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Hearing loss and motorcyclists

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Abstract
Motorcyclists are known to be exposed to excessive wind noise levels when riding. The potential adverse effects of this exposure on their hearing was investigated. Temporary threshold shift (TTS) was assessed by asking 18 riders to undertake a standard test run of one hour at a steady 80 mph, and performing audiometry before and immediately afterwards. Permanent threshold shift (PTS) was assessed by performing pure-tone audiograms on a highly screened group of 246 motorcyclists and comparing their hearing thresholds with those of an appropriate control group obtained from the MRC National Study of Hearing.

Significant TTS was found at 0.25, 0.5, 1 and 2 kHz. The greatest TTS occurred at 1 kHz, with a mean hearing loss of 10.3 dB. The hearing thresholds of the motorcyclists were significantly worse than the controls at 0.25, 0.5, 1 and 2 kHz, and was most marked at 0.5 and 1 kHz where their hearing loss (PTS) was, respectively, 3.7 and 3.6 dB greater than expected.

These findings demonstrate evidence of both temporary and permanent hearing loss from motorcycling and present a strong argument for the need for some form of remedial action.

Key words: Hearing loss, noise-induced, Motorcycles

Introduction

Motorcycles have been around as a source of transport since the latter part of the 19th century, and have long been regarded as irritating and noisy. It is therefore no surprise to find that regulations exist to prevent excess vehicular noise in both urban and sports settings (EEC, 1989; ACU, 1995). These regulations appear to be reasonably successful as accelerating motorcycles with standard exhausts are no louder than motor cars in an urban setting (Kamperman, 1980), and measurements by the Transport Research Laboratory have shown overall motorcycle noise to be within UK legislative limits (Waters, 1984).

One would naturally assume that, as well as protecting the public, these regulations are also designed to protect the rider. However, over the past decade, as motorcycle development has led to quieter machines with radically improved performance, there has been increasing concern that riders are suffering excessive noise levels as a result of turbulent airflow around the riders' helmets, so-called 'wind noise' (Harrison, 1974; Iho and Jonasson, 1981; Van Moorhem *et al.*, 1981; Huttenbrink, 1982; Aldman *et al.*, 1983; Jongepier and Van der Weerd, 1989; Ross, 1989; Maue, 1991; McCombe *et al.*, 1993a).

All of these studies show broadly similar results and confirm that motorcyclists are exposed to excessive noise levels of around 90 dB (A) at 45 mph, increasing to 111 dB(A) at 100 mph (McCombe *et al.*, 1993a). Short-term exposure to noise of this level can lead to temporary worsening of an individual's hearing in the form of temporary threshold shift (TTS) which maybe associated with the short-term perception of tinnitus after the event. Recovery is usually complete. However, long-term exposure to noise of this level can lead to a permanent hearing loss (permanent threshold shift–PTS).

It is therefore surprising that given the fairly obvious potential risk to the rider's hearing, there are only two previous reports that have looked at motorcyclists' hearing thresholds (Fletcher and Gross, 1977; Jongepier and Van der Weerd, 1989). The first of these is of very poor scientific quality (Fletcher and Gross, 1977). They used non-standard audiometric measurements in poor acoustical conditions and inappropriate analysis, and concluded that the high frequency hearing of motorcyclists was poorer than expected. The second is an internal report from the Dutch Police (Jongepier and Van der Weerd, 1989) which looked at 169 of its riders and concluded that their hearing was poorer than expected. Although their audiological methods were

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better, their data analysis was still questionable. The audiometric data for 169 riders (age range 26–49 years) was pooled and compared to standard audiometric data for 35-year-olds (source not disclosed), so adequate account of age was not taken. Nor did they control for previous occupational or firearms noise, to which they acknowledge ubiquitous exposure. These controls are obviously essential if meaningful results are to be achieved. Indeed one of the most common failings of epidemiological studies of noise damage is failure to apply strict and appropriate exclusion criteria to **both** study and control populations. Consequently there is no reliable, published data regarding the potentially damaging effects of wind noise on the hearing of motorcyclists. Nor should it be assumed that this information is of academic interest only. Noise-induced hearing loss is often associated with tinnitus and the nature of the hearing loss leads to severe difficulties in understanding speech in noise. The results are a great deal of distress for sufferers, frequent social isolation, domestic disharmony and depression (Lalande *et al.*, 1988). As treatment is limited to the provision of hearing aids and appropriate counselling, prevention is infinitely more satisfactory. Given that there are approximately 5.6 million full motorcycle licence holders in the UK (Department of Transport, 1991), the potential demand on health service provision and therefore the need for this epidemiological information becomes obvious. This study aims to provide this by investigating the damaging effects of both short- and long-term exposure to wind noise from motorcycling.

Methods and materials

Long-term effects

Motorcyclists were invited to attend for audiometric assessment at a number of test sites: Plymouth, Bristol, Brierly Hill, West Midlands and at Donington Park race track. A mobile test facility was used at the latter location but fixed audiology facilities existed at the base hospitals at all other locations.

A screening process was undertaken for all prospective subjects. A brief telephone screen was first exercised to exclude previous ear disease and occupational noise exposure. Successful candidates were then invited to attend the audiometric facility. Next a thorough clinical history was taken to identify any previous ear disease, severe systemic illness, head injury or 'significant' alternative noise exposure, either occupational or from recreational activities. 'Significant' is a rather nebulous term but for this study would be deemed to have occurred if the subject was required to wear hearing protection at work or if he used firearms more than twice in any year. Clinical examination and tympanometry were then performed with further exclusions for subjects with abnormal findings. The aim was to recruit subjects who were well in all respects and whose only 'significant' noise exposure was motorcycling. It was hoped that by such screening the test group could be compared to an age and sex matched 'otologically normal' control group. After this screening process, successful recruits were then questioned with regard to their motorcycling history. As previous work has demonstrated that the type of helmet worn and machine ridden are relatively unimportant as regards noise levels, these were not asked for (McCombe *et al.*, 1993a). Instead riders were asked their age, number of years of riding experience and average number of miles per year ridden. The first 90 riders recruited were also asked if they had ever suffered any tinnitus after riding, as an indicator of possible temporary threshold shift.

Manual pure-tone audiograms for both air- and bone-conduction were then performed (Anon, 1981). (Air-conduction was performed at the following frequencies: 0.25, 0.5, 1, 2, 4, 6 and 8 kHz; bone–conduction at : 0.5, 1, 2 and 4 kHz). Subjects with air–bone gaps of 10 dB or greater at any audiometric frequency, and therefore indicative of some conductive hearing loss, were excluded from further analysis. To avoid the presence of any temporary threshold shift, subjects were asked not to ride for the 24 hours prior to audiometry.

The tympanometers used were an Electromedics and a GSI 33. The audiometers were either a Graystad GSI 16 (Lucas Grason-Stadler, Milford, NH, USA) or a Kamplex AD 27 (Interacoustics AS, Assens, Denmark) both of which complied with BS 5966 (1980) and were regularly calibrated to BS 2497 (1988) for air-conduction and BS 6950 (1988) for bone-conduction. The background noise levels in the static test rooms met the requirements specified in BS 6655 (1986). Although the mobile audiometric facility did not quite meet these stringent requirements, it certainly satisfied the almost identical national standard DHSS CE (76) D532/74, with ambient sound levels of less than 25 dB(A) overall.

The collected audiometric data was analysed at the MRC Institute of Hearing Research in Nottingham. An appropriate control group was obtained from the MRC National Study of Hearing (NSH) (Davis, 1989). This study is one of the largest British epidemiological hearing surveys ever performed and as such was felt to be completely appropriate to provide controls for our study group. Furthermore the control group was subject to the same stringent exclusion criteria as the study group and comprised 180 males between the ages of 18 and 50 years with no prior history of ear disease or noise exposure. The NSH control group was compared to the motorcycle study group using a case control design, first as a whole group and then against the subgroups of racers, police and 'leisure' riders. The comparison utilized a statistical model that essentially describes the change in hearing threshold with age (from 0–50 years) in each of the specified groups. The statistical model uses the NSH data to provide the baseline (hearing threshold at age 0) and then adjusts for age by the provision of an 'aging factor' which is common to both study and control groups for each comparison; this factor is unique to each

TABLE I
RIDING HISTORY OF MOTORCYCLISTS: MEAN VALUES (+1 SD)

Group (n)	Age	Riding experience (years)	Miles/year ($\times 10^3$)
All (246) motorcyclists	33 (7.6)	13.5 (6.9)	10 (8.5)
Leisure (159)	34 (7.7)	14.4 (7.1)	9.5 (8.5)
Racers (73)	29 (5.9)	10.9 (5.6)	N/A
Police (14)	39 (6.7)	17.4 (6.7)	15.5 (5.3)

frequency (e.g. 0.1 dB/year at 0.5 kHz). The audiometric data from the different motorcyclists' study groups is then modelled in a similar fashion, using the same age correction factor and the study group models are compared to the controls. Any differences between them are noted as a parameter estimate ('correction factor') at each audiometric frequency. This correction factor describes the difference in hearing threshold at that frequency between the two groups. The statistical significance of this parameter was assessed by analysis of the decrease in deviance when the motorcyclists' correction factor was added to the model, using a generalized linear model (GLIM), (NAG, 1993). A normal distribution error structure was presumed. Comparisons were performed for both the better and worse hearing ear in turn and results were assumed to be significant at the five per cent level.

Short-term effects

A large proportion of the first 90 riders recruited for the hearing survey part of this study admitted to tinnitus following prolonged riding. This was felt to suggest the coincidental occurrence of a temporary threshold shift after what would certainly be excessive noise exposure. We felt it important to have some idea of the magnitude of this TTS and therefore performed the following investigation.

Eighteen experienced motorcyclists, all with normal hearing (i.e. thresholds of better than 20 dB(HL) at all standard audiometric frequencies), were asked to undertake a standard test route of approximately 80 miles at a fairly constant 80 mph to give a total riding time of one hour. A manual pure-tone audiogram was performed immediately prior to the test journey and again starting within two minutes of their return from the test run. The audiometrician was 'blind' to the initial audiogram.

The change in audiometric threshold represents the temporary threshold shift and was assessed statistically with a paired *t*-test.

Results

Long-term effects

Over 400 motorcyclists offered themselves for inclusion in the study, many of whom were declined at the first telephone screen due to previous noise exposure or ear disease. Unfortunately the exact number of individuals who failed this screen is unavailable as a variety of individuals performed it. After clinical evaluation, 35 further subjects were excluded on the grounds of excessive noise exposure and 18 on the basis of abnormal audiometry (asymmetrical hearing loss in two and excessive air–bone gaps in 16) A total of 283 subjects survived the screening process and were submitted for statistical comparison with the NSH database. The mean age was 35 years (SD: 9.8). Fifteen (five per cent) were women. Due to their small numbers it was felt appropriate to further exclude all subjects over the age of 50 and all women, leaving a study group of 246 men with a mean age of 33 years

TABLE II
MODEL FOR HEARING THRESHOLDS FOR BETTER HEARING EAR (MEANS AND STANDARD ERROR)

Audiometric frequency (kHz)	0.25	0.5	1	2	4	6	8
NSH Grand mean	5.7	0.9	−2.3	−2.8	−6.3	−0.1	−6.5
(dB for age 0)	(1.33)	(1.30)	(1.16)	(1.50)	(2.13)	(2.52)	(2.43)
Age correction	0.1	0.1	0.2	0.2	0.5	0.6	0.6
(dB per year)	(0.04)	(0.04)	(0.04)	(0.05)	(0.07)	(0.08)	(0.08)
Parameter estimates (additional correction factor)							
All motorcyclists	2.0	3.7	3.6	1.9	0.0 NS	−2.5 NS	−0.6 NS
(n = 246)	(0.74)	(0.72)	(0.64)	(0.83)	(1.18)	(1.40)	(1.35)
Leisure riders	1.9	3.5	3.3	1.3 NS	−0.6 NS	−3.4 NS	−1.6 NS
(n = 159)	(0.86)	(0.83)	(0.74)	(0.96)	(1.36)	(1.61)	(1.55)
Racers	1.9 NS	4.0	3.6	2.7	0.7 NS	−1.8 NS	−0.1 NS
(n = 73)	(1.12)	(1.09)	(0.97)	(1.26)	(1.78)	(2.11)	(2.02)
Police riders	4.7	4.5	5.9	4.5	2.7 NS	4.5 NS	9.8 NS
(n = 14)	(2.39)	(2.33)	(2.08)	(2.69)	(3.82)	(4.52)	(4.34)

NS = Not significant at 5% level.

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TABLE III
MODEL FOR HEARING THRESHOLDS FOR WORSE HEARING EAR (MEANS AND STANDARD ERROR)

Audiometric frequency (kHz)	0.25	0.5	1	2	4	6	8
NSH Grand mean	6.08	3.0	−0.4	−1.4	−1.2	1.3	−4.0
(dB for age 0)	(1.28)	(1.23)	(1.26)	(1.67)	(2.64)	(2.93)	(2.98)
Age correction	0.1	0.1	0.2	0.3	0.6	0.7	0.6
(dB per year)	(0.04)	(0.04)	(0.04)	(0.05)	(0.08)	(0.09)	(0.09)
Parameter estimates (additional correction factor)							
All motorcyclists	2.8	3.4	3.1	2.1	−0.2 NS	−2.9 NS	−2.5 NS
(n = 246)	(0.71)	(0.69)	(0.70)	(0.93)	(1.46)	(1.63)	(1.66)
Leisure riders	3.1	3.5	2.9	1.5 NS	−1.6 NS	−3.5 NS	−3.2 NS
(n = 159)	(0.82)	(0.79)	(0.81)	(1.07)	(1.69)	(1.88)	(1.91)
Racers	1.7 NS	2.7	3.2	3.6	2.3 NS	−2.7 NS	−2.8 NS
(n = 73)	(1.07)	(1.03)	(1.06)	(1.40)	(2.21)	(2.46)	(2.49)
Police riders	5.2	6.1	5.1	0.9 NS	0.6 NS	3.1 NS	8.0 NS
(n = 14)	(2.30)	(2.21)	(2.27)	(2.99)	(4.73)	(5.26)	(5.34)

NS = Not significant at 5% level.

(SD: 7.6) and a mean riding experience of 13.5 years (SD: 6.9). Their riding histories are shown in Table I. For comparison, the NSH control group of 180 was derived from an initial number of 520, after excluding 154 with excessive air–bone gaps and a further 186 with excessive noise exposure.

Persistent tinnitus was reported in 12 out of the first 90 motorcyclists (13 per cent). Worsening of this tinnitus or the temporary occurrence of tinnitus after prolonged riding was reported in 65 riders (72 per cent). This usually meant at least one hour of prolonged high speed riding.

The results of the statistical analysis are shown for the 'better hearing' ear in Table II and for the 'worse hearing' ear in Table III. A positive parameter estimate for the motorcyclists represents a worsening of hearing threshold. The standard errors for each parameter are shown in brackets and those that have $p>0.05$ are marked as NS. It can be seen that the hearing thresholds of the motorcyclists are significantly worse at 0.25, 0.5, 1 and 2 kHz for all motorcyclists. The pattern is essentially similar for the various sub-groups but is most marked for the police motorcyclists.

Short-term effects

Some degree of temporary threshold shift occurred in all test subjects after one hour of relatively high speed riding. The pooled data is shown in Table IV. TTS was most marked at the low/middle audiometric frequencies with the greatest mean TTS occurring at 1 kHz.

Discussion

It would appear fairly conclusively that the noise exposure from motorcycling results in both short- and long-term adverse effects on hearing. We have demonstrated significant TTS after only one hour of high speed riding, and significant PTS when compared to an appropriate control group.

This study is not the first to demonstrate a permanent hearing loss in motorcyclists (Fletcher and Gross, 1977; Jongepier and Van der Weerd, 1989). It is however the first study that has used appropriate and well documented controls (in this case from the NSH), and standard and accepted statistical analysis. This group is also the largest study group to date, and has been thoroughly screened to remove all other potential confounding factors, such as co-existent otological pathology and alternative noise exposure. As such, these results probably represent the first reliable assessment of the long-term effects of motorcycling on hearing.

It is interesting that the predominant hearing loss occurred at 0.5 and 1kHz. One of the first concerns about this low frequency hearing loss is that it may represent environmental masking. This is unlikely given the relative improvement in thresholds at 0.25 kHz, the low ambient sound levels during testing and the results of the temporary threshold shift experiment where the maximal TTS occurred at the same audiometric frequencies. These frequencies are half to one octave above the relatively narrow, A-weighted, 'centre' frequency of wind noise which occurs between 0.25 and 0.5 kHz and decreases by about 10 dB/octave on either side of this. Given the

TABLE IV
TEMPORARY THRESHOLD SHIFT IN MOTORCYCLISTS (18 SUBJECTS; 80 MPH FOR ONE HOUR)

Audiometric frequency (Hz)	0.25	0.5	1	2	4	8
Mean threshold Before (dBHL) (SD)	8.6 (5.0)	5.8 (4.4)	5.7 (4.3)	3.9 (4.8)	6.2 (6.6)	8.6 (6.2)
Mean threshold After (dBHL) (SD)	14.0 (6.4)	15.6 (4.7)	16 (6.0)	12.8 (5.9)	9.3 (6.3)	10.1 (7.2)
Mean TTS (dB)	5.4	9.8	10.3	8.9	3.1	1.5
p-Value	0.0002	0.0000	0.0000	0.000	0.49	0.34

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half-octave rule that says that cochlear damage tends to be greatest at half to one octave above the frequency of the damaging sound (McFadden and Plattsmier, 1982), this lends further support to the hypothesis that 'wind noise' is the predominant damaging noise source for motorcyclists. It also provides further support for the uncommon finding that relatively narrow tonal bands of noise can lead to 'atypical' noise-induced hearing loss outside the 'classic' 3–6 kHz dip (Bernabei, 1953; Knight, 1963; Alberti, 1987). On this point though it is important to remember that the motorcyclists were compared to 'normal' from the more recent NSH and not to the more established 'normal values' found in the National Physics Laboratory (NPL) tables. The NPL 'normals' are not only significantly different but are those usually used in medico-legal assessments.

Had this been the control group our subjects would have clearly demonstrated, in addition to their low-frequency hearing loss, the 'classic' high frequency dip.

It may still be possible that the hearing loss in fact represents some residual TTS despite our stringent efforts to avoid this by asking subjects to avoid any noise exposure, particularly motorcycling, for the 24 hours prior to testing. A similar concern, again with a low-frequency hearing loss, has been previously reported for naval flight-deck personnel. In this group there was a slight improvement in hearing thresholds when tested at least one year after their last flight-deck noise exposure (Knight and Coles, 1966). Serial audiometry, or a longer break from motorcycling, might have helped elucidate this point but was, unfortunately, logistically impossible. However, an examination of the data shows the maximal PTS at 0.5 kHz whereas the maximal TTS was at 1 kHz, perhaps indicating the occurrence of a different process. Until this point can be definitively decided, and on the basis of the available evidence, it is probably reasonable to assert that wind noise exposure is having measurable adverse effects on the hearing of motorcyclists.

It is also noteworthy that the learning loss is greatest for the sub-group of police motorcyclists and least for 'leisure' riders, with the racers falling in between. To some extent this is not surprising: Most leisure riders ride regularly for only a relatively short time each day, often less than half an hour and usually in traffic on their way to and from work. Longer trips are also made but on an intermittent basis and varying in frequency and distance. As for the racers, although their speeds are very high, they rarely spend more than 45 minutes on the motorcycle at any one time and usually less than two hours in total for any one day. In addition their riding is usually restricted to three days around a race meeting for each week. For both of these subgroups this intermittent noise exposure allows time for audiological recovery. The police motorcyclists however, spend many hours on their machines each day and do this for a full working week; many are also leisure riders; riding a motorcycle to and from work and in their leisure time. This is supported by the finding that police motorcyclists record the highest annual mileage (Table I). It is therefore inevitable that their noise exposure will be greatest and their hearing loss worst. Taken together these results all indicate the need for some form of remedial action to reduce the risk of noise damage. In addition, for professional riders, there is the medico-legal consideration of occupational hearing loss. To some extent the risk of personal injury is covered within the contracts of the racers. For dispatch riders, as most are self-employed, the responsibility for personal protection is on the individual. However, for police riders, this remains a potential issue and is a further argument for hearing protection.

An efficacious method of providing earplugs and improvements in the sound attenuation characteristics of motorcycle helmets have both been suggested and successfully piloted. Both methods are effective in reducing noise exposure and the risk of hearing damage (McCombe *et al.*, 1993b and 1994). It is hoped that the motorcycle industry might act positively on these findings to help prevent an unnecessary and unpleasant consequence of motorcycling.

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