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Fatigue and Road Safety: A Critical Analysis of Recent Evidence

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EXECUTIVE SUMMARY

The Department for Transport has identified the need for a critical evaluation of up-to-date evidence to accurately determine the current scale of the driver fatigue problem in the UK, and to highlight evidence gaps that may require further research.

A consortium consisting of Clockwork Research, the University of Leeds and the Transport Research Laboratory (TRL) have worked together to produce a report that meets the objectives of the Department for Transport; namely, to provide a comprehensive and critical review of the literature that synthesises the evidence relating to fatigue and road safety. The report is intended to provide guidance for the Department for Transport Research, Policy and THINK! communication teams.

The Department for Transport research specification identified a list of research questions that were to be addressed by this project. These questions were distributed between the three teams collaborating on the project. Following an inception meeting, each team worked independently to identify and critically evaluate the key sources relevant to their research questions, according to criteria agreed with the client at the inception meeting.

This report is structured around the research questions identified as being of interest by the Department for Transport. Each section begins with a summary of the evidence identified as being of most relevance and importance, and then sets out any evidence gaps that the review identified. A full list of all the evidence gaps identified throughout the report, together with the recommendations for research to address these gaps, is provided in Appendix 2. The final section of the report (Section 10) provides conclusions and recommendations for the Department for Transport Policy, Research and THINK! communication teams.

The key findings from each of the review sections can be summarised as follows.

Definitions

- ‘Fatigue’ is defined as a gradual and cumulative process associated with ‘a loss of efficiency, and a disinclination for any kind of effort’ (Grandjean, 1979; p. 175.
- ‘Sleepiness’ signals the likelihood of falling asleep and can be defined as a difficulty in remaining awake.
- For the purposes of the report, the term ‘fatigue’ is used to encompass both fatigue and sleepiness, as the concepts are inextricably linked and both have adverse consequences for driver performance and road safety.

Section 2: Effects of fatigue on driver performance

- When drivers are fatigued, vigilance and alertness deteriorate, resulting in adverse changes in performance, including increased line crossing and poor speed control. However, performance does not only decline when the driver experiences a microsleep (lapse); rather, sleep loss and extended wakefulness are associated with a progressive, gradual deregulation of neurocognitive performance which presents as both lapses and other performance impairments.
- The effects of sleep loss on driving performance are well recognised as being exacerbated by circadian and time-on-task effects.
- Studies have found considerable variation in the relationship between fatigue and performance. Consequently, it would be incorrect to assume that individual drivers have the **average** group characteristics reported in research papers; indeed, it is recommended that future research continues to explore the inter-individual differences between drivers.

Section 3: Prevalence of driver fatigue

- Historically, there has been significant variation in estimates of the frequency of fatigue-related accidents. Surveys of driver fatigue give some indication of the extent of the problem, but these seem highly sensitive to the way the questions are phrased. Naturalistic studies of driver behaviour offer a depth of insight that is difficult to achieve using other techniques. The results of this technique appear to converge with other previous estimates of accident causation by fatigue and suggest that driver tiredness may be a contributory factor in as many as 20% of all road accidents.
- However, current understanding of prevalence is based on partial information, historic data or overseas research. It is recommended that this issue is addressed through a UK survey of driver fatigue.

Section 4: Psychological and physical factors

- The most widely researched physiological factors influencing driver fatigue are two of the more common sleep disorders: obstructive sleep apnoea (OSA) and insomnia.
- OSA is an under-diagnosed condition, which poses a significant emotional and economic burden, not only in terms of road safety but also other occupational injuries. The main treatment for OSA, CPAP (Continuous Positive Airway Pressure), is effective and the cost–benefit arguments for increasing treatment rates are persuasive.

- Secondary insomnia, associated with a medical or psychological disorder, is almost certainly much more prevalent than OSA. However, despite its prevalence, the relationship between insomnia and road safety has received little attention. Further research to define diagnostic and treatment strategies would assist medical practitioners to manage secondary insomnia and to determine a patient's fitness to drive.
- From a road safety perspective, it is important to improve understanding of the sleep loss and fatigue associated with conditions which may not otherwise preclude drivers from holding a licence, to distinguish between the effects on driver performance of the condition itself, and the medications used to treat the condition.
- Age, individual susceptibility to sleep loss, lifestyle factors such as new parenthood, personality and mood can all influence fatigue. The many causes of fatigue and the large amount of inter-individual variability in fatigue levels are part of the reason why driver fatigue is such a difficult risk to manage. It is important for drivers to understand this complexity and to be made aware of the need to individually assess their own fatigue both before and during driving.

Section 5: Who drives when tired?

- Young, male drivers, particularly those who drive at night, are most commonly involved in accidents in which fatigue was a contributory factor.
- However, the correlation between age, gender and sleep-related accident risk does not imply causality, and exposure effects need to be taken into consideration when attempting to understand who drives tired. Young, male drivers may not necessarily be more susceptible to driver fatigue, but may simply be more likely to drive in situations where fatigue is likely to exert an influence over their ability to control their vehicle safely.
- Similarly, shift workers and commercial vehicle drivers appear to have a higher risk of sleep crashes as a result of a combination of work-related factors.

Section 6: Fatigue and work-related road safety

- Work-related driving poses a considerable risk on UK roads and fatigue is a primary contributory factor. Many professional drivers – in particular drivers of large goods vehicles – often obtain inadequate sleep, report elevated levels of sleepiness, and are involved in a disproportionately high number of fatigue-related accidents.
- Our understanding of the link between fatigue and work-related road safety in the UK suffers from a lack of information. Notably, the Reported Road Casualties Great Britain (RRCGB) annual reports do not include the detail

necessary to reliably assess work-related road safety. In order to more accurately identify work-related crashes, the STATS19 form was amended in 2004 to include a field for 'journey purpose of driver/rider'. However, to date, RRCGB has not reported on journey purpose in any depth.

- There is also a lack of understanding of the crash risk associated with commuting, exacerbated by the exclusion of accidents occurring during a commute from the statistics for work-related accidents. As work arrangements clearly influence fatigue and crash risk, the exclusion of commuting from work-related road safety assessments and initiatives no longer seems reasonable.
- Studies of drivers of light goods vehicles (LGVs), vans, taxis, buses and company cars suggest that these drivers are also likely to be exposed to a relatively high level of fatigue-related crash risk.

Section 7: Attitudes

- International research suggests that many drivers continue to drive tired despite being aware of their tiredness. It is likely that some drivers fail to fully appreciate the risks associated with driving in this state, and education (in the form of public awareness campaigns) may be beneficial for this group.
- However, it is also possible that some form of cost–benefit analysis may be at play when driving sleepy. Past experience, perceived social norms and journey goals combine to produce a situation where the driver justifies their behaviour accordingly. In short, for many drivers the goals and rewards of completing the journey outweigh the calculated/known risk.
- Once drivers' attitudes are set in place, they may be difficult to modify. Consequently, it is recommended that specific education initiatives to raise awareness of the dangers of driving when tired are targeted at pre-driving adolescents.
- In addition, given the high risk associated with young, male drivers, there would be some benefit in a campaign directed at this group to raise their awareness of the effects of fatigue on judgement and self awareness, and the risks of serious injury resulting from sleep-related crashes.

Section 8: Awareness

- Research on drivers' awareness of the impairment resulting from fatigue highlights the conflict between an individual driving when sleepy/impaired and their desire to reach the destination of their journey. For road safety practitioners, and communications teams specifically, these issues present several challenges:

  - to raise the public's understanding of the importance of fatigue danger signals;
  - to develop awareness of these signals (in oneself rather than as a general principle or set of effects that happens to 'people');
  - to improve recognition of the personal temporal course and the meaning of these danger signals; and
  - to understand the nature of the goals, motives, cost–benefit comparison of driving fatigued/sleepy versus reaching the journey's end.

- It is recommended that future THINK! campaigns focus on the costs and benefits of driving while tired to challenge the myth that a journey might be important enough to justify driving while dangerously tired.

- Such campaigns might also highlight the rapid increase in impairment that results when a driver continues to drive when in an advanced state of fatigue, and the dangers of persisting in this state.

Section 9: Public awareness campaigns and other counter-measures

- The majority of driver fatigue campaigns have focused on informing drivers of the signs and dangers of fatigue, and/or providing guidance on what drivers should do before or during a trip to overcome fatigue. However, there have been few attempts to evaluate the effectiveness of these campaigns, in terms of their impact on fatigue-related accidents or changing behaviour.

- While many drivers report awareness of the dangers of fatigue and knowledge of effective counter-measures, there has been little research to measure UK drivers' actual use of these counter-measures. International research has shown that many drivers fail to stop when tired, despite knowing that they should.

- While it is relatively easy to improve drivers' understanding of the dangers of driving while fatigued, the key to reducing the likelihood of their driving while fatigued is to change their attitudes and behaviour.

- It is recommended that communication and training should target high-risk groups identified in other sections of this report, such as young males, shift workers and those driving for work.

- It is suggested that more emphasis be given to primary prevention efforts, such as educating drivers about the importance of getting sufficient sleep prior to driving; the proactive use of naps to reduce hours of wakefulness prior to commencing a drive; and avoiding circadian performance troughs when planning journeys.

- Although dynamic road characteristics (curves, visual stimuli) have been shown to modestly improve driving performance, they do not reliably counteract the effects of sleep loss, nor do they improve driving performance to the level of well-rested controls.

- Rumble strips are effective, but international research suggests that there is a risk that some drivers may rely on them to protect themselves from driver fatigue.

Section 10: Conclusions and recommendations

There is a lack of recent UK-specific research on driver fatigue. Future THINK! communication activity on driver fatigue presents an opportunity for a UK survey of drivers to gain a better understanding of their experiences of the problem, and their use of driver fatigue counter-measures. The report also identifies the following research gaps:

- young male drivers are over-represented in driver fatigue crashes, but the reasons for this are unclear;
- the extent to which sleep disorders contribute to fatigue-related road crashes in the UK is unknown;
- very little research has considered the contribution of fatigue to work-related road collisions in the UK; and
- the exclusion of commuter journeys from the definition of work-related driving means that the true contribution of work-related fatigue in the UK is not possible to gauge.

In terms of future communication activity from THINK!, the report suggests that key areas for attention could be the following:

- The lapse hypothesis, upon which most of the Department for Transport publicity campaigns are based, provides insufficient explanation of the effects of driver fatigue and it is recommended that future communication activities take account of the state instability hypothesis, and thus focus on educating drivers that fatigue can affect performance long before microsleeps occur, as well as in-between microsleeps.
- Drivers continue to drive when tired even where they appreciate the risks of doing so. It is therefore recommended that public information campaigns should challenge the misconception that a journey might be important enough to risk driving in a severely fatigued state, and to provide drivers with the skills to enable them to assess their own fatigue both before and during driving.
- Training and awareness communication activities should target key risk groups, including young (male) drivers, shift workers and professional drivers/drivers of commercial vehicles. The Driver Certificate of Professional Competence would be one route to providing education for professional drivers.

- Changing drivers' attitudes once they are set in place may be difficult. Consequently, it is also recommended that specific education initiatives to raise awareness of the dangers of driving tired are targeted at pre-driving adolescents.

1 INTRODUCTION

Over the past 60 years, considerable research around the world has sought to investigate the relationship between fatigue, performance and safety. During the latter half of the twentieth century, research had begun to consider the effects of fatigue on driver performance (Brown *et al.*, 1966) and the potential for fatigue to be a contributory factor in road collisions (Mackie and Miller, 1978; Duff, 1985; Brown, 1994). Although it is now generally accepted that fatigue plays an important role in road safety, the true scale of the problem is uncertain, and thus adequate resources may not currently be committed or distributed appropriately.

According to government figures, in 2008 (Department for Transport, 2009), a total of 2,538 people were killed and 26,034 were seriously injured on Britain's roads. Of the accidents that were attended by the police, it was estimated that fatigue was a contributory factor in 3% of fatal accidents and 2% of serious injury accidents (Department for Transport, 2009). Based on these figures it is estimated that c.76 fatalities and c.521 serious injuries a year result from fatigue-related collisions. Yet, previous Department for Transport research shows a range of estimates, from 10% of all collisions (Maycock, 1995) to 17% of crashes on motorways and major trunk roads resulting in injury or death being sleep-related (Flatley *et al.*, 2004).

It is likely that the official figures are underestimates of the driver fatigue problem due to a combination of factors, including: the lack of a standardised methodology for recording information about driver fatigue; differences between investigating officers in their understanding of driver fatigue; and difficulties associated with proving driver fatigue as a cause (e.g. driver is wide awake when police officers arrive; driver is unconscious/fatally injured; there are no witnesses; or the driver has fled the scene (Robertson *et al.*, 2009).

Another reason the extent of the driver fatigue problem has been underestimated is because research has tended to focus on the impact of falling asleep at the wheel (Dobbie, 2002) without due consideration of the effects of earlier signs of fatigue. Symptoms such as inattention, poor decision making, delayed reaction times and making mistakes are thought to contribute to a higher proportion of collisions than falling asleep behind the wheel (Dinges, 1995), but are often not captured by current crash investigation approaches.

Previous Department for Transport research has helped to identify effective counter-measures to driver fatigue (Reyner and Horne, 1998; Wright *et al.*, 2007) and has been responsible for educating the general public about both the causes of, and counter-measures to, fatigue through the various THINK! road safety campaigns.

The THINK! campaigns have helped raise public awareness of the risks associated with driver fatigue, but much of the UK research on which they are based dates back to the late 1990s. Not only has considerable worldwide research been conducted since the last significant piece of Department for Transport research on driver fatigue, but major societal changes have taken place within Europe which may have influenced the nature and scale of the driver fatigue problem. One example of these changes is the expansion of the European Union, which has made feasible long distance pan-European road transport (both commercial and non-commercial), such that it is now possible to drive within Europe the sort of distances more commonly associated with Australia and the USA. An understanding of the impact that these changes have had on road safety in the UK and other European member countries may be important if commercial driver fatigue is to be managed effectively.

1.1 Objectives of the report

The Department for Transport has identified the need for a critical evaluation of up-to-date evidence to accurately determine the current scale of the driver fatigue problem in the UK, and to highlight evidence gaps that may require further research.

The main objective of this report is, therefore, to provide a comprehensive and critical review of the literature that synthesises the evidence relating to fatigue and road safety.

The report is intended to provide guidance for the Department for Transport Research, Policy and THINK! communication teams. As such, it will help inform future policy and communication efforts and ensure that these target key risk areas for driver fatigue in the UK.

1.2 Overview of the methods used

The Department for Transport research specification identified a list of research questions that were to be addressed by this project. These questions were distributed between the three teams collaborating on the project: Clockwork Research, the University of Leeds and the Transport Research Laboratory (TRL).

Following an inception meeting, each team worked independently to identify and critically evaluate the key sources relevant to their research questions, according to criteria agreed with the client at the inception meeting (see Appendix 1). The results were then used to compile a short report summarising each team member's critical synthesis of the key evidence relating to each research question. These short reports were then distributed to the other members of the consortium who reviewed each report and provided feedback to the authors.

Once a final version of each short report had been agreed, these were then given to the project manager to produce a first draft of a final report. Comments and feedback received from the consortium members were then used to produce this final version.

1.3 Sources

In order to undertake a comprehensive review of the evidence, it is essential that all possible evidence sources are identified. Our search strategy involved creating a comprehensive list of search terms and key words for each research issue, and using these to interrogate the appropriate publication databases. The following databases were used to search the literature for appropriate articles:

- Ovid;
- PsycINFO;
- PubMed;
- Web of Science;
- Science Direct;
- TRL Library database;
- Transport Database of OVID;
- TRIS; and
- Google and Google Scholar.

In addition, the teams also used the reference lists of relevant papers to identify additional sources and to ensure that all key sources were included in the search process. The websites of organisations involved in road safety and/or sleep research were also interrogated to identify publications that might not appear in library databases.

1.4 Scope

In order to deliver a state-of-the-art review, the search focused primarily on articles produced in the last decade. However, where an article published prior to 2000 was considered a seminal publication, or a primary source of evidence, this was also included where necessary and appropriate. Table 1.1 lists the main search terms used, organised around the research questions addressed by the review.

1.5 Structure of the report

This report is structured around the research questions identified as being of interest by the Department for Transport. Each research question is dealt with in a separate section. However, in a small number of cases, there was significant crossover between two separate questions and so, in order to avoid repetition, these are covered in one section.

Table 1.1: Search terms used to identify relevant research addressing each of the research questions

Research question	Details	Search terms
1	What are the effects of fatigue on driving performance?	*Fatigue (OR sleep*, drows*, tired*, sleep restriction, sleep deprivation) AND driving AND performance AND simulator*
2	What psychological and physical factors, such as mood state and illness, can affect fatigue?	*Fatigue AND contrib* OR mood OR sleep disorder OR OSA (obstructive sleep apnoea) AND diabetes AND depression (OR medicine, medication, drug, alcohol)*
3	Fatigue and road safety campaigns – what approaches have been taken and what have campaign evaluations shown?	*Fatigue AND road safety campaign AND effective* AND survey*
4	What evidence is there regarding the link between fatigue and work-related road safety?	*Fatigue AND work OR occupation* OR commercial drivers OR road safety OR driv**
5	Fatigue as a contributory factor to road accidents/fatalities: what is the accident risk associated with fatigue, and what is the prevalence of fatigue-related accidents?	*Fatigue AND road AND accident (OR crash, collision, MVA, RTA, MVC) AND fatal* (OR serious) AND statistics*
6	What is known about the behaviour and attitudes of road users towards the issue of fatigue and road safety?	*Fatigue AND survey AND road AND attitudes OR road safety OR driv**
7	What counter-measures have been designed for reducing the likelihood of fatigue-related crashes for non-commercial and commercial drivers/riders?	*Fatigue AND countermeasure AND caffeine (OR nap, devices, in-vehicle technologies, medications, exercise, radio, fresh air, aromas, etc.) AND FRMS (Fatigue Risk Management System)*
8	To what extent are road users aware of their fatigue/impairment?	*Fatigue AND subjective AND awareness AND impairment AND driv* AND performance*
9	Who drives when tired? For what proportion of commercial and non-commercial drivers is fatigue an issue?	*Fatigue AND driv* AND road OR road safety AND professional*
10a	When do people drive tired?	*Fatigue AND road AND accident (OR crash, collision, MVA, RTA, MVC) AND fatal* (OR serious) AND statistics*
10b	Why do people drive tired? What measures are they currently taking to avoid driving when tired, if any?	*Fatigue AND driv* AND survey OR strategy OR countermeasure*

Each section begins with a summary of the evidence identified as being of most relevance and importance, and then sets out any evidence gaps that the review identified. The key points from the section are then summarised.

The final section of the report provides conclusions and recommendations for Department for Transport Policy, Research and THINK! communication teams.

Appendix 2 **contains a full list of all the evidence gaps identified throughout the report, together with the recommendations for research to address these gaps.**

1.6 Definitions

With respect to their impacts on road safety, the concepts of fatigue, sleepiness, drowsiness and tiredness can be considered to be similarly debilitating and may be used interchangeably. However, in the academic literature, sleepiness and fatigue are separate concepts. To avoid misunderstanding, the rest of this report will adopt the use of the terms defined below.

1.6.1 Fatigue

Grandjean (1979; p. 175) defines fatigue as a gradual and cumulative process associated with ‘a loss of efficiency, and a disinclination for any kind of effort’. Fatigue increases as time-on-task progresses, for example, during a period of driving or exercise.

1.6.2 Sleepiness

Sleepiness, on the other hand, signals the likelihood of falling asleep and can be defined as a difficulty in remaining awake. Sleepiness is essentially determined by two largely independent mechanisms: the ‘body clock’ and ‘sleep homeostasis’ – the homeostatic balance between how much sleep a person has had and how long they have been awake (Dement and Carskadon, 1982; Åkerstedt and Folkard, 1995; Dijk and Czeisler, 1994).

1.6.3 The body clock

The body clock is located in the suprachiasmatic nucleus in the brain and is responsible for 24-hour rhythms, known as circadian rhythms, which control sleep and wakefulness. The circadian rhythm in sleepiness peaks in the early hours of the morning (c.02:00–06:00), with a rise mid-afternoon (c.14:00–16:00).

1.6.4 Sleep homeostasis

Sleep homeostasis is relatively simple: as waking duration increases, sleep pressure increases, which progressively increases feelings of sleepiness. Sleepiness impairs performance progressively until the drive for sleep is so great that uncontrollable sleep onset occurs. Conversely, sleep reduces sleep pressure.

An important aspect of the distinction between fatigue and sleepiness is that each differs in how it is generated, and what is required to overcome or recover from its effects. Although rest alone can reduce mental and physical fatigue, it cannot resolve the homeostatic drive for sleep (sleepiness). To reduce sleepiness and restore performance, adequate sleep must be obtained.

1.6.5 Sleep onset

An important aspect of the driver fatigue ‘problem’ relates to sleep onset: the transition period during which one moves from a state of relaxed drowsy wakefulness to unresponsive sleep. This transition period has a number of physiological, behavioural and psychological characteristics associated with it (including subjective experience, of which awareness is a part).

This transition period, and the extent to which individuals are aware of and capable of responding to the warnings of the impending sleep that it may convey, is an important feature from a road safety perspective. This has implications for the content and focus of public information campaigns with the objective of addressing driver fatigue.

1.6.6 Use of these terms

In general usage, the terms ‘fatigue’, ‘sleepiness’, ‘drowsiness’ and ‘tiredness’ are used inconsistently and synonymously. There is a tendency, particularly in the road safety community, to use ‘fatigue’ as a catch-all term. This broad use of the word is understandable in that fatigue and sleepiness very often occur together, for example during a long drive undertaken in the afternoon. In addition, fatigue and sleepiness interact, whereby fatigue can promote sleepiness and sleepiness can elevate feelings of fatigue (Phillip *et al.*, 2005a). Moreover, the concepts of fatigue, sleepiness, drowsiness and tiredness are considered to be similarly debilitating in the context of driving safety and thus may be used interchangeably.

For the purposes of this report, the term ‘fatigue’ will be used to encompass both fatigue and sleepiness. This approach has been taken because fatigue and sleepiness are inextricably linked and both have adverse consequences for driver performance and road safety. It also seems unlikely that the general population appreciates the academic distinction between the two concepts. In summary, the definition of fatigue used in this report draws a broad circle around the many reasons drivers experience fatigue on the road, and many of the ways in which driving performance may consequently be impaired.

2 WHAT ARE THE EFFECTS OF FATIGUE ON DRIVING PERFORMANCE?

2.1 Key evidence

2.1.1 Fatigue affects many of the skills necessary for the safe control of a vehicle

While the effects of fatigue on driving performance have long been recognised, recent research has identified the following consequences:

- increased drifting within lane (Biggs *et al.*, 2007; Baulk *et al.*, 2008; Otmani *et al.*, 2005; Arnedt *et al.*, 2001; Fairclough and Graham, 1999);
- crossing the road centre line or side line (Otmani *et al.*, 2005; Philip *et al.*, 2005a; Philip *et al.*, 2005b);
- poor speed control (Baulk *et al.*, 2008; Arnedt *et al.*, 2001; Fairclough and Graham, 1999);
- late corrections to lane positioning (Otmani *et al.*, 2005; Thiffault and Bergeron, 2003); and
- slower reaction time to stop lights and poor avoidance of hazards (Powell *et al.*, 2001).

Fatigue can affect driving skills in three ways: by increasing the **frequency** of errors, the **amplitude** of errors, and/or the **variability** of errors. For example, in the case of lane drift, fatigue increases the number of drifts from the centre of the lane, the distance drifted from the centre and the variability in the driver's ability to drive in the centre of the lane.

2.1.2 Both total and partial sleep loss impact on driving performance

While it has long been known that total sleep loss can have a devastating impact on driving performance, recent research has shown that even one night of partial sleep deprivation (where sleep duration was restricted to four hours) can significantly impair driving performance as assessed by lane drift (Biggs *et al.*, 2007) and the number of line crossings (Otmani *et al.*, 2005).

2.1.3 Fatigue-related accident rates are consistent with circadian variations in sleepiness and performance

The circadian variation in sleepiness and performance is well established. In the early hours of the morning (c.02:00–06:00), sleepiness peaks and performance reaches a minimum. In the afternoon (c.14:00–16:00) a similar effect, of a smaller magnitude, is observed (Dijk and Czeisler, 1994).

Recent research has explored the influence of drive duration on night driving performance. Results indicate that long driving hours can exacerbate the fatigue-related impairment experienced in the early hours of the morning (Sagaspe *et al.*, 2008).

2.1.4 Time-on-task fatigue impacts on driver performance, but results are variable

Driving involves maintaining sustained vigilance and is therefore sensitive to the effects of time-on-task fatigue. However, research into the effects of time-on-task on driver performance provide conflicting results, which may be an artefact of the methodologies used in these studies.

Studies have found a time-on-task effect in **rested** subjects after only 40 minutes' driving in a simulator (Thiffault and Bergeron, 2003). Similarly, in rested subjects the number of line crossings, variability of lateral position and small steering wheel movements gradually increased during a simulated driving task in the afternoon (Otmani *et al.*, 2005).

However, on-road research conducted by Phillip *et al.* (2005a), found that rested subjects did not show significant impairment during a 10-hour drive, broken-up into 105-minute driving periods and separated by 15–30 minute breaks.

While these results suggest some variability, in both simulator and on-road studies, when subjects were sleep restricted (sleep duration was four and two hours, respectively) performance declined to an even greater extent. These findings highlight the importance of avoiding lengthy journeys when sleep deprived (Otmani *et al.*, 2005; Phillip *et al.*, 2005a).

The results of Philip *et al.*'s (2005b) on-road study also reinforce the importance of breaks and highlight that, where longer duration drives are a necessity, it is vitally important that drivers stop regularly to reduce time-on-task fatigue.

2.1.5 'State instability hypothesis' has implications for THINK! campaigns on fatigue

The dominant explanation for the observed impact of fatigue on driving performance has been the 'lapse hypothesis' which centres on 'microsleeps': brief episodes of involuntary sleep lasting several seconds that occur when sleepiness is high. Microsleeps result in a failure to respond to a salient stimulus in a timely manner (a lapse). Drivers experiencing a microsleep demonstrate impairment in speed maintenance, lane positioning and steering control (Boyle *et al.*, 2008). To date, Department for Transport THINK! campaigns focusing on driver sleepiness have been guided by a lapse hypothesis approach to fatigue.

However, considerable research has shown that fatigue is also associated with errors of commission (responding without a stimulus being present or responding to the wrong stimulus). Consequently, the 'state instability hypothesis' (Doran *et al.*, 2001) has been proposed. According to this hypothesis, increasing fatigue is associated with a progressive escalation of performance variability and the deregulation of neurocognitive performance, of which microsleeps are an extreme symptom. The increased variability in performance seen when a driver is fatigued is probably linked to attempts to compensate for fatigue, maintain performance and resist sleep.

The state instability hypothesis highlights the need to educate drivers that fatigue can affect performance well before microsleeps occur, as well as in-between microsleeps and, thus, has important implications for the content, focus and delivery points/mechanisms of driver fatigue public information campaigns.

2.2 Evidence gaps

There is increasing research evidence that there are significant individual differences with regard to fatigue and its effects on performance. The extent to which these individual differences impact on driving performance warrants further exploration.

The majority of the research considered in this section (and elsewhere in this report) involved healthy young males, which is appropriate in that this sub-group of the population are over-represented in fatigue-related crash statistics (see Section 3). However, further research is recommended to determine whether the results from young male drivers can be generalised to other populations, for example professional drivers, females and older drivers.

2.3 Summary

When drivers are fatigued, vigilance and alertness deteriorate, resulting in adverse changes in performance, including increased line crossing and poor speed control. Performance does not only decline when the driver experiences a microsleep (lapse). Rather, sleep loss and extended wakefulness are associated with a progressive, gradual deregulation of neurocognitive performance which presents as both lapses and other performance impairments. The effects of sleep loss on driving performance are well recognised as being exacerbated by circadian and time-on-task effects.

The link between increasing mean fatigue and decreasing mean driving performance is influenced by many factors, including the extent to which drivers are aware of their sleepiness and the associated risk for safety; and counter-measures that are implemented. Studies have found considerable variation in the relationship between fatigue and performance. Consequently, it would be incorrect to assume that individual drivers have the **average** group characteristics reported in research papers; indeed, future research should continue to explore the inter-individual differences between drivers.

3 SOURCES OF DATA THAT INFORM OUR UNDERSTANDING OF THE PREVALENCE OF DRIVER FATIGUE

This section reviews the accident risk presented by fatigue, by examining the characteristics of fatigue-related accidents. The prevalence of such accidents is assessed by a brief review of previous literature in this area and a summary of the most recent available statistics on accident causation in relation to fatigue.

3.1 Key evidence

3.1.1 Fatigue-related accidents tend to occur in the early morning and mid-afternoon

Much of the evidence regarding the timing of fatigue-related accidents was completed prior to 2000. However, the results are still valid and so the key findings are summarised below.

Numerous studies (e.g. Brown, 1994; Pack *et al.*, 1995; Horne and Reyner, 1995; Eskandarian *et al.*, 2007) have identified two daily peaks for fatigue accident risk: one in the early hours of the morning, with a second, smaller peak, in the mid-afternoon. Sleep-related accident peaks during these times have been shown in the UK (Horne and Reyner, 1995), USA (Pack *et al.*, 1995), Israel (Zomer and Lavie, 1990), Finland (Summala and Mikkola, 1994), Sweden (Kecklund and Åkerstedt, 1993) and France (Philip *et al.*, 1996). Wylie *et al.* (1996) and Horne and Reyner (2001) suggest that this time-of-day effect is a stronger, more consistent predictor of fatigue-related accidents than duration of driving (time-on-task), although Brown (1994) states that time-on-task has a significantly stronger effect when driving periods exceed 12 hours.

3.1.2 Fatigue-related accidents tend to be caused by younger drivers, male drivers and drivers with poor sleep tendencies

Accident analysis studies (e.g. Pack *et al.*, 1995; Flatley *et al.*, 2004) and surveys (e.g. Stutts *et al.*, 2003) have repeatedly demonstrated that fatigue-related accidents tend to involve younger, male drivers. Survey research investigating the risk factors that were most closely associated with such crashes (Stutts *et al.*, 2003) has found that there were significant tendencies for younger drivers to have more than one job; to average fewer hours sleep per night; to report experiencing insufficient and/or poor quality sleep; to regularly drive late at night; and to report more frequent experience of drowsy driving.

3.1.3 Fatigue-related accidents tend to be serious due to the absence of corrective action

Accident analysis (e.g. Flatley *et al.*, 2004) has shown that fatigue-related accidents result in more severe consequences. This has been attributed to the lack of avoidance or corrective action on the part of the drowsy driver.

However, it should be noted that this research employed a lapse-based definition of fatigue, and so the finding is confounded by the focus on crashes resulting from microsleeps or lapses. It is possible that an analysis employing a broader definition of fatigue-related collisions, which encompassed the full range of cognitive impairment resulting from fatigue, would have revealed a different pattern of accident severity.

3.1.4 The impairment caused by fatigue is comparable to that caused by alcohol

While there are qualitative differences between the effects of moderate doses of alcohol and the effects of tiredness, performance differences in terms of the behaviours required to maintain safe control of a vehicle are quantitatively comparable.

Studies comparing the impairment caused by fatigue to that caused by alcohol consumption at, or near to, the legal limit for driving (Dawson and Reid, 1997; Williamson and Feyer, 2000; Jones *et al.*, 2006) have shown that, after being awake for c.19 hours, participants' performance on a range of cognitive tasks is comparable to that when they were under the influence of alcohol (blood alcohol concentration (BAC) = 0.05%).

Researchers have also found that, despite recognising that they were tired, sleep-deprived participants were still confident in their own driving performance. This mimics the misplaced confidence effects caused by alcohol and is likely to be a factor in drivers choosing to continue driving despite feeling the effects of tiredness.

3.1.5 Older drivers may be better equipped to resist the onset of tiredness

Driving simulator research (Philip *et al.*, 2004; Lowden *et al.*, 2009) suggests that older drivers are less susceptible to the effects of sleep loss. Philip *et al.* (2004) showed that, in properly rested individuals, the reaction time of older adults is slower than that of younger groups. However, when sleep deprived, only the younger participants showed significant deterioration in performance.

Lowden *et al.* (2009) investigated the brain activity of younger (18–24 years) and older (55–64 years) drivers during an extended drive in the evening and in the early hours of the morning. This study showed that, while all drivers showed an increase in subjective sleepiness over the course of each drive, this was particularly apparent for the younger drivers. The authors conclude that the results may demonstrate that older drivers' effort and brain firing patterns may improve their ability to resist sleep.

These findings support the suggestion that it is not only greater exposure to the conditions most likely to cause tiredness that causes young drivers to be more sleep-crash involved than older drivers, but that older drivers suffer less impairment when awake for an equivalent extended period.

3.1.6 *The true prevalence of fatigue-related accidents is uncertain*

Official statistics and research studies report differing estimates of the relative frequency of fatigue-related road accidents. The discrepancy stems from the origin of the data, the methods used to classify accidents as sleep-related and the severity of the accident included in the sample. Notably, many of the studies reviewed (e.g. Brown, 1994; Horne and Reyner, 1995; Pack *et al.*, 1995; Mahowald, 2000) claim that their estimate of the proportion of accidents in which driver fatigue was a causal factor is conservative.

Surveys estimating the incidence of tired driving (e.g. Maycock, 1997; Sagberg, 1999; NSF, 2005; Vanlaar *et al.*, 2008) report widely varying numbers of respondents stating that they have felt close to falling asleep while driving (from 29% to 60%), have driven while drowsy, or admit to having actually fallen asleep at the wheel (from 4% to 37%). These differences reflect variations in methodologies as well as regional differences.

A recent naturalistic driving field experiment in which 100 cars were fitted with a variety of monitoring equipment for an extended period (Klauer *et al.*, 2006) offers fresh insight into the prevalence of drowsy driving, based on observation rather than subjective recall. The study demonstrated that driver drowsiness was a contributing factor in 20% of all crashes and 16% of all near crashes.

Since 2005 the STATS19 form has included coding of suspected **contributory factors**, one of which is driver/rider fatigue. Table 3.1 shows the number of accidents in which fatigue was listed as a contributory factor, split by vehicle type and accident severity. The table shows data for 2005–08 (all available data as at March 2010) and gives the absolute number of fatigue-related accidents for each vehicle type and (in brackets) this number as a percentage of all accidents for that factor combination. The table shows a higher relative frequency of fatigue as a contributory factor for goods vehicles, particularly for fatal and serious accidents.

Table 3.1: STATS19 accident statistics for 2005 08 where 'fatigue' was listed as a contributory factor, broken down by vehicle type and accident severity

Vehicle type	Fatal	Serious	Slight
Pedal cycle	3 (1.0%)	18 (0.4%)	47 (0.3%)
Powered two-wheeler	12 (0.7%)	59 (0.4%)	71 (0.2%)
Taxi	3 (3.2%)	25 (2.5%)	102 (1.5%)
Car	189 (3.0%)	1,092 (2.1%)	4,824 (1.3%)
Minibus	3 (11.5%)	9 (4.0%)	24 (1.6%)
Bus or coach	2 (1.8%)	11 (1.0%)	33 (0.4%)
Goods < 3.5 t mgw	23 (5.6%)	110 (3.4%)	361 (1.5%)
Goods 3.5–7.5 t mgw	6 (5.6%)	24 (4.1%)	66 (1.5%)
Goods > 7.5 t mgw	47 (9.7%)	112 (5.5%)	325 (2.4%)

3.2 Evidence gaps

The discrepancy between estimates of the prevalence of driver fatigue derived from accident analysis studies and the figures derived from official data is worthy of further research. One explanation for this discrepancy is the lack of formal training for police investigators in how to identify fatigue as a contributor.

While audience surveys often include questions about awareness of driver fatigue, it is 13 years since the last government-funded survey of drivers gathered data on the prevalence of driving while fatigued. During this time, the by Department for Transport has run a number of THINK! campaigns on the subject. There is a real need for further survey work to gauge current prevalence rates for driving while fatigued, the use of effective counter-measures, and to establish any possible differences between commercial and non-commercial drivers. The annual THINK! survey offers an ideal opportunity to collect data on these issues.

3.3 Summary

Historically, there has been significant variation in estimates of the frequency of fatigue-related accidents. Surveys of driver fatigue give some indication of the extent of the problem, but these seem highly sensitive to the way the questions are phrased. Naturalistic studies of driver behaviour offer further insight in a manner that is difficult to capture using other techniques. The results of this technique appear to converge with other previous estimates of accident causation by fatigue. The suggestion, therefore, is that driver tiredness may be estimated to be a contributory factor in as many as 20% of all road accidents.

However, current understanding of prevalence is based on partial information, historic data or research undertaken outside the UK. It is recommended that this issue is addressed through a large-scale survey of driver fatigue, which takes into consideration the methodological issues identified in this section.

4 WHAT PSYCHOLOGICAL AND PHYSICAL FACTORS CAN AFFECT FATIGUE?

4.1 Key evidence

There are over 80 different medically recognised sleep disorders which are usually categorised according to their cause. Sleep disorders, such as obstructive sleep apnoea (OSA; Stradling and Davies, 2004) and primary insomnia (Shekleton *et al.*, 2010), are perhaps the most obvious conditions that result in fatigue. Some of the other relevant chronic illnesses include cancer (Stepanski *et al.*, 2009), gastroesophageal reflux disorder, coronary artery disease, and mood and neurologic disorders (Ancoli-Israel, 2006).

These conditions can promote fatigue via two main mechanisms: by disrupting sleep via pain (Roehrs and Roth, 2005), or by alertness being reduced by the medication used to treat the disorder. In some cases, the same mechanism may underlie both the disorder and associated fatigue. Abnormalities in circadian rhythms, for example, may contribute to the development of mood and psychological disorders, as well as causing sleeping difficulties (McClung, 2007).

The main group – Primary Sleep Disorders – is normally subdivided into two main categories:[1] dyssomnias and parasomnias. Dyssomnias promote sleepiness by disrupting sleep (hyposomnia) during the night and/or promoting excessive sleepiness (hypersomnia) during the day (APA, 2000). Parasomnias are less prevalent and involve abnormal movements, behaviours, emotions, perceptions and/or dreams during sleep. Examples of parasomnias include restless leg syndrome and sleep walking. This report focuses on the two most prevalent dyssomnias, OSA and insomnia.

4.1.1 Obstructive sleep apnoea is a key concern for road safety in the UK

- Studies have consistently shown that drivers with untreated OSA have higher crash rates, with some studies finding two to three times increased risk (Ellen *et al.*, 2006; George, 2001).
- In the UK it is estimated that at least 0.5–1.5% of middle-aged men have moderate to severe OSA (the condition is twice as common in men versus women; Stradling and Davies, 2004).

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1 The DSM (Diagnostic and Statistical Manual of Mental Disorders) organises sleep disorders into four major sections according to their presumed etiology: Primary Sleep Disorders are those in which none of the following etiologies (another mental disorder, a general medical condition or a substance) is responsible.

- The prevalence of OSA is particularly high in the professional driver population. Prevalence figures for the UK are not known, but a variety of studies in the USA, Australia and Sweden indicate that between 12% and 17% of professional drivers are estimated to have OSA (Talmage *et al.*, 2008; Parks *et al.*, 2009; Howard *et al.*, 2004; Carter *et al.*, 2003).
- The high rate of OSA among professional drivers is linked to the high rate of obesity (a risk factor for OSA) in this group. A sedentary lifestyle and poor eating habits contribute to more than 40% of professional drivers being categorised as obese (Howard *et al.*, 2004) or having a significantly elevated body mass index (Carter *et al.*, 2003).
- OSA is very much under diagnosed and it is estimated that approximately 80% of people with the disorder are unaware that they have it or do not seek diagnosis (Gibson, 2005; Finkel *et al.*, 2009).
- Effective treatment for OSA is available (continuous positive airway pressure (CPAP)) and studies of CPAP-treated OSA patients consistently report improved driving performance and reduced crash risk (Ellen *et al.*, 2006). However, it has been estimated that approximately 25% of all patients with OSA discontinue therapy in long-term follow-up (de Zeeuw *et al.*, 2007). A recent Canadian study of the long-term compliance of 80 OSA patients found that, approximately five years after diagnosis, 78% of patients who had commenced CPAP treatment were still using CPAP (Wolkove *et al.*, 2008).
- Recent research (Vakulin *et al.*, 2009) suggests that drivers with undiagnosed or untreated sleep apnoea are more vulnerable to the effects of everyday causes of impairment; namely, partial sleep loss and alcohol. This driving simulator study found that, compared with healthy controls, untreated OSA patients performed significantly worse (greater steering deviation and higher frequency of crashes) after both partial sleep restriction (four hours) and low dose alcohol (blood alcohol concentration (BAC) 0.05%).
- The consequences that OSA has for the crash risk of commercial drivers may be difficult to identify because this group are also at an increased risk due to other fatiguing factors, such as long work hours and increased exposure due to the miles they drive.

4.1.2 Insomnia is often overlooked as a cause of driver impairment, but may be a significant risk factor

Insomnia can be defined as disturbed sleep, including difficulty initiating or maintaining sleep and/or early awakenings, accompanied by self-reported sleepiness during the day (Doghramji, 2006). Insomnia can be categorised as transient (short term) or chronic (long term). Transient insomnia affects the majority of the population at some point in their lifetime and can be caused by environmental conditions (temperature, noise), jetlag, emotional distress or lifestyle issues. New parents are particularly likely to suffer from transient sleep loss, both during pregnancy and post-partum (Gay *et al.*, 2004).

Although only temporary, the fatigue resulting from transient insomnia should not be ignored as driving simulator studies have found that even one night of partial sleep loss (four-hour night-time sleep opportunity) can adversely impact on driving performance (Biggs *et al.*, 2007; Otmani *et al.*, 2005).

Between 10% and 20% of the adult population are estimated to suffer from chronic insomnia (lasting in excess of one month; Doghramji, 2006; Ancoli-Israel, 2006). Chronic insomnia can be further classified as primary insomnia, defined by a collection of insomnia symptoms without a known cause or associated illness, and secondary or co-morbidity insomnia, defined as being associated with other medical or psychiatric conditions. An estimated 2−4% of adults are diagnosed with primary insomnia (Shekleton *et al.*, 2010). There are conflicting results as to whether primary insomnia has consequences for daytime neurocognitive functioning and how large these effects may be (Shekleton *et al.*, 2010; Edinger *et al.*, 2008). Our search of the literature did not identify any studies which directly assessed the driving performance of untreated primary insomniacs.

Medical conditions, including Parkinson's disease (Thannikal *et al.*, 2007), Alzheimer's disease (Lee *et al.*, 2007), rheumatoid arthritis (Swain, 2000) and depression (Ancoli-Israel, 2006), have received the most attention in terms of sleep and fatigue. In the elderly population, secondary insomnia is particularly prevalent and is estimated to affect up to 47% of this demographic (Doghramji, 2006). Despite the high prevalence of secondary insomnia, relatively little research has considered the effect of the resultant fatigue on general psychomotor functioning, or driving performance specifically. This may be because insomnia is often not the primary symptom of concern and it is therefore assumed to be transient, or relatively inconsequential. However, it is clear that co-morbidity insomnia can have a profound negative impact on a patient's quality of life and, in some cases, may exacerbate the underlying disorder (Walsh, 2004; Ancoli-Israel, 2006).

4.1.3 Parasomnias, while less prevalent, also cause daytime drowsiness that can affect driver performance

Parasomnias, such as restless leg syndrome (RLS), also have the potential to severely disrupt sleep quality and duration leading to daytime fatigue (Cuellar *et al.*, 2007). A National Sleep Foundation (NSF) poll in the US found that respondents at risk of RLS were significantly more likely to suffer from insomnia, to report fatigue during the day, and to have driven while drowsy (Phillips *et al.*, 2006).

4.1.4 A number of prescription and over-the-counter medications can promote fatigue

Medications with a stimulant effect can disrupt or prevent sleep, while others (e.g. sedatives, hypnotics, analgesics and tricyclic antidepressants) can cause drowsiness directly. Medications are not considered in depth in this report, as the implications for road safety have been reviewed in Department for Transport Road Safety Research Reports No. 18 (Ward *et al.*, 2002) and No. 24 (Barrett and Horne, 2001).

4.1.5 Medications currently used to treat insomnia may impact on driver performance

It is worth noting that, in the UK, insomnia is increasingly being treated with newer 'Z-drugs' (zaleplon, zolpidem and zopiclone). A questionnaire survey of 84 general practitioners (GPs) in the UK found that GPs believe Z-drugs are more effective, have fewer hang-over effects (daytime sleepiness) and are less likely to contribute to road traffic accidents (Siriwardena *et al.*, 2006). These beliefs are not necessarily well supported and the clinical benefits and disadvantages of Z-drugs and benzodiazepines may be very similar (Siriwardena *et al.*, 2006). Moreover, an on-road study of zopiclone found that even 11 hours after administration of a therapeutic dose, variability of lane positioning and speed was significantly increased compared with a placebo (Leufkens *et al.*, 2009).

4.1.6 Moderate doses of alcohol can exacerbate existing sleepiness

Alcohol is a well-known sedative; its role in road traffic accidents is well researched and is beyond the scope of this report. Importantly, however, simulator studies have shown that interactions between low dose alcohol (below legal limits) and moderate levels of fatigue can impair driving performance (more than either factor in isolation), both during the afternoon dip in alertness (Horne *et al.*, 2003) and in the early morning (1am; Banks *et al.*, 2004).

4.1.7 There are conflicting results on the effects of physical fatigue on performance

Studies considering the negative effects of physical fatigue on driving performance generally fail to distinguish between the effects of the physical exertion and the effects of long working hours/extended wakefulness that are generally associated with this type of exertion. For example, short-haul truck drivers have reported un/loading as a contributory factor to their fatigue (Friswell and Williamson, 2008), whereas a study by Hanowski *et al.* (2003) found that drivers who spent more time loading and unloading showed the least signs of fatigue. It is possible that, in this case, interrupting the monotony of long driving hours alleviated fatigue.

However, there is also evidence to support the benefits of light to moderate exercise during the morning or daytime for improving sleep quality (for a review see Taylor and Dorn, 2002). Furthermore, exercise helps to reduce obesity and thus helps to protect against the severity or risk of OSA (Romero-Corral *et al.*, 2010; Moreno *et al.*, 2004). The effects of short bursts of exercise on driver performance have not been directly assessed. However, studies have shown that light to moderate exercise can improve cognitive processing and reaction times (Kamijo *et al.*, 2009).

It is important to note, however, that physical fatigue can be addressed by resting from the activity, whereas fatigue induced by lack of sleep can only be addressed by taking actual sleep. Thus, physical fatigue is not considered to be as influential a factor as sleep loss, although, in combination, there is evidence to suggest additive effects.

4.1.8 There are significant inter-individual variations in the response to sleep loss

The duration and quality of sleep, as well as the response to sleep loss, can vary considerably with age, genetics and personality.

4.1.8.1 The sleep debt accumulated by young adults may account for their increased risk of being involved in fatigue-related crashes

Levels of fatigue are known to be elevated in the younger (approximately 19–24 years) population because many young people do not obtain sufficient sleep (Eaton *et al.*, 2010). Compared with adults, adolescents require a relatively high amount of sleep (estimated 9 to 10 hours each night; Millman *et al.*, 2005) and they struggle to achieve this due to lifestyle choices, work, academic and social schedules, and physiological factors. The sleep debt accumulated by young people may at least partially explain why this group is at an elevated risk of being involved in fatigue-related crashes.

4.1.8.2 While sleep disorders are more prevalent in older populations, healthy older adults may be more resilient to the effects of sleep deprivation

In older populations, fatigue may result from the increased incidence of sleep disorders such as OSA, rapid eye movement (REM) sleep behaviour disorders and restless legs syndrome, as well as many other co-morbidities that promote insomnia (Roepke and Ancoli-Israel, 2010). In contrast, studies of healthy older people have found that this group is less sleepy during the daytime than young adults (Dijk *et al.*, 2010). Lowden and colleagues (2009) found that older people (55–64 years) reported less subjective sleepiness than young people (18–24 years) during night driving. There is also evidence that, although older people (52–70 years) have slower reaction times than younger people (20–31 years) when rested, their reaction times are more resilient to the effects of sleep deprivation (Philip *et al.*, 2004; Adam *et al.*, 2006).

4.1.8.3 Individuals respond differently to sleep loss

Many studies have found that, following one night of sleep loss, subjective sleepiness and fatigue ratings, neurocognitive and behavioural tests (van Dongen *et al.*, 2004), and driving performance (Ingre *et al.*, 2006) show significant inter-individual differences. In other words, when sleep deprived, some people report higher levels of fatigue and perform significantly worse than others. Recent research further suggests that individual differences in the response to sleep loss are mediated by variations in the genes which control sleep/wake cycles (e.g. the PERIOD3 gene; Archer *et al.*, 2008; Jones *et al.*, 2007). The proportion of the driving population carrying these gene variations, and how this affects driver performance, is currently unknown and warrants further investigation.

4.1.8.4 Personality dimensions give rise to further variation in fatigue levels within the population

Studies have shown that high levels of anxiety and indecisiveness correlate with subjective measures of fatigue (Craig *et al.*, 2006; Wijesuriya *et al.*, 2007). However, studies investigating the association between mood and fatigue are predominantly directed towards the effect of fatigue on mood, rather than the effect of mood on fatigue. For example, several driver performance studies have shown not only a decrease in performance, but also an increase in confusion, anxiety and irritability when fatigued (Matthews and Desmond, 2002; Powell *et al.*, 2001; Dinges *et al.*, 1997).

4.1.8.5 Increasing effort or motivation will not overcome the effects of fatigue

Fatigue and sleep loss result in a reduction in motivation and effort (Fairclough and Graham, 1999; Matthews and Desmond, 2002). The latter researchers have shown that, when fatigued, individuals are unable to sustain performance to their unimpaired levels, despite increasing effort or motivation.

4.1.8.6 Time of day preferences influence cognitive performance, but research has not explicitly considered effects on driving performance

Chronotype refers to an individual's tendency to be a morning type or an evening type. This preference is thought to be genetically determined, but can vary across an individual's lifetime (Archer *et al.*, 2008). For example, adolescents tend be more evening types, whereas the elderly tend to be more morning types. Although a limited number of studies suggest that cognitive and motor performance may be better during an individual's preferred time of day, to our knowledge there are no studies which have addressed the influence of chronotype on driving performance at different times of day.

4.2 Evidence gaps

There is evidence that OSA plays a major role in driver fatigue crashes. There is also evidence that the condition is especially prevalent among commercial drivers. From these data it would be reasonable to expect there to be an increased prevalence of crashes involving commercial drivers suffering from OSA. However, while there have been cases involving commercial drivers who were subsequently found to be suffering from OSA, the number of crashes where OSA was palpably a cause appear lower than might be expected. Hence, it is recommended that further research is undertaken to identify and understand the confounding factors that may be masking the risk of OSA and the extent to which existing controls that are imposed on commercial drivers (e.g. drivers' hours regulations) may reduce this risk.

Similarly, given the prevalence of insomnia in all its forms, further research on the possible links between chronic insomnia and driver fatigue is recommended.

Recent research on individual differences with regard to sleep loss suggests that the effects on individual performance may be varied; further research to explore these differences in the specific context of driving could be beneficial.

4.3 Summary

The most widely researched physiological factors influencing driver fatigue are two of the more common sleep disorders: OSA and insomnia. OSA is very much under diagnosed and compliance with treatment is poor. Consequently, the disorder poses a significant emotional and economic burden, not only in terms of road safety but also other occupational injuries (AlGhanim *et al.*, 2008). As CPAP is a very cost-effective treatment, the cost−benefit arguments for increasing treatment rates are persuasive (AlGhanim *et al.*, 2008; Weatherly *et al.*, 2009).

Secondary insomnia, associated with a medical or psychological disorder, is almost certainly much more prevalent than OSA. However, despite its prevalence, the relationship between sleep disorders and chronic illness is poorly understood. Further research to define diagnostic and treatment strategies would assist medical practitioners to manage secondary insomnia and to determine a patient's fitness to drive.

From a road safety perspective, it is particularly important to improve understanding of the sleep loss and fatigue associated with conditions which may not otherwise preclude drivers from holding a licence, and to distinguish between the effects on driver performance of the condition itself and the medications used to treat the condition.

Even among the healthy population, a wide range of psychological and physical factors can influence fatigue. Age, individual susceptibility to sleep loss, lifestyle factors such as new parenthood, personality and mood are just some of these. The many causes of fatigue and the large amount of inter-individual variability in fatigue levels are part of the reason why driver fatigue is such a difficult risk to manage. It is important for drivers to understand this complexity and to be made aware of the need to individually assess their own fatigue, both before and during driving.

5 WHO DRIVES WHEN TIRED?

Determining who drives when tired has broadly involved two different techniques: surveys asking drivers how often they have driven tired over a given period; and analysis of the characteristics of drivers who have caused accidents by driving in a tired state. The key findings from these studies are outlined below.

5.1 Key evidence

5.1.1 *Young, male, inexperienced drivers are particularly at risk from driver fatigue*

Half of all crashes involving teenagers take place at night, but just 20% of teenage driving occurs at night (Groeger, 2010). Many studies (see Table 5.1) find that younger, male drivers are most likely to be responsible for fatigue-related accidents. Survey research has shown that gender differences remain even when controlling for the relative difference in annual driving distance between male and female drivers, but the higher relative frequency of male drivers in sleep-related crashes was partially explained by the greater likelihood that they drove on high-speed roads.

Table 5.1: Example studies reporting an effect of age and gender on sleep-related crash risk

Authors	Year	Country	Effect of age on sleep-related crashes	Effect of gender on sleep-related crashes
Pack *et al.* (1995)	1995	USA	55% of sleep crashes caused by drivers aged 25 years or younger	Not reported
Horne and Reyner (1995)	1995	UK	47% of sleep crashes caused by drivers aged 17–30 years	Male driver in 82% of sleep crashes
Maycock (1997)	1997	UK	46% of sleep crashes caused by drivers under 35 years	Not reported
Stutts *et al.* (2003)	2003	USA	Mean age of sleep crash drivers: 35.7 years (cf 39.4 years for non-sleep crash drivers)	Male driver in 70% of sleep crashes
Radun and Radun (2009)	2009	Finland	58% of sleep offences caused by drivers aged 35 or under	Male driver in 81% of sleep offences

A recent comparison of novice and experienced drivers' performance on a video-based driving hazard perception task (Smith *et al.*, 2009) showed that, when performing the task in a fatigued state (at 03:00), experienced drivers were relatively unaffected by mild sleepiness, whereas the novice drivers were significantly slowed.

This suggests that the increased fatigue crash risk of young drivers could be in part due to a relative slowing of their ability to anticipate traffic hazards.

5.1.2 *Younger male drivers may recognise their fatigue, but often continue to drive*

Other studies have identified that young drivers frequently drive while at risk of crashing at times of predicted sleepiness and at times they felt themselves to be sleepy (Smith *et al.*, 2005). This research highlights that, while young drivers may be aware of being tired, they still continue to attempt journeys. This finding suggests there would be value in attempting to modify this behaviour through educational interventions.

As highlighted elsewhere in this report, lifestyle issues are one of the contributors to the increased involvement of young (male) drivers in fatigue-related crashes. Recent survey research that tracked young adults over 10 years has shown that the majority of young drivers report achieving insufficient sleep: peaking at around 70% at mean age 15.4 years[2] and remaining above 50% through to a mean age of 21.3 years (Groeger, 2010).

There is also evidence that young drivers may underestimate the risks of driving while tired. An on-road study of young, male, non-professional drivers (Philip *et al.*, 2005b), which compared performance with and without sleep restriction, suggests that, while a tired driver may perceive a short trip as being low risk, fatigue may rapidly impinge on performance after starting a journey.

5.1.3 *The relative frequency of fatigue-related accidents for different age groups changes through the day and through the week*

Many studies have reported two characteristic peaks in the incidence of fatigue-related accidents over the course of the day – in the early hours and in the early afternoon (e.g. Brown, 1994; Horne and Reyner, 1995; Eskandarian *et al.*, 2007). Accident analysis studies in the USA (Pack *et al.*, 1995) and Finland (Radun and Radun, 2009) suggest that younger drivers have a marked increase in crash frequency between the hours of 23:00 and 07:00 (particularly at the weekend), but only a negligible increase in crash frequency in the afternoon. In contrast, for drivers over the age of 65 years, there was a large increase in relative crash frequency between 12:00 and 17:00, but no significant increase in crash frequency in the early hours. The authors conclude that the lifestyles of the members of each demographic dictate at what point over the course of the 24-hour cycle they are most likely to be involved in a fatigue-related accident.

2 In other words, 70% of those aged c.15 report that they do not obtain sufficient sleep.

5.1.4 Fatigue is a more common cause of accidents for commercial vehicle drivers

The next section will explore the issue of work-related driver fatigue in depth, but at this point it is sufficient to highlight the following points with regard to goods vehicles:

- goods vehicles tend to be driven on monotonous inter-urban roads that provide fewer stimuli to the driver;
- they are more likely to be driven at the times when fatigue effects are most severe, due to operational constraints; and
- they tend to be driven by male drivers, who are more likely to suffer from obstructive sleep apnoea (OSA) and snoring, associated with increased daytime sleepiness. A survey of 850 men aged 35–65 years (Stradling *et al.*, 1991) found that the likelihood of having car accidents due to sleepiness was 5.8 times greater for respondents who frequently snored.

5.1.5 Sleep and work patterns affect the risk of driver fatigue accidents

A number of studies in Europe and the USA have sought to identify the driver risk factors associated with fatigue accidents. Table 5.2 shows factors associated with a significantly increased tendency for a crash to be caused by fatigue (Stutts *et al.*, 2003).

Table 5.2: Factors associated with a significant increase in sleep crash risk

Factor	Odds ratio of increase in sleep crash risk
Taking medication with warning of drowsiness	6.22†
Working nights	5.55†
Less than 5 hours' sleep per night	4.64†
5.0–5.9 hours' sleep per night	3.49†
Irregular work pattern	2.24†
6.0–6.9 hours' sleep per night	1.95†
Two or more jobs worked	1.65*
60 or more hours worked per week	1.48*

* $p < 0.05$.
† $p < 0.01$.

Stutts *et al.* (2003) also found that drivers involved in sleep crashes were more likely to report sleep difficulties and driving in conditions of darkness. Reporting previous incidences of driving when drowsy was a very strong predictor of fatigue crash risk, while hours awake was a stronger predictor of fatigue crashes than hours of driving.

This list of factors can be ascribed to employees in many industries, but shift workers and those working in transport and logistics would seem to be particularly at risk.

5.1.6 Shift workers are at particular risk of driver fatigue

The increased risk of shift workers being involved in fatigue-related accidents has been demonstrated by simulator research. Åkerstedt *et al.* (2005) found that, after a night shift, participants showed increased variation in lateral position and more excursions from the correct driving lane. The lateral position measure (standard deviation of lateral position) for the post-shift group was at its highest value (most risky) 25 minutes into the drive and remained significantly worse than the control condition throughout.

It has been estimated (Axelsson, 2005) that 17% of the European workforce is engaged in shift work, with 14% having long shifts of 10 hours or more. Consequently, it is of concern that this group may be placing themselves (and other road users) at significant risk of an accident due to the tiredness they experience after completion of their shift.

5.1.7 'Sensation seekers' may be more sensitive to fatigue on monotonous roads

Research to investigate the effects of monotony of the road environment on driver performance (Thiffault and Bergeron, 2003) found that drivers scoring high on the sensation seeking dimension were more likely to show symptoms of fatigue at the wheel. It has previously been reported (Zuckerman, 1994) that sensation seeking is higher in men than in women and peaks in late adolescence through to the early twenties, steadily declining with age thereafter. This has implications for the age and gender effects seen for fatigue-related accidents, described above.

5.1.8 Fatigue is a different issue for motorcycle riders

Horberry *et al.* (2008) identified that fatigue was a factor in only a relatively small proportion of motorcycle accidents (as shown in Table 3.1). Motorcycle riders experience significantly higher levels of physical (vibration, temperature, wind), auditory (engine noise) and visual (changes in the horizon) stimulation inherent to motorcycle riding as compared with driving other motor vehicles, and the increased vigilance required when driving a powered two-wheel vehicle (e.g. monitoring for potholes, drain covers, sudden lane changes by other vehicles) may be more alerting. Motorcycles are also more limited in range than cars and commercial vehicles, so a rider may have more opportunities to rest and refresh. However, the heightened stimulation described may cause a rider to be more physically fatigued.

Nevertheless, recent research has demonstrated that motorcyclists do experience impairment due to sleep loss. A small study of motorcycle riders (Bougard *et al.*, 2008), which required participants to complete laboratory and motorcycle tests in the morning and early evening after normal sleep and at the same times after one night of total sleep deprivation, showed that the impairments of sleep deprivation were noticeably more severe in the early evening. At this time riders were less able to slow the motorcycle to a precise stop, performed less well in a 'slalom' test, and showed significantly slower reaction times.

This study is a good example of how fatigue can impact on performance before individuals experience lapses, demonstrating again the importance of extending our consideration of driver fatigue beyond the 'end-point' of microsleeps.

5.2 Evidence gaps

Further research into the involvement of young drivers in fatigue-related accidents might help to resolve whether fatigue effects are underestimated by younger drivers, or whether the accident patterns observed are determined solely by exposure and lifestyle. In addition, an exploration of the possible link between an individual's sensation seeking and the risk of driver fatigue might help to establish to what extent this factor contributes to the prevalence of sleep-related crashes within the young, male driver population.

Much work has been done to limit the exposure to fatigue crash risk of those who drive for work. It would be of use to examine the effectiveness of those measures; whether drivers feel that the measures have helped to reduce their exposure to driving while tired, and whether they have had an effect on productivity.

Regarding rider fatigue, the European project, 2-Be-Safe, part funded by the Department for Trasnport, may provide an opportunity to investigate how fatigue effects unfold in a naturalistic setting.

Naturalistic driving studies using instrumented vehicles in which drivers are monitored while completing their usual driving roster may prove a useful technique for further research into driver fatigue, particularly if the sample includes drivers identified as likely to be at risk of driving when tired.

5.3 Summary

The research evidence appears clear that young, male drivers, particularly those who drive at night, are most commonly involved in accidents in which fatigue was a contributory factor. However, the correlation between age, gender and sleep-related accident risk does not imply causality, and exposure effects need to be taken into consideration when attempting to understand who drives tired. Young, male drivers may not necessarily be more susceptible to driver fatigue, but may simply be more likely to drive in situations where fatigue is likely to exert an influence over their ability to control their vehicle safely. Similarly, shift workers and commercial vehicle drivers appear to have a higher risk of sleep crashes as a result of a combination of work-related factors.

6 FATIGUE AND WORK-RELATED ROAD SAFETY

The term 'work-related road safety' is used to refer to at-work road journeys that expose workers and/or members of the public to risks from traffic (WRSTG, 2001).[3] The majority of relevant literature has addressed at-work journeys made by professional drivers in commercial vehicles, including large goods vehicles, taxis, buses and company cars. Less well reported in the literature are at-work journeys made by drivers of emergency service vehicles, vans and motorcycles. Although not traditionally considered to be a part of work-related road safety, this section also covers the road journeys made while commuting to and from work, as these journeys play an integral part in road safety.

6.1 Key evidence

6.1.1 Work-related road crashes: the scale of the problem

In the UK between 2005 and 2008, 12.9% of all road fatalities and 10.2% of all serious injuries involved a bus/coach, heavy goods vehicle (HGV), light goods vehicle (LGV), minibus or taxi. As these figures do not include crashes involving company car drivers or drivers commuting for work, they underestimate the overall number of work-related crashes. Research undertaken in the USA, Canada, Australia and France indicates that road traffic collisions during work, or when travelling to or from work, account for between 25% and 60% of work-related deaths (Boufous and Williamson, 2009).[4]

A critical appraisal of all epidemiological studies investigating risk factors for work-related road traffic crashes and injuries prior to 2007 (Robb *et al.*, 2008) revealed that fatigue and sleepiness were the most commonly researched topics, and that these factors were consistently associated with an increased risk of crashes.

6.1.2 Work vehicles are involved in a greater proportion of fatigue-related crashes

Commercial vehicles constitute less than 2% of the national vehicle fleet and travel only 6% of the distance travelled by all vehicles on UK roads (Department for Transport, 2009), but are grossly over-represented in accident statistics. In addition, in the UK, the percentage of fatigue-related goods vehicle fatal crashes is over twice that for cars (8% versus 3% – see Table 3.1).

3 The Work-related Road Safety Task Group (WRSTG) definition of work-related road safety also includes people working on or near roads (WRSTG, 2001). As this report is focusing on driver fatigue, these non-driver work groups have been excluded from our definition.

4 This paper references the international papers from which this range was created.

6.1.3 A range of work factors account for the prevalence of fatigue among drivers of commercial vehicles

There has been no recent UK research of the effects of fatigue on drivers of commercial vehicles. However, overseas research suggests that professional drivers are exposed to fatigue risk due to long driving and work hours (Robb *et al.*, 2008; Friswell and Williamson, 2008); shift work, particularly night work (Rogers *et al.*, 2001); and insufficient sleep before shifts (Hanowski *et al.*, 2007; Pack *et al.*, 2006; Friswell and Williamson, 2008). A study of long-haul American truck drivers (McCartt *et al.*, 2000) identified the following six independent risk factors associated with self-reported falling asleep behind the wheel:

- daytime sleepiness;
- arduous work schedules (long work hours and limited rest opportunity);
- older, long-time drivers;
- night-time drowsy driving;
- poor sleep on the road; and
- symptoms of a sleep disorder.

Time pressure stress, pay structures, consumer/customer demands, a lack of safe and comfortable rest areas (Sabbagh-Ehrlich *et al.*, 2005), loading or delivery queues, inadequate driver numbers, and poor roster planning and management have also been identified as potential sources of commercial driver fatigue.

6.1.4 Professional drivers frequently obtain insufficient sleep

Many of the factors that promote fatigue risk in professional drivers act via the same underlying mechanism – sleep loss. Multiple studies have reported that professional drivers do not obtain adequate sleep (e.g. Dingus *et al.*, 2002; Carter *et al.*, 2003; Hanowski *et al.*, 2007).

6.1.5 Driver fatigue is a frequent occurrence for many bus drivers

Limited research has investigated the prevalence of sleepiness and accident rates in UK bus drivers, but the one study identified (Vennelle *et al.*, 2010) found that one in five drivers were excessively sleepy during the day and that 12% experienced microsleeps while driving at least once a month. Seven per cent of drivers had had an accident, and 18% a near miss, due to sleepiness.

These results are supported by similar studies in Sweden (Carter *et al.*, 2003), Brazil (Viegas and de Oliviera, 2006) and Australia (Biggs *et al.*, 2009). Bus drivers in the latter study identified the following contributors to fatigue: tight route schedules (reduced availability of rest breaks), turn-around and shift irregularity (newer drivers exposed to greater variability), extended shift cycles (up to 12 consecutive days) and extended commute times (up to 90 minutes).

A comparison of these studies highlights important differences in the contributors to fatigue faced by metropolitan bus drivers and bus or coach drivers covering longer distances. While both groups encounter irregular shifts, long working hours and limited opportunity for rest and sleep during the shift and between shifts, metropolitan bus drivers face stressors from traffic and passenger interactions with frequent stops, whereas long-haul bus drivers are more likely to encounter long, monotonous driving periods.

6.1.6 International research suggests LGV drivers are exposed to fatigue contributors, but are not protected by work and rest rules

Operators of smaller vehicles, such as LGVs, taxis, vans, cars and courier motorcycles are not required to abide by strict work and rest rules. They may also be more likely to be independent or self-employed, and so it is considerably more difficult to control the hours they work. The level of fatigue risk that these vehicle operators encounter is not well understood – no UK research has considered the fatigue of drivers of LGVs. Two studies on this issue have been found: one from Australia (Friswell and Williamson, 2008) and another from the US (Hanowski *et al.*, 2003). These studies revealed that, while the drivers of LGVs are protected from some of the causes of fatigue faced by long-haul drivers, for example night work, they remain exposed to other difficulties, such as irregular start times and long work periods. LGV drivers are also particularly likely to encounter fatigue due to a hard/physical working day and high workload, for example due to driving in traffic and multiple periods of loading and unloading (Friswell and Williamson, 2008).

6.1.7 Company car drivers are unregulated and likely to drive in fatiguing situations

A Department for Transport study (BOMEL, 2004) investigating safety culture among professional drivers and management identified fatigue as the most critical factor for occupational road risk of company car drivers. However, in contrast to other drivers who drive as part of their job, the hours of company car drivers are totally unregulated. It is possible that work demands and work objectives outweigh safety concerns for company car drivers. However, these demands and work priorities may regularly result in company car drivers driving in a fatigued condition, with predictable consequences. Business drivers with a high proportion of work-related mileage have been shown to have over 50% more injury accidents than matched, non-business drivers (Broughton *et al.*, 2003). This same study compared the impact of fatigue on company car drivers and non-business drivers and found that the former group are more likely to drive in fatiguing situations, such as long journeys (greater than 50 miles), after long working hours, and under time-pressure to reach a destination, which may explain their elevated accident risk.

6.1.8 The contribution of commuting to work-related crashes is unknown

Commuter road safety is a significant issue if only because of the sheer number of road journeys that involve travelling to and from work. However, the proportion of crashes on UK roads that involve commuters is not known as such data are not routinely collected in work-related road safety studies.

Overseas research suggests that this is an issue that warrants further investigation: in Australia, between 1998 and 2002, three-quarters of work-related traffic crashes resulting in death or injury involved drivers commuting to or from work, as opposed to driving on duty (Boufous and Williamson, 2006).

6.1.9 Shift workers are particularly susceptible to driver fatigue

A UK survey comparison of shift workers and similar non-shift workers (Rogers *et al.*, 2001; not including professional drivers) found that shift workers self-reported greater sleepiness and driving impairment when driving to early shifts, and to and from night shifts, compared with non-shift workers. Shift workers also reported a higher incidence of falling asleep at the wheel while driving home from a nightshift compared with non-shift workers. Similarly, a robust, case crossover study of 2,737 medical interns in the US found that, at the end of an extended shift (greater than 24 hours), the risk of crash was twice that after a non-extended shift (Barger *et al.*, 2005).

6.2 Evidence gaps

Although fatigue is a primary determinant of work-related road crashes involving all categories of professional and business driver, very little research has considered the contribution of fatigue to work-related road collisions in the UK.

Moreover, the exclusion of commuter journeys from the definition of work-related driving means that the true contribution of work-related fatigue in the UK is not possible to gauge. It is recommended that further research is conducted to determine the fatigue-related risks associated with driving for business and commuting, and the extent to which driver fatigue contributes to work-related road collisions.

6.3 Summary

Work-related driving poses a considerable risk on UK roads and fatigue is a primary contributory factor. Research studies and analyses of crash data show that many professional drivers, in particular drivers of large goods vehicles, often obtain inadequate sleep, report elevated levels of sleepiness, and are involved in a disproportionately high number of fatigue-related accidents. Limited studies have considered the fatigue risk profiles of drivers of LGVs, vans, taxis, buses and company cars, but the existing results suggest that these drivers are also likely to be exposed to a relatively high level of fatigue-related crash risk.

Our understanding of the link between fatigue and work-related road safety in the UK suffers from a lack of information. Notably, the Reported Road Casualties Great Britain (RRCGB) annual reports do not include the detail necessary to reliably assess work-related road safety. In order to more accurately identify work-related crashes, the STATS19 form was amended in 2004 to include a field for 'journey purpose of driver/rider'.[5] However, the RRCGB annual reports published since 2005 do not report on journey purpose in any depth.

There is also a lack of understanding of the crash risk associated with commuting, exacerbated by the exclusion of commute journeys from the definition of work-related driving. As work arrangements clearly influence fatigue and crash risk, the exclusion of commuting from work-related road safety assessments and initiatives no longer seems reasonable.

5 Journey purpose options include: 'Journey as part of work', 'Commuting to/from work', 'Taking pupil to/from school', Pupil riding to/from school' and 'Other/not known'.

7 ATTITUDES AND BEHAVIOUR REGARDING FATIGUE – WHY DO DRIVERS DRIVE TIRED?

Actions, beliefs and motivations may all have some influence on whether or not individuals recognise the signals of fatigue, have a view on driving when sleepy, or do anything to ameliorate the risks associated with driving when fatigued. Beliefs and attitudes towards fatigue and road safety, as determined by past experience, are likely to influence intentions to drive and actual driving behaviour.

7.1 Key evidence

This review highlights a number of issues, based on international research. However, in some cases it is unclear to what extent the researchers' conclusions reflect omissions or deficiencies in public awareness campaigns conducted in those jurisdictions. Consequently, it is uncertain to what extent these conclusions apply to the UK situation. In the absence of UK-based studies, however, it is necessary to consider the data provided by these studies.

7.1.1 'Extra motives' may override attitudes and behaviour towards driving when fatigued

In particular circumstances, attitudes towards driving when fatigued will be irrelevant, or have a minimal influence on behaviour, because individuals may be 'compelled' to drive by other factors. These factors, termed 'extra motives' by Hatakka *et al.* (2002),[6] influence the risks drivers are willing to take, and even affect the extent to which driving behaviour is adapted in response to fatigue. Factors include: work commitments; commuting (which may be especially problematic for shift workers who may need to travel at times when public transport alternatives are not an option); or the need to be at an arranged destination (e.g. travelling to/from an airport, attending a meeting).

Support for the influence of these extra motives comes from an experimental study (Van der Hulst *et al.*, 2001), which found that time-schedule instructions (similar to a driver having to complete a driving task, such as reach a destination, in a given time) caused disruption to the way safety margins were adapted to accommodate the fatigue of prolonged driving.

7.1.2 Past experience of driving while tired may influence current attitudes and behaviour

A related concept is that of 'external motives' (Summala, 2002; Rothengatter, 2002), which could be considered to affect attitudes to sleepy driving and the

6 After Näätänen and Summala (1974).

intentions to drive even when fatigued. This approach emphasises the influence of habitual or previous behaviour (in this case driving while tired), and outcomes of this as a powerful influence on future sleepy driving behaviour (e.g. Rothengatter, 2002).

7.1.3 *Attitudes and motivations to continue driving when sleepy are influenced by journey goals*

A recent survey of drivers' attitudes towards driving while tired (Nordbakke and Sagberg, 2007; conducted in Norway) suggests that drivers may use a range of reasons to justify their decision to continue to drive when tired. For example, they will argue that: it is only a short journey; they need to keep an appointment; it is only a short distance to their destination; they want to return at a reasonable hour or get home from work quickly; it will be alright when they start driving; it is a familiar road; they work as a driver; or the rumble strips will save them.

7.1.4 *Drivers are aware of effective counter-measures, but do not always use them*

Nordbakke and Sagberg (2007) also highlighted the discrepancy between drivers' beliefs and actions. While the fatigue counter-measures rated as most efficient were stopping to get out of the car and stopping to take a nap, only 10% of participants reported choosing to take these counter-measures; It was more common for drivers to report using strategies they rated as being less effective (in-car strategies such as opening a window, playing music, singing, talking to themselves – but not stopping).

Anund *et al.* (2008a) confirmed the incongruity between drivers' awareness of the most efficient sleepiness counter-measures (stopping to nap/sleep) and the limited use of these counter-measures. The top five strategies that drivers reported using when aware of sleepiness were: stop and have a short walk; turn on the radio/stereo; open the window; drink coffee; and talk with a passenger. Stopping for sleep was fourteenth of 23 strategies and was endorsed by only 18% of respondents; by comparison, 26% endorsed eating fruit.

The results of these surveys provide useful insights into the mindset of the tired driver and indicate that educational interventions to combat these misconceptions could be beneficial. However, it should be noted that there may be socio-cultural differences between the drivers sampled in these surveys and those in the UK.

7.1.5 *Drivers do not perceive driver fatigue to be a major concern*

Drivers' level of concern about dangerous driving behaviour is determined, in part, by their perception of other peoples' level of concern regarding those behaviours as well as perceived risks associated with those behaviours. International research suggests that part of the reason that drivers persist in driving tired is that social norms do not indicate fatigue to be a major concern for other drivers (Vanlaar *et al.*, 2008). This finding could inform early educational and driver training initiatives (see below).

7.1.6 *Education to raise awareness of the dangers of driver fatigue should begin before driving commences*

While efforts to educate adult drivers of the dangers of driver fatigue should continue, research suggests that attitudes towards driving develop long before the age at which learning to drive is reached (Waylen and McKenna 2002; 2008). This suggests that it is difficult to change the beliefs formed during a driver's early years later in their life. Mann and Lansdown (2009) have also emphasised the fluid nature of adolescent attitudes towards driving and have suggested that interventions should target individuals before they commence driving.

Pre-driving education on fatigue is already being delivered in Australia. The Victoria Department of Education and Early Childhood Development, in collaboration with key road safety agencies, has developed a traffic education strategy for Victoria which recommends that Traffic Safety Education (TSE) is provided to children in three age groups: Preparatory to Year 2; children transitioning from primary to secondary school; and to all Year 10 students. In Year 10 (average age 15 years) the programme 'Traffic Safety Essentials – for young road users, not crash test dummies' includes a range of core activities in a range of subjects, including fatigue. The activities are designed to help students improve their decision-making skills, and to develop an understanding of consequences. At the time of writing, a baseline evaluation of the programme was currently being finalised and further assessment of its use in schools was planned to be carried out in 2010 (Stough and King, 2010).

7.2 Evidence gaps

This review has identified a range of studies from around the world that have explored drivers' attitudes towards driver fatigue. While informative, there is a concern that some of the findings may not transfer directly to the UK situation, given that attitudes are likely to be shaped by socio-cultural norms and values, as well as public awareness initiatives conducted in these countries. Consequently, there is a real need for further research on these issues with UK drivers.

As well as collecting data on drivers' attitudes, knowledge and behaviour with regard to driver fatigue, such research would provide an opportunity to explore reasons for the apparent incongruence between attitudes and knowledge and actual driving behaviour, identified in other countries.

The THINK! surveys offer an ideal opportunity to collect data on these issues, particularly the apparent incongruence between attitudes and knowledge and actual driving behaviour.

7.3 Summary

The research reviewed in this section suggests that many drivers continue to drive tired despite being aware of their tiredness. It is likely that some drivers fail to fully appreciate the risks associated with driving in this state, and education (in the form of public awareness campaigns) may be beneficial for this group. However, it is also possible that some form of cost–benefit analysis may be at play when driving sleepy. Past experience (e.g. 'I've driven this tired before without consequence'), perceived social norms (driving tired is not socially unacceptable in the way that driving while drunk is) and journey goals combine to produce a situation where the driver justifies their behaviour accordingly: 'I need to get to the destination and past experience has shown me that I can probably make the journey despite feeling sleepy'. In short, for many drivers the goals and rewards of completing the journey (far) outweigh the calculated/known risk.

It may take a generation to change these attitudes, as once drivers' attitudes are set in place they may be difficult to modify. Consequently, it is recommended that specific education initiatives to raise awareness of the dangers of driving tired are targeted at pre-driving adolescents. In addition, given the high risk associated with young, male drivers, there would be some benefit in a campaign directed at this group to raise their awareness of the effects of fatigue on judgement and self-awareness, and the risks of serious injury resulting from sleep-related crashes.

8 TO WHAT EXTENT ARE ROAD USERS AWARE OF THEIR FATIGUE AND IMPAIRMENT?

Sleepiness signals the likelihood of falling asleep, while sleep onset reflects the transition from relaxed drowsy wakefulness to unresponsive sleep. This transition period has a number of physiological, behavioural and psychological factors associated with it, including subjective experience, of which awareness is a part.

8.1 Key evidence

8.1.1 Drivers do not appear to be effective at judging when they might fall asleep or their chances of falling asleep

A number of research studies using a variety of methods (e.g. Brown, 1994; Nabi *et al.*, 2006; Kaplan *et al.*, 2007; Vanlaar *et al.*, 2008; Schmidt *et al.*, 2009) have shown that drivers are capable of judging performance impairments when driving and are well aware of their depleting vigilance capabilities. However, the studies conclude that, despite this awareness, drivers may underestimate the likelihood of falling asleep and are subject to misperception of their actual objective vigilance state.

8.1.2 Despite awareness of fatigue and knowledge of the mitigating actions, many drivers continue driving even when recognising sleepiness

Research examining drivers' actions when feeling sleepy reveals conflicting results. While research in Canada (Vanlaar *et al.*, 2008) suggests that drivers have poor awareness of effective counter-measures, a survey in Norway (Nordbakke and Sagberg, 2007) concluded that many drivers have good knowledge/awareness of the factors contributing to the risk of falling asleep when driving, they are aware of the steps to be taken to prevent falling asleep at the wheel and they seem to be aware of the associated risks/hazards involved. However, despite this awareness and knowledge, many drivers continue driving even when they recognise sleepiness. It appears that the subjective warning signals to take counteractive measures are overridden wilfully.

It has been argued that drivers are aware of their own sleepiness and of their depleting vigilance capabilities (Schmidt *et al.*, 2009) and that continuing to drive is a result of inadequate knowledge of the risks (Vanlaar *et al.*, 2008), or failure to act in line with knowledge possessed (Nordbakke and Sagberg, 2007) – a decision which may be influenced by particular motives, or based on some form of internal cost–benefit analysis.

8.1.3 Drivers may not recognise the early signals as danger signals

Survey research on drivers' experiences of driver fatigue concludes that the signals apparent in the transition to sleep onset may be difficult to perceive because early signals are not recognised as being danger signals. Then, as sleepiness increases and the more imperative it becomes to take action, the poorer the capacity to respond to the signals of sleepiness leading to sleep (Sagberg, 1999).

8.1.4 Awareness of sleepiness does not necessarily prevent drivers having crashes

A large-scale prospective study of self-assessed driving while sleepy and subsequent accident involvement (Nabi *et al.*, 2006) found that the risk of serious road traffic accidents (measured in the three years post survey) increased proportionately with increased frequency of driving while sleepy. Self-reported driving while sleepy (i.e. awareness of driving while sleepy) was a substantial predictor of traffic accidents. The researchers argued that awareness of their sleepiness did not prevent drivers having crashes.

8.1.5 Fatigue's effects on cognitive performance may explain the incongruence between knowledge and behaviour

Fatigue affects many cognitive skills, including selective attention, concentration, judgement, risk assessment and performance insight (Petrilli *et al.*, 2002). Consequently, while an individual may have good knowledge of the dangers of fatigue, in their fatigued state they may underestimate their own level of impairment, the risk of falling asleep, and the severity of the consequences should they do so, and may be ill-placed to address the problem effectively by allocating cognitive or behavioural resources to the task.

8.1.6 There are individual differences with regard to behavioural/ warning signs of fatigue

Research investigating the degree to which drivers could anticipate sleep onset in order to avoid sleep-related accidents indicates that participants appeared to be aware of the signals associated with falling asleep. However, it has been suggested that many drivers' inability to judge sleep onset may result from a low level of physiological/behavioural warning signs in these individuals and a failure to acknowledge the important sleep warning signs (Kaplan *et al.*, 2007)

8.2 Evidence gaps

There appears to be a level of disagreement between different research studies reporting awareness of sleepiness/fatigue signals, or (potential) driving performance impairment. On the one hand, drivers are reported to readily recognise sleepiness signals (and act or not act accordingly), while, on the other hand, some studies advocate a lack of awareness of precursors to falling asleep. It is possible that understanding the significance of these signals is the crucial factor, combined with the motive to continue driving while fatigued.

With regard to research on these issues, the following questions are suggested as meriting further attention:

- Do drivers fully recognise (are they aware of) sleepiness danger signals, or the potential for driving impairment?
- Are there individual differences in awareness levels?
- To what extent does awareness of individual sleepiness correlate with actual driving performance, and are there individual differences in this correlation?
- Are there individual differences in the temporal onset/development of fatigue/sleepiness and driving effects?

8.3 Summary

The research literature presented in this section has highlighted more than ever the contentions relating to the attitudes and behaviour question, especially with regard to the conflict between driving sleepy/impaired and reaching the destination of the journey. In relation to both questions, there appear to be several challenges:

- To develop understanding of the importance of the danger signals.
- To train/develop awareness of the signals (in oneself rather than as a general principle or set of effects that happens to 'people').
- To improve recognition of the personal temporal course and meaning of the danger signals.
- To understand the nature of the goals, motives, and cost–benefit comparison of driving fatigued/sleepy versus reaching the journey's end.

9 DRIVER FATIGUE PUBLIC AWARENESS CAMPAIGNS AND OTHER COUNTER-MEASURES

The counter-measures designed for reducing the likelihood of fatigue-related crashes that are discussed in this section fall into the following categories:

- Public awareness campaigns.
- Road-based and road-side treatments to alert drivers.
- In-vehicle devices for monitoring driver fatigue.
- Methods for managing commercial driver fatigue.

9.1 Public awareness campaigns

9.1.1 Main focus of campaigns has been education about the signs of fatigue and effective counter-measures

In terms of campaigns which have tried to tackle drowsy or fatigued driving in particular, two main objectives are usually outlined:

- that campaigns should be designed to inform drivers of the signs and dangers of fatigue; and
- that campaigns should provide guidance on what must be done by drivers before or during a trip to overcome fatigue.

Examples of comprehensive campaigns promoting safe driving in this context include the UK THINK! campaigns (Department for Transport, 2005) and the North American 'Drive Alert – Arrive Alive' programmes (NSF, 2004). Table 9.1 summarises some of the more prominent campaigns in terms of their messages, media and intended audience.

9.1.2 There has been little evaluation of the effectiveness of driver fatigue public awareness campaigns

A thorough search of the literature suggests that there are currently very few peer-reviewed published journal articles which have systematically assessed the effectiveness of road safety campaigns, designed specifically to target driver fatigue. While an increasing number of campaign initiatives and programmes have been implemented in recent years, in most cases campaigns are not accompanied by a rationale or background to the method used, or any justification of the actual messages utilised.

Moreover, in the majority of cases there is no scientific evaluation of the effects of campaigns on driver behaviour and accident rates (CTRE, 2002). In the UK, the extent to which drivers follow the THINK! advice with regard to taking breaks, or the extent to which adherence to the advice reduces crash risk, have not been directly assessed. However, the 2008 annual THINK! Road Safety Campaign Evaluation (Angle *et al.*, 2008) found that, while immediately after the launch of the 2005 campaign the unacceptability of 'driving when too tired' was 90%, by November 2007 this had dropped to 78%, where it remained a year later.

9.1.3 Driver fatigue campaigns may benefit from a combination of different approaches

A systematic meta-analysis of 24 empirical studies (CTRE, 2002) provides a list of 25 general recommendations for the administration of a successful public information campaign. While not focusing primarily on driver fatigue campaigns, this report is useful in providing an overview of 'what works' in this context and deserves further attention.

This research suggests that there is great advantage in combining a series of different approaches to achieve the maximum impact of road safety campaigns (CTRE, 2002; Fletcher *et al.*, 2005). In contrast, one-off education programmes and isolated initiatives/campaigns were considered to be the least effective methodologies for promoting safe behaviour on the road and a substantial waste of public resources (IIHS, 2001). It is generally argued that, while information and education programmes provide adequate knowledge and awareness about unsafe behaviour, they do not promote attitudinal change by the driver.

9.1.4 US Department of Transportation guidance recommends managing driver fatigue in the same way as driver distraction

The US Department of Transportation (DOT) provides a comprehensive guide to the most effective counter-measures and enforcement techniques for encouraging safe road-user behaviour (NHTSA, 2010). According to this report, management of driver fatigue (in terms of recommended counter-measures and treatments) is assumed to be the same as management of **distracted** driving. It is argued that both distracted and drowsy driving occur as a result of drivers' behavioural choices; are due to societal and cultural influences; and both are difficult to monitor, measure and control. Similarly, reducing this type of unsafe behaviour and enforcing appropriate laws to counteract drowsy and distracted driving are equally difficult.

While campaigns may increase drivers' awareness of the signs of fatigue and consequences of drowsy driving, research suggests that many drivers continue to drive tired (Tapsas, 2006; Nordbakke and Sagberg, 2007). The extent to which this is the case in the UK has yet to be assessed.

Table 9.1: Summary of publicity campaigns designed to tackle fatigued/sleepy/drowsy driving or have these as one of the elements

Campaign name	Jurisdiction/ authority	Year*	Media used	Description	Target audience
Drive Alert – Arrive Alive http://drowsydriving.org/	USA, National Sleep Foundation	2000 onwards	Various, television, radio, audio, web, merchandise, etc.	Various public information/education messages about fatigue and driving	All road users
Microsleep and Circadian Rhythms Campaigns www.rta.nsw.gov.au/roadsafety/fatigue/campaigns/index.html	New South Wales, Australia, Road Transport Authority	2001 and 2003, respectively	Signs, leaflets, posters	Importance of time of day on fatigue-related accidents Linked to driver reviver sites: www.rta.nsw.gov.au/road safety/fatigue/driverreviverstops/index.html	Targeting all motorists
Driver Fatigue campaign 'STOP. REVIVE. SURVIVE' www.dtei.sa.gov.au/roadsafety/resources/archive/driver_fatigue_campaign_2004_archive	South Australia, Department of Transport and Urban Planning,	2004	Billboards, television adverts	Information about microsleeps and the need for breaks during driving	All motorists
Driver Fatigue Strategy www.transport.govt.nz/ourwork/Land/Driver%20Fatigue/	New Zealand, Ministry of Transport	2007	Various	Inter-agency strategy for campaign informing drivers about the signs of fatigue	All motorists
THINK! Driving for Work www.thinkroadsafety.gov.uk	UK, Department for Transport	2008	Video, audio, posters and adverts, VMS messages on motorways	Information and education messages	All road users, but specifically those driving for work
Driver Reviver www.rsa.ie/RSA/Road-Safety/Campaigns/Current-road-safety-campaigns/Drunk-With-Tiredness/	Ireland, Road Safety Authority and Topaz	2009, 2010	Posters and information	Advertising dangers of fatigue – providing free biscuits tea/coffee at various service stations	Targeting all bank holiday travellers

*This date refers to the start of the campaign.

9.1.5 *There is some evidence that tired driver messages encourage drivers to stop for a rest*

To date, very few studies have specifically evaluated the before–after effects of a particular campaign on driver behaviour or crash reduction. One exception is a before–after analysis of the effectiveness of road signage[7] on the I-80 Highway in the State of Utah, conducted for the Utah Department of Transportation. The number of crashes before and after tired driver warning signs was compared, and drivers were also asked to judge the effectiveness of these signs. Results showed that over 70% of those who stopped because of drowsy driving said they had done so because of the signs. In addition, about a third of drivers stated that the signage influenced their decision to stop for a rest (Young, 2007; Schultz and Young, 2007). An analysis of the number of crashes before and after sign installation (over a three-year period) also showed a significant reduction in crashes for eastbound, but not westbound, traffic (Young, 2007). The authors suggest a number of factors that may have contributed to this difference, including driver behaviour, traffic conditions, police reports and weather, highlighting the need for more accurate and better controlled methods for such before–after analysis.

9.2 Counter-measures for tired drivers

9.2.1 *Recent research on in-car counter-measures has considered their effects on fatigue beyond that arising from sleep loss*

The series of UK studies on the effectiveness of counter-measures for fatigue induced by sleep loss, upon which the THINK! leaflet was based (Reyner and Horne, 1997; 1998) are still relevant today. Recent research has also evaluated the effectiveness of a range of in-car strategies for preventing the decline in performance of non-fatigued drivers that occurs in monotonous conditions (Oron-Gilad *et al.*, 2008; Gershon *et al.*, 2009). While most of the counter-measures tested were found to be ineffective, impractical or likely to cause distraction, listening to music throughout the driving session prevented the gradual decline in performance evident in a control group. The finding suggests that music may be useful in combating the effects of time-on-task fatigue in non-sleep deprived subjects. However, conveying this advice unambiguously could present problems for a public information campaign; it would be difficult to deliver the advice without inadvertently giving drivers the wholly inappropriate message that music can also be used to counter driver tiredness.

7 Typical examples here included ‘Drowsy Driving Causes Crashes’, ‘Drowsy Drivers Next Exit 15 Miles’ and ‘Drowsy Drivers Pull Over If Necessary’.

9.2.2 Current Department for Transport advice on driver sleepiness counter-measures is robust, but not appropriate for all drivers

The majority of research regarding fatigue counter-measures has been undertaken in the simulator and it has been suggested that the effects of fatigue seen in this environment are not necessarily indicative of effects in the real world (Philip *et al.*, 2005b). However, the one well-designed study identified that has examined the effects of caffeine (200 mg) and napping (30 minutes) in a real-world setting delivered favourable results (Philip *et al.*, 2006).

The most reliable evidence for the benefits of a driver fatigue counter-measure would be a reduction in crashes. Unfortunately, very few studies have assessed the effects of naps and caffeine on crash rate. An American study comparing drivers involved in road accidents with control drivers using the same stretch of road, at the same time-of-day a week later (Cummings *et al.*, 2001) asked about counter-measures drivers had used during the trip. The study found that crash risk was significantly less for drivers who had used a highway rest stop, had drunk coffee or tea within the last two hours, or had listened to the radio while driving. Interestingly, consumption of caffeinated soft drinks had a negative impact on crash risk rate, perhaps because drivers consuming soft drinks were able to do so without taking a break from driving. Limited naps were reported in the study ($n = 9$), but the fact that eight of the naps were taken by drivers who subsequently caused an accident is of note.

While recent research offers further (albeit limited) support for the current Department for Transport advice regarding driver fatigue counter-measures, the appropriateness of recommending the use of stimulants as a fatigue counter-measure could be questioned. For professional drivers and shift workers in particular, daytime naps and caffeine may have a detrimental effect on the individual's ability to subsequently obtain good quality sleep, with the result that they experience fatigue the following day. In the absence of guidance on the sensible use of caffeine, this is likely to result in a cycle of poor sleep and subsequent reliance on caffeine to cope with the effects of sleep loss the next day.

9.2.3 The true value of caffeine and napping as a counter-measure is difficult to determine

Laboratory research (Reyner and Horne, 1997; De Valck and Cluydts, 2001) has demonstrated that, where a driver takes caffeine, a nap, or both, it improves their subjective alertness and driving performance. The value of these counter-measures from a broader safety perspective is more difficult to determine because their effectiveness depends on factors such as drivers' willingness to use the counter-measure, and how reliably they implement the counter-measure. In addition, individuals vary in their response to caffeine, such that the effects are likely to differ from person to person.

Moreover, evidence suggests that tired drivers are reluctant to stop driving and to implement the most effective counter-measures (Nordbakke and Sagberg, 2007). From a practical perspective, the factors determining implementation include the availability of somewhere safe (and quiet) to stop (not the hard shoulder), caffeine availability and strength (the caffeine content of coffee available at motorways service areas varies considerably).

Functional energy drinks (FEDs) contain a known amount of caffeine and thus overcome one of the practical considerations with regard to caffeine as a fatigue counter-measure for tired drivers. Consequently, FEDs have been proposed as an effective counter-measure for alleviating driver sleepiness (Reyner and Horne, 2002). However, the ready availability of a canned source of caffeine may lead some drivers to consume the drink while driving, rather than stopping, thus missing out on the benefit of taking a break from driving and removing the option of obtaining a nap, which would be of more benefit.

9.2.4 *Napping can be used as a preventative measure as well as an emergency counter-measure*

The Department for Transport's *Wake Up to the Signs of Tiredness* advice leaflet (Department for Transport, 2005) advises drivers to have a good night's sleep before commencing a long journey. In addition, the leaflet includes the recommendation that drivers stop and take a 15-minute nap if they feel tired.

Although the benefits of napping for drivers are usually discussed as a short-term on-road strategy once fatigue has already accumulated during the journey, naps can also be used as a preventative strategy before setting off. Taking a nap **before** undertaking a drive will reduce the hours of wakefulness (and thus the homeostatic drive for sleep; van Dongen *et al.*, 2003), especially if driving at night.

It is often recommended that nap duration should be kept below 30 minutes to avoid 'sleep inertia'; the groggy feeling and associated impairment experienced for up to 30 minutes after waking from deep sleep. However, it could be argued that it is more important to maximise the beneficial effects (and thus the duration) of the nap, rather than shortening nap time to avoid sleep inertia. In the case of proactive napping before a journey, napping can be planned to accommodate for sleep inertia, and the nap can be taken in the comfort of your own home or hotel, where sleep can be obtained with fewer concerns for safety, time pressures and disturbances.

9.3 Road design

9.3.1 Rumble strips are effective, but may give drivers a false sense of security

The road design feature of most relevance to fatigue is rumble strips: raised or grooved patterns placed close to the edge (or the centre line) to alert drivers when they drift from their lane by causing vibrations and audible rumbling.

Reports on the effectiveness of rumble strips vary considerably in the literature, but before and after studies with comparison groups show that continuous shoulder rumble strips installed on freeways can reduce single-vehicle run-off-road crashes by approximately 20% (Griffith, 1999; Hanley *et al.*, 2000).

However, research also suggests that some drivers may rely on them to protect themselves from driver fatigue and that any alerting effects are temporary. Nordbakke and Sagberg (2007) found that 63% of surveyed drivers believed that ‘rumble strips’ will wake-up a driver who has fallen asleep, while a simulator study found that the alerting effects of a rumble strip only lasted for up to five minutes before sleepiness returned (Anund *et al.*, 2008b).

9.4 Devices for monitoring driver fatigue may detect fatigue too late in the process

A variety of in-vehicle devices have been designed to detect signs of fatigue and to subsequently alert drivers. Fatigue detection technology is in its infancy and there are few validated studies supporting the use of current devices. A recent Department for Transport study (Wright *et al.*, 2007) reviewed a large number of these devices and so they are not considered in detail in this report.

It is worth noting, however, that the Department for Transport has long held the view that such devices should be treated with caution. First, many of these devices only respond to the later signs of fatigue, by which time a driver’s performance is likely to already be significantly impaired. Moreover, there has been concern that a driver may rely on the device to warn of fatigue and, therefore, drive until the system alerts them, and then continue driving with the belief that the system will alert them again if necessary. Hence, drivers may take more risks and shift responsibility for recognising fatigue from themselves to the device.

9.5 Methods for managing commercial driver fatigue

9.5.1 Used in isolation, prescriptive limits on work and driving hours are only partially effective

Prescriptive rules, such as the European Union Drivers’ Hours Rules and Regulations, and the Great Britain domestic driver’s rules, combined with a driver’s legal responsibility to be fit for work, are the key counter-measures for professional driver fatigue that are currently utilised. However, there is increasing recognition that these 'prescriptive' approaches to managing fatigue are, in isolation, ineffective.

A particular problem with drivers' hours regulations, as identified by our literature search, is the lack of compliance with these regulations. Figures for compliance in the UK, to our knowledge, are unavailable, but overseas research identifies this as a common problem. A study of long-distance truck drivers in New York State, for example, found that one in five said they often or always drove in breach of hours-of-service regulations by driving over 10 hours consecutively, taking less than eight hours' rest, or falsifying log books (McCartt *et al.*, 2000). However, it should be noted that the tachograph, the principal control on the hours worked by heavy vehicle drivers, is not mandatory in the USA, so it is not certain to what extent these figures are comparable with the UK situation.

9.5.2 Fatigue risk management systems are increasingly being used by other transport industries to manage fatigue

In other transport industries (notably aviation and rail), fatigue risk management systems (FRMS) are increasingly being used as an alternative to prescriptive limits. FRMS offer considerable potential to assist organisations to manage fatigue risk more effectively, but (outside Australia where legislation introduced in 2008 means they are in widespread use) their adoption by the road transport sector is still in its infancy. The Department for Transport has published a literature review (Fourie *et al.*, 2010a) and interview study (Fourie *et al.*, 2010b) with individuals and organisations with experience of FRMS and so they are not discussed further in this report.

9.5.3 Professional drivers would benefit from training in fatigue management

Proactive professional operators have developed training programmes for employees to raise awareness of fatigue, how to tackle the causes of fatigue and which counter-measures they can use to limit the effects of fatigue.

In contrast to the rail and aviation industries, where there are regulatory requirements to provide human factors training for employees, there is no such requirement for road transport operators. However, the benefits of fatigue training have not been formally assessed.

All professional/vocational bus, coach and lorry drivers must undertake periodic training in order to maintain their Driver Certificate of Professional Competence (EU Directive 2003/59). It is recommended that driver fatigue is incorporated into the Driver Certificate of Professional Competence.

9.6 Rider fatigue counter-measures

The annual THINK! review (Angle *et al.*, 2008) found that motorcyclists are less likely than car, van or lorry drivers to agree that carrying on driving while tired is a dangerous behaviour. They are also more likely than car drivers to admit to carrying on driving when too tired. Counter-measures for motorcyclist fatigue are discussed at length in Department for Transport Road Safety Research Report No. 78 (Horberry *et al.*, 2008). The use of caffeine is transferable to this road-user group, but napping is more difficult. However, the causes of rider fatigue appear to be more related to the physical demands of riding a motorbike rather than the drowsiness experienced by car drivers. The aforementioned report recommends regular breaks to stretch rather than taking naps. It does recognise, however, that these breaks, although shown to be beneficial in reliving time-on-task fatigue, do little to reduce sleepiness.

9.7 Evidence gaps

While it is acknowledged that the THINK! road safety campaigns are regularly evaluated in terms of the extent to which drivers rate various driving behaviours as unacceptable, to date there has been little attempt to measure their impact on actual driving behaviour or on driver-fatigue incidents, i.e. the extent to which drivers follow the THINK! advice regarding taking breaks, or the extent to which adherence to the advice reduces crash risk. A research study to explore these issues would help identify those messages that are most effective and help to target resources accordingly.

The majority of research regarding fatigue counter-measures has been undertaken in the simulator and the extent to which the results of such studies extend to the real world is uncertain. Moreover, it is uncertain to what extent drivers actually use these counter-measures, or how effective they are.

The provision of fatigue management training for professional drivers, for example via the Driver Certificate of Professional Competence, would be desirable. However, the benefits of fatigue training have not been formally assessed.

9.8 Summary

To date the majority of driver fatigue campaigns have focused on informing drivers of the signs and dangers of fatigue, and/or providing guidance on what drivers should do before or during a trip to overcome fatigue. However, there have been few attempts to evaluate the effectiveness of these campaigns, in terms of their impact on fatigue-related accidents or changing behaviour. The limited research that has been identified suggests that tired driver messages displayed via variable message signs (VMS) may encourage drowsy drivers to take the break they need.

In general, the counter-measures that have been researched are short-term counter-measures, such as caffeine, that only mask underlying sleepiness. While many drivers report awareness of the dangers of fatigue and knowledge of effective counter-measures, there has been little research to measure drivers' actual use of these counter-measures by UK drivers. International research has shown that many drivers fail to stop when tired, despite knowing that they should.

Improving drivers' understanding of the dangers of driving while fatigued is relatively easy to achieve through appropriately targeted educational initiatives and information. However, changing drivers' attitude and behaviour is the key to reducing their likelihood to drive while fatigued. To maximise the effectiveness of road safety campaigns promoting safe driving behaviour, it is recommended that campaigns and initiatives should adopt a multidimensional approach, using a range of methods. It is also recommended that communication activities and training should target high-risk groups identified in other sections of this report, such as young males, shift workers and those driving for work.

It is suggested that more emphasis be given to primary prevention efforts, such as educating drivers about the importance of getting sufficient sleep prior to driving, the proactive use of naps to reduce hours of wakefulness prior to commencing a drive, and avoiding circadian performance troughs when planning journeys.

Although dynamic road characteristics (curves, visual stimuli) have been shown to modestly improve driving performance, they do not reliably counteract the effects of sleep loss, nor do they improve driving performance to the level of well-rested controls. Rumble strips are effective, but some drivers may rely on them to protect themselves from driver fatigue.

10 CONCLUSIONS AND RECOMMENDATIONS

This report has critically reviewed research on driver fatigue conducted post-2000, in order to provide answers to questions asked by the Department for Transport, detailed in the introduction (Section 1). As a result of the review, the following conclusions can be made.

10.1 There is a lack of recent UK-specific research on driver fatigue

Between 1995 and 2005 the Department for Transport conducted considerable research on driver fatigue and related issues, but there has been little recent research conducted in the UK to explore this issue. For the most part this is not a major concern; much of the research completed when the Department for Transport was active in this area is still relevant today, but in several areas the lack of recent data is more problematic.

Current understanding of the prevalence of driver fatigue, its impacts on casualty rates, and on drivers' actual – as opposed to stated – behaviour (for example in the use of counter-measures to combat fatigue) is based on partial information, historic data or international research. Future Department for Transport THINK! communication activities on driver fatigue presents an opportunity for undertaking research to assess drivers' understanding of driver fatigue, their use of counter-measures and the effectiveness of current approaches.

10.2 The lapse hypothesis, upon which most of the Department for Transport publicity campaigns are based, provides insufficient explanation of the effects of driver fatigue

At the time the majority of the Department for Transport research was conducted, the dominant hypothesis for the effects of fatigue on performance was the lapse hypothesis, whereby the detrimental effects of fatigue are considered to result from microsleeps, or lapses. However, there is now considerable evidence that the effects of fatigue impact upon performance much earlier in the process, which has led to the development of the state instability hypothesis. From this perspective, fatigue is associated with a progressive escalation of performance variability and the deregulation of neurocognitive performance, of which microsleeps are an extreme symptom.

It is recommended that future THINK! communication activities take account of the state instability hypothesis and thus focus on educating drivers that fatigue can affect performance long before microsleeps occur, as well as in-between microsleeps.

10.3 Young, male drivers are over-represented in driver fatigue crashes, but the reasons for this are unclear

There is ample research from around the world to support the view that young, male drivers are over-represented in driver fatigue crashes. However, there is some debate as to the reasons for this finding. There is some evidence to suggest that young (male) drivers may be more susceptible to the effects of sleep loss than older drivers, or may be poorer at detecting and responding to the warning signs of fatigue. However, it is also the case that this group may be more at risk due to higher exposure rates (young men being more likely than other drivers to drive at night) and lifestyle factors (young people report obtaining insufficient sleep on a regular basis).

10.4 The extent to which sleep disorders contribute to fatigue-related road crashes is unknown

Research from around the world has consistently highlighted the role of sleep disorders, particularly obstructive sleep apnoea (OSA), in accident rates. OSA is very much under diagnosed and compliance with treatment is poor. Commercial vehicle drivers are known to be at higher risk of having OSA, but to date there has been little independent research in the UK to explore the effect that OSA is having on road crashes.

However, OSA is just one of a number of sleep disorders, and insomnia in all its forms is likely to be far more prevalent. To date, there has been no consideration of the effects of insomnia on road safety.

10.5 Very little research has considered the contribution of fatigue to work-related road collisions in the UK

International research suggests that many professional drivers, in particular drivers of large goods vehicle, often obtain inadequate sleep, report elevated levels of sleepiness, are at higher risk of sleep disorders, and are involved in a disproportionately high number of fatigue-related accidents. Few studies have considered the fatigue risk profiles of drivers of other commercial vehicles, but the available data suggest that these drivers are also likely to be exposed to a relatively high level of risk.

Understanding of the link between fatigue and work-related road safety in the UK suffers from a lack of information. Notably, the Reported Road Casualties Great Britain (RRCGB) annual reports do not include the detail necessary to reliably assess work-related road safety.

Given the major consequences that arise when a driver of a commercial vehicle loses control of their vehicle, it is recommended that future research on driver fatigue gives consideration to these groups.

10.6 Exclusion of commuter journeys from the definition of work-related driving means that the true contribution of work-related fatigue in the UK is not possible to gauge

Currently, commuting is not included within the definition of work-related driving. As a consequence, there is a lack of understanding of the crash risk associated with drivers commuting to and from work. As work arrangements clearly influence fatigue and crash risk, the exclusion of commuting from work-related road safety assessments and initiatives no longer seems reasonable.

10.7 Drivers continue to drive tired even where they appreciate the risks of doing so

International research suggests that many drivers continue to drive tired despite being aware of their tiredness. While some drivers may fail to appreciate the risks associated with driving in this state, it is also possible that some form of cost–benefit analysis may be at play when driving sleepy. Past experience, perceived social norms and journey goals may combine to produce a situation where the driver justifies their behaviour accordingly. Moreover, it is apparent that the specific motivations for making a journey are often deemed more significant than the perceived risks associated with driving while tired. As a consequence, many drivers continue to drive in an impaired state, placing themselves and others at risk.

It is therefore recommended that public information communications should challenge the misconception that a journey might be important enough to risk driving in a severely fatigued state, and to provide drivers with the skills to enable them to assess their own fatigue both before and during driving.

10.8 Training and awareness campaigns should target key risk groups

Throughout this report a number of common themes emerge. In particular, for a variety of reasons certain groups are at an elevated risk of involvement in fatigue-related crashes and are over-represented in the accident statistics. The groups of most concern are young (predominantly male) drivers, shift workers and professional drivers/drivers of commercial vehicles. It is recommended that public information campaigns should be developed to address these particular groups, by focusing on the lifestyle and work-related issues that place these groups in the high-risk category.

10.9 Driver fatigue education should begin before individuals learn to drive

However, changing drivers' attitudes once they are set in place may be difficult. Consequently, it is also recommended that specific education initiatives to raise awareness of the dangers of driving tired are targeted at pre-driving adolescents. Driver education for adolescents, covering a range of topics including fatigue, is currently being implemented in Victoria, Australia. It is recommended that the results of this programme are monitored, with a view to developing something similar for the UK.

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APPENDIX 1: Methods used to identify and evaluate sources

Each source identified during the search process was assessed according to the following criteria.

A1.1 Initial appraisal

- **Source** – primary sources (journal articles and conference proceedings written by experimenters reporting the results of their research) were weighted more highly than secondary sources.
- **Publication type** – sources appearing in peer-reviewed journals with a high-impact factor were rated most highly, followed by government reports.
- **Authors** – research conducted by individuals and groups with an established reputation in the specific area were rated more highly than research conducted by less established authors, or groups without a track record in the area.
- **Recency** – recent research that meets the criteria for quality was given precedence over older publications whose findings may now be out of date. However, some older texts considered to be of seminal importance were also included.
- **Relevance** – research that has direct relevance to the UK and European situation was rated as more relevant than research conducted in areas of the world that may have different characteristics (e.g. distances driven, environmental conditions, regulatory approaches, road safety culture).
- **Support** – research findings that are supported by multiple studies in different regions were rated more highly than one-off studies.

A1.2 Content analysis

Research that met the quality criteria and was considered to be of particular relevance was analysed in more detail to determine the quality of the evidence presented.

The following list of evaluation criteria was agreed at the inception meeting:

- **Methods adopted** – are the methods used to research the issue appropriate and sufficient? Are the methods employed consistent with those used in similar research studies? Are there any gaps in the methods adopted – would an alternative approach have been preferable?

- **Sample details** – is the demographic profile of participants in the research representative of a wider population (e.g. a broad age range, male and female) or from a narrow population (e.g. young, male students)? Can the findings be generalised to a broader population and specifically to the UK situation?
- **Validity and reliability** – are the conclusions valid and statistically reliable? Are the arguments or recommendations proposed supported by the data?
- **Objectivity and impartiality** – are the author's opinions and conclusions objective and impartial?

APPENDIX 2: List of evidence gaps and recommendations provided in each section

Evidence gap	Section	Issue	Recommendation
Extent to which individual differences with regard to fatigue impact on driving performance	2	Advice aimed at the average person may not be appropriate: there are differences between individuals in how they experience fatigue and how this affects their performance	Research to explore individual differences
Most research has used young males as participants	2	Concern as to whether the results from young, male drivers can be generalised to other populations, for example professional drivers, females and older drivers	Research should consider groups other than young males
Discrepancy between driver fatigue prevalence estimates derived from accident analysis studies, and figures derived from official data	3	Lack of formal training for police investigators in how to identify fatigue as a contributor	Consider working with the police to develop a course on identifying and investigating driver fatigue accidents
It is 13 years since the last government-funded survey of drivers gathered data on the prevalence of driving while fatigued	3	During this time the Department for Transport has run a number of THINK! campaigns on the subject. It is unclear what effect these campaigns have had on driver attitudes and behaviour	There is a need for a large-scale UK driver fatigue survey to gauge current prevalence rates for driving while fatigued, the use of effective counter-measures, and differences between commercial and non-commercial drivers
There has been little robust, independent research into obstructive sleep apnoea (OSA) in the UK	4	There is evidence that OSA plays a major role in driver fatigue crashes, particularly those involving commercial drivers	Given the estimated prevalence of the condition in professional drivers, more research on this issue would be beneficial
The possible impact of insomnia on driver fatigue has not been considered	4	Insomnia is a widespread condition, but has received little attention in terms of its effects on road safety	Research on the effects of insomnia on daytime drowsiness and driver performance

Research has not considered individual differences with regard to the effects of sleep loss on individual performance	4	Little is known about this subject and road safety campaigns are generally based on the performance of the 'average' respondent, typically young males	Further research to explore these differences in the specific context of driving could be beneficial
Reasons for young drivers' increased involvement in fatigue-related crashes are unclear	5	It is unclear whether young drivers are over-represented in fatigue-related accidents because fatigue effects are underestimated by younger drivers, or whether the accident patterns are determined by exposure and lifestyle	Further research to consider reasons for the prevalence of young drivers in fatigue-related crashes
The effectiveness of counter-measures aimed at commercial drivers has not been considered	5	While much work has been done to limit the exposure to fatigue crash risk of those who drive for work, little research has been conducted to examine the effectiveness of those measures	A UK survey on driver fatigue could explore these issues
UK research on driver fatigue has been conducted in simulators	5	There is concern that people respond differently in a simulator and in the real world; to what extent are the results obtained from simulator studies transferable to real-world behaviour?	Naturalistic driving studies could explore this issue. However, it is acknowledged that such an approach is expensive
Very little research has considered the contribution of fatigue to work-related road collisions in the UK	6	Fatigue is a primary determinant of work-related road crashes involving all categories of professional and business driver	Survey research should explore the impact of fatigue on work-related road safety
Commuter journeys are excluded from the definition of work-related driving	6	The true contribution of work-related fatigue in the UK is impossible to gauge	Further research should be conducted to determine the fatigue-related risks associated with driving for business and commuting, and the extent to which driver fatigue contributes to work-related road collisions
There is a lack of recent UK evidence on drivers' attitudes towards driver fatigue	7	There is a concern that some of the findings from international research may not transfer directly to the UK situation, given that attitudes are likely to be shaped by socio-cultural norms and values, as well as public awareness initiatives conducted in these countries	It is recommended that survey research on these issues should be conducted with UK drivers

There appears to be disagreement between different research studies reporting awareness of sleepiness/fatigue signals, or (potential) driving performance impairment	8	Some studies report that drivers readily recognise sleepiness signals (and act or fail to act accordingly). Other studies argue that drivers lack awareness of precursors to falling asleep. It is possible that understanding of the significance of these signals is the crucial factor, combined with the motive to continue driving while fatigued	Research could consider the following issues: Do drivers fully recognise (are they aware of) sleepiness danger signals, or the potential for driving impairment? Are there individual differences in awareness levels? To what extent does awareness of individual sleepiness correlate with actual driving performance, and are there individual differences in this correlation? Are there individual differences in the temporal onset/ development of fatigue/sleepiness and driving effects?
There has been little attempt to measure the impact of THINK! campaigns on actual driving behaviour or on driver-fatigue incidents	9	To what extent do drivers follow the THINK! advice regarding taking breaks? Does adherence to the advice reduce crash risk?	A UK survey of driver fatigue would provide an opportunity to address these questions