet-engine noise showed the expected severe perceptive deafness; the further marked deterioration after eighteen months of such noise exposure was very evident. There was a bilateral increased hearing loss of 20–40 dB at all frequencies.

Presbycusis: In only one case was there clear-cut evidence from the history that the effects of age change were complicating previous acoustic trauma. This occurred in a retired man aged 64, who had been noticeably deaf in one ear following an episode of acute acoustic trauma in World War I. Recently he had become increasingly aware of deafness in the opposite ear and had also found that in the presence of noise his hearing became confused.

Mastoid pneumatization: Routine temporal bone X-rays are now included as one of the standard investigations in any case of suspected noise-induced deafness. The earlier cases in this series were not, however, all examined in this way. Results to date suggest that there may be a higher proportion of poorly pneumatized mastoid processes in patients showing severe acoustic trauma than one would find in an unselected group of the normal population. In this respect the observations of Ottaviani & Mazzoleni (1959) are to be noted: in a study of the relationship between mastoid pneumatization and loss of hearing in 187 boiler-makers, they found that the progress of noise-induced deafness was more rapid in cases showing no pneumatization.

A Typical Noise Problem

Illustrating some of the difficulties encountered in dealing with industrial noise a case in point arose recently. A spinning mill was in process of modernization; equipment some fifty years old was being replaced by new high speed automatic machinery. Complaints were made by spinners transferred to these new machines that the noise levels were much higher. Many of them had worked in this mill for over forty years. It was possible to walk directly from a shop containing the original machinery into another shop housing the new. Even without taking recordings of sound pressure levels it was immediately evident that much higher and more obtrusive noise intensities were being emitted from the new machines.

Octave band analyses showed an overall sound pressure level of about 95 dB from the old machines but the noise environment of the new was in the region of 110 dB. An interesting point

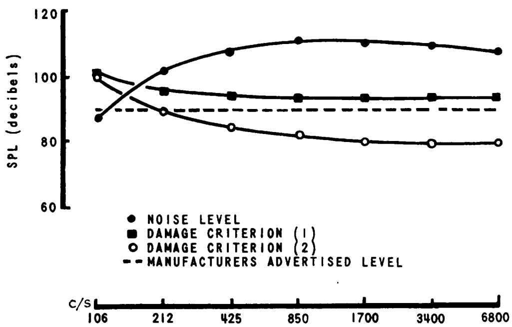

Fig 2 *Spinning mill noise*

was that the new machines had been advertised as having a noise level of about 92 dB.

Fig 2 illustrates some of these findings and compares them with two suggested damage risk criteria. The upper one is that proposed by Rosenblith *et al.* (United States Air Force 1953). The original machine noise was below this level. The lower one is in keeping with the levels suggested by Burns and Littler and quoted in the Wilson committee's report. It is in agreement also with the British Medical Association's view that 'working conditions involving continuous exposure throughout working hours for a prolonged period to noise where intensity exceeds 85 dB in the speech frequency range may cause permanent damage to hearing.' Both the old and the new equipment showed sound intensities above these recommended safety levels.

In view of the findings of an overall sound pressure level of some 110 dB, recommendations in line with current practice to reduce the noise were made. These included reduction of the noise level at source by modifying the machine bearings, the fitting of baffles and treatment with sound absorption panels. Protective ear-muffs were made available to the workers.

Conclusions

Noise problems similar to the one just outlined can be found in many industries. That a noise hazard exists in many factories is still often ignored, the introduction of satisfactory hearing conservation programmes tardy and effective noise reduction expensive.

In this country at the present time occupational deafness is still not a prescribed industrial disease. This disability is not eligible for compensation under the National Insurance (Industrial Injuries) Act. Nevertheless it seems clearly evident, judged by the numbers seeking relief for this defect, that a considerable proportion of the community do suffer directly from the effects of industrial deafness. It is to be hoped that more just and effective legislation for this condition will not long be delayed.

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DISCUSSION

Dr T S Littler (*Medical Research Council, London*) said that traumatic and industrial deafness as well as hearing conservation were now receiving much attention, although the subject had been debated frequently over the last thirty years. There had been a number of discussions in the Section of Otology and a presidential address by Air Vice-Marshal Dickson fourteen years ago (*Proc. R. Soc. Med.*, 1953, **46**, 139).

Many national bodies were endeavouring to bring out standards for hearing conservation: all the viewpoints were to be put forward at a meeting of the International Standardizing Organization in Prague in April 1966, with the hope of progress towards one international standard of acceptable levels of continuous and intermittent noise.

Mr Chadwick had dealt with a number of topics associated with occupational noise and had described some interesting cases in which noise of one kind or another had been blamed for the complaint. As a result of attention now being given to the matter by many industrial firms, improvement could be expected in the future.

Indications of the nature of the mechanism of industrial deafness were derived from a number of investigations. The evidence came from the hydrodynamics of cochlear behaviour, masking phenomena, temporary threshold shift and other laboratory studies. All these investigations as well as surveys under actual conditions of industry had indicated the asymmetrical nature of excitation of the end organ of hearing, namely that, when the cochlea was excited by sound in a given band of frequencies, regions of the basilar membrane specific to higher frequencies were excited as well, whereas regions of lower frequency specificity were not. Another important characteristic was that transmission of excitation to regions of low frequency specificity took a time which was greater the lower the frequency. Laboratory studies as well as industrial surveys had demonstrated that there were appreciable differences in individual susceptibilities.

For many years a sound pressure level of 90 dB overall had been looked upon as that at which, on the average, the normal phenomenon of adaptation changed to that of aural fatigue, which if maintained for prolonged periods resulted in permanent threshold shift; but later work showed that the level was a function of frequency. The overall level then lost favour and was replaced by damage risk criteria in which noise levels were specified in octave bands. In these criteria it was considered that higher noise levels could be permitted in the lower frequencies than in the higher. At the present time a consensus of opinion believed the following could be considered the limit for continuous exposure of 8 hours per day:

Centre of octave band c/s	125	250	500	1,000	2,000	3,000	4,000
Sound pressure level in dB	98	93	89	87	85	85	85

An alternative method which had many attractions was to use a noise level reading on a meter which gave appropriately less weighting to low frequencies and for this the A scale on a sound level meter was suitable. The above criterion was approximately covered by a reading of 90 dB on the A scale.

For intermittent exposures somewhat higher levels, based at present on temporary threshold shift experiments, could be accepted. In the field studies in which Dr J J Knight and Dr Littler had been co-operating, the nature of the TTS had been found not to be the same as that of permanent hearing loss, and much further work would need to be done in the actual factory situation.

The joint MRC/NPL investigation of occupational deafness was originally put forward by the DSIR in 1957 and sponsored by the Ministry of Pensions in 1962. There were very considerable difficulties and complexities in such an investigation. The problem could be approached in two different ways, both with their own limitations. The retrospective method studied a group of noise-exposed workers and attempted to relate the degree of deafness to the duration and severity of the noise exposure. The advantage was that all the subjects were immediately available. The disadvantage was dependence on the subject's evidence for assessing his noise exposure, and this was scientifically unacceptable. In the prospective method a group of young people with normal hearing were chosen before they entered a noisy situation, and their hearing was tested at intervals. This had the advantage that the noise level in which they were working could be monitored at will. The difficulty was that of every 100 suitable subjects 60 or 70 might be lost during the survey. For obvious reasons the second method was chosen, but as it had become apparent that the yield of suitable subjects was sparse the survey was supplemented by studying an extra group of workers who had already sustained a few years of noise exposure. The plan was to determine how much further deterioration occurred in a given time. By this method it was hoped to compare the initial hearing loss sustained with the later one observed after further exposure.

The investigation depended very heavily on the validity of the criteria, on the stability of the apparatus and on the accuracy of information regarding the individual's noise exposure. The clinical criteria were laid down by Mr I A Tumarkin, who was a member of the working group. The hearing was measured by self-recording Békésy fixed frequency audiometers which were calibrated daily to ensure that no drift occurred.

The assessment of noise exposure was a complex matter. The plan in a given factory was to assess by noise measurement not only the intensity of the noise but also its distribution throughout the different frequencies. It was essential to know how much time each worker spent in each different noise locus. The survey was therefore concentrated on large factories with a large labour force of stable employment with reasonably constant levels of noise exposure. Work was also proceeding on temporary threshold shift studies. It was expected that the investigation would continue for another two or three years, by which time it should be possible to reach an internationally acceptable damage risk criterion. It must be emphasized, however, that this was still only a statistical concept and did not answer the question of what would happen to a given individual in a given factory.

Mr P H Beales (*Doncaster*) said it was still too widely assumed that to be harmful to hearing noise must be very loud, only met with in certain factories, and so on. This was a facile assumption and Mr Beales believed that the everyday noise met with by all who lived in towns had by now reached a harmful intensity. Various studies had been made on the hearing acuity of people living in a relatively noise free environment. Rosen *et al.* (1962) had studied the hearing acuity of the Mabaans, a tribe living in such an environment in a remote area of the Sudan. It was of interest to compare the loss of hearing found among the Mabaans with increasing age with the hearing acuity at various ages of a healthy population living in the USA. The figures of Rosen *et al.* showed that a Mabaan at the age of 70–79 years had a hearing acuity rather better than that of the age group 30–39 in the sample from the USA.

Presbycusis had been attributed to many factors such as hereditary predisposition, smoking, arteriosclerosis and hypertension, anæmia, vitamin deficiency, acoustic trauma; but of these only acoustic trauma had a constant bearing on presbycusis. Mr Beales hoped it would before long be appreciated that all loud noise was potentially damaging to hearing, and that this applied not only to the extreme noise met within industry but to all loud noises.

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Dr R Hinchcliffe (*London*) asked Mr Chadwick: (1) Had he not met any cases of acoustic accident of the type described by Antoli-Candela (1959), Boenninghaus (1959) and Becker & Matzker (1961), or did he not recognize such an entity? (2) Was his classification of his cases of noise-induced hearing loss based on a taxonometric procedure or was it based merely on a clinical impression? (3) Were personality data obtained on the cases of 'unsteadiness'? (4) Had Mr Chadwick considered whether, in the cases with conductive deafness who showed a greater than expected degree of noise-induced hearing loss, this was due not to the absence of a functioning stapedius muscle but to the absence of the dampening effect on the tympanic membrane at 4,000 c/s of a poorly pneumatized mastoid, as indicated by Onchi (1966)?

Regarding the study by Rosen *et al.* Dr Hinchcliffe commented that the Mabaans had no birth certificates. Absence of valid data on date of birth was a notorious source of error in determining biological changes as a function of age. Preliminary results on a similar non-noise-exposed ethnic group living in a tropical climate, but where there was valid evidence of the age, indicated that the particular sample had worse, not better, hearing than comparable British populations (Hinchcliffe 1964).

Dr Hinchcliffe endorsed Mr Chadwick's finding regarding the cochlear-damaging effects of 12-bore guns. Five years ago a significant correlation had been shown between the hearing level at 2,000 c/s and the stated number of round of 12-bore ammunition that had been fired (Hinchcliffe 1961).

With regard to deaf people being cited as more susceptible to noise-induced hearing loss, Burns *et al.* (1964) had shown that, in a factory population, the degree of deterioration in auditory threshold at 4,000 c/s was inversely related to the initial hearing level. Working at the Institute of Laryngology and Otology, Ferris (1965) had also shown that stapedectomized individuals were less, not more, prone to temporary noise-induced hearing loss.

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Mr Harold Zalin (*Liverpool*) said it was a matter of regret that the problem of acoustic trauma, which was international and involved such complexities, could not be tackled by international co-operation.

Nixon and Glorig had encountered the same problems and had reached certain interesting conclusions (Nixon *et al.* 1965): (1) That TTS was inversely related to hearing loss. They made no attempt to explain the mechanism which must involve consideration of conductive and perceptive deafness, which surely behaved differently. Conductive deafness implied attenuation at all times whilst the effect of perceptive deafness was not so obvious since there was no protection. Presumably antecedent damage resulting in high tone perceptive deafness had already eliminated those nerve elements which might have suffered. (2) That TTS was, in fact, a valid measure of the individual's liability to PTS and they offered an equation by means of which the hearing loss a year later could be calculated on the basis of the existing hearing level and the TTS.

According to these authors the only practical method of determining whether an individual was susceptible to a particular noise was to put him in that noise and observe what happened. This was something of a blow to prospects of establishing definite damage risk criteria for noise. The reason was twofold: (1) Individuals seemed to vary considerably in their sensitivity and it was even suggested that there were tough and tender ears. (2) It was extremely difficult to measure noise objectively. A steady state noise could easily be analyzed but there was the almost insuperable problem of impulse noise. Kryter & Garinther (1965) in fact said: 'It is quite possible that PTS from impulse noise follows a much different pattern from PTS due to steady state noise.'

Mr Zalin therefore asked Dr Littler (1) Had he found that TTS did in fact vary inversely with existing hearing loss and if so did he agree that two differing processes were involved in conductive and perceptive deafness respectively? (2) Had he done any work on impulse noise and could he give any information on the relative importance of peak impulses of short duration versus steady state noise? (3) Had he any evidence that there were tough and tender ears?

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Mr Ian G Robin (*London*) said it was obvious that with an improvement in hearing conservation programmes and the probability of an increase in medicolegal cases, the reliability of audiometric readings must be ensured. This meant that technicians must be adequately trained, as well as audiometers properly calibrated.

The new scheme of the Ministry of Health for the regional training of technicians made otologists fully responsible for their efficiency. It was to be hoped that proper standards would be maintained.

Mr Colin C Wark (*Brisbane*) said that the problem of assessing percentage of hearing loss for calculation of compensation was yet to be solved. Speech audiometry, while theoretically good, was unsatisfactory because of differences in language and dialect. Pure tone audiometry was now the basis of work, but the method of calculation left much to be desired.

Mr Chadwick, in reply, thanked Dr Littler for opening the discussion. He was heartened to hear that improvements in the industrial field could be expected in the near future, and of the progress of the MRC/NPL investigations. That Dr Knight and Dr Littler had found the TTS to differ from permanent hearing loss was most interesting since it accorded with his own views, that to be able directly to predict one from the other was an unjustifiable assumption.

In answer to Dr Hinchcliffe, while he recognized the low-tone incidents described, none had been observed in the cases under discussion; as indicated in the title of the paper, the approach was essentially a clinical one. Mr Chadwick was well aware of Dr Hinchcliffe's particular interest in the relationship between vertigo and the patient's psychological make-up. Disturbances of balance had been noted in only about 20% of the cases, and in most of these there had been nothing to suggest any obviously abnormal psychological factors. It had, however, not been practicable to investigate patients in detail with regard to personality data, but this aspect would be borne in mind in future studies.

Mr Chadwick agreed that the exact reason why some cases of conductive deafness showed excessive perceptive losses was unknown and that there were several possible alternative hypotheses.

Mr Robin and Mr Wark had both stressed the need for reliable audiometry and the necessity for devising a formula for accurate assessment of hearing loss, and Mr Chadwick expressed the hope that a suitable method would be evolved in the near future. He pointed out, however, the widespread variations which existed at present in different States in the USA, and also considered that the possibilities of speech audiometry should not be ruled out, but should be carefully explored, since this gave the nearest approximation to a person's actual disability.

Dr Littler, in reply to Mr Zalin, stated that the term 'tough and tender ears' had been used to express what had been repeatedly observed in a number of investigations, namely that in response to approximately the same quantified noise exposure different subjects showed different degrees of permanent threshold shift. Experimental work had shown that, on average, TTS varied inversely as existing PTS and this would be expected considering that the progress of PTS slowed up asymptotically with years of exposure to a final value achieved in the first few years of exposure. He agreed with Mr Zalin that there should be some qualification of this observation according to whether an existing deafness was conductive or perceptive. A conductive deafness was a protection as far as noise exposure was concerned and equivalent to a reduction of the noise exposure by the magnitude of the hearing loss. In general, industrial noise investigations were concerned only with perceptive deafness and subjects with conductive deafness were not usually included in the statistics. It had been his experience that impulsive noise environments of high intensity such as weaving, chipping, boiler-making, gunfire, &c., were more damaging to hearing than steady state noises such as spinning and rotating machinery but there was, at present, no universally acceptable definition or criterion regarding the characteristics of impulsive noise. The peak levels of the impulsive noise environments that were so damaging to hearing were much higher than the average levels indicated on a noise level meter whereas for the so-called steady noises peak and average levels were closer in magnitude.

Middle Ear Muscle Activity

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The middle ear muscles are activated not only by sounds but also by a great number of non-acoustic stimuli (Salomon & Starr 1963). In addition to activity in response to discrete stimuli, the stapedius muscle shows spontaneous activity both in man (Salomon & Starr 1963) and in animals (Salomon & Starr 1965, Wigand & Brauer 1964).

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Since the middle ear muscles respond to such a variety of motor patterns and sensations, it is not clear whether activity would be recordable in the absence of any activating factors. The term 'spontaneous' implies only that activity seemingly unrelated to any particular factor present can be recorded.

Using impedance techniques in man, several investigators have shown that subliminal acoustic stimulation was facilitated by simultaneous subliminal non-acoustic stimulation and *vice versa* (Jepsen 1963). Electromyographic (EMG) studies of the middle ear muscles in cats have shown not only facilitatory interaction but also inhibitory interaction. Furthermore, interaction is present between successive stimuli with time intervals of up to 0·1 sec (Salomon & Starr 1965).

Studies of the middle ear muscles in relation to a single activating factor are therefore much too limited. Experiments must be designed to tell us how successive stimulating factors are integrated from moment to moment. A technique for this type of investigation has been established.

Technique

Electromyographic activity (DISA myograph) in the middle ear muscles of cats was recorded via two chronically implanted bipolar stainless steel electrodes. In response to a loud click both muscles give a response pattern consisting of an initial burst of activity (latency 4·5–10 msec), a pause and then a later and more sustained period of activity (latency 34–56 msec, duration up to 1 sec) (Salomon & Starr 1965). By decreasing the intensity of the click or by repeating the click, the late response disappears. The integrated electrical activity of the electromyogram is proportional to the muscle force of the contraction (Bigland & Lippold 1954, Rosenfalck 1959).

A quantitative measure of the middle ear muscle contraction could therefore be obtained by integrating the EMG response of these muscles. As it was our aim to measure responses to successive stimuli with inter-stimulus intervals of as little as 8 msec, the integration time for a suitable integrator had to be so short that each response maximum was separately recognizable. Therefore the integration time had to be less than 4 msec. In addition, the pulse response from the integrator had to be so near to a rectangle that the output from one response did not contribute to the integration of the output from the following response (less than 8 msec total duration of the pulse response). Fig 1 shows the circuit with alternative integration times for the integrator that was developed. The first two valves amplify the myographic activity so that rectification can be later obtained in a linear way by the two germanium diodes. The first half of the last valve