

Road Safety Research Report No. 78

**Motorcycle Rider Fatigue:
A Review**

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EXECUTIVE SUMMARY

The Department for Transport commissioned the Transport Research Laboratory (TRL) to undertake a literature review of motorcycle rider fatigue. The aims of the review were to:

- investigate the incidence of fatigue-related accidents among riders;
- investigate the causes, symptoms and effects of fatigue on riders;
- assess the impact of fatigue in riders on possible accident causation; and
- explore possible countermeasures to combat the effects of fatigue and review campaign strategies that have addressed fatigue and its dangers.

The term ‘fatigue’ is defined and interpreted in many different ways in the literature. For the purpose of this review, it is used as an umbrella term encompassing internal states and performance decrements associated with:

- a need for sleep (sleepiness/drowsiness);
- tasks/environments that are mentally or physically demanding (excessive task demands or ETDs); and
- tasks/environments that are insufficiently stimulating (under-stimulation).

However, due to the nature of the motorcycle riding task (which includes exposure to noise and vibration, and the need for the rider to maintain physical balance), the final component is not generally a major problem for riders.

The review covered data from a wide variety of sources, including publications in the open literature and ongoing work by major transport research centres. Overall, it found that there have been few studies investigating the causes and effects of rider fatigue. Where they do exist, they tend not to provide a definition for fatigue and also not to separate the definition into the above three components of fatigue, namely sleepiness, ETDs and effects due to under-stimulation, which may have quite different effects on performance. Additionally, there tends to be a reliance on self-report questionnaires rather than on directly observed effects of task performance or safety. Similarly, the literature does not provide much evidence for the effectiveness of potential countermeasures or campaign strategies specifically to combat the effects of rider fatigue. However, information from the literature about driver fatigue and fatigue in general has, with careful interpretation, provided some insight into the possible causes of fatigue and the likely effects that it can have on motorcycle riders.

The main findings from the literature review are as follows:

- There is very little direct research evidence or information concerning motorcycle rider fatigue and, therefore, it is difficult to draw firm conclusions on the incidence of rider fatigue.
- Some of the causes and effects of rider fatigue are shared with those of driver fatigue and fatigue in general. These include lack of prior sleep or time of day of riding. However, there are strong reasons to focus specifically on motorcycle rider research, mainly because the motorcycle riding task makes different demands of people from the car driving task, and riders are exposed to a far more hostile environment than drivers. These differences may have important consequences for the way fatigue develops and affects drivers and riders.
- Three main studies investigating rider fatigue have been identified. A pilot study conducted in Australia examined the effects of a recreational day ride on reported fatigue and performance. A much older UK study examined riders' reaction times after riding a test route before and after a night's rest. Finally, in a brief qualitative internet study of riders, a questionnaire was sent to American motorcyclists. The questions in this questionnaire all related directly to motorcycle fatigue and ranged from riders' concepts of fatigue to preparation prior to rides, detection of fatigue and countermeasures to fatigue.
- In the questionnaire study, riders commonly reported insufficient breaks, long riding hours and monotonous roads as possible causes of rider fatigue. Elsewhere in the literature, heat stress, stress from cold, noise or vibration, posture/discomfort stress and night-time riding were identified as causes of rider fatigue.
- Few countermeasures or campaign strategies with a firm scientific basis have been developed specifically to help riders avoid riding when fatigued, or to combat the effects of fatigue on riders. However, remedial measures to combat fatigue in **drivers** have been extensively discussed in the literature. The most common are: formal fatigue management programmes; taking regular breaks; ingesting caffeine; setting realistic targets for the journey; and taking 'power naps'.
- Measures suggested specifically for minimising **rider** fatigue focus on reducing the physical and mental demands of the (riding) task and include: having a windshield on the motorbike; correct configuration of the motorcycle; and using hearing protection. However, hard evidence of their effectiveness is lacking.

The investigation of the incidence of rider fatigue in UK accidents was carried out by identifying fatigue-related motorcycle accidents in four accident databases ('On the Spot', STATS19, 'Fatals' and 'Motorcycle Accident In Depth Study'). The main findings were:

- fatigue was identified as a factor in only a relatively small proportion of the motorcycle accidents in the databases;
- the small number of fatigue-related motorcycle accidents for study meant that it was not possible to draw conclusions about any associations with other factors (time of day, etc.); and
- it is likely that the small number of fatigue-related motorcycle accidents identified is due, at least in part, to the practical difficulty of gathering information about the fatigue state of accident-involved motorcyclists, either at the scene or retrospectively.

Taken as a whole, the available literature and accident data provide very little scientific information specifically on the subject of rider fatigue. The knowledge gaps found are introduced at the end of this report, and it is recommended that the first step should be to establish much more clearly the importance of motorcyclist fatigue as a road safety problem – for example, by more precisely quantifying the level of involvement of fatigue in motorcycle accidents (including through the use of rider self-report survey data). This should provide a firmer basis for justifying research expenditure on the other aspects of motorcyclist fatigue.

1 INTRODUCTION

1.1 Background

Motorcycling is a popular form of transport. In Great Britain, there are around 1.6 million motorcycles, with 2.7% of all households owning one. The motorcycle ownership rate is highest in the south-west of England and lowest in Scotland. Over the 10-year period between 1993 and 2003, motorcycle traffic increased by 49%. Motorcycles travelled about 5.6 billion kilometres in 2003 (DfT, 2006a) and the number of motorcycle riders has been increasing after a long period of decline – after dropping from nearly 1.5 million in 1982 to about 0.6 million in 1995, the total number of UK motorcycles started to rise in 1996 (Elliott *et al.*, 2003). Furthermore, Elliott *et al.* (2003) identified that trends seem to be moving towards larger engine sizes, usually over 500 cc.

Motorcycle riders are more at risk of being killed or injured in a road traffic accident than any other type of vehicle user (Sexton *et al.*, 2004). National accident figures show that motorcycle riders are a particularly vulnerable group of road users. For example, in 1997, the fatality rate for riders was 12 per 100 million vehicle kilometres compared with only 0.3 for car drivers (Elliott *et al.*, 2003). According to Sexton *et al.* (2004), in 2001 there were over 580 motorcycle riders or passengers killed in road accidents, 7,305 killed or seriously injured and over 28,800 involved in reported injury accidents. Road casualty figures published by the Department for Transport (DfT, 2006b) found that just over 6,500 riders were killed or seriously injured in road accidents in Great Britain in 2005 and 569 riders were killed. This is a small reduction from the previous years, when 585 riders were killed in 2004 and 693 were killed in 2003.

Growing proportions of casualties are older riders and involve bikes over 500 cc. Peaks in accidents occurring in summer and at weekends are consistent with a significant increase in recreational riding at these times. Motorcycles and motorcycling have a number of characteristics that are at least potential contributors to the high accident liability of motorcyclists. Being ‘single track’ vehicles, motorcycles can easily become unstable and capsize if braking, accelerating or if slippery road surfaces cause a wheel to lose adhesion. This is particularly critical if the motorcycle is leaning to take a bend; braking can also lead to motorcycles changing their trajectories on a bend. Such characteristics make motorcyclists particularly vulnerable when they take bends too fast to be able to stop within the distance that they can see to be clear, and to sudden changes in road surface. In addition to the problems of instability, motorcycles and their riders are vulnerable in other ways. Examples include:

- lack of crash protection;
- not being seen by car drivers; and

- being vulnerable in impacts with crash barriers that have been designed for other vehicle types (Elliott *et al.*, 2003).

Furthermore, a UK study by Clarke *et al.* (2004) showed that in two-vehicle collisions involving motorcycles the other driver is found to be at fault in approximately 44% of cases, a figure that has been supported by research in Hawaii (Kim and Boski, 2001). Commonly, other motorists ‘look but do not see’ motorcycles and cause accidents by turning in front of them (for example). This emphasises a need for a high level of concentration and quick reactions on the part of the motorcycle rider to avoid accidents (Brühwiler *et al.*, 2005), though the importance of more defensive riding strategies should not be forgotten.

Rider behaviour might be affected by several factors that may increase the risk of accidents among riders. Factors such as rider age, gender, experience, type of road and characteristics of the motorcycle have all been investigated by a number of researchers (e.g. Sexton *et al.*, 2004). However, human factors that could also affect accident risk and rider behaviour have been largely neglected by research. Examples include rider sensation-seeking or distraction; however, perhaps the most prominent of these human factors are those related to fatigue.

In previous research it has been estimated that falling asleep at the wheel kills around 300 people a year in the UK, with many more seriously injured (DfT, 2005). Consequently, driver fatigue is a reasonably well-researched area. In contrast, very little research in the UK has been conducted on the incidence and effects of motorcycle rider fatigue. Clearly, with approximately 1 in 5 of serious and fatal road casualties being a motorcyclist, a better understanding of the issues relating to fatigue and motorcycle safety is required. Some motorcycle safety research (e.g. Elliott *et al.*, 2003; Ma *et al.*, 2003) has recommended that specific rider-fatigue research is needed to assess the size of the problem; depending on the outcome, further research may also be needed for the development of countermeasures.

Although it may be tempting to rely on the wealth of driver fatigue literature to inform guidelines and interventions for rider fatigue, there are strong reasons to carry out fatigue research that relates specifically to motorcyclists. One of the key reasons for this is that the demands of the motorcycle riding task are rather different from those of the car driving task. These task differences may have significant consequences for the ways in which fatigue develops and affects riders and drivers respectively (Ma *et al.*, 2003).

This report presents the results of a study specifically of motorcycle rider fatigue, commissioned by the Road User Safety Division of the Department for Transport. The study involved three main tasks:

- targeted review of the literature;
- investigation of the incidence of rider fatigue; and

- identification of knowledge gaps.

1.2 Structure of the report

- **Section 2** outlines a working definition of fatigue as it will be used in this report.
- **Section 3** is a targeted review of literature, which presents both the data collection methods and the results of the review of published and ongoing rider fatigue research in the UK and overseas. It summarises the main findings of the literature review relating to rider fatigue, initially focusing on studies that deal directly with rider fatigue. It then presents an overview of the causes of fatigue and what effect it has on the rider. Thereafter, it outlines the potential countermeasures to rider fatigue.
- **Section 4** outlines the incidence of rider fatigue. It both describes the investigation methods used to quantify the incidence of rider fatigue and the main findings.
- **Section 5** outlines knowledge gaps that were identified in the review.
- Finally, **Section 6** concludes the review.

2 FATIGUE – A WORKING DEFINITION

Although the phenomenon of operator fatigue in transport has been widely researched, no commonly accepted definition of the term ‘fatigue’ has been established. In particular, there is inconsistency in the literature over whether fatigue should be defined to include phenomena associated with sleepiness or whether it should be reserved for task-induced effects. It is important that a suitable definition is adopted for two key reasons, as follows.

Firstly, any definition of rider fatigue needs to conceptually separate **sleepiness** from **task-induced performance decrements**, as the causes and countermeasures for these two phenomena are generally quite different. For example, sleepiness can be due to a lack of prior sleep or circadian cycle issues, whereas time on task and task demands associated with riding can affect performance without causing sleepiness. Likewise, whereas the best countermeasure for sleepiness is obtaining good-quality sleep, the countermeasures for other task-induced effects may include changing the physical or mental demands of the riding task (e.g. by adding a windshield to the motorcycle).

Secondly, there is simply a need for consistent terminology to enable research results to be understood, compared and communicated clearly to those who need to use them.

The purpose of the remainder of this section is to present our preferred definition of the concept of rider fatigue for the purpose of the present report. In so defining fatigue, we were faced with a difficult situation, since:

- in the literature on driver and rider fatigue, including the most recent, the term is either vaguely defined or covers a very broad range of phenomena;
- standard terms to distinguish between different phenomena are needed; and
- in the main study, in order to have attempted such a definition, sleep-related effects were excluded from the definition of fatigue.

Ideally, what is needed is an umbrella term to cover all the separate phenomena, and specific terms for each phenomena. The obvious options are:

- (i) to use fatigue as the umbrella term; or
- (ii) to find another umbrella term and reserve fatigue for the task-induced subset of phenomena.

To avoid the need, in effect, to redefine the terminology of almost the entire literature on driver/rider fatigue, we prefer option (i) – and have therefore adopted the following definitions for use in this report (see Box 2.1). A fuller discussion of

the background to this decision, including a brief outline of some previous attempts at defining fatigue in transport, is given in Appendix 1.

Box 2.1: Definitions used in the report

Fatigue

An umbrella term covering internal states and performance decrements associated with a need for sleep, tasks/environments that are mentally or physically demanding, and tasks/environments that are insufficiently stimulating. Fatigue may involve subjective states of sleepiness/drowsiness, weariness/exhaustion or boredom. However, performance decrements caused by fatigue are not necessarily accompanied by such subjective states.

Sleepiness/drowsiness

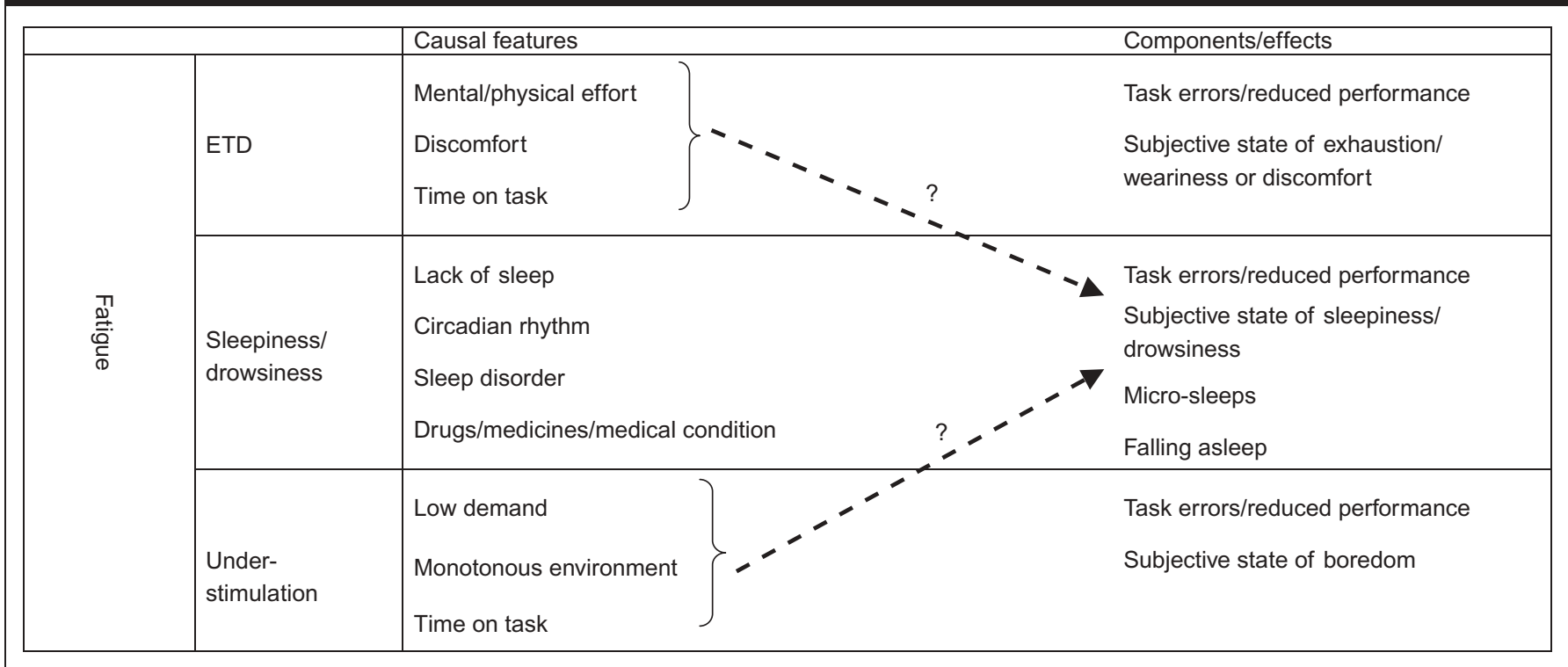
A propensity to fall asleep, have microsleeps or make related task errors, caused by a need for sleep/lack of sleep, circadian effects, a sleep disorder or other medical condition, or drugs/medicines; and possibly permitted or exacerbated by a low level of task or environmental stimulation. There will generally be a subjective state of sleepiness or drowsiness, but the driver/rider will not necessarily be aware of how close he is to falling asleep, and task errors may occur before the subjective state becomes apparent.

Excessive task demand (ETD)

A propensity for reduced performance caused by continued mental or physical effort at a demanding or prolonged task, or in an uncomfortable or hostile environment. This may be accompanied by a subjective state of exhaustion, weariness or physical discomfort, but performance decrements may occur before such states become apparent.

Figure 2.1 is a conceptual map illustrating these definitions and associated phenomena. It must be acknowledged that there is an overlap among the factors described in Figure 2.1. For example, under-stimulation or ETD may increase effects related to sleepiness or drowsiness.

Figure 2.1: A conceptual map illustrating the different definitions and associated phenomena of the term 'fatigue'



3 TARGETED REVIEW OF LITERATURE

3.1 Approach

A wide variety of data collection methods were employed to examine the issue of rider fatigue, as outlined below.

Searches of the TRL Knowledge Base were conducted in order to identify literature to be reviewed. The Knowledge Base comprises a number of databases, including the Transport Research Abstracting and Cataloguing System (TRACS). This is the main catalogue of transport research publications held both in the TRL library and elsewhere. It contains bibliographic references and abstracts of English and foreign language articles from journals, books and research reports. It is the English language version of the worldwide ITRD database (International Transport Research Documentation) and contains abstracts from publications in the USA, Australia, Scandinavia, the Netherlands and Canada, in addition to UK material. The database has been updated daily since 1972 and now comprises 260,000 items. This is the prime literature resource for transport research. The Knowledge Base also includes the PROJEX database that contains summaries of current and recently completed research projects undertaken in ITRD member countries.

The searches of the Knowledge Base were conducted using a number of combinations of the following key words, including:

- generally – ‘fatigue’, ‘motorcycle’, ‘research’, ‘accidents’;
- driver fatigue/tiredness/sleepiness/falling asleep;
- motorcycle rider fatigue/tiredness/sleepiness/falling asleep;
- fatigue/tiredness/sleepiness/falling asleep and accidents;
- motorcycle/rider discomfort/posture/seating position/thermal stress/noise stress;
- sleep deprivation/task demands/environmental stress;
- protective clothing/helmet/comfort;
- pilot fatigue; and
- military vehicle operator fatigue.

The PsycINFO database was also used to identify additional literature from other behavioural domains. PsycINFO is an abstract database of psychological literature from the 1800s to the present day, combining a wealth of content from a number of domains relating to psychology. TRL has access to PsycINFO through its library.

In addition to examining the driver fatigue literature, research into aviation operations was considered in the review, as this is another area where research into fatigue has been conducted that may be relevant to motorcyclists.

Further studies were identified by browsing (e.g. using the reference lists of other publications to identify relevant pieces of work). Where possible, researchers working in the field of driver/rider fatigue were contacted for advice and assistance with identifying the appropriate literature; these researchers include those working at European research institutes, such as members of FERSI (Forum of European Road Safety Research Institutes), the University of Caen, EMPA and on the COST357 programme. Contact was also made with Murdoch University and the Monash University Accident Research Centre in Australia. Many of the contacts stated that there was minimal literature in the field of motorcycle rider fatigue. Contact was also made with various police forces in order to gain understanding of whether fatigue is dealt with in professional rider training.

In addition to these approaches, internet searches were conducted to identify further relevant ongoing research, and official documents and standards were searched. As a crosscheck, professional TRL library staff also conducted searches of specialist, subscription-only websites and international libraries to check for any ‘gaps’. The search criteria used included:

- ‘fatigue and motorcyclists’;
- ‘fatigue/tired/sleep/asleep’; and
- ‘motorcyclist’ as well as ‘motorbike and rider’.

During the final stages of the preparation of this report, an investigation into fatigue-related motorcycle crashes that had been completed in May 2006, but appears not to have been published until December 2006, became available (Haworth and Rowden, 2006). This has been included in the current literature review with regard to motorcycle accident data in Australia; some of the definitions presented in the Haworth and Rowden (2006) review have been used to supplement our definition and findings.

The data collection methods are summarised in Table 3.1.

Table 3.1: Summary of data collection methods	
Order	Data collection methods
1	Searches of TRL’s extensive database ‘Knowledge Base’ and other database (e.g. PsycINFO, Medline, Psychlit) searches
2	Internet searches, including through ‘Google Scholar’
3	Personal contacts and professional networks, including contacting other major European transport institutes (e.g. FERSI members)
4	Official documents – standards/guidelines (e.g. <i>Highway Code</i>)/Government White Papers/Department for Transport road safety strategies
5	Searches of specialist, subscription-only websites and international libraries

3.2 Findings

3.2.1 *General incidence of fatigue in transport accidents*

Fatigue is a growing concern within transport operations. According to a group of international sleep experts, ‘fatigue (sleepiness, tiredness) is the largest identifiable and preventable cause of accidents in transport operations (between 15 and 20% of all accidents), surpassing that of alcohol or drug related incidents in all modes of transportation’ (Åkerstedt, 2000). They state that high incidences of fatigue can be found particularly in road transport (driver/rider fatigue) and in aviation.

Driver sleepiness is a major cause of road accidents, accounting for up to 20% of serious accidents on motorways and monotonous roads in Great Britain (Reyner and Horne, 2000). With increased work pressure, longer hours and more people working shifts, there are more people driving and riding in a fatigued state. However, relatively little information is available about the incidence of fatigue or its development in motorcyclists.

The Australian Transport Safety Bureau (ATSB, 2002) has developed an operational definition for identifying fatigue-related accidents. This concentrated on the sleepiness component of fatigue. The operational definition:

- includes single vehicle crashes that occurred during ‘critical times’ (midnight–6am and 2pm–4pm);
- includes head-on collisions where neither vehicle was overtaking at the time; and
- excludes crashes that:
 - occurred on roads with speed limits under 80 km/h;
 - involved pedestrians;
 - involved unlicensed drivers;
 - involved drivers with high levels of alcohol (blood alcohol over 0.05 g/100 ml).

It should be noted that several types of accident not related to fatigue would also be captured by this definition, for example rider suicide, rider drug usage/medical disorders, road geometry (e.g. bends), poor weather/reduced visibility conditions or motorcycle mechanical defects.¹ Furthermore, important contributory factors in single-vehicle accidents for riders include high speeds on bends, poor weather conditions and poor road surface (e.g. holes); as such, the definition as presented above does not directly cover such aspects.

¹ With regards to alcohol, it should be noted that the ATSB do state that low levels combined with other factors (e.g. time of day) can also increase the risk of being involved in fatigue-related crash.

Using the ATSB definition, the New South Wales (NSW) Roads and Traffic Authority (RTA, undated) concluded that 716 fatigued riders were involved in reportable traffic accidents in NSW over the period between 1996 and 2001. Of these accidents, 94% resulted in the motorcyclist being killed or injured (NSW RTA Traffic Accident Database). Fatigued riders made up 5.4% of all the riders involved in accidents during this period – a significantly higher percentage than for any other types of road users who were involved in accidents and who were fatigued; no further details of this study were published (Ma *et al.*, 2003). In the years 2000–04, 645 motorcycle crashes occurred in NSW; these crashes resulted in the deaths of 27 motorcyclists and in 607 injured. In this period, fatigue was associated with 9% of all fatal motorcycle crashes.

Taking the assumed relationship between single-vehicle accidents, time of day and fatigue that is implicit in the ATSB definition, it is interesting to note the results of other Australian research concerning motorcycle accidents. The Motorcycle Council of NSW (undated) has published that the majority of single-vehicle crashes occur on weekends, whereas collisions with other vehicles are more likely to occur during the week and be due to the other driver. In NSW, motorcyclists are more likely to be involved in a fatal crash on a weekend than on a weekday. Between the years 2000 and 2004, 49% of all motorcycle crashes and 55% of all fatal motorcycle crashes occurred on a weekend. A third of the fatal weekend crashes were single-vehicle crashes.

The following research studies were cited in Haworth and Rowden's (2006) literature review. A document produced by the RTA (2004) notes that 66% of motorcycle casualty accidents occur on weekdays, with almost a quarter of accidents occurring between 3pm and 7pm. Haworth and Rowden (2006) conclude that this is indicative of possible fatigue during the afternoon circadian low, with riders potentially losing concentration during critical manoeuvres. However, the authors add that we cannot ignore other factors, such as inexperience, as a potential influence on riders.

Moreover, Queensland Transport in Australia analysed accident data for 2001–05 and identified a total of 136 (1.9%) casualties (riders and pillion) as 'fatigue-related'. The majority of those accidents occurred between 2pm and 4pm. In order to identify those fatigue-related accidents, Queensland Transport (2005) used their own definition of 'driver fatigue crash' which identifies 'driver fatigue crash' based on either police reported data or a statistical surrogate:

‘... the numbers based on police assessment have been augmented to include single vehicle-type crashes (such as roll-overs or hit objects) on open roads, during high risk times for fatigue (that is 2pm to 4pm and 10pm to 6am)’.

It should be noted that the statistical surrogate does have certain limitations in that it does not, for example, exclude drugs/alcohol, loss of vehicle control (independent of fatigue) or roadway/weather factors (although such factors might be included in the police assessment). It should be further noted that loss of vehicle control is likely to be more of a problem for motorcycles than for cars (due to the nature of the riding task); hence this aspect of the definition is particularly limited for rider fatigue. Likewise, although acknowledged by Queensland Transport, the statistical surrogate may still underestimate fatigue, as it ignores, for example, crashes at other times of day or crashes in urban areas.

The Victoria road crash dataset in Australia does not include any specific guidelines of how to identify fatigue-related accidents. From the Victoria road crash data, Haworth and Rowden found that there are relatively few single-vehicle accidents between midnight and 6am but far more accidents between 2pm and 4pm, particularly on weekends. However, it should be noted that there are far more motorcycles (and more traffic overall) on the UK roads between 2pm and 4pm than between midnight and 6am.

Aircrew fatigue is also an area that has been highlighted as a problem in both civilian and military aviation operations, largely because of the unpredictable work hours, long duty periods, circadian disruptions and insufficient sleep. Although estimates vary, official statistics indicate that fatigue is involved in at least 4–8% of aviation mishaps, and regulatory efforts aimed at limiting flight hours and ensuring at least minimal periods of crew rest have, to some extent, mitigated fatigue-related difficulties in the cockpit (Dinges *et al.*, 1996). Moreover, measures such as education about the danger of fatigue, the causes of sleepiness on the flight deck and the importance of proper sleep are recommended for countering fatigue in aviation.

3.2.2 *Introduction to other research into fatigue*

The lack of research into rider fatigue may tempt us to rely on the wealth of driver fatigue literature to inform guidelines and interventions for rider fatigue; however, there are strong reasons to carry out fatigue research that relates specifically to motorcyclists. One of the key reasons for this is that the demands of the motorcycle riding task are somewhat different from those of the car driving task. These task differences may have significant consequences for the ways in which fatigue develops and affects riders and drivers respectively (Ma *et al.*, 2003). For example, a fatigued driver may simply drift across the road in a micro-sleep, whereas a fatigued rider may be quite alert but be more likely to crash on a curve while overtaking due to judgement errors. Motorcycle crashes that are assumed to be a result of rider error may instead be the result of poor judgement and attention loss due to fatigue. Although hard data are lacking, it has been suggested that rider fatigue is more likely to be a response to excessive physical demands than to monotony; other factors include dehydration and exposure to the elements (Motorcycle Council of NSW, undated).

On average, the human adult requires approximately eight hours' sleep for optimal performance and alertness; some people, however, require as little as six hours' sleep and others as much as 10 hours (Grandjean, 1988). Furthermore, it was found that sleep loss can degrade potentially any (and every) aspect of human performance, including vigilance, decision making and reaction time (Neri *et al.*, 1997), and fatigue can increase with task workload and the time spent engaged on a task (Matthews and Desmond, 2002).

Many researchers have studied fatigue in general, as well as the effects it might have on the driver and the causes of driver fatigue (e.g. Charlton and Baas, 2001; Horne and Reyner, 1995). However, only a few researchers have studied rider fatigue, the causes of rider fatigue and the effects it might have on the rider. These studies are described in the next section and in Appendix 2. Based on the few rider fatigue studies, subsequent sections will then expand on the causes and effects of rider fatigue. Information about rider fatigue will be supported by the causes and effects found in the literature on driver fatigue.

3.2.3 *Existing research into rider fatigue*

Three studies specifically examining rider fatigue were identified in the present review. Only two of these studies were empirically supported. Some other publications are information fact sheets whose scientific basis is unclear (e.g. Arthur, 2005). None of the research identified specified a definition for fatigue and none distinguished between fatigue as an overall term and its three components identified here (ETD, sleepiness/drowsiness and under-stimulation), though it is usually possible to infer what aspects the authors are intending to cover.

One pilot study conducted in NSW aimed to examine the effects of a recreational day ride on reported fatigue and performance (Ma *et al.*, 2003). A small sample of 20 motorcyclists were tested on two weekend days (a week apart from each other). One day of the study involved participants riding approximately 279 kilometres; the ride contained three compulsory stops totalling 1 hour 10 minutes; the entire trip averaged 5 hours 54 minutes. The participants were asked to start the ride between 8am and 9:20am, and to arrive back at the testing centre approximately six hours later. The other day acted as the control condition; participants were asked to refrain from recreational riding. To counterbalance the conditions, the order of days was reversed for half of the participants. Participants' reaction time and concentration levels were tested at the start and end of each day (six hours after the start of the ride); subjective fatigue was also rated at these times and throughout the day. For this, participants were given the following definition of fatigue:

‘By FATIGUE we don’t ONLY mean feeling DROWSY or SLEEPY. We ALSO mean being TIRED, LETHARGIC, BORED, UNABLE TO CONCENTRATE, UNABLE TO SUSTAIN ATTENTION and being MENTALLY SLOWED.’

Reaction times and concentration levels were tested by participants completing two computerised performance tests that were sensitive to changes in fatigue. The first performance measure was a simple reaction time task; the second was the Mackworth Clock Vigilance (MAK) task. Both measures scored reaction speed, variability in reaction speed and number of missed responses. The findings revealed that higher levels of subjective fatigue were reported at the end of both days; however, there was little evidence that the ride itself affected subjective fatigue more than the control days. However, as the ride began between 8am and 9.20am, and lasted six hours, then the time they were being tested in the afternoon was during the 'post-lunch dip', so any effects found may be purely due to the time of testing (in a circadian low point). No evidence of deteriorated concentration was apparent across either of the conditions; reaction times were more inconsistent at the end of each day than at the start, but again, this was not related to the ride. However, riders did report more physical fatigue at the end of the ride day than on the control day, especially for body regions that might be affected by the ride, such as the back, arms and hands.

The overall findings from this study suggest that the riding tasks employed did not generate levels of fatigue that would adversely affect motorcycle riders' abilities to perform information-processing and action-initiation (i.e. the riding tasks did not generate **mental** fatigue). The study did, however, reveal that physical fatigue was generated during the ride and this was positively correlated with subjective fatigue on the ride day. Thus, it was found in this study that the riding task might have had an effect on physical fatigue but did not have a detectable effect on mental fatigue. The authors took these findings to indicate that a day ride of almost six hours should not impair the reaction time and attention in motorcyclists, provided that they have had the appropriate amount of sleep prior to the ride and took regular breaks, but recommended further study into rider fatigue to focus on the impact of longer rides (e.g. seven or more hours). The authors also stress the importance of objective empirical data to provide a more complete understanding of rider fatigue. The final recommendation is for further research to be carried out, directly comparing the fatigue effects of drivers and riders.

The methodology employed in Ma *et al.*'s study appears to be reasonably robust in that it uses a combination of qualitative and quantitative data collection methods, which is something of a rarity in the area of rider fatigue. However, it seems possible that what was termed 'mental' fatigue, and was found **not** to be influenced, may have been interrupted by the change from the motorcycle ride to the study task at the end of each day. Physical fatigue, which **was** found to be influenced, may be less likely to be interrupted; however, the timing of the afternoon testing (during a rider's post-lunch dip) may have influenced the findings.

Gillen (1998) conducted a brief internet survey into motorcycle rider fatigue (12 respondents, 9 questions). Fatigue was not defined, but respondents were asked to say how they themselves would define it. The survey identified that riders have

different views on what constitutes fatigue and have varying degrees of awareness of the rider fatigue problem. The research found that riders employ several techniques to extend their riding time once signs of fatigue are detected. Gillen was unable to identify a consensus regarding countermeasure effectiveness. The study found that, in general, participants regarded sleep as being the principal countermeasure for rider fatigue. The participants' responses also indicated that rider fatigue and its countermeasures have considerable variance among individuals. While Gillen's small (self-selecting) sample was inadequate for scientific research, it confirmed that fatigue is certainly an issue for some riders and raised some interesting research questions, discussed below. Gillen also concluded that motorcycle riders primarily rely on their own experiences and some limited discussion with other riders to ensure that they remain alert while riding (see Appendix 3 for example attitudes of the riders to rider fatigue). According to Gillen, the dissemination of existing information related to fatigue and its countermeasures is urgently required in the motorcycling community. The article also raised several important research questions:

- Are motorcyclists more or less affected by fatigue than passenger car or truck drivers?
- Do the previously verified indicators of fatigue and drowsiness for other motorists apply to motorcycle riding?
- Do engine and wind noises play a role in rider fatigue and, if so, to what extent?
- Does machine vibration play a role in rider fatigue and, if so, to what extent?

Gillen's study was entirely based on subjective comments and observations; therefore, unlike the Ma *et al.* (2003) study, it was not based on objective data (such as riding performance measures or reaction times). Moreover, as a definition of fatigue was not identified in the Gillen study, it is impossible to draw concrete conclusions and directly relate the findings to any type of rider fatigue as such.

In their 1980 study, Travers and Jennings investigated the effects of fatigue on motorcyclists' reaction time and decision-making ability. They monitored an unstated number of riders' pulse rates during a 12 mile ride and compared the riders' reaction times with those reaction times from a control group, which carried out the same reaction tests but did not undertake the 12 mile ride. Reaction times for both groups were measured at 3pm (i.e. after the ride) and then at 10am the next morning. The results of the control group showed that, in normal conditions, reaction times were not slower in the afternoon than in the morning. In simple reaction tests, all reaction times were longer after the ride compared with the control group. A correlation between distance covered and the slowing of reaction time was also found. No specific details of comparisons made between the experimental and control groups were reported in the study. These results suggest that the further a rider travelled, the greater the effect of rider fatigue. In this study, the term 'rider

fatigue' was defined as sleepiness/drowsiness caused by riding, and the authors suggest taking frequent breaks as a countermeasure for rider fatigue.

Travers and Jennings (1980) concluded that more research into the area of rider fatigue would lessen the incidence of motorcycle accidents. However, it must be noted that performing the reaction time test at 3pm would likely correspond to a circadian dip in alertness (the post-lunch dip). As such, the study is flawed due to the timing of the reaction time test. Also, unless a sufficiently large sample was used (which was not reported), and the riders in the control and experimental groups were carefully matched on a wide range of criteria (including the amount of sleep obtained in the previous night), then comparisons between the two groups may be invalid due to the influence of confounding factors. Finally, as the study is almost 30 years old, the findings may be no longer valid – the design of motorcycles has substantially changed during that period, the amount of traffic on the highways has increased and rider training has changed.

3.2.4 Causes of fatigue

In all causes of fatigue it is important to distinguish between the different phenomena that fall under the fatigue umbrella discussed in Section 2 of this report. It is important to separate **sleepiness** from **ETD** and **under-stimulation**, as the causes of these phenomena are generally quite different. For example, sleepiness can be due to the lack of prior sleep or circadian rhythm issues, whereas time on task and task demands can affect performance without causing sleepiness.

3.2.4.1 Causes of driver fatigue

As previously discussed (Section 2 and see Appendix 1), in the reviewed literature the characteristics of **driver** fatigue include the subjective experience of sleepiness, reduced arousal and alertness, and decreases in the ability to maintain attention and to respond quickly (Charlton and Baas, 2001; Lisper *et al.*, 1986; Nilsson *et al.*, 1997; Williamson *et al.*, 1996). According to Brown (1994), driver fatigue can be caused by both the need to sleep and the task itself. Furthermore, the Queensland Travelsafe Committee (2005) stated that the amount of time spent on a task such as long distance driving is recognised as a main cause for fatigue. For example, driving performance has been found to decline after only 40 minutes of a repetitive simulated driving task (Thiffault and Bergeron, 2003).

Further research by Horne and Reyner (1995) found that monotonous tasks, such as highway driving, appear to be more susceptible to inducing fatigue than more arousing tasks such as urban driving. In the case of truck drivers, three common causes of fatigue have been identified, which are lack of prior sleep, time of day and time on task (Horberrry *et al.*, 2001).

Overall, the causes and symptoms of fatigue are well documented in the driver

fatigue literature, and it is likely that many of these symptoms may also apply to riders; however, it is both necessary and important to review material on the causes of fatigue and see what applies **specifically** to riders. It is also necessary to identify **why** the symptoms occur.

3.2.4.2 Specific characteristics of motorcycle riding that may contribute to fatigue

Riders are typically exposed to a far more hostile environment than drivers (as such ETD, primarily related to physical demands, is usually higher for riders than drivers). However, many factors associated with driver fatigue also apply to riders; for example, Ma *et al.* (2003) found that the majority of the 20 riders in their study highlighted the role of insufficient breaks, long riding hours and monotonous roads as contributing factors to fatigue.

As Coyne (1996) and the Motorcycle Council of NSW (2005) have pointed out, it is well established that thermal, noise, vibration and postural stress can cause discomfort and performance decrements. As mentioned above, motorcyclists are likely to be more subject to such stresses than car drivers. The Motorcycle Council of NSW states that sitting in the same position with limited movement for extended periods of time is unnatural and can lead to muscle stiffness and reduced blood flow, resulting in discomfort, fatigue (ETD) and concentration loss. However, it must be borne in mind that riders experience a range of factors that increase physical and mental workload, and at lower levels such factors do not necessarily lead to ETD. *Motorcycle Roadcraft* recommends riding with a relaxed posture (even during emergency riding) because it results in lower levels of fatigue (ETD) (Coyne, 1996). It should be noted that this advice relates purely to the task demands/environmental conditions of the motorcycle riding task; further, it should be noted that the scientific basis for such countermeasures is not given in these two reports.

Coyne stated that fatigue (ETD) can be caused by both hot and cold conditions. In warm weather, light-coloured garments were recommended to help riders to keep cool as well as to increase conspicuity. Cold weather was said to be dangerous because, as the body's core cools, the rider becomes sluggish and loses attention. The extremities cool more quickly than the body and, in cold weather, the average temperature of riders' hands (even when wearing gloves) is around 14–15°C (at which point, most of their sensitivity is lost).

Coyne (1996) also mentions other causes of rider fatigue, though again the research basis for these is not given:

- at night, dazzle and constantly changing conditions of visibility quickly result in fatigue, with any slight eyesight irregularity potentially causing stress and fatigue;
- medication (some types of medication have been found to be a common source of drowsiness); and

- riding for long periods of time in monotonous conditions, such as low-density traffic, fog, night or motorway riding, reduces stimulation and promotes fatigue.

Although Coyne (1996) did not explicitly define which aspect of fatigue he was dealing with, it is reasonably clear that he was concentrating on ETD and under-stimulation rather than sleepiness.

At the 2006 Motorcycle Safety Conference held in California, only the paper by De Rome and Stanford (2006) considered rider fatigue (ETD, rather than sleepiness or under-stimulation). The focus of this paper was protection from injury by the use of effective protective motorcycle clothing, but the authors suggested that comfort, in terms of protection from the elements, is important in reducing fatigue (ETD), although no scientific support for this was mentioned. Given the relative importance of the rider fatigue issue (in terms of the likely number of crashes that have fatigue as a causal factor), the under-representation of this topic at a relevant international conference is noteworthy.

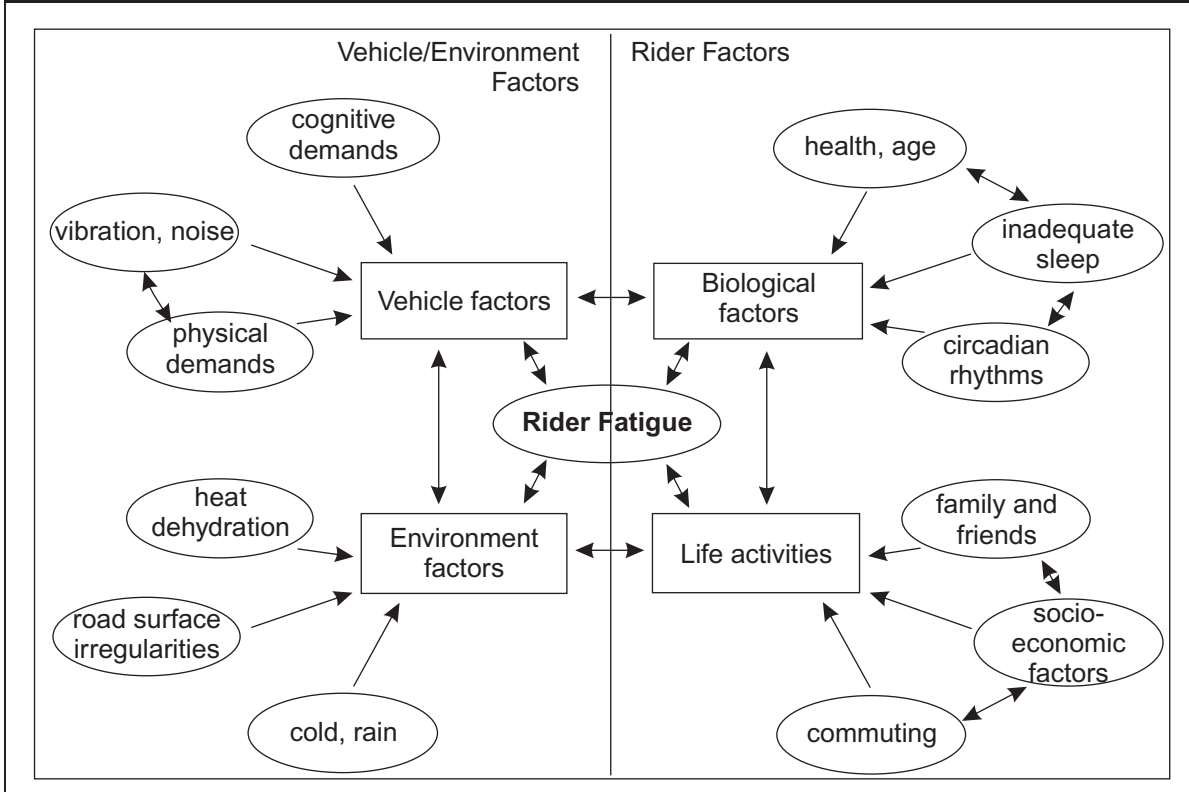
Alcohol and drugs can also be a cause of rider fatigue; this is primarily in terms of sleepiness, although they might also reduce a rider's resources to cope with the mental and/or physical demands of riding, so could lead to ETD. According to McKim (2003), drowsiness is a common effect of alcohol, cannabis, opiates, benzodiazepines, barbiturates and other medications such as antihistamines. The effects of alcohol and drugs may induce riders' drowsiness or they can add to the effects that lack of sleep has on riders (e.g. if lack of sleep is combined with alcohol).

Finally, Haworth and Rowden (2006) modified a previous diagram developed for truck drivers (National Transport Commission, 2001) to describe the factors that potentially contribute to fatigue in motorcycling (see Figure 3.1). The modified diagram was based on a review of the causes and effects conducted by Haworth and Rowden (2006), although the authors stated that they found limited evidence.

As shown in Figure 3.1, there are many factors that may cause the rider to be fatigued. Haworth and Rowden included factors such as environmental factors (e.g. cold, heat, road surface), biological factors (e.g. lack of sleep, circadian rhythms, health/age), life activities (e.g. commuting) and vehicle factors (e.g. cognitive and physical demands).

To compare directly the above diagram of factors with the definition presented earlier in this report (for example, in Figure 2.1) may be misleading, as the models use a slightly different set of terminologies and presentation approaches. Whereas the Haworth and Rowden model explicitly separates rider factors from environmental/vehicle ones, it does not explicitly separate types of fatigue (nor does it mention under-stimulation). It is argued here that a more explicit elucidation of the umbrella term 'fatigue' is useful to understand not only the contributory factors

Figure 3.1: Adaptation of diagram from NTC (2001) to show factors that potentially contribute to fatigue in motorcycling



(as is also shown in the Haworth and Rowden model) but also their different effects (e.g. errors, falling asleep or task-induced boredom). Furthermore, the fatigue taxonomy presented in this report is argued to lead to a better understanding of the underlying components/mechanisms, and thus can result in more effective countermeasures (for example, some countermeasures focusing on obtaining good-quality sleep, or others to reduce the physical demands of the riding task).

3.2.5 Effects of fatigue

3.2.5.1 Effects of fatigue on drivers

There is a large amount of literature about falling asleep while driving (e.g. Maycock, 1997; Engleman *et al.*, 1997; Marshall *et al.*, 2004). Falling asleep behind the wheel is more common than is generally realised. It accounts for a considerable proportion of vehicle accidents under monotonous driving conditions, and many of these accidents are related to work – for example, drivers of lorries, goods vehicles and company cars (Horne and Reyner, 1999). Stein (1995) found that the ability to perform tasks such as steering and lane tracking deteriorate when a driver is sleepy. Moreover, in a study conducted by Williamson *et al.* (1992), truck drivers reported poorer gear changing, poorer steering, slowed reactions and failure to maintain vehicle speed as the primary effects of sleepiness on their driving performance. The capacity for self-awareness of symptoms of sleepiness in car and lorry drivers was

investigated by Horne (2000), and this research was specifically examining sleepiness rather than other aspects of fatigue. It was found that in more sleepy states, drivers often lose their capacity to be accurately aware of their own levels of sleepiness, so are not best placed to make decisions about when to stop driving due to excessive sleepiness. It seems likely that a similar effect may equally apply to riders.

Since it has been shown that fatigue can reduce the ability of the driver to drive safely (e.g. Dingus *et al.*, 2006; Ferguson, 2003; Pertidou and Moustaki, 2000; Williamson and Boufous, 2006), it is very plausible to assume that there is some correlation between fatigue or sleepiness and car accidents. In addition, sleep-related accidents tend to be more severe than other accidents, perhaps because the monotonous roads on which they tend to occur are those permitting higher speeds, but also because the driver cannot take any preventative or avoiding action, for example braking prior to the collision (Horne and Reyner, 1995).

3.2.5.2 Effects of fatigue on riders

In contrast to driving, very few studies have dealt specifically with the effects of fatigue on riders. Travers and Jennings (1980) stated that, even before a rider is aware of fatigue, reactions and arousal levels would have deteriorated, though the basis of this assertion is not given. However, the above-mentioned flaws in their study (with the timing of the reaction time test, and probably lack of experimental control of the matched groups) should be noted. Again without any clear empirical support, they also argued that research into rider fatigue will help to lessen the incidence of motorcycle accidents. The results of Ma *et al.*'s (2003) evaluation showed that motorcycle riders' ratings of fatigue increased over a day involving a recreational ride, but this increase was not statistically significantly greater than that reported by the same people after they had spent a day resting at home. However, Ma *et al.* were also unable to find any evidence of rider fatigue affecting speed or accuracy of performance on simple reaction time or vigilance tests.

Based on his personal experiences as a rider, and as US Navy Surgeon General, Arthur (2005) suggested that mental processing power slowly reduces as the amount of fatigue increases (as with much other work in this area, he did not explicitly discuss which aspect of fatigue he was dealing with, although it is understood to be ETD). He also suggested that, while individual differences are evident in response to fatigue (most probably ETD), three factors appear to be common predictors of a motorcyclist's functional decrement. These factors are task skill level, level of training and innate biological factors. It is presumed that he was discussing ETD because tuition, experience or aptitude would not stop a rider from falling asleep if they were experiencing the type of fatigue categorised here as sleepiness. Vicente (1999) suggests that, in terms of task skill level, the more practised, automated and proficient one becomes in a given task, the less effortful the task becomes. As such, it follows (although not specifically mentioned by Vicente) that this might lead to a

reduction in ETD. Similarly, Arthur (2005) proposes that better training and more experience may have protective effects against fatigue (this was not explicitly defined, but the definition of fatigue seemingly focuses on ETD). According to Arthur, there is no counterbalance to innate biological factors, but he asserted that, in general, less experienced riders are at greater risk of suffering the effects of fatigue (ETD) than those riders who have built up their experience, thus slowly building up a set of riding limits and coping strategies.

Again, based on his experiences, Arthur (2005) lists some effects of rider fatigue, which are reproduced in Table 3.2. These effects could be due to several fatigue-related phenomena, including sleepiness. In the final three columns of the table, the types of fatigue that may be applicable to the effects mentioned are highlighted (these are created by the report authors based on the taxonomy used here, and therefore do not come from Arthur).

Table 3.2: Some effects of rider fatigue (source: Arthur, 2005) and the type of fatigue likely to be involved				
Effect	Example of effect	Possible type of fatigue involved		
		ETD	Under-stimulation	Sleepiness
Slow reaction time	<ul style="list-style-type: none"> Braking hard to avoid a hazard 	Potentially in some situations	Yes	Yes
Reduced awareness/vigilance	<ul style="list-style-type: none"> Driving slower than normal Being surprised by a passing car Tailgating Not seeing road hazards 	Potentially in some situations	Yes	Yes
Impaired memory	<ul style="list-style-type: none"> Passing a petrol station when low on fuel Forgetting your wallet after fuelling 	No	Potentially in some situations	Yes
Impaired decision-making	<ul style="list-style-type: none"> Not stopping to rest when tired Taking an inappropriate route 	No	Potentially in some situations	Yes
Loss of situational awareness	<ul style="list-style-type: none"> Failure to recognise stop signs or signals Not putting the kickstand down Failure to put feet down when stopping Stopping in a high gear Failing to 'go' when traffic lights turn green 	No	Potentially in some situations	Yes
Performance decrement	<ul style="list-style-type: none"> Inability to formulate routing plans Failure to communicate with riding buddies Task fixation 	Potentially in some situations	Potentially in some situations	Yes

In Gillen's 1998 informal survey, the 12 riders were asked questions about how they defined and identified fatigue, from their own experience. Seemingly by design, fatigue was not explicitly defined, although from the responses received this is likely to have resulted in his respondents reporting issues that included both sleepiness and other types of fatigue. Phrases common to several responses regarding the definition of rider fatigue included:

- the inability to concentrate;
- a conscious effort to remain alert being required; and
- delayed reaction times.

The participants were asked what fatigue symptoms they experienced while riding. The responses reported by Gillen typically centred on physical symptoms, such as reduced visual function, along with tight muscles and yawning.

3.3 Countermeasures to combat the effects of rider fatigue

3.3.1 *Range of countermeasures*

Remedial measures to combat fatigue in **drivers** have been discussed in the literature for a number of years – these mainly focus on sleepiness. In this section, countermeasures that could be used to combat the different types of rider fatigue are discussed. It should be noted that there is some overlap between the countermeasures (for example, some studies have investigated the use of rest breaks in conjunction with the ingestion of energy drinks and/or caffeine).

3.3.1.1 **Fatigue management programmes/plans**

It is recognised (e.g. Horberry *et al.*, 2001) that measures such as undertaking formal Fatigue Management Programmes (FMPs, also occasionally referred to as Fatigue Management Plans) can be effective in order to manage fatigue mainly due to sleepiness. A number of different types of FMPs exist, but they usually are training programmes for the control and management of **driver** fatigue (focusing largely on sleepiness, but also covering ETD (such as time on task), and possible under-stimulation (at least on the road types in some countries, such as rural areas in Australia)). They aim to promote understanding of the causes and effects of fatigue in the commercial vehicle industry, as well as teaching the skills to prevent aspects of fatigue (such as good sleep hygiene to prevent sleepiness). Upon completion of the FMP, participants should be able to:

- identify and describe the causes and effects of fatigue-related accidents;
- identify and describe the personal warning signs that precede the onset of fatigue;
- describe development strategies that prevent and reduce driver fatigue; and

- identify and describe those practices that are most effective in combating the causes of driver fatigue (especially focusing on sleepiness).

3.3.1.2 Caffeine/energy drinks

The use of caffeine in coffee, tea, cola and other drinks is a commonly-used countermeasure in transport to delay the onset of sleepiness (Hartley and Arnold, 1995). Looking at empirical studies, Horne and Reyner (1996) found that 150 mg of caffeine, plus naps (under 15 minutes long) effectively and separately reduce sleepiness in drivers for up to one hour (although the beneficial effects of napping were not as strong as caffeine). Further research by Reyner and Horne (1997) into the suppression of sleepiness found that the combination of a slightly higher dose of caffeine (200 mg) and napping could reduce sleepiness for up to two hours.

Accidents to car, truck and van drivers caused by sleepiness occur more frequently between 2am and 6am, and 2pm and 4pm (Horne and Reyner, 1995). As a result of these findings, Reyner and Horne (2000) investigated early morning driver sleepiness. They found that 2–3 cups of coffee prior to driving reduce this type of sleepiness for about 30 minutes following no sleep the night before and for around two hours after a restricted night's sleep (the participants' sleep was restricted to five hours from midnight).

Similar results have been found in related domains. For example, Dinges *et al.* (1996) found that caffeine used strategically (i.e. started 30 minutes before the effect is required) was found to be successful in countering sleepiness in commercial aircrew.

Likewise, studies undertaken in a driving simulator have also found broadly similar results. The consumption of energy drinks containing carbohydrates and caffeine was found to help sustain driver alertness and reduce the impact of fatigue on the driver's performance (Parkes *et al.*, 2001; Parkes *et al.*, 2002). It should be noted, however, that the participants in these studies were not specifically sleep deprived, but they were tested in their post-lunch dip. The authors of these two studies concluded that consuming such energy drinks in conjunction with a rest break could be an effective strategy to assist drivers in coping with fatigue (sleepiness and ETD). Given the demanding nature of the driving tasks undertaken in the simulator (e.g. tasks requiring high visual demand and/or complex manoeuvring), it is unlikely that under-stimulation was a factor in these studies.

Parkes *et al.* (2005) conducted an additional study examining energy drinks containing glucose and caffeine, and found similar results to the previous two studies. The results indicated that the driving performance improved even after drinking a low-caffeine energy drink (40 mg caffeine): performance in lane keeping, reaction time and following tasks was superior after drinking the energy drink as compared with before consuming the drink.

Therefore, the weight of evidence is generally in support of the use of caffeine to delay the effects of sleepiness in some circumstances. However, the best countermeasure for sleepiness is proper sleep, and also it should be noted that negative effects from using caffeine may result. For example, Penetar *et al.* (1993) found that the stimulant effect of caffeine may decrease with regular use; this was based on results from a study in which they assessed the ability of high doses of caffeine to reverse changes in alertness and mood produced by prolonged sleep deprivation.

3.3.1.3 Naps/rest breaks

As mentioned in the above section, naps have often been investigated in combination with caffeine (and where they have been compared, the effects of caffeine were stronger in terms of delaying sleepiness). However, the use of naps and breaks is a frequently used countermeasure (for riders, mentioned by Ma *et al.*, 2003).

The effectiveness of brief naps has also been established in other domains. For example, a study conducted by NASA, examining the effects of a 40-minute rest period on commercial aircrew, found that, during actual operations, a brief nap can significantly increase performance and alertness (Dinges *et al.*, 1996).

Napping for motorcyclists is, however, not easy to achieve. Unlike a truck driver, who can nap in his/her vehicle (often in a bed in the rear of the cab), the motorcycle is far from ideal for this purpose. Also, given the UK climate and lack of provision of rest areas near highways, the rider often cannot easily nap near their motorcycle.

As such, usually the best option of this type open to a rider is to take a break, but not to nap. Owing to the physical demands of the motorcycle riding task, this may include stretching or physical activity (including stopping to re-fuel). For commercial aircrew, Dinges *et al.* (1996) found that physical activity can be used to ward off sleepiness, provided that breaks are allowed for muscle recovery. Specifically for riders, the RTA (2003) recommends making regular stops to walk around and stretch. It is therefore possible that such breaks may be beneficial for all three types of fatigue mentioned in this report; however, any beneficial effects for sleepiness are likely to be short-lived at best. Despite this, such breaks could be particularly beneficial for ETD in riders, and thus it is recommended that more research is undertaken to further explore this issue.

3.3.1.4 Environmental stimulation

Environmental stimulation can play a significant role in minimising under-stimulation. For example, research has shown that solitary environments, with sedentary posture, are the most vulnerable to performance degradation (Neri *et al.*, 1997); as such, this seems somewhat applicable to the motorcycle riding task.

Environmental stimulation (e.g. meaningful conversation or changes in tasks) was found to reduce some effects of sleep loss in commercial aircrew (Dinges *et al.*, 1996). Of course, conversation while riding is difficult (although not always impossible). Likewise, options for changing the riding task are very limited (although small changes to posture are usually possible).

Reyner and Horne (1998), examining such potential countermeasures for sleepiness, evaluated 'in-car' countermeasures to sleepiness in the forms of cool air and the use of a radio. In their study, 16 young adult drivers had their sleep restricted to five hours the night before and drove an interactive car simulator in the afternoon for 2.5 hours, under monotonous conditions. After 30 minutes of driving, participants were exposed to three conditions:

1. cold air to the face from the vehicle's air vents;
2. listening to the vehicle's radio/tape player (according to the participant's own choice of music); or
3. no treatment.

If a participant drifted over a lane marking, this was considered to be an 'incident'. In addition to this, electroencephalograms (EEGs) were recorded and participants responded to the Karolinska Sleepiness Scale (KSS) every 200 seconds. The results showed that the radio and air conditions had no significant effects on incidents. The authors conclude that, compared with other countermeasures such as caffeine and a brief nap, cold air and radio countermeasures are, at best, only temporary measures to reduce driver sleepiness. While these measures may be useful for temporarily alleviating the effects of sleepiness in drivers, it is unlikely that they would be useful for **riders**, particularly the cold air condition, as the nature of the riding task exposes them to cold air throughout their ride, and, as discussed above, it has been suggested (e.g. by Haworth and Rowden, 2006) that the airflow can actually contribute to other types of rider fatigue (ETD from the physical demands of a task).

3.3.1.5 Highway engineering and technological measures

The above types of countermeasure (e.g. adequate pre-journey sleep, plus napping and caffeine during journey breaks) may help the driver delay the onset of sleepiness and its related effects on performance. Other countermeasures aim to help the driver recognise the onset of sleepiness or its effects on performance, so that he/she can take remedial action. These include in-car devices that monitor steering behaviour or eyelid movements, or detect lane departures, and external devices such as lane-edge rumble strips (e.g. Horberry *et al.*, 2001).

Fatigue detection technologies (based on rider state or riding performance) promise a great deal, but as yet have not been systematically investigated in motorcycle riding. They are beginning to be used more in commercial vehicle, military and

mining operations (Horberry *et al.*, 2001), however, at the time of writing, no single technology is dominant in the market. As such, it seems that effective devices that detect, or predict, rider fatigue will not be widespread in the near future.

Road protection systems, such as crash barriers, have the potential to help to reduce either the number or severity of crashes due to types of fatigue. However, their effectiveness for motorcycles is less than for cars and trucks. For example, wire crash barriers are a particular problem for motorcyclists because, unlike car drivers, they are not protected by the vehicle's shell if they hit the barrier, and thus the injuries they sustain can be more severe.

Further, there has been a significant body of research in recent years which has been aimed at reducing accidents through the re-engineering of the road environment. A number of engineering measures have been developed to raise drivers' and riders' levels of alertness when they are approaching a hazardous situation after travelling long distances on relatively featureless roads. Examples are the use of transverse 'yellow bar markings' on the approach to rural roundabouts (Helliar-Symons, 1981; Haynes *et al.*, 1993), and the use of 'Countdown' signs and other brightly coloured road markings on the approach to villages (Wheeler *et al.*, 1994; Wheeler and Taylor, 1999). While these measures have been primarily designed to reduce speeds, it is worth noting that transverse yellow bar markings, in particular, were found to reduce accidents substantially **without** reducing speeds. This suggests that drivers'/riders' concentration levels in these situations may be lower, possibly as a result of a type of fatigue (especially sleepiness), and that the measure successfully alerted drivers to the coming hazards.

3.3.1.6 Groups of countermeasures possibly effective for rider fatigue

As mentioned above, countermeasures have often been evaluated in combination. Equally, as evidenced in Fatigue Management Programmes, it seems likely that a combination of measures may be more effective than simply relying on one single solution. Such proposed lists of countermeasures are examined here.

Several countermeasures against sleepiness were identified in a study of flight deck operations on aircraft carriers (Neri *et al.*, 1997). Based on the responses to operational questions on the effects of sleep loss and fatigue countermeasures, they identified six areas which they felt helped to counterbalance the effects of sleepiness:

- caffeine;
- napping;
- social interaction;
- physical activity;

- organisational factors; and
- diet.

Very few details of the methodology of this study were reported – for example, no details of the number of participants were provided in the paper. Despite this, most of the items on this list have been shown in the above sections to be effective for riders in some situations. Although no direct evidence of the benefits of correct diet to combat fatigue for riders has been found, it could be speculated that correct diet may, in theory, be slightly beneficial in reducing ETD arising from a harsh physical environment. Similarly, good diet might be more likely to lead to good sleep patterns.

Focusing specifically on rider fatigue, despite the lack of scientific studies in this area, there have been several published attempts to produce guidance for motorcyclists on how to combat fatigue. For example, the Motorcycle Council of NSW lists some strategies and exercises to help keep riders alert. These suggestions, and commentaries by the authors of this report, are as follows:

- Making regular stops to walk around and stretch – the RTA (2003) recommend doing this at least every hour and a half. As seen above, this would focus on reducing the physical demands of the task, so focused on ETD.
- Working out realistic time targets for trips before setting off, and ensuring that time for rest breaks is taken into consideration, thus reducing pressure. As such, this measure may be beneficial for all types of fatigue.
- Drinking plenty of water. The argument here was that, if riders do not drink water, they are likely to become dehydrated because of their exposure to the elements, which will accelerate the onset of fatigue effects due to the physical demand of the task. Thus, if valid, it is applicable to combat ETD.
- Avoidance of coffee and soft drinks – this is because their effects are short-lived and can ultimately leave riders sleepier (at least in the case of the negative rebound effect from sugar in soft drinks (White and Wolraich, 1995); the evidence for the caffeine rebound effect is less compelling). So, to a degree, this differs from the research evidence reviewed earlier in this report (where positive effects for caffeine were obtained to delay the effects of sleepiness in some circumstances). Therefore, if this point is valid, it would be applicable to help combat sleepiness.
- Avoidance of alcohol – alcohol is a depressant drug, so even small amounts can increase any existing levels of fatigue. As such, this measure may be beneficial, primarily to combat sleepiness.
- Eating light snacks frequently rather than heavy meals is recommended, as digesting heavy meals (containing complex carbohydrates) requires more physical energy than light snacks and therefore can increase sleepiness. The

exact evidence for this is unknown, and in the opinion of the authors of this report it is not of great use. Riders cannot snack while riding, so must stop to eat meals. It is argued here that obtaining sufficient nutrition and energy is perhaps of more importance than requiring riders to assess the digestibility of a potential meal.

Again, it should be noted that the scientific basis of these countermeasures is not given in the Motorcycle Council of NSW document. However, sometimes the above list does seem to conflict with research results in this area (e.g. in the case of avoiding caffeine) or the evidence upon which they are based is uncertain (in the case of eating light meals that contain a low amount of complex carbohydrates).

Based on his riding experience, but informed by his professional expertise as US Navy Surgeon General, Arthur (2005) put together a list of possible measures to counter the effects of rider fatigue. The emboldened text below is quoted directly from Arthur (2005) and covers both sleepiness and task-induced fatigue. Again, the scientific basis of the recommendations, and the evidence for their effectiveness, are not discussed by Arthur, so the authors of this report have given a view where appropriate (in non-bold font).

- **‘Motorcycle and equipment – the bike should be configured to produce the least fatigue.’** It is presumed that Arthur is discussing ETD, not sleepiness, but such optimisation may reduce the physical demands of the riding task, so possibly reduce ETD. Although the evidence is not available, it would seem possible, and is, in general, supported by Haworth and Rowden (2006) in terms of the physical demands of riding.
- **‘A windshield sufficient to significantly reduce wind pressure and deflect rain will considerably increase fatigue tolerance.’** As above, this may reduce ETD by reducing the physical demands placed on the rider.
- **‘Hearing protection significantly decreases noise stress caused by the constant din of the road.’** Although such noise may be annoying, no specific research linking it to rider fatigue has been identified. More general research (e.g. Grandjean, 1988) has linked excessive noise to reduced work performance. However, it is questioned whether that can be classified as a fatigue issue.
- **‘Eliminate from the ride wherever possible:**
 - Severe time constraints
 - Bad weather
 - Excessive heat or cold
 - Unfamiliar roads
 - Monotonous scenery
 - Extended night riding
 - Increased threats – wildlife and traffic
 - Riding conditions beyond the rider’s ability

- Complex tasks required while riding
- Distractions – mechanical or family problems.’

Many of these issues have been mentioned in this report, and in the Haworth and Rowden (2006) review. However, some do not appear to be specific fatigue issues (e.g. threats from wildlife or traffic), but are more general rider safety issues.

- **‘Effective resting.’** As discussed earlier, breaks could be beneficial, especially to reduce ETD.
- **‘Socialisation.’** As discussed earlier, communication may have a temporary stimulating effect. However, it is not easy (or safe) while riding.
- **‘Exercise and other external stimulation.’** Similar to effective resting, such breaks/stimulation may have an effect on types of fatigue (although for sleepiness, this effect may be very short-lived).
- **‘Nutrition and hydration.’** As with the Motorcycle Council of NSW list, the exact evidence for this is unclear, but it may have some benefit to reduce ETD.
- **‘Caffeine.’** Contrasting to the Motorcycle Council of NSW list, caffeine is recommended here. This more closely matches the research literature on the topic about the possible benefits of caffeine in some situations (provided it is not used excessively).

Similarly, countermeasures to combat rider fatigue (mainly focusing on sleepiness and reducing strain of the riding task) proposed by the Police Foundation (in Coyne, 1996) are detailed below. The emboldened text below is quoted directly from Coyne; the authors of this report have given a view where appropriate (in non-bold font):

- **‘Ensuring that riders do not feel sleepy before riding’** – as discussed above, obtaining appropriate prior sleep is vital. Of course, ways to assess if a rider feels sleepy would generally need to rely on self-reports.
- **‘Using any adjustments available to make the riding position comfortable’** – as mentioned in the earlier lists, optimising the riding position may reduce physical demands, so could reduce ETD.
- **‘Adopting a comfortable position on the machine with the instep resting on the foot rests’** – as above in terms of optimising the riding position.
- **‘Wearing internal ear protectors (ear plugs) to reduce noise’** – as discussed in the list by Arthur, the use of noise protection might be beneficial to performance, but the links to fatigue are not clear.
- **‘Wearing clothing that provides physical protection as is appropriate’** – similar to the above point, physical protection should have a safety benefit to the rider. However, it is questionable if this can be classified as fatigue (in the view of the authors, at best clothing might reduce the physical strain of the riding

task, so might partially impact upon ETD). However, no research evidence has been identified to support this.

Coyne (1996) also stressed the importance of taking regular rest breaks to recover from the onset of fatigue (presumably ETD). He argued that most people need a rest break of at least 20 minutes. *Motorcycle Roadcraft* advises that, on long journeys, riders should plan a series of rest breaks, recognising that each successive break gives less recovery than the one before.

Finally, in Gillen's small 1998 survey, the question '**what techniques/actions do you use to overcome fatigue once identified?**' yielded mixed responses. Some participants chose 'on-bike' activities in an attempt to overcome fatigue – such as singing, isometrics, some limited body movement and increased air supply. Others chose stopping for food or drink, to exercise and stretch, or to have a 'power' nap. Beyond these techniques, sleeping for one to two hours was undertaken in an attempt to pay back 'sleep debt'. Other responses included 'as much sleep as possible/reasonable prior to starting; light meals'. One participant's response to this question was that riding with a full-face helmet with the visor closed caused fatigue. He believed that this may decrease oxygen intake because the rider is partially breathing in their own exhaled air. This has some scientific resonance: Brühwiler *et al.* (2005) conducted research into CO₂ and O₂ concentrations in integral motorcycle helmets. They found that an oxygen-deficient environment caused by wearing integral helmets may diminish human cognitive abilities by reducing concentration and slowing reaction times. Furthermore, it was found that natural feedback mechanisms, such as opening the visor, do not automatically eliminate the accumulated CO₂. Although the methodology employed in this study appears to be fairly robust (average concentrations of CO₂ and O₂ were measured both in the lab and in the field, allowing the effects of the slipstream to be replicated, and typical helmets were used), it is impossible to be certain how representative or accurate the measurements were.

Much of the literature referred to above concentrated on the problem of **driver** fatigue, and this was then either extrapolated to riders, or based on anecdotal evidence. In general, countermeasures that are effective for drivers would also be expected to be relevant to motorcycle riders. What is very uncertain is the relative importance of the various aspects of fatigue for motorcyclists, though we might speculate that sleepiness and under-stimulation are likely to be relatively less important for motorcycle riding than they are for driving (partly because riding is usually more stimulating than driving), and that fatigue effects associated with excessive task demand and physical stress are more important for riders than for drivers.

3.3.2 Rider training

TRL also reviewed whether fatigue was covered in motorcycle rider training programmes.

3.3.2.1 Professional rider training courses

Contact was made with several police forces across the country to ascertain whether any type of fatigue training (based on previous research and/or experience) was provided to professional riders.

The police training college at the Metropolitan Police in Hendon advised that the rider training provided by the Metropolitan Police does focus on rider fatigue, and the elements that it examines specifically include:

- posture (so focusing on reducing riding task demands);
- length of time on duty (so focusing on reducing task demands or sleepiness);
- shift sleep patterns (so examining sleepiness); and
- circadian rhythms (so also examining sleepiness).

Two key references are used as the basis for the Metropolitan Police rider training schemes:

- *Motorcycle Roadcraft* (Coyne, 1996); and
- *Human Aspects of Police Driving* (Sharp, 1997).

The college also said that the majority of rider training is based on **driver** fatigue literature and modified where needed.

The Driver Training School at Surrey Police also advised that their rider training is based on *Motorcycle Roadcraft*, the police riders' handbook. Fatigue is covered within chapter one of *Roadcraft* and all students are expected to be fully conversant with its content; fatigue is not covered as a separate issue. It was reported that Surrey Police motorcyclists do not have any serious fatigue issues.

One of the police motorcycle rider trainers from the Thames Valley Police force advised that the Thames Valley Police typically focus on training fatigue through experience and base the theoretical side of training on *Motorcycle Roadcraft*, the *Highway Code* and Sharp's *Human Aspects of Police Driving*. Contact with the Cambridgeshire Constabulary also confirmed that the key texts mentioned above were used as a basis for police rider training schemes.

Given that most of the police forces contacted rely on one short chapter in the Police Riders' *Motorcycle Roadcraft* book specific to rider fatigue to base their training on,

it might be beneficial to supplement this with driver fatigue literature (i.e. taken from the *Human Aspects of Police Driving* book). This indicates that training literature (specific to motorcycles) is needed to enable training programmes to be designed for riders.

3.3.3 *Published guidance that has addressed fatigue and its consequences*

In the literature search, only a few guides to combat rider fatigue were located. One of these was the *South Australian Motorcycling and Road Safety Strategy 2005–2010* (Government of South Australia, 2005). In this guide, priorities have been made in the ‘construction, upgrading and maintenance section for the provision of rest areas with amenities that are friendly and motor-cyclist friendly to stop, thus avoiding the hazards of fatigue’. In the legislation, education and enforcement section of the strategy, priorities have been made for the promotion of an awareness campaign about the hazards of rider fatigue; promoting the idea that fatigue is the ‘silent killer’ and exploring ways to educate riders about fatigue. While this strategy appears worthy of praise as seemingly the only one of its sort, the level of both of these priorities has been set as ‘low priority’.

Gillen (1998) argued that public awareness guides need to be developed in order for any rider fatigue research taking place to be communicated to the motorcyclist community that it affects. The lack of rider fatigue published guidance is not surprising, given the paucity of actual rider fatigue research.

4 INVESTIGATION INTO THE INCIDENCE OF RIDER FATIGUE IN ACCIDENTS

4.1 Aim

The aim of this task is to investigate the extent of the involvement of fatigue in motorcycle accidents by analysis of the various accident reporting databases. Apart from providing information about the incidence of rider fatigue in accidents, these databases potentially also provide information on some of the other characteristics and contributory factors involved in fatigue-related motorcycle accidents. By examining these characteristics and reported causation factors, we will aim to have a better understanding of the impact of fatigue on accidents.

4.2 Approach

Four different databases were examined: 'On the Spot' (OTS), STATS19, 'Fatals' and Motorcycle Accident In Depth Study (MAIDS). They are described in Appendix 4. All these databases consist of accident data that includes contributory factors such as fatigue. The analysis concentrated on identifying the other characteristics (e.g. the month of accident, road class and type, weather, and day of the week the accident occurred) of fatigue-related accidents.

4.3 Findings

Only a limited number of fatigue-related motorcycle accidents were identified in the four databases. Of the 242 motorcycle accidents available from OTS, only one case was found to have fatigue as a contributory factor (among other factors). Fifty-seven STATS19 motorcycle accidents had fatigue as one of the contributory factors, and 15 fatal motorcycle accidents were thought to have been caused by rider fatigue among other factors. Finally, in the MAIDS database, fatigue was considered to be one of the contributory factors in 27 of the 921 accidents investigated. The main results from the analysis of the four databases are summarised in Table 4.1 and in Sections 4.3.1 to 4.3.4.

Database	No. of cases found with 'fatigue' as CF (<i>n</i> = total number of motorcyclists)
OTS (Phase 1 and 2)	1 (<i>n</i> = 242) ²
STATS19 (over a 5-year period)	57 (<i>n</i> = 34,982)
Fatals (years 1991–92)	15 (<i>n</i> = 376)
MAIDS	27 (<i>n</i> = 921)

2 Data are presented up to September 2006 when data collection was ongoing for OTS phase 2.

4.3.1 *OTS*

One case was found to have fatigue as a contributory factor in the OTS database. One of the possible causations for the accident was impairment through fatigue, although the OTS team also found other factors that might have contributed to the accident.

4.3.2 *STATS19*

Of the 34,982 motorcycle accidents examined, there were 57 (0.16% of the total) in which fatigue was assigned as a contributory factor. Thirty (53%) of these were single-vehicle accidents and 20 (35%) were accidents involving a car. The remainder involved other types of vehicle. It was found that only one of the 57 accident-involved riders had braked before the accident occurred. The remaining 56 riders were 'going ahead' and did not brake before the accident. Twenty-nine (51%) of the 57 fatigue-related accidents occurred on an 'A' class road and 9% occurred on a motorway.

4.3.3 *Fatals*

Fifteen of the 376 fatal motorcycle accidents (3.99% of the total) were found to have fatigue as a causative factor. Of the 15 accidents, 10 (67%) were single-vehicle accidents. The road condition during all but four of the accidents was dry. Three of the accidents occurred on a wet road and one occurred on a frosty road. Visibility during all of the 15 accidents was good. All riders were wearing helmets at the time of the accident. Eight of the 15 accidents occurred on an 'A' road, one occurred on the motorway and the remaining six occurred on smaller 'B' or unclassified roads. Although all 15 accidents had fatigue as one of their contributory factors, nine of them also included alcohol as a contributory factor. Other factors included 'failure to judge other person's path or speed', 'inattention/careless', and 'lack of judgement of own path'. As such, it is difficult to confidently assert that fatigue was a major contributory factor given the other factors identified. In general, the low sample size (of 15 Fatal cases) did not allow any meaningful analysis.

4.3.4 *MAIDS*

Fatigue was recorded as a possible contributory factor in 27 of the 921 motorcycle accidents in the MAIDS database (2.93% of the total). Of these 27 accidents, 10 were recorded as single-vehicle accidents and of those, only one accident occurred on a motorway. Other factors, such as the time of accident, weather at the time of accident and day of the week the accident occurred, were also recorded by MAIDS, but again the low sample size did not allow meaningful conclusions to be drawn.

4.4 Discussion

Owing to the low numbers of fatigue-related motorcycle accidents identified from the four databases it has been difficult to draw any meaningful conclusions about the associated accident characteristics from the available data. Moreover, the analysis showed some inconsistencies with the data collection and recording in the four databases, which may have contributed to a difference in the representation of fatigue-related motorcycle accidents between these databases.

The low incidence of fatigue in the four databases could be due to:

- the small number of actual fatigue-related motorcycle accidents across Great Britain and Europe; and
- that the contribution of fatigue to motorcycle accidents is being under-recorded.

It seems very likely that under-recording of fatigue will be part of the explanation. As we have highlighted already in the present study, there is no commonly agreed definition of fatigue. But probably more importantly, from discussions with some of the project teams assembling the data, it is clear that it is very difficult for those teams, or the police, to ascertain that an accident occurred because the rider was fatigued. This may be because the information available to the team does not always provide specific details about the rider's condition or behaviour prior to the accident.

Perhaps the most informative database for this purpose is the Fatals database, where information is gathered from witnesses and family members who spent time with the rider before the accident and who could provide relevant information (e.g. whether they seem tired beforehand or had just come back from a long shift at work). With the other three databases, although the project team or police gather as much information as possible from the scene of the accident and occasionally through discussions with the rider, it is more difficult for them to establish fatigue as a contributory factor (especially where the rider was killed or seriously injured). The higher proportion of fatigue-related accidents found in the Fatals database, compared with the other three databases, is likely to be, at least in part, a result of this difficulty.

5 IDENTIFICATION OF KNOWLEDGE GAPS

Gaps in current knowledge were determined from a systematic analysis of the findings of the preceding literature review and from discussion with TRL researchers. The knowledge gaps identified, and the proposed action to be taken, are presented in Table 5.1, in a manner that may allow proposals for future rider fatigue research to be generated.

Table 5.1: Knowledge gaps identified

	Knowledge gap identified	Action to be undertaken
1	<p>General lack of research specifically on rider fatigue The paucity of scientific studies specifically into rider fatigue and evidence-based countermeasures means that current knowledge is based largely on: generalising from driver fatigue or general fatigue research; the judgement of researchers; or the opinions of riders or rider interest groups. The extent to which research on driver fatigue and its countermeasures will generalise to rider fatigue is unknown, as is the effectiveness of the rider fatigue countermeasures described in published guidelines.</p>	<p>See more detailed entries below.</p>
2	<p>The importance of rider fatigue – prevalence, subjective states, effects on performance Knowledge gap no. 2 is the lack of good evidence on the prevalence of (a) fatigue-related effects on motorcyclists’ riding performance and (b) subjective states related to fatigue.</p> <p>Substantial further research would be needed if the knowledge gap identified at no. 1 is to be filled. However, in deciding how much of this research should be funded under the Department for Transport road safety research programme, it will be necessary to judge the importance of motorcyclist fatigue as a problem. Unfortunately, there is a serious knowledge gap here as well: the accident statistics throw little light on whether fatigue is a causal factor in many motorcycle accidents, and the published self-report studies on fatigue do not give a robust estimate of its prevalence. The only observational study to investigate the effects of rider fatigue on performance-related variables found little evidence of such effects – but this cannot be regarded as decisive evidence that fatigue does not have important effects (especially given the flaws in the methodology mentioned earlier and inconclusive findings). There are, however, indications in the literature that rider fatigue is a common experience and that it might have important safety implications.</p> <p>The lack of information available on fatigue as a contributor to motorcycle accidents is included as a separate knowledge gap below (knowledge gap no. 3).</p>	<p>Gather improved evidence on the importance of rider fatigue as a problem for road safety. This might include some or all of the following:</p> <ul style="list-style-type: none"> ● Self-report surveys of riders (both qualitative and quantitative). Surveys of the general rider population, as well as surveys of riders during journey breaks, may be useful here. ● Simulator studies – ideally using a motorcycle simulator, but possibly using tasks designed to represent important aspects of the riding task. ● Field studies in which some or all of the following are monitored during rides: <ul style="list-style-type: none"> ● riders’ performance at secondary tasks (such as tuning on the radio on larger bikes with radios, or checking the condition of the bike when stopped at traffic lights). Such secondary task performance may both help demonstrate current workload (so potentially ETD) and show if a rider is distracted with other issues that are not directly relevant to the primary riding task; ● aspects of rider/bike behaviour; ● physiological indicators of fatigue; and ● self-reported sleepiness and fatigue. <p>This work could also generate useful information on countermeasures.</p>

Table 5.1: (continued)		
	Knowledge gap identified	Action to be undertaken
3	<p>Contribution of rider fatigue to crashes Little is known about the incidence of fatigue-related motorcycle accidents, and hence about the importance of rider fatigue as a safety problem. Rider fatigue does not appear as an important factor in accident statistics in the UK but it is not known whether this reflects the true contribution of fatigue. In Australia, however, several working definitions for identifying fatigue-related accidents have been developed; based on these definitions, there have been some statistics published describing fatigue-related accidents. However, the overall lack of data about the contribution of rider fatigue to crashes seems, at least in part, due to the considerable limitations inherent in collecting suitable information about the state of fatigue in accident-involved riders.</p>	<p>The following actions should be considered:</p> <ul style="list-style-type: none"> ● Improve the statistical information on the contribution of fatigue to motorcycle accidents. This will involve developing suitable operational definitions of fatigue-related motorcycle accidents which can be applied consistently and retrospectively, even when the rider is fatally injured. ● Improve the education for accident investigators to help them better identify rider fatigue. Such an approach has been undertaken with some police forces in the UK, and a widening of such training measures is recommended. ● Conduct a self-reported accident survey of motorcyclists, in which the importance of fatigue as a risk factor is assessed analytically as well as by direct self-report. This could be combined with other fatigue-related surveys mentioned in other cells. ● Conduct a survey of motorcyclists who have been involved in an injury accident reported to the police. ● Conduct a survey of motorcyclists identified by insurance claims.
4	<p>Operational definitions and assessment methods for fatigue Knowledge gap no. 4 is the lack of operational definitions and assessment methods for rider fatigue and its effects</p> <p>In order to be able to attribute fatigue as a causal factor in an accident investigation, and to investigate the causes and prevalence of fatigue, we need ways of defining it and measuring it and its effects. As found in this review, there is no commonly accepted definition of 'rider fatigue', though the basis of such a definition was put forward during the review. Metrics to identify sleep-related vehicle accidents have been put forward (e.g. Horne and Reyner, 1995). However, these identification metrics are not specific to, and may not apply well to, sleep-related motorcycle accidents. Studies have used self-reports of fatigue and sleepiness, measurements of performance on special tasks, and physiological variables (e.g. heart rate) as indices of fatigue, but the approach has been largely piecemeal, rather than a coordinated attempt to produce metrics suitable for general use and covering all the important aspects of fatigue.</p>	<p>Filling this knowledge gap will require the following actions:</p> <ul style="list-style-type: none"> ● Further review of specialist literature. ● Consultation with fatigue experts. ● The development and trial of operational definitions and assessment methods.

Table 5.1: (continued)

	Knowledge gap identified	Action to be undertaken
5	<p>Causes and effects of rider fatigue Knowledge gap no. 5 is the lack of knowledge of the specific causes and effects of motorcycle rider fatigue. This knowledge gap is closely related to knowledge gap no. 4.</p> <p>The causes of rider fatigue are not formalised. The research either implicitly implies that the causes are the same as for other types of transport fatigue (e.g. time on task) or mentions specific motorcycle factors (e.g. motorcycle vibration).</p> <p>Similarly, there is little scientific information on the specific effects that fatigue has on riders.</p>	<p>The Department for Transport could take the lead in commissioning further rider fatigue research, especially focusing on the causes and effects of rider fatigue. Possible approaches might include those mentioned under knowledge gap no. 2 above, and research covering both gaps could usefully be combined.</p>
6	<p>Rider recognition of fatigue To know when to apply certain types of countermeasure and, in general, to adapt their behaviour to the risks of fatigued riding, riders need to be able to recognise when their performance is degraded or threatened by the onset of fatigue. It is not known how well they are able to do this, or how their ability could be improved. There is little published guidance to assist them with this.</p>	<p>The Department for Transport could consider commissioning work which helps riders to recognise when they are getting fatigued, so that they are able to deal safely with this. Again, some of the activities listed at knowledge gap no. 2 would be useful here.</p>

Table 5.1: (continued)		
	Knowledge gap identified	Action to be undertaken
7	<p>Rider fatigue countermeasures</p> <p>General countermeasures to driver and pilot/flight deck fatigue are available in the literature, though these concentrate on dealing with sleepiness. How appropriate these are for motorcyclists (who may anyway be more subject to other aspects of fatigue) is not known. Although, in general, many countermeasures for driver sleepiness may also be applicable to rider sleepiness, they are certainly not identical (for instance, as mentioned earlier, riders cannot nap as easily). Rider fatigue due to task demands is unique to motorcycling, and very little research evidence is available. Self-reports and expert/interest-group judgement are the principal source of proposed countermeasures specifically related to motorcycling. For example, the Motorcycle Council of NSW in Australia has published on its website strategies and exercises with the aim of helping to keep riders alert. However, there is no direct scientific evaluation of the effectiveness of such sets of countermeasures applied to motorcyclists. There is little advice available to UK riders on countering types of rider fatigue. This applies both to general riders and to specific groups, such as the police, despatch and delivery riders.</p>	<p>It would be useful to commission work to review rider fatigue countermeasures, drawing on countermeasures used in driving or aviation, but critically evaluating these for their applicability to motorcycling. The knowledge produced by other actions in this table will also be crucial.</p> <p>The effectiveness of such rider fatigue countermeasures should be evaluated.</p>
8	<p>Rider education and training</p> <p>Rider education material and resources for trainers covering fatigue are sparse. The robustness of their scientific basis is not clear, and their effectiveness has not been scientifically assessed.</p>	<p>Building on the work to fill knowledge gap no. 7, it would be useful for the Department for Transport (and possibly other agencies) to commission work to systematically review rider fatigue countermeasures, and then develop suitable publicity and educational/training interventions. The effects of such interventions should be evaluated. Fatigue countermeasures, and possible training strategies, for specific rider groups should be developed.</p>

6 CONCLUSIONS

The main objectives of this project are to review the relevant literature and ongoing research on rider fatigue, to investigate the incidence of rider fatigue, to identify gaps in knowledge and to outline specifications for future research.

This report presented the findings of both the literature review and the investigation of the incidence of rider fatigue in order to identify gaps in knowledge. Overall, it was found that there was a significant paucity of rider fatigue research, especially studies that employed appropriate experimental control. The few studies found mainly relied on self-report data. There is little information on the link between fatigue and directly observed effects on rider performance or accidents. Likewise, there is little evidence on the effectiveness of countermeasures specific to motorcyclists. As such, there are large gaps in the research literature, for which several key areas of future research can be proposed.

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APPENDIX 1

Background to our working definition of fatigue

As indicated in the main report, there is a need for consistent terminology in presenting and discussing the results of research concerning rider fatigue. Different researchers have used the term in different ways.

The term ‘fatigue’ as used by the Fatigue Expert Group (2001) refers to ‘a combination of symptoms, such as impaired performance and subjective feelings of drowsiness, as well as contributory factors, such as prolonged activity, insufficient sleep and disruption of circadian rhythms’. This definition thus includes both task-induced effects and sleepiness under the general umbrella of ‘fatigue’.

The Australian Transport Safety Bureau (ATSB, 2002) cites three main determinants of ‘fatigue’, the third of which clearly covers task-induced effects.

- **Lack of sleep or ‘sleep debt’³** – as little as two hours’ sleep loss within a 24 hour period can result in degraded reaction time, cognitive functioning, memory, mood and alertness. Cumulative sleep debt significantly reduces alertness and performance, especially on attention-based tasks such as driving (Rosekind, 1999; Dinges, 1995; Hartley and Arnold, 1995; EPDFS, 1997).
- **Time of day** – during the night or the early hours of the morning and during the afternoon, the level of sleepiness is high (Hartley *et al.*, 2000). During these periods of sleepiness, functions such as alertness, performance and subjective mood are degraded (Rosekind, 1999).
- **Time on task** – as time spent on a task is increased, the level of fatigue is increased, reaction time is slowed, vigilance and judgement is reduced, and the probability of falling asleep during the task is increased (EPDFS, 1997; HORSCOCTA, 2000).

ATSB also acknowledge that individual factors such as age, physical fitness and medical condition (e.g. sleep disorders) may also affect the incidence of fatigue (HORSCOCTA, 2000).

The Road and Traffic Authority (RTA) in New South Wales, Australia, has developed a definition of fatigue, judging whether fatigue has contributed to an accident (RTA, 2002). According to the RTA, fatigue is considered to have been involved as a contributing factor to a road traffic accident if that accident involved at least one ‘fatigued’ motor vehicle controller. A motor vehicle controller is assessed

3 ‘Sleep debt’ refers to the difference between the minimum amount of sleep needed to maintain appropriate levels of alertness and performance, and the actual amount of sleep obtained (Rosekind, 1999).

as having been ‘fatigued’ if the conditions described under (a) or (b) are satisfied together or separately:

‘(a) The vehicle’s controller was described by police as being asleep, drowsy or fatigued.

(b) The vehicle performed a manoeuvre, which suggested loss of concentration of the controller due to fatigue, that is:

- the vehicle travelled onto the incorrect side of a straight road and was involved in a head-on collision (and was not overtaking another vehicle and no other relevant factor was identified); or
- the vehicle ran off a straight road or off the road to the outside of a curve and the vehicle was not directly identified as travelling at excessive speed and there was no other relevant factor identified for the manoeuvre.’

Clearly the RTA includes sleepiness or drowsiness in its concept of fatigue. This is mentioned specifically in condition (a) and is reinforced by the fact that the accidents described in condition (b) are typical of falling asleep at the wheel, and are similar to the criteria developed by Horne and Reyner (1995) for identifying sleep-related accidents. What is not clear is whether the RTA intended to include task-induced (non-sleepiness) effects in its concept of fatigue. There is no evidence from the above that it did, though the point was not discussed specifically by the RTA (2002).

In a small US survey (Gillen, 1998), a sample of motorcycle riders were asked to define what they thought rider fatigue was, and the responses included:

‘Impairment, reduced ability to concentrate, comprehend, react and multi-task.’

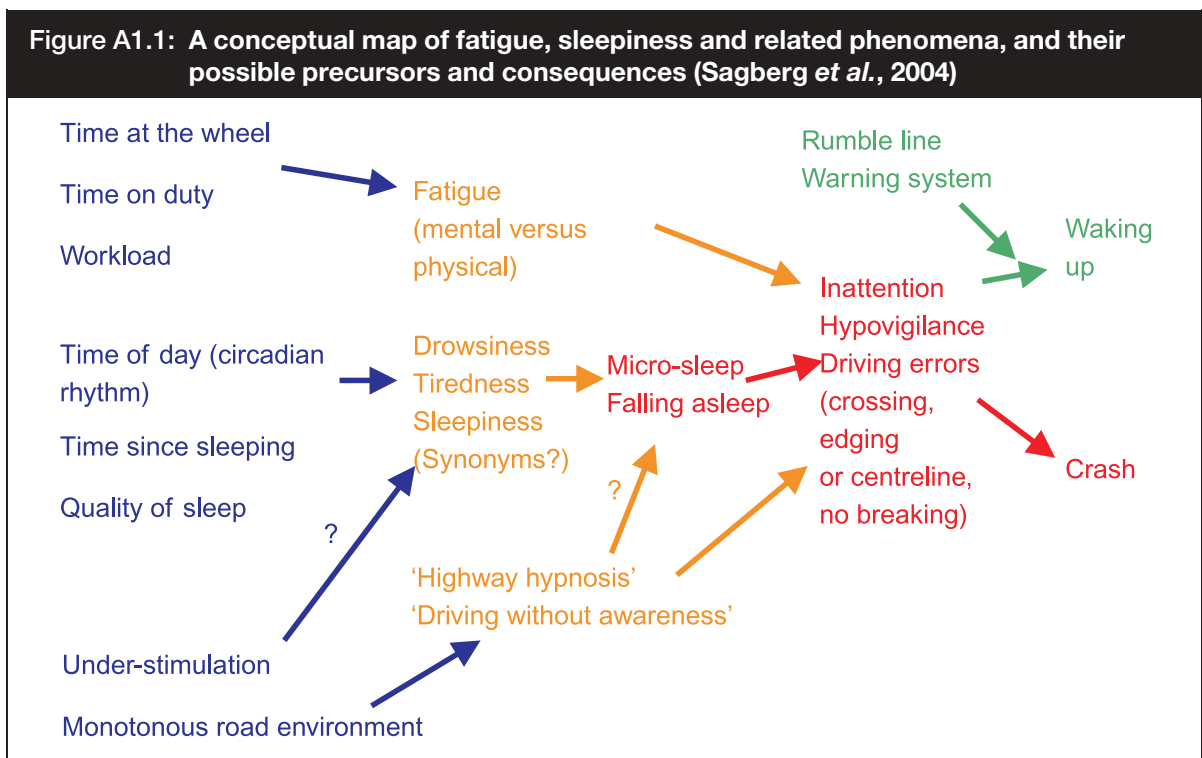
‘When reaction time is too slow to effectively/safely operate a motorcycle.’

These are just two examples of how riders themselves would define fatigue. The variety of answers obtained to this question suggests that there is no consensus among riders about what fatigue is. Moreover, it seems as if the riders were merely describing the effects of fatigue rather than what they thought of as its definition.

Haworth and Rowden (2006) point out that fatigue is commonly defined in terms of a subjective state (e.g. sleepiness) and/or objective measurable performance (e.g. increased reaction time). They also follow both the Fatigue Expert Group (2001) and Harrison (2006) in interpreting fatigue as covering both task-demand and sleep-related factors – though at one point they also state that ‘sleep is the only ultimate solution to fatigue’. Haworth and Rowden also cite the following:

- Harrison (2006) as pointing out that fatigue may or may not involve a subjective state of sleepiness;
- Desmond and Hancock (2001) who distinguished between active and passive fatigue states, the former being induced by prolonged perceptual or motor adjustments, and the latter by constant monitoring over time; and
- Brown (1994) who distinguished between mental and physical fatigue.

In a workshop that investigated ‘Fatigue, sleepiness, and reduced alertness as risk factors in driving’ (Sagberg *et al.*, 2004), the general problem under investigation was described as ‘reduced vigilance due to fatigue or sleepiness’, and a conceptual model (after Sagberg *et al.*, 2004) was presented which distinguished fatigue (mental and physical) from sleepiness/drowsiness in terms of the driver’s appreciation of his own condition, the former being caused by task-related factors and the latter by insufficient sleep and possibly by under-stimulation. A third type of phenomenon – driving without awareness (highway hypnosis) – was also noted as being associated with a monotonous road environment (see Figure A1.1). It was noted later in the report that, although it has been assumed that a monotonous road environment may facilitate sleepiness, it is not clear whether this can occur in drivers who are sufficiently rested. The idea that monotony and boredom may permit but not cause sleepiness was put forward, as was its converse that stimulation may mask sleepiness.



Elsewhere in the same report, Kruger (one of the authors) distinguishes between three phenomena:

- impairment of vigilance (diminished readiness to act) caused mainly by task characteristics;
- fatigue (weariness or exhaustion from labour, exertion or stress) caused by time on task; and
- drowsiness and sleepiness caused by insufficient sleep or a sleep disorder.

It is clear from the above that, in most of the literature on driver and rider fatigue, the term ‘fatigue’ is either vaguely defined or covers a very broad range of phenomena, though some authors have excluded sleep-related effects from the definition of fatigue. What is needed is an umbrella term to cover all the separate phenomena, and specific terms for each. The obvious options are:

- (i) to use ‘fatigue’ as the umbrella term; or
- (ii) to find another umbrella term and reserve ‘fatigue’ for the task-induced subset of phenomena.

To avoid the need to redefine the terminology of most of the literature on driver/rider fatigue, we prefer option (i) and have adopted the following definitions for use in this report:

- **Fatigue** – an umbrella term covering internal states and performance decrements associated with a need for sleep, tasks/environments that are mentally or physically demanding, and tasks/environments that are insufficiently stimulating. Fatigue may involve subjective states of sleepiness/drowsiness, weariness/exhaustion, or boredom. However, performance decrements caused by fatigue are not necessarily accompanied by such subjective states.
- **Sleepiness/drowsiness** – a propensity to fall asleep, have micro-sleeps or make related task errors, caused by a need for sleep/disrupted or poor quality sleep/lack of sleep, circadian effects or a sleep disorder and possibly permitted or exacerbated by a low level of task or environmental stimulation. There will generally be a subjective state of sleepiness or drowsiness, but the driver/rider may underestimate how close he or she is to falling asleep. Moreover, task errors may occur before the subjective state becomes apparent.
- **Excessive task demand (ETD)** – a propensity for reduced performance caused by continued mental or physical effort at a demanding or prolonged task, or in an uncomfortable or hostile environment. This may be accompanied by a subjective state of exhaustion, weariness or physical discomfort, but performance decrements may occur before such states become apparent.
- **Under-stimulation** – a propensity for reduced performance caused by prolonged low levels of task demand or environmental stimulation. May be accompanied by a subjective state of boredom, but performance decrement can occur without this.

APPENDIX 2

Publications related specifically to rider fatigue

Name of study	Author(s)	Description	Summary of results
<i>A Pilot Study of Fatigue on Motorcycle Day Trips</i>	Ma, Williamson, and Friswell (2003)	Twenty motorcyclists took part in a pilot study of fatigue during a day ride. Participants were tested on two weekend days, a week apart. On one of the days, participants rode approximately 279 km. The other day acted as a control condition and participants were asked to refrain from recreational riding. Subjective fatigue was rated and reaction times were calculated.	<ul style="list-style-type: none"> ● Higher levels of subjective fatigue at the end of both days. ● Reaction times were more variable at the end of each day than at the start.⁴ ● No evidence of deteriorating concentration across either the ride day or the control day. ● Overall, the riding regime employed in the study did not produce fatigue at levels that would adversely affect riders' abilities to process information and initiate action.
<i>Motorcycle Rider Fatigue: Survey Results</i>	Gillen (1998)	A nine-question motorcycle rider related survey was completed by 12 riders. All of the questions related directly to motorcycle rider fatigue and its components. The survey included questions concerning riders' concept of fatigue, rider preparation, detection of fatigue, countermeasures and when to stop riding.	<ul style="list-style-type: none"> ● Riders have varying degrees of awareness of the problem, and many take some precautions both before the ride and while riding. ● There are many different techniques riders use to extend their riding time once signs of fatigue are detected. ● There is no consensus regarding the effectiveness of these fatigue countermeasures. Some require almost immediate rest, while others can extend their ride for long periods. ● Generally, motorcycle riders recognise sleep, in varying forms, as the primary countermeasure for fatigue.

⁴ These were found to be not related to the ride.

Name of study	Author(s)	Description	Summary of results
<i>The Arousal State of Motorcyclists</i>	Travers and Jennings (1980)	Riders completed a test route before and after a night's rest, which consisted of 12 miles of riding through a city centre, suburban roads, dual carriageways and narrow country lanes. The riders' reaction times before a rest (that were measured via a heart rate telemeter) were compared to their reaction times after the rest. A control group also carried out the two reaction tests under identical conditions.	<ul style="list-style-type: none"> ● Simple reaction times were longer after the ride than they were after a night's rest, indicating a performance decrement presumably due to time of day and exhaustion. ● Similarly, choice reaction times were longer after the ride than they were after a night's rest. ● Positive correlation between distance covered and the slowing of reaction times, indicating a performance decrement due to time on the task. ● State of arousal gradually falls when riding in motorway conditions, indicating a performance decrement due to monotonous tasks.
<i>Investigation of Fatigue-related Motorcycle Crashes – Literature Review</i>	Haworth and Rowden (2006)	An investigation of the extent to which fatigue contributes to motorcycle crashes. The report outlines the way in which fatigue affects motorcycle riders, its probable contribution to motorcycle crashes and the crash risk for motorcyclists of fatigue. The report uses mainly Australian literature as its basis.	<p>More information is needed regarding:</p> <ul style="list-style-type: none"> ● the extent to which motorcycle riders experience both mental and physical fatigue, and the circumstances under which these occur; ● the rider, vehicle and trip factors that influence the development of mental and physical fatigue; ● the extent to which riders believe fatigue has contributed to their crashes and near misses; and ● methods of preventing or reducing mental and physical fatigue.

APPENDIX 3

Example attitudes of 12 riders to rider fatigue (Gillen, 1998)

	Question	Example attitudes of riders
1	How do you define 'rider fatigue'?	<ul style="list-style-type: none"> • Inability to concentrate • Feel like falling asleep • Requires conscious effort to remain alert • Physical and mental impairment • Diminished awareness • Delayed reaction time • Adversely affect my riding abilities • Lack of focus • Being tired
2	What techniques/actions do you use, prior to getting on the bike, to ward off fatigue?	<ul style="list-style-type: none"> • Sufficient sleep and adequate rest • Proper hydration • Reduce noise-induced fatigue with earplugs • Take multivitamins • Light meals • Stretching • Comfortable, weather-sensitive clothing
3	What clues do you use to identify fatigue while riding?	<ul style="list-style-type: none"> • Inability to focus • Yawning • Loss of concentration • Impaired judgement • Poor memory of recent events • Slowing reaction times • Droopy eyelids • Tight muscles • Daydreaming
4	What techniques/actions do you use to overcome fatigue, once identified?	<ul style="list-style-type: none"> • Sing songs and talk to myself • Stand up or do knee bends while riding • More air by breathing or opening helmet visor • Stop, stretch and jump around • Nap, power nap, sleep • Light food, drink • Caffeine • Mental exercise, like calculate fuel mileage
5	What factors would lead to a decision to pull off the road?	<ul style="list-style-type: none"> • Eyes closing and droopy eyes • Nodding off and scaring myself • Loss of concentration and mental focus • When efforts to recover alertness have failed • Inability to drive smoothly and steadily
6	How far do you ride before fatigue is normally identified?	<ul style="list-style-type: none"> • Monitor time rather than distance • Depends greatly on rest and activity prior to riding • Late afternoon brings fatigue

	Question	Example attitudes of riders
7	How effective are the techniques you use to overcome early fatigue (i.e. how far do you ride utilising those techniques)?	N/A ⁵
8	Do you find fatigue to be more of a problem when riding behind a fairing, or nekkid ⁶ ?	<ul style="list-style-type: none"> • Four respondents never use a fairing and one has never ridden without one. • Of the remaining seven, one clearly is less fatigued on a naked bike and two are less fatigued on a bike with a fairing. • Of the remaining four, there are more varied comments. For instance, physical fatigue is more of a problem on a naked bike while mental fatigue is more of a problem on a bike with a fairing. Or, when exposed (naked) fatigue occurs quickly in the cold. In the heat, fatigue occurs more quickly behind a fairing. One respondent notes, 'On many fairings the increased turbulence can add more to fatigue than sitting in "clean" wind'.
9	Have you ever had training re: motorcycle rider fatigue?	<ul style="list-style-type: none"> • None of the respondents have experienced anything approximating formal training. • One rider feels fatigue to be such an individual phenomenon he is capable of learning about it all on his own.

5 According to Gillen (2005), this question was poorly worded and therefore riders' attitudes were not considered here.

6 Nekkid (read: naked) is motorcyclist slang for a motorcycle without any mounted windscreen of any type.

APPENDIX 4

Description of databases

A4.1 STATS19

STATS19 is the system for collating personal injury road accident data recorded by police officers in Great Britain. The data comprise details of attendant circumstances held on the accident record, together with vehicle and casualty data (Department for Transport, 2005) This database provided general background information on motorcyclists involved in accidents by, for example, rider's age, time of day, road type, lighting, and weather and road surface condition. In addition, the linked information provided by the Driver and Vehicle Licensing Agency (DVLA) enabled the make, model and size of the motorcycle to be investigated.

For the years 1999 to 2004, 10 police forces in Great Britain have voluntarily adopted the national scheme to collect information on contributory factors (Broughton *et al.*, 1998) on personal injury road accidents. All the data on accidents within these 10 police force areas (which included 34,982 motorcycle accidents) were analysed for the presence of rider fatigue. Factors that were analysed included motorcycle type, road type, weather, rider's age, manoeuvres before collision, and location of the accident.

A4.2 'On the Spot' (OTS)

The OTS project, now completing its second phase, involves teams of investigators attending accident scenes in the immediate aftermath of the accident in two areas of England: Thames Valley and the Midlands. The database is an extensive one which provides very detailed information covering human and behavioural characteristics, as well as highway and environment factors and vehicle factors. OTS has developed in recent years, with greater emphasis placed on crash reconstruction activities to improve the descriptions of the directions and rates of travel of the road users. There are 242 accidents involving a motorcyclist in the OTS database. There is a rider questionnaire that provides information on:

- purpose of journey;
- expected journey time;
- how long into the journey before the accident occurred;
- distraction; and
- 'feeling tired'.

Specifically, the analysis looked at the type of accident in which the rider was involved. For example, a single-vehicle accident with evidence of the rider having

ridden a long time since a break, and being near the end of a long day's ride, may indicate that fatigue was a causation factor.

A4.3 Fatafs

For some years the police forces in England and Wales have sent to TRL their fatal accident reports when they are no longer required for investigation. These files have been linked to their STATS19 accident record and contain additional information, such as a plan of the accident, the vehicle inspector's report, witness statements, use of safety equipment, post mortem reports, and information on contributory factors using the system developed for STATS19 (Broughton *et al.*, 1998). The proportion of files received varies among police forces, and thus some areas of the country may be under-represented. In addition, the files are often received some years after the accident has occurred, so they do not include the most recent accidents. Those files received since early 2003 have been linked to STATS19, but the Additional Intermediate Database (IDB) variables, including contributory factors, have not been recorded electronically. Nevertheless, these files contain a valuable source of information about fatal accidents (Lynam *et al.*, 2001). Three hundred and seventy-six fatal motorcycle accidents occurring between 1991 and 1992 were considered in the present study.

Paper copies of the Fatafs police files were examined to identify case studies for those Fatafs cases that were noted to have fatigue as one of the contributory factors. Other factors, such as weather, road class and visibility, were also considered in the analysis.

A4.4 Motorcycle Accident In Depth Study (MAIDS)

MAIDS is a database of motorcycle accidents from five European countries. The International Co-ordinating Committee (ICC) successfully developed a common international methodology for in-depth motorcycle accident investigation, which provided a common standardised structure for accident data recording. Thus detailed accident data from around the world could, in theory, be scientifically compared and lead to the design and implementation of motorcycle accident countermeasures.

The findings from the MAIDS report of 921 European accidents (ACEM, 2004) were examined in the present study for areas with particular relevance to rider fatigue – for example, time of day the accident occurred, use of helmet, weather and road type. The ACEM team assisted with retrieving and interpreting the data.