1.0 Introduction

It has long been recognised that motorcycles are a noisy form of transport, with a cacophony of exhaust, tyre and induction noise. As such, legislation has been introduced to decrease environmental levels. To meet these legislative requirements manufacturers have been developing quieter machines, while simultaneously modern engineering principles have allowed increasingly faster motorcycles. It is this factor of greater speed that is of concern to the rider; not just from greater risk of injury, but from noise induced hearing loss (NIHL). This is due to the turbulent airflow around the rider's helmet, so called 'wind noise' (Hetherington et al 2002, Kortesuo & Kaivola 1996, Lower et al 1996, McCombe et al 1995, Ross 1989).

An ever increasing list of studies are confirming that motorcyclists are exposed to excessive noise levels (Hetherington et al 2002, Kortesuo & Kaivola 1998, Lower et al 1996, McCombe et al 1993, Ross 1989). Typical levels of 90 dB(A) at 48 km/h (30 mph) rising to 116 dB(A) at 193 km/h (120 mph) have been recorded (Lower et al 1996).

Lower et al (1996) also noted that speeds above 64 km/h (40 mph) the wind noise generated by the airflow over the motorcycle, the helmet and the rider exceeded that from the engine and tyres.

Binnington et al (1993) states that riders not wearing a helmet would be exposed to marginally higher noise levels than those that do (some American states do not enforce motorcycle helmet usage). This provides the hypothesis that helmets provide little attenuation against the noise exposure and at certain frequencies the helmet can resonate and produce levels higher than expected (McCombe et al 1995).

The ear may be damaged by noise in two ways. High level, short duration exposure exceeding 140 dB(A) can stretch the delicate inner ear tissues beyond their elastic limits, then rip or tear them apart. This type of mechanical damage, called acoustic trauma, occurs rapidly and results in immediate hearing loss. Noises capable of producing acoustic trauma include explosion, firecracker detonating near the head, firing shotguns and other firearms. Exposure to noise levels between 85 and 140 dB(A) damages the cochlea metabolically rather than mechanically and causes damage relative to the duration of the exposure. This produces NIHL which, in contrast to acoustic trauma, develops slowly over years, and is the form of damage most commonly associated with motorcycle exposure.
Much has been written about the assessment, surveillance and control of NIHL in fixed workplaces such as factories, engineering activities and construction sites where the noise is generated by machines and tools (Reilly et al, 1998, Wood, 1990) but little about the risks to workers exposed to high noise levels from less obvious sources. This topic of motorcycle wind noise is beginning to receive attention in the professional and specialist motorcycle press and from trade unions with calls for more research, educational campaigns, enforcement action and self protection action by motorcyclists (TUC 1999, MCN 1999).

European (EEC 1986), American (OSHA 1986) and Australian (OSHR 1996) legislation requires employers to initiate actions to protect workers above noise levels of 85 dB(A). This equates to 8 hours travelling at speeds of 60 km/h (37 mph) or above for motorcyclists in dry conditions (Hetherington et al 2002).

For this legislation to be applied the persons involved must be at work and as such, occupational motorcyclists (people who ride a motorcycle as the main function of their job) were chosen as the primary research group. This group are also the most likely to be riding motorcycles daily, for prolonged periods, over a number of years; hence more likely to suffer noise induced hearing loss.

The jobs of occupational motorcyclists vary greatly, from 9-5, Monday - Friday, full-time workers to self-employed, agency riders. The times and speeds of the riders also varies from a part-time pizza delivery boy driving at relatively low speeds around a busy city, to a full-time police motorcyclist pursuit officer on an open motorway. It should also be noted that recreational rider's are equally susceptible to NIHL if they chose to ride for prolonged periods.

A significant development in the UK is the legal action for negligence taken by a former police motorcyclist against his employers, West Midlands Police Authority. Serious hearing damage to the motorcyclist (aged 32 years) was discovered during a routine medical examination. In the legal action he claimed that, despite wearing custom made earplugs, his hearing had been damaged through exposure to wind generated noise, noise from his radio communications system and road noise. The case was settled out of court with the payment of £5500 compensation, although the judge ratified the compensation providing some justification for the case to be cited as a precedent.

This paper presents the rider at ear noise levels found in a exploratory study involving a range of variables including weather conditions, speeds, helmet types and visor positions. Furthermore from these results, the hearing handicap of selected occupational motorcyclists could be estimated.
2.0 Methodology

Measurement of noise inside a motorcycle helmet, which is travelling at speeds of up to 120 km/h, is by no means an easy task. The standard method of measurement as stated in the HSE’s Noise at Work ‘Noise Assessment, Information and Control’ 1998 for the Noise at Work Regulations (1989) would be made in the ‘undisturbed field’ i.e. in the absence of the person whose exposure is to be measured, with the microphone located in the area normally occupied by the person’s head. As this would not be possible the HSE’s document, goes on to stipulate that miniature microphones should be used to measure sound pressure levels under headsets and gives the example of a motorcycle helmet.

However, operating a sound level meter at speed would be unsafe and that a recording on to a Digital Audio Tape (DAT) was the only viable option. A miniature electret microphone, powered by a small 9v battery, provided the best compromise between size, sensitivity and frequency response.

To calibrate the system, wide band noise at 90dB was recorded onto the DAT from which all other recordings would be later referenced. The recording level of the DAT recorder was fixed in place to prevent alteration later.

The miniature microphone was placed over the entrance to the ear canal of the rider, so not to be in contact with any part of the ear (Plate 1.0). Sticky plasters were used to hold the wire to the side of the rider’s face to prevent movement. The DAT recorder and battery was stored under the rider's clothing to prevent the wires from flapping in the wind. The helmet was dawned in such a way as to avoid any displacement of the microphone or wires.

A straight, 5km (3 mile), flat, asphalt section of public road with a generally low traffic flow and few adjoining road junctions was selected as the test road. When a gap in the traffic became available the rider travelled along the road at set speeds for 20 seconds at a time. The rider shouted out the speed e.g. ‘50 km/h’ at the start of the run and shouted ‘Stop’ at the end of the run which would allow easier data recovery at a later stage. A number of runs were recorded using different helmet types (closed and open face helmets), speeds (50, 60, 70, 80, 90, 100, 110, 120 km/h), weather conditions (wet and dry) and helmet visor positions (up or down).

The motorcycle used was a Yamaha XJ600N with a specification as follows: 4-stroke, air cooled DOHC, 4 cylinder, 598cc, 44.8kW power at 8,500rpm, fitted with 110/80-17 57H tyres and no fairing or windscreen. The helmets used were an 'AGV' full face helmet (Plate 2.0) and the 'Nolan' open face helmet (Plate 3.0). Both helmets complied with British Standard BS 6658 'Specification for Protective helmets for vehicle users’ (1985), which applies to all helmets for use by riders on public roads in the UK. It should be noted that BS 6658 does not include any requirements or testing regarding noise levels.
The 01dB Acoustics Package was used to analysis the DAT recordings of each run. The average noise levels ($L_{eq}$) of each run were noted and a correction factor added with reference to the calibration tone. To help identify the source of the noise an octave band frequency analysis of each run was also conducted.

Using an estimated, typical driving pattern for selected occupational motorcyclists daily exposure levels ($L_{Aeq, 8\text{hour}}$) were calculated. Recreational motorcyclist's typical driving patterns are too varied to estimate with any accuracy. This exposure level was then used to determine the long term ‘noise imission level (NIL)’ which takes account of the length of time in years to which a worker is likely to be exposed to noise. The risk of hearing handicap resulting from such exposure was assessed, using the method of British Standard BS 5330 (1976) which considers the NIL and age of the subject.
### Table 1.0 Wet Run noise exposure level results

<table>
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<th>Speed km/h</th>
<th>Full Face Closed, Noise Level (dB)</th>
<th>Full Face Open, Noise Level (dB)</th>
<th>Open Face Closed, Noise Level (dB)</th>
<th>Open Face Open, Noise Level (dB)</th>
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<td>94.67</td>
<td>98.86</td>
<td>99.17</td>
<td>102.33</td>
</tr>
</tbody>
</table>

### Table 1.1 Dry Run noise exposure level results
Fig. 1.0: At-ear Noise Levels - Dry Road

Fig. 2.0: At-ear Noise Levels - Wet Road
4.0 Discussion

4.1 Noise Exposure Levels

Occupational noise-induced hearing loss causes problems for the individuals concerned (Hallberg et al 1995) and also their families (Hallberg et al 1993) and co-workers (Hetu et al 1994). For employers the cost of deafness claims has been substantial. In 1980 no fewer than 8661 deafness claims had been made against British Rail (Times 1983) and by 1989 16,080 claims had been settled against Harland and Wolff at the cost of almost £17 million (IRLR 1990). This is the third most common occupational assessed claim behind hand-arm vibration and tenosynovitis.

Figures 1.0 and 2.0 illustrate the relationship between road speed and overall noise level. At all speeds measured, the noise level was found to be above 80 dB(A), the level above which it is accepted that there is a quantifiable risk of hearing damage to persons continually exposed over an extended period (McCombe et al 1994). At 50 km/h (30 mph) on a dry road, the noise level varied from 81 dB(A) to 83 dB(A) depending on helmet type and visor position (open or closed) and the equivalent figures for a wet road were 86 dB(A) to 90 dB(A). At 90 km/h (55 mph) on a dry road, the noise level ranged from 89 dB(A) to 93 dB(A) with equivalent figures 94 dB(A) to 96 dB(A) in wet conditions. On average the noise level was 5.4 dB higher in the wet than the dry.

It can be clearly seen from figures 1.0 and 2.0 that the noise levels were greater with the open face than the full face helmet and that the relative levels of noise with the visor closed and open diverge with increasing speed.

At speeds greater than 60 km/h (37 mph) in dry conditions, the level of noise exceeded 85 dB(A) (the level at which in Europe, USA and Australia specific employer actions must be initiated to protect workers). The investigation found that as speed increases, noise levels increase. For every 10 km/h increase in speed, the noise level the rider was exposed too increased by 4 dB, with measurements of over 100 dB(A) were recorded. Such levels are higher than those experienced by many workers in the traditionally noisy industries. A significant number of people are employed as occupational motorcyclists; thus there is a need for a greater understanding of the levels of noise exposure, the degree of risk to hearing damage, the noise source(s) involved and the means of minimising exposure.

The measured results were found to correlate at low speeds with those of Lower et al (1996), who found that a speed of 48 km/h (30 mph) gave noise exposure levels of 78 – 90 dB(A). They also found that at 193 km/h (120 mph) noise levels of 114 – 116 dB(A) were recorded. McCombe et al (1995) reviewed noise exposure measurements of motorcyclists from a number of researchers and concluded that riders are exposed to levels of around 90 dB(A) at 72 km/h (45 mph), increasing to 111 dB(A) at 160 km/h (100 mph). Ross (1988) recorded levels of 95 dB(A) at 48 km/h (30 mph) and 103 dB(A) at 96 km/h (60 mph) with a full face helmet. These levels do not seem to
agree with the test results in Figures 1.0 and 2.0, which indicate levels between 81 and 90 dB(A) at that speed, depending on the helmet type and position and the road conditions. The results of Ross (1989) would appear to indicate a much higher exposure level than others. It has not, however, been possible to make a direct comparison between measurements because of the absence of a standard measurement protocol. One significant factor likely to affect measured levels is the passage of wind over the microphone, (as opposed to noise generated by wind turbulence on the exposed edges of the helmet). Unless the microphone is adequately protected from the passage of wind over the diaphragm, the apparent noise level is likely to be distorted. This effect was noticed, in the results of measurements made with an open face helmet and the visor in the open position.

It is evident from all the research considered that even at moderate speeds, motorcyclists are at risk of exposure to high levels of noise.

4.2 Estimated Hearing Handicap

NIHL results from prolonged exposure to high levels of noise. It is recognised that exposure equivalent to 85 dB(A) for 8 hours per day presents a quantifiable risk of permanent hearing damage (HSE 1998). The equivalent daily exposure ($L_{ep,d}$) of a worker is determined by taking account of the level(s) and time(s) of exposure, normalised to an 8 hour period using the following formula:

$$L_{ep,d} = 10\log_{10} \frac{1}{8} \sum 10^{\frac{L_i}{10}} \times t_i$$

where:
- $L_i$ = ‘A’ weighted sound levels
- $t_i$ = relevant time periods

For example, a police motorcyclist on motorway patrol might spend 3 hours per day cruising at 120 km/h (75mph), 3 hours at 90 km/h (56 mph) and 2 hours at 60 km/h (37 mph). Here the equivalent daily exposure would be approximately 103 dB(A) based on our noise level measurements.

The cumulative effect of long term exposure to high noise levels can be assessed using the method of British Standard BS 5330:1976, *Method of test for estimating the risk of hearing handicap due to noise exposure*. This method combines the typical daily exposure level and numbers of years exposure to give the ‘Noise Immission Level’ (NIL) and then estimates the likelihood of hearing handicap (which is defined as 30 dB reduction in hearing in the speech frequencies) considering the subject’s age.

In the case of a 37 year old police motorcyclist with 15 years riding duty, the NIL would be approximately 102 dB(A). According to BS 5330:1976, there is a 2-3 % chance that the motorcyclist will have suffered a 30 dB hearing handicap. In a more extreme set of circumstances of exposure for 4 hours per day on wet roads at 110 km/h, the resultant NIL would be 116 dB(A), with 23 to 30 % chance of 30 dB hearing loss. It should be noted that this
investigation did not measure the contribution from radio communications equipment commonly used by police motorcyclists. The sound level from this is likely to be high to ensure audibility over background noise. This would further increase the noise dose and hence NIL.

Another more recent example, would be the 127 mph lap of David Jefferey's at the Isle of Mann TT. Over the six lap race he averaged 123.5 mph which lasted almost 2 hours. It is estimated the noise level at 123.5 mph would be in the region of 115 dB(A). This would give an equivalent $L_{EP,d}$ of 109 dB(A), with resultant NIL of 119 dB(A), with 40% chance of 30 dB hearing loss in a 30 year old racer who had been racing for 10 years. This would probably be an overestimation of the chance of the rider suffering from hearing loss as a rider would not race 5 days a week. However, most do ride and test at least 3 times a week with practice and qualifying prior to race days. Speeds of over 200 mph are often reached on a long straight. The noise exposure level would be impossible to predict accurately, but would probably be over 125 dB(A).

Figures 3.0 and 4.0 illustrate the contribution made to the overall noise level from the various frequency bands within the audible spectrum. The relative ‘band’ noise levels have been ‘A’ weighted to show the contribution in each band. Frequency analysis indicates that low frequencies (500 Hz and below) predominate. The measurements in this study showed that the low frequency content increased with increasing speed. This is indicative of the measured noise levels resulting principally from turbulence generated by airflow around the helmet. This raises an important issue with regard to protecting the rider from the high noise levels. Conventional earplugs, which are commonly presented as a means of noise exposure control, do not provide significant attenuation at low frequencies.

5.0 Good Practice

Currently, the only methods of noise reduction available to occupational motorcyclists are to drive slower (unlikely) or the use of earplugs. However, as discussed earlier, the low frequency bias of the noise spectrum due to wind noise would not be able to be significantly attenuated with conventional earplugs. This leaves the question, what is the next step? A number of noise reduction methods may be available in the future with the introduction of new motorcycle helmet designs incorporating active noise reduction and aerodynamic additions. Motorcycle fairing design can also have a major effect on the exposure noise levels.

6.0 Conclusions

The motorcyclist's motorcycle, hours of use, helmet type and average speed travelled all vary greatly and hence each individuals noise exposure is unique.

Recreational riders (UK 900,000 DETR) and occupational riders (UK 26,500) are exposed to high levels of noise and as such, the risk of noise induced hearing loss are great, with an estimated hearing handicap of 30 dB in 1-14%
of the population. All occupational motorcyclists in this investigation were noted to have $L_{EP,d}$'s above the second action level of the Noise at Work Regulations (1989). This will require their employers to reduce noise exposure as far as is reasonably practicable by means other than personal ear protectors. This could be done by reducing time spent at particularly noisy activities, i.e. driving the motorcycle.

There is a need for a standardised protocol for measurement of noise exposure of motorcyclists which could be used to provide employers with a practical means of conducting an assessment of the risks to occupational motorcyclists.

The value of conventional hearing protectors in the reduction of noise exposure of motorcyclists is likely to be limited due to the high level of low frequency noise generated by wind turbulence.

Research initiatives from employers, health and safety agencies and the manufacturers of motorcycles/crash helmets should be focused on remedies to counteract these damaging noise levels.
7.0 Bibliography


BS 5330 (1976) Method of test for estimation the risk of hearing handicap due to noise exposure. HMSO: London


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Times (1983) *Kirkup v British Rail Engineering Ltd*, The Times 21/6/83


Plate 1.0  Placement of microphone over rider’s ear

Plate 2.0  ‘AGV’ Full Face Motorcycle Helmet
Plate 3.0 ‘NOLAN’ Open Face Motorcycle Helmet