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DRIVER FATIGUE : CONCEPTS, MEASUREMENT AND CRASH COUNTERMEASURES

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Abstract

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DRIVER FATIGUE: CONCEPTS. MEASUREMENT AND CRASH COUNTERMEASURES

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EXECUTIVE **SUMMARY**

This report addresses the topic of driver fatigue, an issue which is receiving increasing attention in the road safety field. A range of subject areas is reviewed in detail, including concepts and theories directly related to fatigue, the measurement of fatigue, factors contributing to the onset and development of fatigue, the degree to which fatigue is associated with road crashes, countermeasures having potential for offsetting the degrading effects of fatigue on safety, and an identification of research issues having promise for reducing the role of fatigue in crashes.

Concepts and theories of fatiaue

There is a lack of an agreed definition of fatigue, even as to whether the term refers to a phenomenon or a theoretical entity (intervening variable or hypothetical construct). Fatigue has subjective, objective (performance) and physiological components which may occur in the short-term or as a chronic state.

Many theories of fatigue have been proposed, varying in their precision and the type of concepts they employ. Neural models may be more suited to the explanation of muscular fatigue than to driver fatigue. Arousal theories can explain why fatigue develops in the low demand situation of highway driving, they link the concepts of attention and fatigue and they allow for psychological and physiological measures of fatigue. One

disadvantage of these theories is that the physiological measures sometimes give inconsistent results. Other theories attempt to link the concepts of fatigue and stress.

Janssen's (1979, in Sanders, 1986) hierarchical model of driving holds promise for predicting specific performance effects of driver fatigue. The model of fatigue as an increased probability of falling asleep at the wheel proposed by Naatanen and Summala (1978) has direct implications for fatigue measurement and countermeasures.

Measurement of fatigue

Clear criteria are available and should be used to decide whether fatigue is measured on-road or in a simulator (Willumeit, Kramer and Neubert, 1981). Regardless of which experimental setting is chosen, several continuous measures should be collected.

It is inadvisable to use a performance measure on a new task which follows the supposedly fatiguing task. Subjects seem able to motivate themselves to mask the effects of fatigue, resulting in an inability to gauge the true magnitude of impairment.

Steering movements or lateral placement has been shown to be a valid measure of fatigue both on-road and in simulators. In contrast, speed maintenance or variation, brake reaction time and accelerator behaviour cannot be recommended as fatigue measures.

Rating scales seem to be the best measures of the subjective component of fatigue because they allow assessment of both frequency and severity of symptoms.

Heart rate (and related measures) cannot be considered a valid index of driver fatigue. Recording EEG enables one to tell if the driver has fallen off to sleep or is on the verge of doing so, and has been shown to validly measure fatigue. Eye movements change to a less efficient scanning pattern with fatigue and give a good index of the decrease in driving skill with fatigue.

The subsidiary auditory reaction time task has been shown to be a valid on-line measure of driver fatigue. However, it is unclear to the current authors whether the task may not in itself affect levels of driver fatigue.

Tests of persistence, the Stroop effect and Critical Flicker Fusion have been shown to give an index of fatigue largely unaffected by drivers' attempts to compensate for fatigue.

Analyses of bodily fluids are not recommended as fatigue measures.

Another indicator of the presence or severity of fatigue is the time taken to recover from it. This measure allows the separation of acute and chronic fatigue and it allows the fatiguing effects of different tasks to be compared.

Fatiaue and road crashes

The inadequacy of epidemiological research means that a precise estimate of the contribution of fatigue to road crashes in Australia cannot be made. The research that has been conducted, however, suggests that the involvement of fatigue is probably lowest in all (property-damage only, casualty and fatality) crashes, higher in casualty crashes and highest in fatal crashes. The true incidence probably ranges between 5 and 10% in all crashes, about 20 to 30% in casualty crashes and about

25 to 35% in fatal crashes. The contribution of fatigue may even reach 40 to 50% in particular types of crashes, for example, fatal single-vehicle semi-trailer crashes. It is likely that alcohol is also involved in many fatigue-related crashes.

Countermeasures and further research

Two types of educational countermeasures are proposed: teaching drivers to recognise the signs of fatigue and teaching attention maintenance strategies to actively "fight" fatigue.

Better design of log books, including time stamping of fuel receipts and bills of lading would make detection of violation of regulations limiting the length and distribution of hours of work easier. Field fatigue tests and incidental driving performance tests are two enforcement strategies which should be explored.

Countermeasures which involve changes to road design may be expensive and take a long time to implement. However, these may be useful if confined to particular areas which have a record of a large number of fatigue-related crashes.

Subsidiary reaction time devices have been shown to be effective as fatigue monitors. At present there is no empirical evidence to support or deny the claim that they may encourage drivers to drive for longer periods.

Laboratory studies show that stimulants may have short term benefits in counteracting fatigue but they may increase driver risk taking and have adverse effects in the long term.

Auditory input in the form of a car radio may be helpful in counteracting fatigue.

There are good prospects for progress in defining and alleviating the role of fatigue in road crashes. Such progress would involve further research in widely varying aspects of fatigue in driving: concepts and theories of fatigue, the nature of the fatigue-crash relationship and the development of countermeasures. Research in concepts and theories of fatigue and the fatigue-crash relationship are longer-term notions, not so directly related to the implementation of countermeasures but necessary to understand more about the relationships between fatigue, hours of service and driving performance.

GENERAL INTRODUCTION

This report addresses the topic of driver fatigue, an issue which is receiving increasing attention in the road safety field. A range of subject areas is reviewed in detail, including concepts and theories directly related to fatigue, the measurement of fatigue, factors contributing to the onset and development of fatigue, the degree to which fatigue is associated with road crashes, countermeasures having potential for offsetting the degrading effects of fatigue on safety, and an identification of research issues having promise for reducing the role of fatigue in crashes.

Given the aims of this project, the intent of the authors has been to prepare a comprehensive review of the literature closely associated with these topics. Computer search of several literature data bases was used to ensure that, to the extent possible, directly relevant publications were identified and considered. However, in order to keep the project tractable, some bounds were necessarily placed on the breadth of coverage of the field. Specifically, only the models and theories of human performance that have been specifically linked in the literature with the topic of fatigue were addressed. Topics not yet considered by researchers within the framework of the fatigue issue, or those less centrally related, are not discussed. In our judgement, there exists considerable scope for further theoretical developments based on a synthesis of human information processing concepts that could assist the understanding of the relationship between fatigue and performance. We would await the outcome of such a future research effort with interest.

STATEMENT OF THE PROBLEM

In recent years, there has been significant renewed interest in the topic of driver fatigue and road safety. While the degree to which fatigue is associated with road crashes is not yet fully understood, there is an increasing view that it constitutes a major contributing factor to crashes, particularly single vehicle crashes (McDonald, 1984).

Driver fatigue has been identified as a major issue by those concerned with safety in the trucking industry. In the United States, the strong economic pressures on drivers to drive longer than permitted by regulation is recognised as contributing to the fatigue problem. This is a problem of real concern to American agencies (Baker, 1985).

To illustrate the extent of the problem, it was recently reported in the United States that the risk of semi-trailer truck drivers having a crash almost doubled when their driving time exceeded eight hours compared with those who had driven for a shorter time (nes and Stein, 1987).

What is needed is the application of appropriate counter-measures to combat the driver fatigue problem. The establishment of an effective safety program will require further research directed at the development of such countermeasures.

This report will review the appropriate literature and address issues relating to fatigue that have implications for the development of the most cost-effective directions for research activity in the area of driving fatigue. Earlier investigations attempting to assess the extent of the problem on the road will be reviewed. The concept of fatigue will be examined in detail. What is known in general about the effects of fatigue on human performance capabilities will be assessed, along with the current state of theories of fatigue. To the extent possible, what factors in the overall road system contribute significantly to the onset of fatigue will be identified. How such fatigue manifests itself specifically in the driving environment will be discussed along with strategies for reducing fatigue. The literature relating to possible countermeasures will be considered in detail, in terms of their possible effectiveness. The information from each of these areas will be used to propose topics for future research.

CHAPTER ONE

THE CONCEPT OF FATIGUE

Cameron (1973) noted that most writers have found it necessary to point out the lack of an agreed definition of fatigue. The problem is greater than that of a lack of agreement among writers, many writers use the term fatigue differently in the course of one article (e.g., Holding in 1983 refers to fatigue in different ways in his introduction and the body of the chapter). This makes understanding difficult. The lack of a clear, accepted definition has led to inconsistencies in the use of the term, to a degree of imprecision which has hampered research in the area.

PHENOMENON OR THEORETICAL ENTITY?

To clarify the meaning of the term fatigue it must first be established whether the term refers to a phenomenon (which is something that can be observed) or a theoretical entity such as a hypothetical construct or an intervening variable. Many writers refer to fatigue as a phenomenon (e.g., Bartlett, 1943; Cullen, 1978; Holding, 1983), as an effect rather than a cause. They define fatigue as a particular kind of change in the pattern of performance, e.g., as a decrement in performance or an increase in error rate with increasing time at task. Thus Holding (1983) states in his introduction that "a broad definition of fatigue would encompass all the consequences resulting from deprivation of rest, thus including the effects of loss of sleep" (p. **145).** Consequences are phenomena. Bartlett's **(1953)** definition is also of the phenomenal type. He considered fatigue to be "those determinable changes in the expression of an activity which can be traced to the continued exercise of that activity under its normal operational conditions, and which can be shown to lead... to results within the activity which are not wanted" (Bartlett, **1953** in Cameron, **1973).**

Fatigue is sometimes regarded as having the status of an intervening variable or hypothetical construct, as a factor which leads to a change in the pattern of performance. In this sense it is a psychological variable like memory, which is a well-known and accepted hypothetical construct. Both memory and fatigue as a hypothetical construct are not observable but exist and have observable effects on situations and behaviour (Hyland, 1970). If someone claims that fatigue is a cause of road crashes he or she is using the term to denote an intervening variable.

The use of fatigue as a theoretical construct can be identified by the use of phrases such as "the effects of fatigue". One of the earliest definitions of fatigue, put forward by Ash in **1914**, was of this type. He stated that

> Fatigue is a comprehensive term which in its widest application embraces all those immediate and temporary changes, whether of a functional or organic character, which take place within an organism or any of its constituent parts as a direct result of its own exertions, and which tend to interfere with or inhibit the organism's further activities. Its principal effect is loss of efficiency, a lessening of the capacity to do work or to sustain activity; its most obvious sign is depression, a lowering of sensitivity so that a given stimulus calls forth a response of less magnitude and intensity after exertion than before. (p. **1)**

If fatigue is regarded as a theoretical entity an operational definition is needed to allow experimentation. Holding gives "hours on duty" as an example of an operational definition of fatigue.

FATIGUE AS A PHENOMENON

Even if it is agreed that the term fatigue is to be used to refer to a phenomenon, the nature of the phenomenon still needs to be defined. Bills (1934) distinguished between subjective, objective and physiological fatigue. Subjective fatigue corresponds to feelings of tiredness. Objective fatigue is usually portrayed as a phenomenon of output, a performance decrement. Physiological fatigue is the sum of the physiological changes that accompany extended performance.

Definitions of fatigue as a subjective phenomenon have a surprisingly long history. As was noted, Bills (1934) acknowledged subjective fatigue but some of his contemporaries viewed the subjective effects of continued performance as the only effects which should be termed fatigue. Bartley and Chute (1947) said that fatigue was the subjective residue of feelings of bodily discomfort and aversion to effort whilst physiological effects should be termed impairment. Barmack (1939) considered that fatigue was a motivated change of attention away from work.

Most fatigue research seems to address objective fatigue. Since before the First World War there has been research (particularly in England) into ways of reducing fatigue, and so enabling industrial production to be increased.

Other researchers have conceived of fatigue as physiological change. Some have equated fatigue with muscular fatigue, which results from a build-up of lactic acid after prolonged activity. Tsaneva and Markov (1971) argue that fatigue is determined by the production of a metabolite that raises the synaptic threshold between a nerve and the organ it controls. One problem with physiological definitions of fatigue is that they do not apply as easily to fatigue which occurs as a result of mental activity.

THE TEMPORAL DIMENSIONS OF FATIGUE

Cameron (1973) has pointed out that there are certain features common to definitions of fatigue. The most common feature is the claim that time is a variable relevant to fatigue. Yet writers disagree about the temporal dimensions of fatigue. Some claim that fatigue is short-term, being task-induced and that the individual's performance improves after a short rest or when he or she changes task (Bartlett, 1943). Some writers (e.g., Bartlett, 1953; Holding, 1983) hold to an operational definition of fatigue which allows only short-term effects despite acknowledging that chronic fatigue exists and is worthy of study. Holding claims that limiting the operational definition to hours of duty neglects long-term effects but "it offers the only practical starting point for research" (pp. 145-146).

There has been quite a lot of consideration of fatigue as a long-term or chronic phenomenon (Austin, Cameron, Cumming, Lennox and Moffit, 1968; Cameron, 1973). Many modern writers (e.g., Nairn, 1987) conclude that task-induced and chronic forms of fatigue exist and that both need to be addressed.

Cameron (1973) has described another aspect of the temporal dimension of fatigue: given that fatigue has performance, physiological and subjective components, in what order are these effects experienced? Bartley and Chute (1947) interpreted the subjective feelings as a warning to the body that its resources were being overtaxed and expected that the subjective feelings would be the first effects of fatigue to be manifest. Bartlett (1953) thought that the warnings generally arrived too late. If an analogy is drawn between fatigue and anxiety, Lovibond's (1965, in Cameron, 1973) work suggests that the physiological effects may be delayed in a high-demand situation.

FATIGUE AND EXHAUSTION, BOREDOM AND STRESS

Fatigue, exhaustion and boredom are terms which have been used synonymously by some authors. However, other authors use the terms to refer to different, though related entities and this approach will be continued here.

In everyday use exhaustion has the connotation of nothing remaining: if one's reserves are exhausted then no more can be done. We propose that use of the term exhaustion should be limited to situations like that in common speech. If a person is unable to continue activity because of muscular exhaustion, then he or she may be said to be exhausted. Holding (1983) has pointed out'that this stage is rarely reached, since a psychological boundary usually precedes the physiological limit. The term exhaustion should be used to denote one end of a continuum of fatigue of which the other end is unimpaired performance.

Davies, Shackleton and Parasuraman (1983), in their summary of past research into monotony and boredom, have defined these terms in relation to fatigue. They regard boredom as an individual's emotional response to an environment that is perceived to be monotonous (unchanging or changing only in a predictable manner). Boredom is one of the causes of the performance decrement which we call fatigue. Thus boredom is a hypothetical construct which may cause the phenomenon of fatigue. The arousal theories of fatigue which will be addressed later consider boredom as resulting from too little arousal, and fatigue as resulting from too much. This is not in the type of definition of fatigue that we have decided to adopt.

The relationship of the concepts of stress and fatigue is a little more complex. This possibly results from inconsistencies in the definition of both terms. Some authors have referred to fatigue as a stressor and others have said that stress may lead to fatigue. For example, Cameron (1973) conceives of fatigue as a generalised response to stress over a period of time. Those authors who treat fatigue as a stressor are probably using the term fatigue as a theoretical construct whilst the others consider the term fatigue to refer to a phenomenon.

AN EVALUATION OF THE CONCEPT OF FATIGUE

One of the earliest and most influential critics of the concept of fatigue was Muscio (1921). He claimed that in order to find a test of fatigue we need to know what is meant by the term and we need to have some method other than the suggested fatigue test by which we can know that different degrees of fatigue are present at certain, different times. Since, in his opinion, neither of these conditions were met, he suggested that the term fatigue be banished and that attempts to obtain a test of fatigue be abandoned.

Perhaps a definition in terms of a phenomenon suffers less from Muscio's criticism. One disadvantage of defining fatigue as a phenomenon is that such a definition says nothing about the cause of the phenomenon. For that reason such definitions are often a feature of the early stages of research. Yet fatigue research has a long history, as was noted earlier.

CONCLUSION

This chapter has outlined some of the difficulties in the general concept of fatigue. There is a lack of agreed definition, even as to whether the term refers to a phenomenon or a theoretical entity (intervening variable or hypothetical construct). Fatigue has subjective, objective (performance) and physiological components which may occur in the short-term or as a chronic state.

In response to the difficulties found with a general concept of fatigue, many writers have found it helpful to operationalise the definition and so restrict definition to the domain of their enquiry. This is a useful practice in the short-term but may retard theoretical advances in the area.

CHAPTER TWO

THEORIES OF FATIGUE

Theories of fatigue differ both in the detail with which they are elaborated and the mechanisms that they propose. Most theories are qualitative, specifying the type of effect a given change in the situation will have but unable to quantify the size of the effect, or to state which of several variables will have the greater effect. The only formal, or mathematical models which we have found are those of Tsaneva and Markov (1971) and Haight (1972).

NEURAL MODELS

Neural models of fatigue have a surprisingly long history. Early debate centred on whether fatigue was central or localised at muscles. Sherrington maintained that fatigue is central, and occured at synapses rather than in the body of neurons (Sherrington, 1905, 1906 cited in Ash, 1914).

A neural model of mental fatigue was propounded by Bills in 1931. He found that the performance of subjects required to perform a mental task for a long time showed blocks, periods of time in which no responses were made. He concluded that "the rests afforded by these blocks keep the individual's efficiency up to an average level in spite of the changes which fatigue has wrought in his nervous system" (p. 244). He speculated that the neural mechanism involved was a cumulative refractory phase, "a periodic breakdown in the central facilitative mechanism, commonly called an attention wave" (p. 244).

The model proposed by Tsaneva and Markov is based on the ideas that "fatigue is a biological reaction which should protect the working organ from exhaustion.. ..[and] that the mechanism of transmission of excitation between nerve and working organ is achieved by means of changes in the membrane permeability which is determined by the release of free acetylcholine" (1971, p. 12). Theirs is a neural feedback model in which the relations between parts of the system can be described mathematically. Tsaneva and Markov claim that their

> equations permit the quantitative study of the properties of a biological system working on the basis of the proposed control sequences. The model allows the study of fatigue in such a system, the optimal regime of work and rest and how this optimal regime depends on different physiological and external physical factors. (1971, p. 15)

Tsaneva and Markov's model is certainly precise but its application is probably limited to fatigue occurring as a result of muscular action - the kind of fatigue which results from hard physical labour or exercise. It is unlikely to be applicable to fatigue which results from mental labour. This caveat should be applied to other models of muscular fatigue, for example, that proposed by Grandjean (1969).

Crawford (1961) argued that an increase in neural noise underlies fatigue effects. "The changed signal-to-noise ratio will account for sensory fatigue effects, the internal noise will impede decision processes, reaction times, and fine motor control, and will heighten irritability and discomfort" (Holding, 1983, p. 162). This model contrasts with those that assume that nervous pathways become less responsive as a result of fatigue. The disadvantage of this model is that it is not currently testable by direct models. Holding speculates that Crawford's model might correspond to the high-activation form of fatigue which has been put forward by many who see fatigue within the framework of arousal theory.

AROUSAL THEORIES OF FATIGUE

The arousal hypothesis

Many theories of fatigue have been constructed within the arousal framework. There is agreement among neurophysiologists and neuropsychologists (e.g., Duffy, 1962; Hebb, 1955) that arousal, or alertness, is maintained by impulses sent to the cortex by the brain stem reticular formation. "Frequent sensory stimulation maintains a high level of arousal, thus facilitating perception, coordination and other higher brain mechanisms, which are inhibited when sensory input is lacking" (Brown, 1967a, p. 134). Research stemming from the work of Yerkes and Dodson (1908) has shown that the relationship between arousal and performance follows an inverted-U shaped curve: Performance is poor when arousal is very low or very high and is optimum when arousal is at some intermediate level. In one study Davey (1974) showed that performance on an attention task improved when compared to a rest condition after a moderate level of physical exercise (pedalling a bicycle ergometer) but deteriorated after very severe exercise.

From this framework fatigue theorists have assumed that fatigue could result from under- or overarousal. Some writers (e.g., Davies, Shackleton & Parasuraman, 1983) restrict fatigue to overarousal and consider poor performance in conditions of underarousal to be effects of boredom. Fatigue (or boredom) resulting from underarousal is more likely to result from continued rural or highway driving whereas fatigue resulting from over-arousal seems to be more likely a product of sustained city driving.

Advantaaes and disadvantages

Brown (1982) has pointed out that the arousal hypothesis is compatible with Bartley and Chute's (1947) claim that fatigue results from conflict.

> Where prolonged working conditions reduce the operator's level of stimulation, yet the task demands alertness, concentration, and readiness to execute skilled responses, then the optimal level of arousal required for efficient performance will be incompatible with the actual determinants of arousal....Where errors in performance may have serious consequences, this conflict between the demands for, and determinants of, an optimal level of arousal will therefore result inevitably in subjectively experienced fatigue and it may also account for the variety of emotional reactions to prolonged working, reported by Bartlett. (Brown, 1982, p. 86).

Construction of models of fatigue within the arousal framework has had several advantages. One of the major advantages is that it has allowed findings from a number of areas to be related. An example is the link that arousal has enabled between attention and fatigue. Selectivity of attention has been shown to be affected by arousal and fatigue is often reported to have a component of attention lapses. Increases in arousal lead to greater selectivity of attention, whereas lower arousal produces a diffusion of attention. Prolonged work lowers arousal, diffuses attention and thus increases the risk that important task demands are overlooked.

Another advantage of considering fatigue within the arousal framework is that arousal theory produces hypotheses which need to be tested by the use of both psychological and physiological measures. Fatigue has long been claimed to have both kinds of effects (e.g., Bartley & Chute, 1947).

One drawback of the use of the arousal framework has been the lack of agreement between various physiological indices in reflecting an individual's level of arousal (Brown, 1982). The lack of an independent measure of arousal makes prediction of performance deficits somewhat arbitrary (but see Pribram and McGuinness, 1975).

Recent refinements

A number of recent refinements to arousal theory have implications for theories of fatigue.

Pribram and McGuinness (1975) have developed a theory of attentional control processes which ties arousal concepts to particular brain structures and distinguishes between arousal and activation, terms which have often been used interchangeably. They propose three neural systems which control cortical arousal, response activation and coordinative effort. Arousal is defined in terms of phas. physiological responses to input and the arousal control c rcuits centre on the amygdala. Tonic physiological re .ness to respond is termed activation and this system is centreu on the basal ganglia of the forebrain. The system which coordinates arousal and activation demands effort and is centred on the hippocampus.

It is possible, using Pribram and McGuinness's model, to predict the psychophysiological effects of different tasks. Arousal precedes activation during categorizing but the reverse is true during reasoning. They relate these changes to specific measures such as heart rate and blood flow. Whilst this model is certainly a refinement of previous conceptions of arousal, its application to everyday tasks has yet to be specified clearly.

Cameron (1973) claimed that the activation hypothesis provided a reasonable explanation of the results of fatigue studies and that fatigue is "a convenient label for a generalised response to stress over a period of time" (p. 646). Thus he considered that placing fatigue in the arousal framework subsumed it under the general rubric of stress and its effects.

Hamilton, Hockey and Rejman (1977) conceptualise stresses as vectors describing the direction and amount of change in central control processes.

Schonpflug (1983), like Cameron (1973), considers fatigue to be a response to continued stress. He has developed a model of stress which addresses the relationship between coping efficiency and situational demands. In his model fatigue is represented as a variable which acts to reduce capacity and thus increase the individual's vulnerability to stress. The earlier onset of fatigue with more difficult tasks (Bornemann, 1956, 1957, and Schmidtke, 1965, bot.. in Schonpflug, 1983) supports the capacity reduction view of igue. But the model also includes a more complex role for fatigue. A reduction in the capacity component may be associated with a drop in activity (Bills, 1931). Whilst these omissions are a cause of inefficiency, a lower activity rate may also be associated with a lower incidence of ineffective and problem-generating behaviour. In this way, fatigue may counteract stress. This has been demonstrated in some studies in which sleep deprivation (a fatiguing agent) has reduced the impact of noise (an environmental stressor) during a choice-reaction time task (Corcoran, 1962; Wilkinson, 1963).

MODELS OF DRIVER FATIGUE

Haight's (1972) model of driver alertness is one of the two mathematical models of fatigue. The model is very complex, having ten parameters and was developed in an attempt to conceptualize driving hazard in a quantitative form. Fatigue is not explicitly treated in the model but it is likely to affect the values of a number of parameters. For example, scanning rate, reaction time and tolerance of hazards may differ between fatigued and nonfatigued drivers. Haight's model has yet to be applied to studies of driver fatigue to assess its validity.

Janssen (1979, in Sanders, 1986) has developed a hierarchical model of driving performance which may be useful in integrating the findings about the effects of fatigue. He distinguishes between three levels: strategic, manoeuvring and control.. The strategic level outlines the route, time constraints and ot [illegible] general features of the trip. It determines speed-accuracy and risk taking criteria. The manoeuvring level solves short-term problems such as overtaking, signal decisions, searching for relevant cues and alertness for unexpected events. The control level operates at a largely automatic and noncognitive level and is concerned with maintaining constant vehicle speed and direction.

A number of variables affect which level will be used in dealing with a particular situation. The higher levels require more attention and interfere only with lower levels when normal processing capacities fail to solve a particular problem. The higher levels are slow and flexible, the lower levels being fast but inflexible. Practice has the effect of enabling actions to be performed at a lower level whereas driving in fog or heavy rain may have the opposite effect (Sanders, 1986). It is likely that fatigue may cause higher levels to be used and so result in longer response latencies and the need to use more attention. Both Janssen's hierarchical model of driving and Schonpflug's (1983) effort regulation model propose that the effect of fatigue is to make performance more effortful.

FATIGUE AS FALLING ASLEEP AT THE WHEEL

It was noted in the conclusion of the previous chapter that there is a trend for researchers to opt for an operational definition of fatigue in order to avoid the difficulties with the general concept of fatigue. Naatanen *and* Summala (1978) have proposed a model of driver fatigue based on an operational definition of fatigue as falling asleep at the wheel. They note five sources of fatigue

(1) Driving with insufficient recovery periods

(2) Lack of sleep and insufficiency of other kinds of recovery periods

(3) Certain phases of circadian rhythms

(4) Certain medicines

(5) Certain aspects of the stimulus condition (e.g. monotony of visual stimulation in highway driving). (Naatanen and Summala, 1978)

Naatanen and Summala consider fatigue to be the effect of any of these agents on the organism, which is most clearly seen as an increased probability of falling asleep at the wheel. They claim that all other effects of fatigue on driving may be compensated for and so are less likely to contribute to crash risk.

THEORIES OF VIGILANCE

Theories from the research area of vigilance or sustained attention are not specifically theories of fatigue and for this reason they are not presented in detail. These theories may have some relevance to driver fatigue in describing the ability to detect visual stimuli in monotonous night-time highway driving. The reader is referred to Wickens (1984) for descriptions of the memory load, arousal and expectancy theories of vigilance.

SUMMARY

Many theories of fatigue have been proposed, varying in their precision and the type of concepts they employ. Neural models have a lon history and can be quantitative. Yet they may be more suited to the explanation of muscular fatigue than to driver fatigue. Arousal theories have enjoyed a lot of popularity although they have been questioned recently. Arousal theories can explain why fatigue develops in the low demand situation of highway driving, they link the concepts of attention and fatigue and they allow for psychological and physiological measures of fatigue. One disadvantage of these theories is that the physiological measures sometimes give inconsistent results.

A number of theories attempt to link the concepts of fatigue and stress. This relationship has been quite clearly developed in Schonpflug's (1983) model of coping efficiency and situational demands.

Several models specifically addressing driver fatigue have been presented. Haight's model of driver fatigue is mathematical and limited in scope, but Janssen's (1979, in Sanders, 1986) hierarchical model of driving holds promise for predicting specific performance effects of driver fatigue. The model of fatigue as an increased probability of falling asleep at the wheel proposed by Naatanen and Summala (1978) has direct implications for fatigue measurement and countermeasures.

Theories of vigilance are related to fatigue but not directly relevant to most issues.

CHAPTER THREE

THE MEASUREMENT OF FATIGUE

Despite Muscio's (1921) early pronouncement that a test for fatigue was not possible, attempts to measure fatigue have continued. A vast amount of research has been conducted, as befitting the importance of the issue, but many researchers are disappointed with progress to date. Broadbent in 1979 delivered a reply to Muscio entitled "Is a fatigue test now possible?" which concludes "not yet". Nevertheless this section outlines some of the indices of fatigue which have been developed. An alternative way of assessing fatigue effects in driving, that of examining crash statistics, is addressed in detail in Chapter Five.

CRITERIA APPLIED TO METHODS OF MEASURING FATIGUE

A number of criteria may be applied in the choice of a fatigue measurement technique. These include several factors which determine whether driver fatigue research is carried out on the road or in a simulator. Regardless of the testing environment, Sharp Grant (1971) has claimed that there should be detail and synchrony of behavioural and physiological measures. In addition, Grandjean and Kogi (1971) have pointed out that the best method for measuring fatigue may depend on the nature of the supposedly fatiguing task. Details of these criteria follow.

Real simulation

Willumeit, Kramer and Neubert (1981) have remarked that to "obtain relevant features of driving performance it is desirable to carry out experiments which simulate real driving as closely as possible" (p. 45). This suggests that a real vehicle would be the best driving simulator but, as they point out, there are some difficulties with this approach. On-the-road studies are less likely than other studies to give reproducible results and measurement, particularly of psychophysiological variables, is often much cheaper in the laboratory. The table which they provide comparing simulator and road test methods is reproduced below.

Table 1. Advantages and disadvantages of simulator and road test studies. From Willumeit, Kramer and Neubert, 1981, Table 6.1.

	Advantage	Disadvantage
Simulator	Low expense of measurement	High costs of 'high fidelity' simulation
	Simple variability of dynamic parameters	Deficiency of presented information
	Dangerous driving tasks without risks	
	Reproducibility of experimental results	
Road test	Provides relevant results	High expense of measurement
		Restricted variability of dynamic parameters
		Only normal and limited driving tasks performable

Detail and synchrony

Sharp Grant (1971) argues that both behavioural and physiological measures should be taken in detail and synchrony. In his demand for detailed recordings he declares "before-and-after" measurement techniques inadequate and recommends continuous, or at least time-series, recordings. He comments that "a parameter of total effort expended would only be worth measuring if the same measure could also be applied to micro-analysis of behaviour" (p. 116). To perform such a micro-analysis requires detail in measurement.

There are two reasons for requiring synchrony of recording. If the time,relationships between behaviour and physiological events are well preserved, antecedents can be established. It is even more helpful to record simultaneously the events in the environment ahead of the driver. These allow the researcher to assess the effect of stimuli (signals, etc.) on the driver and make possible the practical use of the research for recommendations on how to improve that environment. Sharp Grant advocates the use of film as a record of behaviour for this reason and for further training purposes.

Task-specific measures of fatigue?

It is possible that the most effective method of measuring fatigue will depend upon the nature of the fatiguing task. Perhaps fatigue resulting from heavy manual work could best be measured using a physiological measure. This is congruent with the view that the actual after-effects of continued work (fatigue) will differ with the nature of the work.

Grandjean and Kogi (1971) argue that a discrimination needs to be made between the

> changes directly indicative of the physical or mental demand of work or external loading and changes characteristic of fatigue effect by a relatively prolonged activity. This distinction is easy for physical. exercise, whereas it is rather hard for mental strain.... mental. strain can be indicated by such physiological measures as increase in heart rate, reduction of sinus arrhythmia and some others and claimed that these are not indicating fatigue. Another approach of indicating mental strain is the measurement of 'spare mental capacity'. (pp. xxvi-xxvii)

They propose that "a different group of methods should be applied to each of particular work situations. Visual performance, for example, would be an indispensable variable for studying fatigue of inspection workers" (Grandjean and Kogi, 1971, p. xxvii).

Given that different tasks have different demands and so may produce different fatigue effects, what sort of task is driving? There is some research on car driving and also a considerable amount of research on locomotive driving. One may assume that the tasks of long-distance driving (particularly of a heavy vehicle) and locomotive driving have many features in common. Sharp Grant (1971) described the nature of the work of a railway driver. He pointed out that modern railway drivers perform little or no heavy work and so measurement of the expenditure of physical energy may not be an appropriate way to assess fatigue levels. Instead he regards the driver as a skilled information-processor whose main tasks are to take in information from the environment and then decide how to act.

TYPES OF FATIGUE MEASURES

Grandjean and Xogi (1971) have compiled a list of six main methods for studying fatigue. They are

1. the study of work performance (output) as a function of previous working hours;
2. the study of work errors or other signs of performance defects as a function of working duration;
3. evaluation of subjective feelings of fatigue by means of self-rating tests;
4. psychophysiological changes continuously recorded during work, such as heart rate, respiration, skin resistance, motor activity, eye movement or electroencephalogram;
5. physiological and psychological tests before, during and after a work period, including determination of visual performance, skill, mental performance, reaction time, critical flicker fusion, or certain performance tests given as a subsidiary task;
6. findings of urinary excretion or concentration in blood of metabolites associated with tissue activities or pituitary-adrenalcortical system. (p. xxvii)

(See Willumeit, Kramer and Neubert, 1981 for a different taxonomy of measures which focusses on the driver-vehicle-environment system.)

Each type of measure will be addressed in turn.

1. Output as a function of previous working hours

Output measures of fatigue may be collected during performance of the task of interest or on an interpolated or subsequent task.

Directly measuring output. Measuring output during performance of the task has a long history of use in the study of work behaviour (see Murrell, 1971) and has been referred to as the measurement of work rhythms. Measurement of industrial output as a function of time was popular in the 1920s and 1930s but there are few recent studies (Murrell, 1971).

Bills (1931) investigated fatigue in mental work. In homogeneous tasks with a high degree of continuity, he observed the presence of "blocks", short periods in which performance is not possible. Using an arithmetic task he found that blocks occur about three times per minute but the frequency and size of blocks increases with fatigue. The bunching of responses between blocks is also exaggerated by fatigue and errors tend to occur near blocks.

There is a large body of literature detailing performance tests for muscular fatigue (Caldwell and Lyddan, 1971). The methods used require sustained contraction or repeated contraction and commonly investigate the relationship of contractile strength and blood flow and the effect of rest periods. Caldwell and Lyddan reported that performance in early sessions was affected by knowledge of future requirements, which is evidence that psychological factors influence what might be thought a physical task. Most of the muscle fatigue literature concerns very short term fatigue and so is not likely to be directly relevant to the longer-term fatigue effects observed in driving. Neverthe ss, the measurement of muscular fatigue may be necessary in assessing overall fatigue levels of truck drivers who may assist with loading or other strenuous activities.

In general, studies of output as a function of previous working hours have shown a warm-up effect in the first few hours followed by a performance deficit from about the third hour of work. This deficit is assumed to reflect the effect of fatigue (Burtt, 1929; Katzell, 1950; Robinson and Heron, 1924; all in Murrell, 1971). There is also some evidence that the level of performance at the beginning of the work period is influenced by the subject's knowledge of the length of the period (Barmack, 1939; Caldwell and Lyddan, 1971).

The interpretation of data from work rhythm studies requires care. Variations in rate of output across the day may reflect the influence of circadian rhythms, the operator adjusting work rate to achieve the day's target, or the effect of factors other than fatigue.

Performance on a subsequent *task.* Performance tests for fatigue, using a new task administered after the fatiguing task, are unlikely to provide a good measure of fatigue. Such tests have had little success in the past (Cameron, 1973). Broadbent (1979) describes the breakdown in skill which was observed in the control behaviour of pilots and concludes that,

> by taking fairly complex measurements a good deal of success had been achieved in demonstrating that prolonged work did show these failures of organisation. It was another matter however to show similar changes in a totally fresh performance, introduced after the event. (p. 1279)

The reason for the failure of such tests seems to be that persons can summon together all their resources and, by expending a great amount of effort, can mask the effects of fatigue for a short period. In more psychological terminology, the fatigue test itself is an arousing stimulus which leads to an improvement in behaviour. This caveat has been shown to apply to tests of the effects of sleep deprivation, of time of day and many other factors which are considered stressors (Poulton, 1970).

Measuring vehicle control over time. Studies of changes in driving performance over time in continuous driving have varied in regard of the length of the driving period and the dependent variable that has been used as an index of vehicle control. Perhaps the longest period tested was 24 hours of continuous driving (Safford and Rockwell, 1967). Dependent variables have included frequency of steering wheel movements, lateral position or acceleration of the vehicle, number of near crashes and speed.

When using measures of vehicle control to assess fatigue it is necessary to employ a sizeable pool of subjects to counter individual differences in driving skill and style. An example of a study which suffered from this problem is that of Safford and Rockwell (1967). They asked subjects to drive for 24 hours on a highway in Ohio whilst they measured the mean and the variability of speed and steering wheel and accelerator reversals. Some variables were highly correlated with elapsed driving time for some subjects but no variable was a reliable indicator of the onset of fatigue across subjects. It is likely that these results were unclear because there were only six subjects of which only three completed the whole experiment.

Measures of steering movements or resulting lateral placement. These measures have been used to assess levels of fatigue in both simulator studies and on the road. The claim has been made that fatigue effects are likely to be observed more quickly in a simulator than in real driving, since the simulator environment is much more monotonous (Dureman and Boden, 1972). Nevertheless, measures of steering movements or resulting lateral placement have proven effective in both simulator and on-road studies. Some studies which have used these measures will now be outlined.

Decrements in tracking in simulator driving were observed by Mast, Jones and Heimstra (1966) and Dureman and Boden (1972). Both studies showed deteriorations in steering performance during four hours of simulated driving and Mast et. al. found a greater decrement in the group of subjects who operated the simulator for six hours than the group who operated it for four hours.

McFarland and Mosely (1954, cited in Crawford, 1961) measured the frequency of steering wheel movements in bus drivers during 3.5 hour periods. The frequency of movements was much lower in the last half hour. A study of truck and bus drivers by Harris and Mackie (1972) collected performance and physiological measurements on the job. Steering wheel reversal rate and lane drift frequency showed some effects of prolonged driving, but these did not reach significance.

Lane drift frequency was used as the major performance measure of fatigue during four or five hours of driving by O'Hanlon and Kelley (1977). This was scored as the number of times that the left or right wheels of the car inadvertently crossed lane lines or the edge line per minute of driving. Lanes were 12 feet wide. In addition they measured mean speed and standard devi ion of speed, and the frequency of steering wheel movements in each of a number of amplitude bands (.75-2, 2-4, 6-8, 8-10 and >10 degrees). Lauer and Suhr (1958, in Brown, 1967a) also measured lateral positioning on the road and lateral accelerations imposed on the vehicle in addition to other, nonperformance measures.

Lane drifting was assessed as the standard deviation of lane position by Riemersma, Sanders, Wildervanck and Gaillard (1977). Lane drifting gradually increased during the first part, decreased after a fuel stop and reached a maximum near the end of the eight-hour night drive. Thus the measure seems to be sensitive to fatigue effects.

Speed maintenance or variability. Speed maintenance and speed variability are the reverse of each other. Both are expressed in terms of the standard deviation of vehicle speed. Like the measures of steering accuracy just discussed, speed maintenance or variability has been investigated both in simulators and on the road.

In a simulator the speed maintenance task showed trends of a decrement with four or six hours continued performance but these were not always significant (Mast et al., 1966).

Vehicle speed variability/maintenance was not recommended as an index of driver fatigue by Riemersma et al. (1977). In their study vehicle speed showed a trend to increase in variability but this failed to reach significance. This was despite significant fatigue effects on their measures of steering control.

Brake reaction time. When Mast, Jones and Heimstra (1966) measured brake reaction time during prolonged simulator driving they were surprised to find that reaction time dropped, rather than increased, during the session. In a similar study Dureman and Boden (1972) found no change in brake reaction time in four hours of simulated driving.

Acceleration. Lewis (1956) assessed the consistency of driver performance by plotting accelerations imposed on the vehicle around standard corners and determining the degree of coincidence of the curves. Whilst this measure was sensitive to individual differences, Shaw (1957) reported that it was unaffected by six hours of driving on the road.

Test batteries. Herbert (1963) gave a driving test after 0, 1, 3, 7 or 9 hours of continuous driving. The components of the test were precision steering (forward and reverse on a straight path 6.5 ft. x 200 ft.), Figure 8, slalom course, no-slip back and no-slip forward (starting on a 15 degree incline without use of handbrake), mirror reversing, non-visual driving (keeping left wheels on a crushed rock path while driving blindfolded), parallel parking, trailer backing, backing through a maze and driving in a contour pan. Total time, number of errors, distance in error, number of direction changes and time in error were used as measures for various of the component tests. The first three tests (precision steering, Figure 8 and slalom course) were not found to be useful.

Herbert and Jaynes (1964) presented a reanalysis of Herbert's (1963) data. He showed that all remaining measures were correlated with number of hours driving with the exception of parallel parking to the left.

Brown (1967a), in a review of driver fatigue research, points out that interpretation of performance studies is complicated by the confounding of fatigue and time of the day effects

> Effects of fatigue from prolonged driving are confounded with other effects on performance which could have resulted from circadian fluctuations in physiological activity. Research in this area not only offers a possible explanation of many negative findings on driving fatigue, but also allows predictions to be made on the effect of continuing driving beyond the normal working day. (p. 134)

The effect of time of day on performance is discussed in Chapter Four. Simply put, those studies in which working periods began in the early hours of the morning may have underestimated the effect of prolonged driving and those which began late in the day may have produced overestimates.

2. Work errors as a function of work dur

The study of the effect of working duration on errors is an alternative to measuring output. The choice of measure can be made on the basis of Grandjean and Kogi's (1971) criterion of task-specificity of measure. Measuring errors is more effective when the nature of the work means that errors are possible and the effect of fatigue on output is difficult to measure. If output is machine-paced, fatigue will not produce a reduction in output, but is likely to increase the number of errors made. The method of error measurement is also useful for assessing fatigue in the performance of tasks in which vigilance is an important component (e.g., quality control inspection and driving).

Potts (1951) observed the number of near crashes that occurred per hour when seventeen truck drivers drove for nine hours. Brown (1967b) had police drivers assess the driving skill of subjects who had driven for zero or seven hours, There was little difference in skill in vehicle control but a deleterious effect on perceptual skills and courtesy to other road users.

There is some support for the claim that in assessing the effect of fatigue on performance of a complex task with a large skill component, the measure should be one of risk taking, rather than error commission.

Bartlett (1943) criticised early methods in the study of mental fatigue, particularly those adapted from the study of muscular fatigue. He considered the tasks to be too simple and the attempt to describe results in terms of diminution of quantity or quality of work done to be facile. His studies of aircrews led to the conclusion that, in tasks requiring highly developed skills (of which driving is one), fatigue is seen in a deterioration of the standards accepted by the operator and a mistiming of actions.

In aircraft simulators Drew (1940, in Brown, 1967a) demonstrated that, with increasing time on task, performance and accuracy decreased, and subjects almost ignored instruments outside the immediate range of attention. Broadbent and Gregory (1965) have shown that these deteriorations in working standards may be noticeable before a drop in output or other overt changes in behaviour.

In driving, the effects demonstrated by Drew and by Broadbent and Gregory should be manifest as an increase in risk taking behaviour with time on task. Several studies have investigated this. Fuller (1981) has investigated the effect of continued driving on vehicle time headways (shorter headways reflecting greater risk taking) and Brown, Tickner and Simmonds (1970) have studied another aspect of risk taking, the changes in overtaking criteria with continued driving. In the first and last three hours of a twelve-hour driving period the experimenter recorded the number of overtaking manoeuvres begun with what he judged to be an unduly high level of risk.

3. Psychological rating of human fatigue

There is general agreement that the subjective component of fatigue is important (Bartley and Chute, 1947; Bills, 1934; Cameron, 1973). It seems intuitive that this component of fatigue could be measured by means of a questionnaire or rating scale in which subjects are asked how tired they feel.

A questionnaire has been developed by the Industrial Fatigue Research Board of Japan which is called the Fatigue Scale (Kashiwagi, 1971). The scale assumes that fatigue has dimensions which can be defined factor analytically as weakened activation, weakened motivation and physical disintegration (Saito, Kogi and Kashiwagi, 1970). Subjects are asked questions about how tired they feel and are asked to respond to statements in the questionnaire. The number of checked items is counted to give the frequency of complaints of fatigue. The frequency of complaints of fatigue is used as a measure of the degree of feeling fatigue. There are two problems with the Japanese Fatigue Scale, though, the intensity of complaints cannot be inferred and the items have not been evaluated.

A rating scale can give a better measure of the intensity of fatigue than a questionnaire (Yoshitake, 1971). Perhaps the earliest fatigue rating scale was devised by Poffenberger (1928). In his seven-point category scale, feelings were described as

1. Extremely good
2. Very good (as after a good night's rest)
3. Good
4. Medium
5. Tired
6. Very tired (as at the end of a hard day's work)
7. Extremely tired

An alternative nine-point scale was used by McNelley (1954):

1. About to fall over
2. Fagged
3. Let down
4. A little tired
5. Average
6. Fairly well
7. In gear
8. Very good
9. Terrific

McNelley's scale illustrates the need to adapt terms to keep pace with changes in language usage. Unfortunately such changes require that the rating scale be revalidated. Yoshitake (1971) minimised the problem of labelling when he constructed a nine-point scale with 1 labelled, "Feeling fit, rested" and 9 labelled, "Feeling extremely tired, exhausted" and the intermediate points being indicated by numbers only.

One way of evaluating the validity of questionnaires and rating scales is to compare assessments of fatigue using them to assessments made using other methods. There are surprisingly few studies which make such comparisons.

Poffenberger (1928) measured output on subjects' tasks of continuous addition, sentence completion, judging compositions and completion of intelligence tests and had subjects rate their feelings on the seven point scale described earlier. He concluded that

When the records of a number of subjects are averaged there appears to be no positive relationship between changes in output of work in a variety of activities and changes in feelings. When individual cases are examined there is at least a suggestion that those who show the greatest falling off in output also show the greatest change in feelings, and those who show the least falling off in output also show the least change in feelings. (Poffenberger, 1928, p. 467)

Another early validation of a subjective measure of fatigue was conducted by Barmack (1939). In his study he measured rate of adding six-place numbers and at the end of each fifteen-minute period had subjects fill out a rating sheet indicating their feelings of boredom, strain, irritation, fatigue, sleepiness and attentiveness. The feeling tone judgements became unfavourable as work output decreased. Barmack concluded that the two types of measures are likely to agree if the task is homogeneous. Otherwise, feeling tone and output may vary independently, he claims.

Still others have compared the results of fatigue scales and subjects' self-reports of fatigue symptoms. Yoshitake (1971) found extremely high correlations between ratings of fatigue on his scale and the frequency of symptoms reported by his sample of Japanese bank and broadcasting workers. This provides support for the use of his rating scale.

Kashiwagi has constructed a rating scale from the questionnaire-style Japanese Fatigue Scale. It is not a self-rating scale, but ıther an attempt to assess fatigue in others by their appearance. In this respect it is more of an objective measure. It was validated on Japanese railway workers and factor analysis shows it to have components of weakened activation and weakened motivation only. Some example items from the scale which indicate weakened activation are: too lazy to walk, unsteady voice, absent minded, hollow-cheeked and avoid conversation. Some items from the Fatigue Rating Scale which indicate weakened motivation are: many misstatements, avoid others' eye, difficult to speak to, sluggish, and restless. The weakened activation component seemed to be most affected by work. This scale fills a need for an instrument to be used by supervisors in the assessment of workers' fatigue levels.

Driver questionnaires. Fuller (1984) administered questionnaires to truck drivers before, 5.5 hours into and at the end of an 11-hour driving period. The questionnaires were answered with a five-point rating scale and covered the driver's perception of his driving performance as well as his feelings of fatigue and motivation to continue driving. Performance ratings sampled included driving ability, observation, decision making, control of vehicle, riskiness and courtesy to other road users. Feelings of fatigue sampled included drowsiness, exhaustion, awareness of actions, daydreaming, hallucinations, physical comfort, boredom, awareness of time and irritation.

The questionnaire responses included more symptoms of performance deterioration and feelings of fatigue when drivers started their shift later in the day, which suggests that the questionnaire was a valid measure, except for one observation. The questionnaire responses were not mirrored by objective performance deteriorations as measured by a decrease in time headway, an increase in riskiness. Instead, there was a trend for time headways to increase. Perhaps when drivers are aware of their fatigued state, they drive more cautiously.

4. continuous Wsvchowhvsioloaical recordinas

Fatigue has been measured by continuous recording of heart rate and other cardiovascular indices, electroencephalogram (EEG) and eye movements.

Heart rate. The effect of prolonged night driving on drivers' heart rate was measured by O'Hanlon and Kelley (1977) in a study conducted on Californian highways. ECG recordings were made from which were computed heart rate, standard deviation of heart rate and the coefficient of variability of heart rate (standard deviation divided by the mean). Heart rate declined from the initial rest period throughout the drive (Harris and Mackie, 1972 also observed this). Drivers who showed more lane drifting (poor drivers) had greater heart rate variability as indexed by the coefficient of variability.

Riemersma and his colleagues (Riemersma, Biestra and Wildervanck, 1978; Riemersma, Sanders, Wildervanck and Gaillard, 1977) have also found decreases in heart rate and increases in heart rate variability in eight hours of night driving. They have raised arguments against relating heart rate and fatigue, though. They claim that a steady decline of heart rate is usually observed as subjects get better adapted to the experimental situation, so the decline should not be taken as a sign of fatigue (Riemersma, Sanders, Wildervanck and Gaillard, 1977). They comment that heart rate may be higher than normal at the beginning of the task and may decline to something like a "normal" value. There are several aspects of their argument against the heart rate decline being indicative of fatigue.

1. The decline occurred in the first few hours of driving (a similar pattern being reported by Harris and Mackie, 1972) rather than in the later hours of driving. A later decline would be expected if it was due to the build-up of fatigue.

2. The magnitude of the decrease was small and has been observed in tasks of quite short duration where fatigue effects would be unlikely (e.g., in a two-hour tracking task by Strasser, 1974, cited in Riemersma et al., 1977).

3. The heart rates of subjects who anticipated driving all night were higher on the pretest than the heart rates of those who anticipated sleeping between pre- and posttests.

4. Trend effects during a circuit were only found during the pretest and early runs of night driving.

5. On the posttest, heart rate did not distinguish those subjects who had driven all night from those who had slept.

Riemersma, Sanders, Wildervanck and Gaillard (1977) concluded that the observed decreases of heart rate were produced by adaptation, which includes decreasing stress and habituation to sensory stimulation, rather than fatigue. They also noted that any effects of fatigue are also confounded with diurnal rhythm in their study.

The validity of heart rate variability as an index of fatigue has also been questioned by the results of the study conducted by Riemersma et al. (1977). In contrast to their expectations, heart rate was more variable in the posttest (in which traffic density was higher) than the pretest and was less variable after the fuel stop.

In a laboratory study, Ettema and Zielhuis (1971) measured the effect of various levels of mental load on heart rate, sinus arrhythmia, blood pressure and breathing rate. The task was choice reaction time in which subjects were presented with high and low tones through earphones. A high tone required a pedal to be pressed with the right foot and a low tone, a pedal to be pressed with the left foot. Mental load was manipulated by changing the number of signals per minute (0, 20, 30, 40, 50 signals/minute). There was a rise in heart rate, systolic and diastolic blood pressure and in breathing rate and a suppression of the sinus arrhythmia score during mental load. The effect was larger when mental load was greater.

In Ettema and Zielhuis' experiment electrodes were placed on the chest of subjects, breathing was measured with an impedance pneumograph and blood pressure was measured each minute while performing the task. Improvements in technology since 1971 may allow continuous measurement of blood pressure. Nevertheless, it is clear that measurement of fatigue using continuous psycho-physiological recording requires that the task and recording apparatus do not interfere with each other. This precludes the use of such methods in studying the fatiguing effects of some tasks.

Electroencephalogram. The idea of using brain activity, as represented by the electroencephalogram (EEG), to assess levels of fatigue seems promising. The onset of sleep can be identified by a change in the EEG spectrum. Drivers' EEG has been measured during long periods of driving on the road (Lemke, 1982; O'Hanlon and Kelley, 1977) and on a simulator (Lemke, 1982).

O'Hanlon and Kelley measured EEG as part of a battery of psychophysiological measures in an attempt to find what differentiated drivers who were capable of remaining alert during long periods of night driving from other drivers who were unable to do so. Different drivers participated on three routes which were Californian highways. On two of the routes used their results showed that the EEG of the better drivers remained at the same level during the 4 to 5 hour drive whereas that of the poorer drivers showed a mean increase in mean alpha power. On the third route the mean alpha level was lower for the poor drivers than the good drivers and both groups on this route had lower levels than the drivers on the other routes.

The effects of prolonged driving on the delta and theta bands were less clear and significant differences between the two driver groups were few. Clear EEG signs of sleep were found in the recordings of two of three subjects who were judged by the experimenter to have fallen asleep. These were poorly developed K-complexes which are characteristic of light sleep (Stages 1 and 2). There was even some EEG evidence of deep sleep (delta bursts).

Lemke (1982) showed that EEG measurement could show increasing fatigue: the EEG parameters showed a frontal displacement as a result of prolonged driving. They warn that their results should be interpreted cautiously because of the small number of subjects. Their experiment involved some sophisticated statistical analyses of EEG, control and mechanical signals and from these analyses they concluded that EEG measurement was possible as an indicator of driver fatigue but that performance measures (particularly accelerator activity, which they measured and analysed) were more effective.

Eye movements. Eye movements have been studied because they should provide information on what visual stimuli an individual is attending to. Kennedy (1977) conducted experiments into the relationship between vigilance and eye movements induced by vestibular stimulation. His aim was to determine the applicability of eye movements as a measure of alertness in moving environments. He found that vigilance, as indexed by eye movements, was affected by an interaction of personality factors (introversion-extroversion) and task complexity. Extroverts did relatively poorer on simple forms of the task and relatively better on more complex forms.

The influence of fatigue on driver eye movements has been studied by Kaluger and Smith (1970, in Cohen, 1978). After nine hours of driving, drivers' fixation locations became closer to the front of the car. The mean vertical direction of fixation was lowered by 2 degrees, resulting in drivers no longer fixating at the focus of expansion (the most efficient fixation point).

The effects of 24 hours sleep deprivation were similar to those of prolonged driving. The visual search strategy was less concentrated and fixations occurred on targets which would normally be monitored by peripheral vision. Fatigued drivers behaved like alcoh intoxicated drivers, exhibiting long fixation times. The locations, directions and times of fixations and the number of pursuit eye movements were similar for fatigued and inexperienced drivers. These findings support the use of eye movement measurement as a technique for assessing fatigue as they suggest that eye movements indicate a loss of skill resulting from fatigue (in line with Bartlett's, 1943, definition).

5. Physiological and psychological tests before, during and after a work period

Tests used during a work period. One of the most popular types of test used during a work period is the subsidiary task. There is some evidence that impairment due to fatigue or alcohol or other drugs can be more sensitively measured by the use of a subsidiary task than by measuring performance on the task of interest (Brown, 1962; Laurell and Lisper, 1978; Lisper and Eriksson, 1980; Lisper, Eriksson, Fagerstrom and Lindholm, 1979; Moskowitz, 1974 all in Sanders, 1986).

The theory behind the use of subsidiary tasks is that the impairing agent (fatigue) reduces the information processing capacity of the individual (Brown, 1962; Sanders, 1986). The individual's degree of skill may be great enough for him or her to continue performing quite well on the task of interest (driving) but there is unlikely to be enough spare information processing capacity to allow good performance on the subsidiary task.

Brown (1962) carried out an early study to test the sensitivity and safety of a subsidiary auditory task in field studies of driving. He had subjects detect patterns in auditorily presented series of digits whilst driving in residential or shopping areas (Expt 1) or under conditions emphasising memory or attention (Expt 2). Brown concluded that the technique was sensitive to both variables he had manipulated and was safe.

An improvement upon Brown's early technique was the change from the requirement of a verbal response which was scored as correct or incorrect by the experimenter to the implementation of an auditory reaction time task in which a button-pressing response was required. This measure has been developed by Lisper and his colleagues (Fagerstrom and Lisper, 1977; Laurell and Lisper, 1978; Lisper, Laurell and van Loon, 1986). The validity of the technique was investigated by Laurell and Lisper (1978) who showed that reaction time (RT) was highly negatively correlated with detection distance to roadside obstacles. Lisper, Laurell and van Loon (1986) found that RT was a good predictor of the length of time before a driver fell asleep at the wheel.

Tests used after a work period. Some tests cannot be performed while the subject is driving for safety or technical reasons and these are often interposed between driving periods. Ryan and Warner (1936) proposed that driving requires fine sensory discriminations and accurate motor control in steering, braking and acceleration; sustained attention; and complex motor responses. They chose a battery of tests to measure these attributes: colour naming and mental addition tests to measure sustained attention; speed and accuracy in the performance of composite pattern reactions; a postural steadiness test; hand-eye coordination test and a test of visual efficiency. Tests were administered after one hours driving (the pretest) and about eight to nine hours driving. Their study showed that long drives increase unsteadiness in standing; decrease the accuracy of hand-eye coordination; decrease visual efficiency; decrease the speed and accuracy of naming colours and decrease the speed and accuracy of mental addition. The fact that the tests were conducted late in the evening may have led to poorer performance due to circadian effects, but Ryan and Warner (1936) controlled for this by testing subjects on days that they did not drive in addition to driving days.

Critical flicker fusion (CFF) is another method that has been used to assess the after-effects of a supposedly fatiguing task. Baschera and Grandjean (1970, in Broadbent, 1979) showed that some kinds of work result in a change in critical flicker fusion (the frequency at which a pulsing light is reported to be steady) but the effects have to be determined with great care and they do not always correlate with subjective feelings. A fall in critical flicker fusion is usually interpreted as indicating a fall in arousal which is then describing as representing drowsiness or fatigue.

Oshima (1981) presented curves of recovery of CFF after truck driving. Recovery was quicker when driving time was 3.5 hours than when it was 5.5 hours, which supports the claim that it is a valid measure of fatigue.

The function of maintaining concentration (TAF) was measured before and after wor by Takakuwa (1977). He had subjects line up a gun barrel on a target which fed information to an oscillograph. From the graph the mean error and standard deviation in sighting were calculated over the three minute test. Takakuwa found that error scores were greater for subjects tested after afternoon shift than after day or night shift, increased after piloting jets and were greater when inspection was performed without a conveyor belt than with a conveyor belt. Takakuwa claims that "the TAF test can express quantitatively the integrated output of mental activities and physiological functions" (1977, p. 238).

Indicator tests. Indicator tests are characterised by their lack of obvious relation to the fatiguing task. Nevertheless they seem to be unaffected or less affected by the motivational problems of performance tests of the after-effects of continued effort which were described earlier.

The earliest use of an indicator test of fatigue may have been in the experiments on mental fatigue conducted by Ash (1914). The fatiguing task that he used was addition which was followed by testing of reversal rates for ambiguous figures. Fatigue had the effect of slowing these rates which he interpreted as an indication that fatigue had resulted in a loss of the degree of control necessary to carry out the reversal.

An indicator test that has been used by Cohen and Spacapan (1978) and Rotton, Olszewski, Charleton and Soler (1978 in Broadbent, 1979) is a test of persistence. Subjects are given complex line drawings which they are asked to trace without raising their pencil from the paper. Some puzzles are included which are imposr .le to solve and the time that subjects persist in attempting to solve these problems is the measure of persistence.

The persistence test was considered to be a valid test of fatigue because it showed greater performance decrements after longer than shorter periods of work and after higher than lower rates of work (Cohen and Spacapan). Rotton et al. showed in a division of attention task that the greater the load in a secondary memorising task, the greater was the performance deficit on fhe subsequent persistence test.

Indicator tests have been used to assess the effect of factors of a similar nature to fatigue, such as noise. Exposure to loud noise has been shown to impair performance on a subsequent Stroop test (Broadbent, 1979; Glass and Singer, 1972). The Stroop test measures the degree of interference from irrelevant stimulation and so could be considered an index of division of attention. There are many variations of the Stroop test but it usually involves naming the colour in which words are printed (the relevant stimulus) when the words are names of colours (the irrelevant stimulus).

Broadbent (1979) concludes that the effects of continued work which are shown by indicator tests are of two types, a general reduction of effort and a neglect of peripheral activities.

6. Analysis of bodily fluids

A number of physiological measures have the disadvantage that they can only be collected after the period of continuous work. This may be because the measuring device impedes performance of the task (which may occur with some psycho-physiological devices) or because the physiological change is very gradual (e.g., changes in blood or urinary metabolite levels).

Cameron's (1973) view that fatigue is a generalised response to stress continuing in time underlies much of the use of physiological methods for measuring fatigue. Similar methods to those used for measuring heat and noise stress, for example, have been adopted as measures of fatigue. One of these methods is the analysis of urinary metabolites.

Urinary metabolites can be studied with reasonable ease since samples are not hard to obtain (in contrast to the resistance of subjects to giving blood samples).

Concluding remarks. There are difficulties in interpreting some physiological measures. Fatigue results in some physiological changes which are interpreted as indicating an increase in arousal (e.g., increase in excretion of catecholamines) and some which indicate a decrease in arousal (e.g., increase in CFF). The use of physiological measures which index the body's state of arousal as measures of fatigue are hampered by the lack of a linear relationship between fatigue and arousal levels. Grandjean concluded in 1969 that "at present there is no practicable physiological or psychological objective test of fatigue which can be used in industry with success" (in Broadbent, 1979, p. 1280).

SUMMARY AND CONCLUSIONS

Clear criteria are available and should be used to decide whether fatigue is measured on-road or in a simulator (Willumeit, Kramer and Neubert, 1981). Regardless of which experimental setting is chosen, several continuous measures should be collected.

The driving task involves little or no heavy work so it may be unnecessary to collect measures of muscular fatigue (except for truck drivers who may be involved in loading).

The review of the literature on measurement of driver fatigue has shown that it is inadvisable to use a performance measure on a new task which follows the supposedly fatiguing task. Subjects seem able to motivate themselves to mask the effects of fatigue, resulting in an inability to gauge the true magnitude of impairment.

The use of vehicle control measures of fatigue requires that a sizeable number of drivers be studied because large individual differences in driving skill and style exist. A number of different vehicle control measures of fatigue were reviewed. Steering movements or lateral placement has been shown to be a valid measure of fatigue both on-road and in simulators. In contrast, speed maintenance or variation, brake reaction time and accelerator behaviour cannot be recommended as fatigue measures.

Rating scales seem to be the best measures of the subjective component of fatigue because they allow assessment of both frequency and severity of symptoms. Fuller (1984) has validated a fatigue questionnaire for drivers which could be converted to a rating scale.

Three continuous physiological measures of fatigue were reviewed: heart rate and related cardiovascular measures, electroencephalogram (EEG) and eye movements. Changes in heart rate are observed with prolonged driving but Riemersma et al. (1977) have concluded that this may show adaptation to the experimental situation, rather than fatigue. Therefore, heart rate (and related measures) cannot be considered a valid index of driver fatigue. Recording EEG enables one to tell if the driver has fallen off to sleep or is on the verge of doing so, and has been shown to validly measure fatigue. The disadvantages of this measurement technique are that sophisticated analyses are necessary and performance measures may be simpler (Lemke, 1982). Eye movements show a change to a less efficient scanning pattern with fatigue and give a good index of the decrease in driving skill with fatigue.

British and Swedish researchers (Brown, 1962; Laurell and Lisper, 1978; Lisper, Laurell and van Loon, 1986) have shown the subsidiary auditory reaction time task to be a valid on-line measure of driver fatigue. However, it is unclear to the current authors whether the task may not in itself affect levels of driver fatigue.

Indicator tests are measures of fatigue which appear unrelated to the driving task. Several of these, including tests of persistence, the Stroop effect and Critical Flicker Fusion have been shown to give an index of fatigue largely unaffected by drivers' attempts to compensate for fatigue.

Analyses of bodily fluids have several disadvantages as fatigue measures. They can only be collected after the task has been completed, so they are not a continuous measure. Such measures are intended to index arousal but it is unclear as to whether fatigue resulted from an increase or decrease in arousal.

Cameron (1973; see also Austin, Cameron, Cumming, Lennox and Moffitt, 1968) has proposed that the best indicator of the presence or severity of fatigue is the time taken to recover from it. He points out that this measure would allow the separation of acute and chronic fatigue and it would allow the fatiguing effects of different tasks to be compared. Time to recover was used as a measure of fatigue as long ago as 1914 (Ash, 1914).

CHAPTER FOUR

CAUSES OF FATIGUE

TIME ON DUTY

Most definitions of fatigue assume that it is a deficit that results from prolonged activity (Bartlett, 1953; Cameron, 1973). For this reason many studies have tested the effect of time on duty on various measures of fatigue.

One of the earliest studies of driver fatigue, the 1935 US National Safety Council report, pointed out that in assessing driver fatigue the important variable is time on duty (hours of work), rather than merely driving time. In addition to driving, time on duty includes time spent loading the truck and carrying out maintenance or other activities prior to or following driving. This point has been made in more recent studies as well (Mackie and Miller, 1978; McDonald, 1980).

Not all studies have found a decrement in driving performance with prolonged driving. Brown (1966) embedded a driving performance test in a continuous driving task. He measured drivers control skills during a twelve-hour driving period and compared these with measurements taken when driving during the tests only. He found no adverse effects of continuous driving and concluded that "the findings ... support the hypothesis that prolonged driving leads to greater automatization of control skills, which increases the time available for the perceptual requirements of the driving task" (Brown, Simmonds and Tickner, 1967, p. 665).

Doubts about the sensitivity of Brown's study led Brown, Simmonds and Tickner (1967) to conduct another study in which performance tests were included throughout the driving period and the subsidiary task differed. Subjects were given driving tests in city traffic at 7 and 10 a.m. and at 1, 3, 5 and 8 p.m. On one day they drove around a test track between driving tests (experimental day) and on another day they carried on with their normal work during tests (control day). This functioned as a control for time-of-day effects. The study showed few differences in car control skills between experimental and control days.

Herbert and Jaynes (1964) found that performance on a battery of driving tasks deteriorated after three or seven hours of truck driving. A third group of subjects tested after nine hours of driving showed better performance than the subjects tested after seven hours, though. Herbert and Jaynes speculated that these subjects may have reacted to their subjective feelings of fatigue by increasing effort and thus increasing performance.

The assertion was made by McDonald (1980) that "fatigue is not simply a function of time spent working or driving" (p. 139). He attempted to evaluate the contribution of hours of working to fatigue by assessing drivers' preparedness to continue driving. In the survey conducted in Dublin, drivers recorded after each working day whether or not they would have liked to have stopped driving before they did, and if so, how much earlier. McDonald correlated these reports with the drivers' actual hours of work and of driving. The analysis indicated that hours of work contributed 21.5 percent of the variance of preference to continue driving and hours of driving contributed 15.6 percent. Thus, using a subjective measure McDonald has demonstrated a relationship between hours of work, hours of driving and driver fatigue.

The contribution of time on duty to crash causation has been investigated in depth in many studies. A detailed review of such studies is presented in Chapter Five. A selection of results are presented here, all of which refer to truck and/or bus drivers. Harris and Mackie (1972) found an increasing ratio of obtained to expected crashes between the seventh and tenth hours of driving. Harris (1977) showed that about twice as many crashes occurred in the second half of a driving trip. The crash rate was at its most inflated during the fifth and sixth hours and diminished somewhat thereafter. A study of French truck drivers (Hamelin, 1980, personal communication cited in McDonald, 1981) found that the crash rate was 2.5 to 3 times higher after 14 or more hours of work than for working periods of 10 hours or less. A recent US report by Jones and Stein (1987) has found that the crash rate for semi-trailers approximately doubles after eight hours of driving.

In summary a number of assumptions which describe the performance of a fatigued driver is presented.

1. Driver fatigue will have an effect on the steering wheel reversal rates, speed change rates, and the average speed of the vehicle.

2. As the driver becomes fatigued, he will accept wider tolerances bf both vehicle tracking and speed control.

3. As the driver gets tired, his speed may increase or decrease depending on whether his sensitivity to speed change or steering reversal rate is lost first.

4. The driver will usually take more risks as he becomes more fatigued. This will be indicated by an increase in tracking tolerance, and consequently by a decrease in steering reversals if the vehicle is constant.

5. As the driver becomes tired, his speed change rate increases but he compensates for this by modifying his accelerator reversal rate.

6. The most severe fatigue is encountered when the speed change rate increases and the accelerator reversal rate decreases. This indicates that the driver has ceased to care about controlling his speed. (Platt, 1963 cited by Safford and Rockwell, 1967, pp. 69, 71)

SLEEP LOSS INCLUDING SHIFTWORK

Subiective reports

Subjective reports of alertness, boredom and fatigue have been demonstrated to follow circadian variations (Dermer and Berscheid, 1972 in Fuller, 1984). Train drivers report that it is hardest to remain vigilant in the early hours of the morning (Foret and Lantin, 1972 in Fuller, 1984) and truck drivers' subjective well-being declines in late night and early morning trips (Mackie and Miller, 1978). Harris (1977) collected hourly reports of truck drivers in 9 hours of driving over a 12 hour span. He found decreased alertness and increased fatigue.

Circadian error distribution

Hildebrandt, Rohmert and Rutenfranz (1974) plotted the daily frequency distribution of automatically induced warning signals and emergency braking incidents in locomotives in West Germany.

They found that the curve had maxima at 3 a.m. and 3 p.m. They conclude that fatigue might have the effect of super-imposing a 12 hour cycle on the 24 hour circadian rhythm.

A similar study to Hildebrandt et al.'s was conducted in Japan. Kogi and Ohta (1975) analysed daily recordings of near crash events by 288 locomotive drivers. Improper operation of controls due to drowsing occurred most frequently between the hours of midnight and six a.m.

Prokop and Prokop (1955) reported that the frequency of car crashes involving drivers falling asleep at the wheel was greatest in the early hours of the morning and the early afternoon. Harris (1977) analysed U.S. interstate truck crash data and noted a circadian effect in crashes involving dozing drivers. About twice as many of these crashes occurred between midnight and 8 a.m. as in the rest of the day and about half of the single-vehicle crashes had occurred in the early morning hours. Hamelin (1980, personal communication cited in McDonald, 1981) found the same pattern of a preponderance of night driving crashes in his study of French truck drivers. Mackie and Miller (1979) obtained a similar pattern of results. Circadian effects are not as prominent for multiple-vehicle crashes because of the lower traffic density during the early hours of the morning. This may account for the lack of a significant effect of time of day in the analysis of truck crashes by Jones and Stein (1987).

Data detailing distances travelled and crash involvement at various times of the day have been presented for the Queensland Vehicle-mile Performance Study (Foldvary, 1975). The data show that the within-day variation of crash frequencies is similar to the pattern by which the vehicle-mile performance varies within the day, on average. Both variables peak between 8 am and 10am and between 4pm and 6pm. The variables differ with respect to the timing of their morning low, though. Vehicle-mile performance is lowest between 2 and 4 am but the crash rate is lowest between 4 and 6 am. The 2 am to 4 am hours have neither high mileage levels or high crash rates but the crash risk is very high at these times.

Table 2. Two-hourly variation of vehicle-miles of travel, crash involvement and involvement rates per 100,000,000 miles driven, Queensland 1961 (from Foldvary, 1975, Table 3).

Two-hourly period	Annual total miles driven during 2-hourly periods		Annual total crash involvements during 2-hourly periods		Annual crash involvement rates of 2-hourly periods	
	in 100 million miles	% of annual total	no of vehicles	% of annual total	per 100 million miles	ratio annual overall involvement rate
12 - 2 am	14.6	0.6	1,031	3.7	7,071	6.77
2 - 4 am	7.9	0.3	458	1.7	5,774	5.53
4 - 6 am	31.0	1.2	231	0.8	745	0.71
6 - 8 am	248.8	9.6	1,601	5.8	643	0.62
8 -10 am	433.1	16.7	2,507	9.1	579	0.55
10 -12 noon	369.1	14.2	2,504	9.0	678	0.65
12 - 2 pm	273.9	10.6	2,354	8.5	860	0.82
2 - 4 pm	297.1	11.5	3,131	11.3	1,054	1.01
4 - 6 pm	452.0	17.4	5,256	19.0	1,163	1.11
6 - 8 pm	215.7	8.3	4,017	14.5	1,862	1.78
8 -10 pm	94.7	3.7	2,249	8.1	2,375	2.27
10 -12 mn	66.4	2.6	2,352	8.5	3,542	3.39
Total	2,632.2	100.0	27,691	100.0		
Overall rate					1,045	1.00

performance measures

There is evidence of a post-lunch dip in performance from a variety of sources (e.g., Hildebrandt, Rohmert and Rutenfranz, 1974; Prokop and Prokop, 1955). Hildebrandt et al. showed that the magnitude of the post-lunch dip increased with the number of hours worked beforehand, thus strengthening the claim that fatigue is a causative factor.

There is further discussion of performance changes across the day in the later section entitled "Shiftwork".

Physiological changes

Torsvall and Akerstedt (1982) measured a number of physiological variables during day or night train driving. Day driving did not affect any of the variables but during night driving the EEG records showed increased alpha and theta wave activity. The amount of eye closure increased, heart rate decreased and rated sleepiness increased. There were reductions in noradrenaline and adrenaline levels during night train driving. Large individual variations were observed.

Reaction time

Lisper, Eriksson, Fagerstrom and Lindholm (1979) used performance on a subsidiary auditory reaction time task to assess the relative effects of fatigue and time-of-day effects on driving. Subjects drove for three hours, starting at 3 a.m., 9 a.m., 3 p.m. or 9 p.m. Differences in the rate of increase in reaction time were not observed. The authors concluded that "biological rhythm as a single variable has only a minor influence on this type of performance. Consequently the diurnal rhythm of traffic crashes must be attributed to other factors such as long hours of driving and/or sleep deprivation which culminate during the morning hours" (Lisper, Eriksson, Fagerstrom and Lindholm, 1979, p. 1).

Sleep deprivation

Forbes, Katz, Cullen and Deterline (1958) studied the effect of extreme and spaced sleep deprivation on highway driving. They note that spaced sleep deprivation is likely to be more common among drivers. Driving efficiency was less in sleep-deprived runs and in the latter parts of the five-hour driving period in normal runs. Four out of five acutely sleep-deprived subjects actually fell asleep at the wheel whilst similar, but less severe behaviour was observed in the spaced sleep-deprived subjects.

Sleep disorders

Sleep disorders may produce in some individuals fatigue symptoms like those resulting from continued activity and render them more likely to have crashes.

Lavie, Kremerman and Wiel (1982) found that industrial workers who complained about their sleep, particularly excessive daytime sleepiness (narcolepsy), had significantly more work accidents, especially repeated accidents, and significantly more sick days per work accident. They conclude that their results "suggest that sleep habits and sleep disturbances can provide valuable information regarding the worker's accident potential" (Lavie et al., 1982, p. 311).

There have been claims that some of the instances of drivers falling asleep at the wheel have been the result of sleep disorders, rather than the response of the normal individual to prolonged activity. Sulc and Vorel (1984) examined 30 drivers who claimed to have run off the road because of a microsleep attack. An examination of the driver's health and driving record led to the conclusion that polysymptomatic narcolepsy was only one possible cause of the crashes: nonpathological sleep, distraction of the driver's attention, poor driving skills and acute cerebral stroke were likely other causes.

Drivers who reported frequent problems staying asleep at the wheel were studied by Fagerstrom and Lisper (1976, 1978). The authors devised a behavioural treatment for the problem which consisted of training in active driving and covert conditioning of alertness responses. The treatment was still successful when the subjects were followed up six and 24 months later. Fagerstrom and Lisper noted that the subjects tended to fall asleep in a number of monotonous situations, not merely driving. McBain (1970) has also found that resistance to monotony seems to generalise from driving to laboratory tasks.

Shiftwork

Shiftwork has been the focus for a vast amount of research because of its practical importance and, to a lesser extent, because of theoretical interest. The most general conclusion which can be drawn from the literature is that a period of adaptation is needed before performance on a changed shift improves and in the absence of complete adaptation (the most common occurrence) performance is less than optimal.

Folkard and Monk have conducted many studies of the effects of shiftwork (e.g., Folkard, Monk and Lobban, 1978; 1979; Monk and Folkard, 1983). Folkard et al. (1978) described the differences in adjustment of the circadian rhythms of full- and part-time night nurses. Not even full-time night nurses showed a complete adaptation to night work but their greater degree of adaptation was regarded as an effect of the increased extent of scheduling their lives toward night work. As part of the same study, Folkard et al. (1979) administered a questionnaire to the permanent night nurses to assess what factors contributed to successful adaptation. These were found to be rigidity/ flexibility of sleeping habits, ability/inability to overcome drowsiness and morningness/eveningness. Such a questionnaire could be quite helpful in selecting personnel for shiftwork.

The nature and severity of fatigue complaints by aircraft crew was investigated by Austin, Cameron, Cumming, Lennox and Moffit (1968). They found that poor sleep habits were widespread because of the disturbance to circadian rhythms caused by international flights. It was the distribution, rather than the total number of flying hours, that determined the fatigue levels of the crew.

Several studies of the effect of shiftwork on truck drivers have been conducted. Adam (1975, cited in McDonald, 1980) found that many drivers, particularly younger and older drivers, experienced difficulty in adapting to shiftwork. Almost all shiftworking drivers reported drowsiness at least some of the time in studies conducted by Edmondson and Oldman (1974, in

McDonald, 1980) and McDonald (1978, in McDonald, 1980).

Mackie and Miller (1978) showed that truck drivers "operating on an irregular schedule suffer greater subjective fatigue, physiological stress, and performance degradation than drivers who work a similar number of hours on a regular schedule" (p. vi). The performance measures showed that steering on irregular schedules became coarse after fewer hours of driving than did steering on regular schedules. Late night/early morning trips seemed to be the most fatiguing for drivers on irregular schedules. During these trips performance of a critical tracking task was poorer, there was a larger number of critical incidents involving drowsiness, adrenaline excretion rates were higher and drivers were less able to sleep.

ALCOHOL AND OTHER DRUGS

Alcohol

When they studied the role of alcohol in crash causation, Treat, Tumblas, McDonald, Shinar, Hume, Mayer, Stansfin and Castellen (1977, in Smiley, 1986) found that the most common effect of alcohol was to increase by a factor of five the likelihood of the driver blacking out or falling asleep. This occurs because of the depressant effect of alcohol on the central nervous system. Thus alcohol can be considered a fatiguing agent in addition to its role as an intoxicant.

The effect of alcohol on driver fatigue has been tested on driving simulators (Nelson, Ladan and Carlson, 1979 and Stein, Wade Allen and Cook, 1985). Nelson et al. asked subjects who had high blood alcohol (BAC > 0.08 g/100 ml), low blood alcohol (BAC < 0.08 g/100 ml) and no blood alcohol to operate a driver trainer until they felt unable to continue. Endurance declined and reports of personal distress increased as blood alcohol level increased.

In the study reported by Stein et al. it was hypothesised that fatigue accompanies low levels of arousal. These low levels can result from low driver workload or alcohol. They had subjects with blood alcohol levels of zero, 0.075 g/100 ml and 0.12 g/100 ml operate a driving simulator for two hours under high or low attentional demand conditions. Stein et al. expected to find less fatigue under the high attentional demand condition and more fatigue shown by subjects in the alcohol groups. Whilst general fatigue effects (faster driving, greater lateral acceleration and slower, more variable reaction times) were observed and alcohol led to more "crashes", alcohol did not result in greater fatigue.

Why did Nelson et al. but not Stein et al. find that alcohol increased fatigue levels? Stein et al. reported that they made their task more arousing to prevent drivers from falling asleep and this may have led to lower overall fatigue levels in their experiment which was both shorter and more interesting than Nelson et al.'s.

Other drugs

A number of papers presented at the First International Symposium on Prescription Drugs and Driving Performance (O'Hanlon and de Gier, 1 6) pointed out that sedative or fatiguing effects are common to many classes of drugs. These include some antianxiety agents, hypnotics, stimulants, hallucinogens, marijuana, lithium, narcotic analgesics, ganglionic blocking agents, insulin and sulphonylurea derivatives. Drowsiness may also be produced by anticholinergics, antihistamines, antidepressants, antipsychotics, phenylbutazone, indomethacin, alpha-methyldopa and beta blockers (Seppala, Linnoila and Mattila, 1979).

Barbiturates. The fatiguing effects of various drugs have been difficult to distinguish from other effects of the drugs in epidemiological studies. One approach in assessing the effect of drugs as fatiguing agents is to investigate the effects on crash rates of drugs which have a strong sedative effect. The barbiturates are one such group of drugs. Sharma (1976) reviewed the literature on barbiturates and driving. He reported that the incidence of barbiturates in traffic involvement has been variously estimated as from 2 to 9%. Since sedation, in addition to mood alteration, is one of the major effects of barbiturates, this figure implies that barbiturates as fatiguing agents contribute significantly to road crashes.

Sharma noted that sampling different populations, collecting data at various times of the day and varying laboratory techniques for identifying barbiturates in the body fluids may have led to the variability in the estimates. This is true for most drugs, not just barbiturates.

Another approach to assess the extent of drug-induced driver fatigue is to measure drug levels in the types of crash which are often fatigue-related. Most driver falling asleep at the wheel crashes occur between midnight and six a.m. *and* are single vehicle crashes. An analysis of fatal single vehicle crashes in California (California Highway Patrol, 1967, cited in Sharma, 1976) showed that 9% of victims had taken barbiturates or tranquilizers. Turk, McBay and Hudson (1974, cited in Sharma, 1976) found barbiturates in 2.5% of drivers involved in single car crashes.

Marijuana. A number of studies, both laboratory and field, have investigated the effect of marijuana on skills related to driving. Moskowitz (1976) summarised the results of the laboratory studies as follows: "There is considerable evidence of a performance decrement under marihuana when the subject is faced with stimuli which demand constant attention, which appear at random, unexpected intervals, or which require additional central processing such as storage and retrieval" (p. 22). The laboratory studies of tracking under marijuana which were reviewed by Moskowitz (1985) led to the conclusion that large and reliable decrements in tracking ability are observed.

A study by Pliner, Cappell and Miles (1972, cited by Moskowitz, 1976) compared the effects of marijuana and alcohol. Ratings showed marijuana subjects to be less aggressive, less anxious, with less concentration or vigour and more fatigued. Simulator studies have shown that drivers under the influence of marijuana take longer to make decisions about overtaking and take fewer risks (Dott, 1972; Ellingstad, McFarling and Struckman, 1973; both cited in Moskowitz, 1976).

Epidemiological studies have been hampered by the difficulty in assessing marijuana levels from blood samples. The problem is that, unlike blood alcohol measures, blood concentrations of tetrahydrocannabinol (the active ingredient in marijuana) drop extremely quickly and are not a good indicator of the degree of impairment (Moskowitz, 1985). Objective impairment is not even adequately assessed by the presence of the subjective "high".

combined drug effects

Another point which has been stressed very strongly is that many drivers combine alcohol and other drugs (prescription and nonprescription). Finkle, Biasotti and Bradford (1968 in Mortimer and Howat, 1986) found that of 3,000 drivers who had been arrested for drink-driving, 21% involved simultaneous use of other drugs. Tranquilizers were the class of drug most commonly involved, with sedatives, hypnotics and analgesic narcotics also present. A similar result was reported by Cosbey (1968).

In an Australian study, Milner (1969, in Mortimer and Howat, 1986) found that of 153 patients, 14% of those attending psychiatric clinics and 8.5% of general practice patients were prescribed drugs, particularly phenothiazines, sedatives and minor tranquilizers. Among the males using such drugs, 85% also drank alcohol, 60% were licensed to drive and 51% were at risk for both drinking and driving. The corresponding figures for females were 75%, 42% and 35%.

There are sev ral sources of evidence that point to widespread combined use of barbiturates and alcohol, both substances which can produce drowsiness. A number of studies have shown that alcoholics and drink drivers may use barbiturates (Devenyi and Wilson, 1971; Finkle, 1969; Glatt, 1962; all cited in Sharma, 1976). In pedestrian fatalities 3% had both alcohol and barbiturate present and 2.5% of single vehicle crashes involved drivers intoxicated with barbiturates and alcohol.

Empirical studies of the effects of combined drugs on driving have been conducted. From these Sharma (1976) concluded that whilst the exact mechanisms involved in the combined metabolism of alcohol and barbiturates have not been elucidated, it is clear that the combination produces an increased deterioration in driving skill. The impairment in driving which results from alcohol ingestion (particularly small quantities) is increased by the ingestion of hypnotics (Seppala, Linnoila and Mattila, 1979).

NOISE

Noise has been variously identified as increasing or decreasing fatigue levels (Jones, 1983). This has been a consequence of placing fatigue within the arousal framework. Within this framework noise is treated as an arousing stimulus. Thus it is likely to reduce fatigue if fatigue results from low levels of arousal or increase fatigue if fatigue has resulted from prolonged high levels of arousal. This section treats noise as a cause of fatigue and its role as a possible countermeasure is discussed in Chapter Six.

Generalisations about the effect of noise on performance were made by Broadben: and Little (1960). They concluded that an effect of high intensity, meaningless, and continuous noise may appear on working efficiency in laboratory tasks which are long and require continuous attention. The effect of noise is to increase the frequency of momentary lapses in efficiency rather than to produce decline in rate of work, gross failures of coordination, or similar inefficiency. Effects have never been shown with noises of less than 90 dB. (p. 133)

Using a serial reaction time task, Hartley (1973) investigated why noise seems to have its effect at the end of a work period. "One possibility is that execution of the task results in some kind of fatigue or stress which builds up as the period of work proceeds, noise, through its action as a stressor, acting to exacerbate this tendency. The other possibility is that the effects of task and noise are independent. The cumulative effect of prior work being unnecessary for the effect of noise to be manifested" (Jones, 1983, p. 76). Hartley used a 20 minute serial reaction time task which was preceded by either task performance or rest and either noise or quiet. His results suggest that the effects of noise and fatigue are independent.

MONOTONY AND PREDICTABILITY

Monotony and predictability are related concepts which have both been identified as causes of fatigue (Grandjean and Kogi, 1971; Wertheim, 1978). Monotony is the objective unchangingness of the physical and cognitive situation whereas predictability may occur in a regularly changing situation.

Monotony

In Chapter One the distinction between monotony and boredom was made. Monotony is the characteristic of the situation and boredom the emotional response.

Grandjean and Kogi (1971) have described the neuro-physiological basis of the relationship between monotony and fatigue. They state that the fatiguing effects of monotony occur because initial stimulation of the reticular activating system is lacking. This decreases the individual's readiness to perform and react and results in the feeling of boredom, a class of fatigue.

Monotony is likely to lead to boredom when work requires attention and activity only intermittently and does not make great demands on the worker's skill. If work is of a continuously repetitive nature boredom may not occur if motivation is high and demands on skill and attention are made. Thus boredom is not a necessary characteristic of all production-line work.

Thackray, Bailey and Touchstone (1977) studied physiological, subjective and performance correlates of reported boredom and monotony of subjects performing a simulated radar control task. The subjects who reported higher levels of boredom and monotony showed greater increases in long response times, heart rate variability and strain and a greater decrease in attentiveness. Thackray et al. concluded that boredom and monotony affect the attentional processes of subjects, rather than influencing their general level of arousal.

Predictability

Wertheim (1978) studied the visual aspect of driver fatigue which has often been termed "highway hypnosis". He described the phenomenon as "a lowered state of alertness leading to the development of drowsiness and failure to react adequately to changes in the road situation" (p. 111). His study showed that the chief cause of the phenomenon is the predictability of visual stimulation.

To understand the way in which the predictability of visual stimulation causes highway hypnosis it is necessary to describe the mechanisms involved in movement of the eyes in more detail. The oculomotor control system enables the positioning of the eyes in the direction that we want to look. It has two components - the attentive component which refers to feedback from the retina and the intentive component which refers to the intention to move our eyes. In order to detect real movement in our surroundings a mental comparison has to be made between the information from the two components. If visual stimulation is predictable, the influence of the intentive components increases at the expense of the attentive component and detection of changes in the visual field, such as movement or new objects is impaired.

CHAPTER FIVE

THE FATIGUE-CRASH RELATIONSHIP

Determining the strength of the fatigue-crash relationship from crash statistics is fraught with difficulty. Interpretation of these statistics requires judgements of whether they include a control for exposure to crash risk (in terms of kilometres driven per time period), whether they separate classes of vehicle and/or classes of crash, the country in which the statistics were collected, the manner of collection and so on. In general, it can be stated that studies that have endeavoured to assess the contribution of fatigue to road crash involvement have been limited (Jones and Stein, 1987).

To answer the question of whether the fatigue-crash relationship is stronger for heavy vehicles than cars is not even straightforward. Few studies have been conducted to assess the role of fatigue in car crashes, the focus being on heavy vehicles because these drivers drive longer hours and so are at a greater risk of driving-induced fatigue. Overall, it is likely that more heavy vehicles are involved in fatigue-related crashes but should the exposure-corrected figures be used instead, these figures may show that the probability of a fatigue-related crash per 10,000 km of travel is greater for car drivers. Indeed, the Queensland Vehicle Population Study (Foldvary, 1975) showed that the exposure-corrected overall crash rate (from various causes) was lower for truck. than cars.

INDIRECT EVIDENCE

Direct and indirect measures of the strength of the fatigue-crash relationship are available. Direct measures assess whether fatigue can be identified as a contributing factor in particular crashes. Indirect measures indicate the involvement of fatigue as likely. One source of indirect evidence would be that trucks and buses, the drivers of which drive for longer hours than car drivers and so are more likely to be fatigued, have more crashes. Additional indirect evidence that fatigue is a contributing factor would be that crashes are more likely in the early hours of the morning when drivers are likely to doze at the wheel.

Crash severity

The contribution of fatigue is likely to be greater for serious or fatal crashes than for minor crashes. Two bodies of indirect evidence suggest this: the greater severity of crashes involving heavy vehicles than those involving cars alone and the often fatal nature of single-vehicle run-off-road crashes.

Crash severity appears to increase with vehicle size. McDonald (1980) cites British road crash statistics which show that heavy goods vehicles have a lower crash involvement rate per vehicle mile than most other types of vehicle but have a higher involvement rate in fatal crashes and account for a disproportionate number of deaths of other road users (Baker, Wong and Masemore, 1975; Robertson and Baker, 1975; Gissane and Bull, 1973; all cited in McDonald, 1980). Similar statistics are available from the United States. Jones and Stein (1987) cite a study of large truck crash causation conducted by Eicher, Robertson and Toth (1982) which found that large truck crashes accounted for 6 percent of all crashes but 12 percent of all fatal crashes.

Recent Australian research (Vulcan, 1987) has shown that articulated vehicles are much more likely to be involved in fatal crashes than rigid trucks. Semi-trailers travel longer distances than rigid trucks but even when this is controlled for their rate of involvement in fatal crashes is about four times as great. Table 3 presents the estimated involvement of articulated vehicles, rigid trucks, cars and station wagons, and buses in fatal crashes in Australia in 1983. In accord with the relationship between vehicle size and crash severity, analysis of the crashes resulting in hospital admission shows less over-involvement of articulated vehicles (Vulcan, 1987, Table 2).

Table 3. Estimated involvement in fatal crashes - Australia 1983. From Vulcan, 1987, Table 1.

	Articulated Vehicles	Rigid Trucks	Cars and Station Wagons	Buses
Number of vehicles involved	234	157	2150	40
Rate per 100 million vehicle km	7.4	1.7	2.1	3.9
Rate per 10,000 registered vehicles	48.5	3.2	3.3	

Further indirect evidence of the fatigue-crash relationship being stronger for articulated vehicles than rigid trucks has been presented by Nix-James (1977, in Linklater, 1980). Data for New South Wales in 1974-5 showed that articulated vehicles had more single vehicle crashes as a percentage of all crashes, particularly in rural areas. Linklater comments that

> long distance intercity commercial transport is more likely to be by means of articulated than rigid trucks and single vehicle crashes are particularly likely to arise from specific vehicle or driver linked factors like fatigue, since in these crashes there are no other vehicles or drivers directly involved. (1980, p. 193)

Crash-time of day relationship

Another indirect index of the contribution of fatigue to road crashes is the crash-time of day relationship. It is generally assumed that many crashes that occur at night have fatigue as a contributing factor. Thus the crash-time of day relationship can give an indirect index of the strength of the fatigue-crash relationship.

The crash-time of day relationship indicates the effects of fatigue when it incoporates a control for exposure (the number of vehicles on the road at that time). Most such studies have shown a peak in crashes in the early hours of the morning when drivers are likely to doze and some studies have found another peak in the afternoon, about 12 hours later. In his study of single-vehicle truck crashes, Harris (1977) controlled for exposure and found that the crash rate peaked at 5 a.m. Langlois, Smolensky, Hsi and Weir (1985) cite the results obtained by Prokop and Prokop (1955) which showed that drivers' reports of falling asleep at the wheel peaked at 2 a.m. and in the mid-afternoon.

There is some evidence that the crash-time of day relationship varies as a function of type of vehicle and location. Vulcan (1987) reports a study undertaken by the Victorian Road Traffic Authority of crashes in which at least one person was killed or admitted to hospital between 1977 and 1984. In the metropolitan area most crashes occurred between 6 a.m. and 6 p.m. (not corrected for exposure) for articulated vehicles (74%), rigid trucks (84%) and buses (66% 8 a.m. to 10 a.m., noon to 6 p.m.). However, outside the metropolitan area the crash rate for articulated vehicles showed little diurnal pattern whilst rigid trucks and buses retained the metropolitan pattern. If one makes the not unreasonable assumption that traffic flow was less during night time hours, then a correction for exposure would show that night time crashes (likely to involve fatigue) were more likely for articulated vehicles than rigid trucks and buses.

DIRECT EVIDENCE

The sources of direct evidence as to the contribution of fatigue to crash causation are of two main types, although some differences in methodology exist. Most studies are of the first type, investigating many crashes in order to assign a probable cause. These studies vary from limited analysis of police reports to in-depth studies in which teams assess immediate and past factors which may have contributed to crash causation. An alternative source of evidence has been questioning drivers about their incidence of falling asleep at the wheel and crashes or near crashes which have resulted.

<u>Limited studies</u>

Analyses of police crash reports to assess the strength of the fatigue-crash relationship have been conducted for both cars and other vehicles. The assessed contribution of fatigue has varied between very low (Brown, 1967a) and 30 to 50% (Hubert, 1972, in Nelson, Ladan and Carlson, 1979).

Table 4. Causes of fatal and serious crashes in Britain during 1965 (Ministry of Transport, cited by Brown, 1967a). The data are number per million vehicles at risk.

Class of Vehicle	Fatigue	Driver Intoxicated	Learner Driver	Speed	Slippery Road	Dog in Road
Motor Bicycles	40	20	5101	1296	4741	155
Cars and Taxis	39	55	225	593	3910	20
Public Service Vehicles	21	31	186	660	16691	72
Goods Vehicles	51	85	213	68	6258	30
All Vehicles	40	54	866	697	3904	40

Brown (1967a) cites a study of the causes of fatal or serious road crashes conducted by the British Ministry of Transport in 1965. The results are given in Table 4. He concludes from it

1. that the overall risk of crash from fatigue is low,

2. that the risk is low as compared with many other causes of crash, and

3. that the risk is greater for professional drivers who drive continuously for long periods than it is for those who drive vehicles of a similar size for shorter periods. (Brown, 1967a, p. 131).

Hulbert (1972, in Nelson, Ladan and Carlson, 1979) suggested that 30-50% of all driver fatalities were attributable to some form of driver fatigue.

The United States Bureau of Motor Carrier Safety (1969) found that 30% of single-vehicle truck crashes seem to have involved a sleeping driver and 13% of these drivers had violated the regulations covering hours of driving (cited by Linklater, 1980).

Care needs to be exercised in the interpretation of the assessments of the magnitude of the fatigue problem which these limited studies have produced. A more detailed study of fatal single-car crashes by Corfitsen (1986) suggested that police reports underestimate the frequency that fatigue contributes to crashes. She analysed the prevalence of intoxication in day and night-time fatal single car crashes and found that more drivers were killed during the night than would be predicted from their levels of intoxication. She concluded that "fatigue is an often overlooked but most obvious cause to an otherwise unexplainable crash in night-ti traffic" (p. 3). The study was conducted in Denmark and repr nted almost all data from the city of Copenhagen but only about half the data from some country police districts (see limitations of in-depth studies). An interesting point made by the author was that the analyses showed fatigue to be an important factor but fatigue was only classified by police as the cause of the crash in 2 of the 101 crashes studied.

Evidence from in-depth studies

A study conducted in Indiana by Treat (1980) identified the relative contribution of various factors in crash causation. Inattention (which might have been a consequence of fatigue) was a contributing factor in 15% of crashes, and was reported to be a common factor in rear-end collisions.

Estimates of the contribution of fatigue to crashes vary from 1% (McLean, Austin, Brewer and Sandow, 1979) to 4% (Treat, 1980) to 7% (Storie, 1975). Storie's study is the only one which provided a 24 hour coverage and so is likely to be the most accurate. According to that study, fatigue ranks second behind alcohol as a cause of crashes.

The American Automotive Association Foundation for Traffic Safety conducted an in-depth study of 221 truck crashes during 1983-4 (Transport Research and Marketing, 1985). Driving hours and mileage were calculated from bills of lading, fuel receipts, and weigh station and inspection tickets. The study concluded that driving in excess of 15 hours was the probable cause in 41% of crashes and a contributing cause in a further 18% of crashes. Jones and Stein (1987) have questioned the quality of the control sample in this study, however, and state that the only strong conclusion that can be drawn is "that 41 percent of the drivers in crashes had been driving excessive hours compared to less than 7 percent c -he truck drivers that were surveyed" (Jones and Stein, 1987, p. 2).

One of the most experimentally rigorous in-depth studies was conducted recently by Jones and Stein (1987) in Washington State. It was a case-control study in which for each large truck involved in a crash, three trucks were randomly selected from the traffic stream at the same time and place as the crash but one week later. These vehicles were inspected. The cases and controls were compared with respect to driver factors (age of driver, hours of driving, and logbook violations) and truck characteristics (carrier type, carrier operation, truck load and fleet size). The factors which were associated with an increased risk of crash involvement were driving longer than eight hours, violation of logbook regulations, young drivers, interstate carrier operations and equipment defects. Jones and Stein concluded that "the relative risk of crash involvement for drivers who reported driving time exceeding eight hours was almost twice that for drivers who had driven fewer hours" (abstract).

Limitations of in-depth studies. In-depth studies may underestimate the contribution of fatigue to crash causation. Hampson (1984) has listed a number of limitations of in-depth studies which may be responsible for over- or underestimating the importance of some contributing factors.

In-depth studies attempt to identify the immediate factors leading to the crash. They usually restrict their interest to the 24 hours prior to the crash. If a driver was found to have slept for an adequate length of time in that period and had not been driving for an excessively long period prior to the crash, fatigue would be likely to be ruled out as a contributing factor. In-depth studies are not sensitive to the presence of chronic fatigue.

Another limitation of in-depth studies in the assessment of the contribution of fatigue to crashes is that their temporal and geographical coverage is often restricted. Late night and early morning crashes (in which fatigue is most likely to be implicated) may be least likely to be investigated. Often difficulties of access by the investigating team means that only crashes in urban areas are studied. Again, fatigue-related crashes are more likely to occur in rural areas.

In-depth studies may be biassed in their selection of crashes to be studied. Hampson (1984) points out that minor crashes, such as rear-end crashes and many minor single-vehicle crashes, are often not notified and so cannot be selected for investigation. On the other hand, in investigations based on samples where the crash vehicle had to be towed, the data may be biassed towards single vehicle crashes (as noted in Jones and Stein, 1987). Other evidence (e.g., Jones and Stein, 1987) suggests that fatigue is a prominent factor in both single-vehicle and multiple-vehicle crashes.

It must also be kept in mind that fatigue-related crashes have the potential to be more severe than other crashes and are often fatal. In-depth studies have not identified contributing factors as a function of crash severity.

In-depth studies may underestimate fatigue's contribution to crashes by cla ifying errors caused by fatigue under other headings e.g., a "failure to look" error by a tired driver might be classified as a perceptual error.

Fatiaue questionnaires

A number of studies have asked drivers of vehicles involved in crashes to fill out questionnaires designed to assess the role of fatigue and other factors in causation of the crash. Other authors have surveyed the incidence of driving when fatigued.

A population survey of the incidence of drowsiness as a component of driver behaviour and its characteristics, including crash causation was conducted by Tilley, Erwin and Gianturco (1973). Respondants were 1500 applicants for driving licence renewal in Durham, North Carolina. The questions relevant to the incidence of fatigue and the proportion of the respondents who answered never, sometimes and frequently are outlined in Table 5. Almost 10% of those subjects who reported difficulty with drowsiness admitted to having had a near crash because of drowsiness or falling asleep and more than 10% of the same group reported they had had one or more crashes resulting from drowsiness or sleeping at the wheel.

Table 5. Items and responses to drowsiness in driving questionnaire administered by Tilley, Erwin and Gianturco (1973).

	Frequency of response (%)		
	Never	Sometimes	Frequently
I have become drowsy while driving.	34	62	2
I have gone to sleep for short periods while driving.	91	7	<1

When I drive, there is someone else in the car.	2	60	34
While driving I become drowsy before I am aware of it.	76	19	>1
I have gone to sleep for short periods while driving without being aware that I am going to sleep.	92	5	<1
If I become drowsy while driving it is after eating a meal.	52	41	3
If I drink alcohol I become drowsy while driving.	69	15	>1
I have taken medicine which made me become drowsy while driving.	85	12	<1
If I become drowsy while driving it is usually during a particular part of the day.	51	35	10
If I become drowsy while driving it is when I get less than my usual amount of sleep.	39	47	11
If I become drowsy while driving I can do something to alert myself without stopping the vehicle.	35	36	24
I have trouble staying awake in situations other than driving.	62	32	<1
I take driving trips lasting longer than two hours.	13	55	30
I have had near auto accidents because of drowsiness or falling asleep.	92	6	<1
I have had one or more accidents because of drowsiness or sleeping at the wheel.	98	<1	<1
I have used stimulants such as No-Doz, pep pills, or amphetamines to combat drowsiness.	91	7	<1
Others in my family have trouble staying awake.	61	33	2

In New South Wales a study of driver fatigue was conducted in which drivers of trucks and cars were interviewed at roadside restaurants (Linklater, 1980). Interviews were conducted over all hours of the day. Relative crash rates were calculated from reported crashes and reported exposure (average annual hours spent at the wheel or average annual km). The relative crash rates were lower for car drivers than truck drivers. For truck drivers the relative crash rates increased when the typical number of driving hours in a week was greater than 55. In interpreting relative crash rates it must be remembered that they do not take into account crash severity which is likely to increase with vehicle size.

Storie (1984) conducted a study of the involvement of goods vehicles and public service vehicles in crashes on British motorways. Her data comprised police reports and personal interviews using a questionnaire. The features of the questionnaire which are relevant to the assessment of the role of fatigue are the bored and sleepy items in the state of mind section and the number of miles driven the day of the crash. The breakdown of these data are shown in Table 6. It shows that the percentage of drivers reporting that they were bored or sleepy prior to the crash ranged from 3 to 14%, increasing as a function of the total miles driven. Evidence from the police reports suggested that about 4% of car drivers and 5% of heavy goods vehicle drivers fell asleep or momentarily nodded off immediately prior to the collision.

Table 6. The incidence of boredom and sleepiness and total miles driven in drivers of heavy goods (HG) and public service vehicles *(PSV)* and cars involved in crashes on British motorways. (From Storie, 1984, p. 13)

Total miles driven	11-100		101-200		>200	
Drivers	HG/PSV	Car	HG/PSV	Car	HG/PSV	Car
Number	456	321	234	79	69	21
% Bored	6	6	9	10	19	14
% Sleepy	2	3	5	4	10	14

CONCLUSION

The inadequacy of epidemiological research means that a precise estimate of the contribution of fatigue to road crashes in Australia cannot be made. The research that has been conducted, however, suggests that the involvement of fatigue is probably lowest in all (property-damage only, casualty and fatality) crashes, higher in casualty crashes and highest in fatal crashes. The true incidence probably ranges between 5 and 10% in all crashes, about 20 to 30% in casualty crashes and about 25 to 35% in fatal crashes. The contribution of fatigue may even reach 40 to 50% in particular types of crashes, for example, fatal single-vehicle semi-trailer crashes. Whilst these estimates seem high, it must be noted that each crash may have several contributing factors and so the contributions of all factors sum to greater than 100%. It is likely that alcohol is also involved in many fatigue-related crashes.

CHAPTER SIX

FATIGUE COUNTERMEASURES

This report has shown that concern about the role of fatigue in road crashes is widespread and justified. Effective countermeasures are needed and a wide range of these are presented in this section. They range from deterrents to driving when fatigued (such as education, legislation and enforcement) to devices designed to alert the driver to his or her current level of fatigue.

EDUCATION

Wertheim (1978) proposes that drivers be taught to recognize the early signs of fatigue such as misjudgement of velocities, crossing marked lines, slow responses and yawning. Once these events occur drivers should rest. Lisper, Laurell and van Loon (1986) had drivers drive until they fell asleep and reported that in every instance the driver was aware that he was going to sleep and spent from a few minutes to an hour fighting sleep before succumbing. Other researchers have also shown that drivers experience signs of fatigue before the critical incident of falling asleep (Bocher, 1970; Ponsold, 1968; Prokop and Prokop, 1955; Prokop, 1958; all in Lisper, Laurell and van Loon, 1986). These findings support the view that it is possible to teach drivers to recogni[illegible] signs of fatigue and to rest.

In a study of truck drivers' susceptibility to monotony, McBain (1970) discovered that drivers engaged in behaviour designed to reduce the monotony of highway driving. He reports that "drivers spotlighted deer by the side of the road with practiced accuracy, signalled to other drivers, observed and commented on the idiosyncrasies of other drivers, pointed out changes in road and other construction projects visible since they had last been seen, and in these and many other ways kept themselves almost constantly occupied" (p. 518). An education program could inform drivers of the benefits of such game-playing in maintaining attention.

Two methods of educating drivers about the dangers of fatigue and ways of reducing fatigue seem possible: incorporation of learning about fatigue in driver training courses and mass media campaigns.

Teaching about fatigue in driver training courses has advantages and disadvantages. The advantage is that the educational programme may be tailored to the type of driver, which would allow more emphasis and detailed information to be given to trainee truck drivers who are the group most likely to be driving while fatigued. The disadvantage of confining education about the effects of fatigue to driver training courses is that only drivers taking such courses would be reached.

The New South Wales Road Freight Industry Council in a submission to the Standing Committee on Road Safety (1984) listed desirable characteristics of heavy road freight vehicle drivers and suggested that these could be acquired by education, apprenticeship, experience and training. In their submission they noted that some large transport companies had formalised driver training schemes but most companies had none. There was no information available from the companies, police or the insurance industry to evaluate whether the training schemes are effective in reducing road crash rates. Nevertheless they advocated elevating heavy vehicle operation to trade status with technical and/or classroom tuition, structured apprenticeship and periodical testing.

The effectiveness of mass media campaigns to alert drivers to the dangers of driving while fatigued has not been evaluated. Such campaigns have not been implemented in Australia, although a range of articles has appeared in motorists' and truck drivers' magazines (Anon, 1977a, b; Ford, 1971; Kiss, 1977; Road Patrol, 1981). These articles may form some basis for a more widespread publicity campaign if one is launched. Any campaign would have to be followed up carefully to assess whether the expected benefits occur and whether they are of a long- or short-term nature.

LIMITATION OF HOURS OF WORK

It has been pointed out that there is a need to reduce excessive hours of driving and to redistribute them. Both Fuller (1984) and McDonald (1984) conclude that "the effects of prolonged driving depend in part on when that prolonged driving takes place rather than simply on its actual duration" (Fuller, 1984, p. 381).

The crash rate varies markedly across the hours of the day, even when adjusted for changes in traffic volume (Lisper, Eriksson, Fagerstrom and Lindholm, 1979). The traffic volume-adjusted crash rate reaches a peak between 2 and 6 a.m. as a result of drivers falling asleep at the wheel (Lisper, 1970, 1973; Penn, 1963; Prokop and Prokop, 1955; all in Lisper et al., 1979). Falling asleep at the wheel is even more likely if drivers have completed a day's work before beginning an overnight drive (Anon, 1977a; Lisper et al., 1979). It is relatively simple to advise noncommercial motorists to avoid driving at that time.

McDonald (1980, 1981) has expressed concern that some British and EEC legislation designed to reduce hours of work and hours of driving may have a deleterious effect. They may decrease safety by causing an increase in shiftworking which is likely to lead to an increase in crashes caused by drowsiness and falling asleep at the wheel.

Recommendations of methods of reducing the ill-effects of shiftwork abound in the literature. For example, Rutenfranz, Knauth and Colquhoun (1976) presented the following criteria for optimal shift schedules:

1. Single night shifts are better than consecutive night shifts.

2. At least 24 hours free time should be allowed after each night shift.

3. The cycle of a shift system should not be too long.

4. The length of the shift should be related to the type of work.

5. In connection with continuous shiftwork as many free weekends as possible should be arranged. (p. 331)

There is a need to ensure adequate sleep before driving. This applies to both commercial and noncommercial driving. Even if regulations limiting hours of work are obeyed, there may not have been adequate sleep.

In NSW truck drivers are prohibited from driving more than 72 hours per week. There is some evidence that within this limit the crash risk of drivers has already begun to rise. Linklater (1980) found that crash rates were higher for drivers who drove 55 or more hours per week.

In Chapter Four it was pointed out that time on duty is instrumental in causing fatigue, not merely time spent driving. This has been recognised in some local legislation. The Victorian Motor Car Act of 1958 and the later Road Safety Act of 1986 impose controls on hours of driving vehicles used for trade with an unladen weight of greater than two tonnes (1958 Act) or 4.5 tonnes (1986 Act). These Acts give an explicit definition of "time spent driving" which includes hours actually driving, time spent as a passenger (but not in a sleeper cab) and time spent on loading. The maximum legal length of a driving period is five hours and driving periods have to be separated by a break of at least half an hour. The maximum number of hours driving in 24 hours is 12.

Regulations which demand the use of log books to enable a record to be kept of hours of driving have been implemented widely. One shortcoming of log books is that they do not apply (in Victoria at least) to trips of less than 80 km. Thus a truck driver delivering goods in an urban area is not restricted by hours of work limitations.

Ensuring that truck drivers comply with regulations governing hours of work and hours of rest has proved difficult in the past, especially given the differences in legislation from State to State. The use of log books has helped but falsification of records is known to occur. The New South Wales Road Freight Industry Council (1984) reported that "there is widespread abuse of the present log book system with approximately 5600 offenses being detected in 1982" (p. 4). The number of undetected offenses is likely to be much greater. In addition log books are easily obtainable and many drivers operate with more than one log book which allows them to spend more time on the road than is legally allowable (New South Wales Road Freight Industry Council, 1984).

A recent US study (Jones and Stein, 1987) showed that drivers with logbook violations were significantly over-involved in truck crashes. Frequent monitoring of logbooks, if a satisfactory system can be devised, may thus be an effective countermeasure. This view is supported by survey results that indicate that in America at least 70 percent of drivers regularly exceed hours-of-service regulations (Beilock, 1987).

An alternative way to improve compliance with regulations would be to make the use of tachograph recorders compulsory (Kiss, 1977). This proposal has been supported by other investigators (Jones and Stein, 1987). Tachographs seem less liable to interference than log books.

Another alternative to log books has been proposed in a recent American study. The study of the role of fatigue in heavy truck crashes prepared by Transportation Research and Marketing (TRAM, 1985) found that one in three drivers exceeds the ten hours per day standard set by the US Bureau of Motor Carrier Safety. They suggest that police officers would be able to detect violations of hours of service regulations if legislation required;

1. shippers to put the date and time on the bill of lading,
2. all dispensers of diesel fuel to date and time stamp all receipts, and
3. carriers to carry a copy of these documents in the cab.

Using the bills of lading and fuel receipts police officers could determine from a mileaged map and the normative speed whether the hours of service of that driver were excessive.

REST PERIODS

An issue related to hours of work is the length and frequency of rest periods. The length of rest periods has been legislated but this applies only to drivers of commercial vehicles. The hours of driving restrictions of the Victorian Motor Car Act (1958) and the Road Safety Act (1986) include a number of rules about the length of rest periods. Breaks between driving periods must be not less than half an hour and the driver must be able to obtain rest and refreshment. Drivers must have had at least five hours rest in the previous 24 hours. In addition they are required to have had greater than 24 consecutive hours of rest or greater than 48 hours in two periods of greater than 24 consecutive hours each in the 14 preceding days.

What is the optimum length and distribution of rest breaks? Wertheim (1978) recommends short naps. He says that closing the eyes should enable the neurological system responsible for attentive oculomotor control to relax and recover. Wertheim does not mention how long the short naps should be or how frequently they should be taken. Australian Road Research Board studies cited by Anon (1977b) and Vondra (1977) conclude that driving for ten hours or more without a break of at least two hours is dangerous. They recommend that food or rest stops are scheduled about every 90 minutes to two hours during daylight hours and more often at night.

Lisper, Laurel1 and van Loon (1986) tested the common advice to drivers who feel themselves falling asleep to stop and take a five-minute walk. They found that subjects fell asleep again after an average of 23 minutes. Lisper and Eriksson (1980) investigated different schedules for a total of 30 minutes rest during 6 hours of driving. They found no differences between one, two and five pauses and a control in which there was no pause. In another study they found no difference between breaks of 15 and 60 minutes but noted that eating during breaks seemed to have a positive effect.

ENFORCEMENT

Dart and McKenzie (1972) concluded that most single-vehicle run-off-roadway crashes they surveyed resulted from careless driving, driving while fatigued or overreaction by inexperienced drivers. They believe that “the only effective countermeasure appears to be the imposition of serious penalties for individuals detected in violation of a traffic regulation because of such failures" (p. 13).

Whilst the imposition of serious penalties for drivers in crashes who are shown to be fatigued may have a deterrent effect, enforcement may be more profitably used to identify fatigued drivers before they cause crashes. An analogy can be drawn here between fatigue and alcohol intoxication. Both lead to impairment of driving performance and to crashes.

If the effects of alcohol and fatigue are in any way analogous, alcohol tests may be adapted to measure fatigue. It has long been recognised that the identification of intoxicated drivers before crashes occur is useful. Random breath testing is commonly used to allow such an identification. There is no breath test for fatigue but other tests to detect alcohol intoxication, such as field sobriety tests and performance tests show some potential for adapting to measure fatigue.

Field fatiaue tests

In the US field sobriety tests were developed in the 1970s to identify alcohol-impaired drivers and are gaining more widespread acceptance (Burns, 1985). The National Highway Traffic Safety Administration standardised field sobriety test involves a battery of three tasks, Horizontal Gaze Nystagmus, the Walk-and-Turn Test, and the One-Leg Stand (Burns and Moskowitz, 1977).

The Walk-and-Turn Test and the One-Leg Stand are measures of balance and coordination and, importantly, require the subject to attend simultaneously to more than one thing. Both alcohol and fatigue have been shown to result in greater impairment when subjects are required to divide attention (Lisper, Dureman, Eriksson and Karlson, 1971; Smiley, 1986). Horizontal gaze nystagmus is a jerking movement of the eyes that appears as the eyes are moved sideways. The jerking is more distinct if the subject has ingested alcohol or other central nervous system depressants.

Field sobriety tests have also been developed and evaluated in Finland. Penttila, Tenhu and Kataja (1971, 1974 in Burns, 1985) tested almost 7000 suspected drunken drivers and recommended that nystagmus, walking and balance tests be included in a test battery.

Field sobriety tests have the advantage of being quite quick to administer, not requiring sophisticated equipment and having a deterrence effect. Effective testing requires that police officers be trained in administering the test. Practice on a supervised sample of intoxicated persons has been used in a number of US states (Burns, 1985).

How could field sobriety tests be adapted to test driver fatigue? It is possible that nystagmus, walking and balance tests could show an effect of fatigue but the best way of developing and validating a field fatigue test would be experimentally. A large number of drivers could be fatigued by requiring many hours of performance on a driving-like task, a driving simulator or a test track and then given a battery of tasks. Those tasks which distinguished fatigued drivers from a control group could be incorporated into a battery which would form the field fatigue test.

Performance tests

The other type of alcohol impairment test which could possibly be adapted to detect fatigued drivers is a performance test. Performance tests are very much more similar to the driving task than field sobriety tests and so may be accepted more quickly. There is little evidence to show that performance tests are more effective in identification of alcohol impaired drivers than are field sobriety tests, though.

Performance tests can be classified into tests which are conducted on the road without the knowledge of the drivers involved and those which require the driver be stopped and asked to perform a driving task. These may be termed incidental and intentional performance tests. There are a number of reasons for preferring incidental tests.

1. They do not inconvenience non-impaired drivers.
2. The driver cannot attempt to adjust his driving (e.g., by expending more effort) in order to pass the test. This advantage would be even more important for fatigue tests than alcohol tests.
3. It is likely that incidental tests would take less time and thus allow more drivers to be tested.

Unfortunately, attempts to devise an effective incidental performance test for alcohol impairment have met with little success. Damkot (1977, in Bragg and Wilson, 1980) used a computer-linked television pattern to monitor drivers' weaving behaviour. He was unable to detect differences in weaving, lateral displacement or speed between impaired and unimpaired drivers. The only difference he detected was in the rates of deceleration of impaired and unimpaired drivers when asked to stop by a police officer.

Bragg and Wilson (1980) commented that observing the traffic stream may not be sensitive enough to detect alcohol impaired drivers because drivers are free to choose their speed and road position within quite a wide range. Instead they advocate the development of a more structured incidental performance test. Earlier experimental research has shown that intoxicated drivers show an impairment in maintaining lateral position when they are required to simultaneously travel at a stipulated speed (Mortimer and Sturgis, 1975 in Bragg and Wilson). Bragg and Wilson had subjects perform a similar task who had zero, .OS and .10 blood alcohol concentrations. Subjects were tested on a specially lane marked airfield taxi-way in a car with dual controls and roll bars. Both the driver and the passenger (subject) wore seat belts and crash helmets. If the pass-fail criterion was set at failure on two of the three measures, 30% of the impaired trips were correctly identified and only one sober trip (of 300) was falsely classified as impaired. Application of the more stringent criterion of failure on one measure only resulted in correct identification of 66% of the impaired trips but misidentification of 24% of the sober trips. Bragg and Wilson note that in the real life situation in which many intoxicated drivers have blood alcohol levels above .10 (and consequently have a greater degree of impairment) the test is likely to be more effective.

ROAD DESIGN

There are a number of ways of alerting the attention of drowsy drivers or of minimising the often fatal consequences of running off the road.

Wertheim (1978) showed that highway hypnosis was produced by the predictability of the road. He ruled out the countermeasure of reducing the degree of predictability because such a change would increase the risk of mechanical breakdowns and driver errors. Putting in a curve would make the road less predictable but could lead to more drowsy drivers continuing to travel in a straight line off the road. But there are ways of reducing the predictability of the road which are not dangerous.

It is possible to alert dozing drivers by the use of rumble strips, which are studs or bands of different texture on the road. Such modifications would probably be most beneficial prior to curves on straight stretches of road or at other hazardous locations. Raised studs and centrelines that cause a drumming sound when the car passes over them serve a similar function to rumble strips (Vondra, 1977). Another fatigue countermeasure which involves changes to road design is that of providing shoulders with very different texture to that of the road surface.

A reduction in the discrepancy between the levels of the road and the shoulder may be helpful in preventing tanker roll-overs when a dozing driver lets his vehicle wheels drop off the edge of the roadway (Linklater, 1980).

Eliminating roadside obstacles such as some posts and mounds may reduce the severity of run-off-the-road crashes (Vondra, 1977).

FATIGUE MONITORS

Broadbent (1979) and many other authors have pointed out that whilst fatigue may strongly impair performance on a task it is often difficult to demonstrate an aftereffect of fatigue if the individual is tested on another task. For this reason the use of fatigue monitors which measure the individual's degree of fatigue or some specified indicator while performing the task (driving) would seem more likely to be successful than testing performance after driving (e.g., using a test adapted from a field sobriety test or using an intentional performance test). On-line performance measures afford the possibility of detection, in real time, of any sudden effect e.g., eye-closing, head-nodding. Then appropriate alarms may be sounded.

Psychophysiological devices

Most fatigue monitors measure some psychophysiological response of the driver. Lemke (1982) developed a warning device which was based on the electroencephalogram (EEG) of the driver. Others have measured muscle activity by an electromyograph (EMG) or eye movements by an electrooculograph (EOG) (e.g., Wertheim, 1978) or heart rate. How effective are these devices?

The devices can only be effective if the psychophysiological response that they measure is affected in a reliable manner by fatigue and, to a lesser extent, if it is not affected by other factors (such as movements needed to control the vehicle). It is possible that a dozing driver would not be making interfering vehicle control movements, however.

Lemke (1982) showed that the loss of precision in the control behaviour of drivers was correlated with an anterior displacement of the resting potentials in the EEG data. He had assumed that the EEG signals could be used to predict control activity (since both were affected by fatigue) but this was not found. Instead control activity predicted EEG patterns. This means that a fatigue warning signal could be built with input from the steering wheel, brakes etc., rather than EEG measures. Such a device would be simpler (and perhaps less expensive) and is likely to be more reliable than one based on EEG monitoring.

Reaction time monitors

Research groups headed by Brown in the United Kingdom and Lisper in Sweden have produced a large body of evidence that reaction time to an auditory signal increases with hours of continuous driving and so can be used as an index of fatigue (Brown, 1967b; Brown, Simmonds and Tickner, 1967; Lisper, Dureman, Eriksson, Fagerstrom and Lindholm, 1979; Lisper, Laurell and Stening, 1971; Lisper, Laurell and van Loon, 1986). An implication of this finding is that a fatigue monitor could be built comprising an auditory signal and reaction time clock which would sound a warni , signal if the reaction time was beyond a certain limit. Such a device could possibly include adjustment to the normal, unfatigued reaction time of the driver since there is some baseline variability (e.g., with age) in such measures.

Crash avoidance systems

Crash avoidance systems are electronic devices designed to prevent crashes caused by a range of factors (e.g., excessive speed, intoxication) including fatigue. Clorfeine (1973) introduced the concept of a Driver Alert and Inhibition (DAI) system in which the driver is alerted each time he behaves in a manner which is considered to be unsafe. Persistance in the action leads to the system taking inhibition steps, e.g., automatic violation recording. A DAI system would include central control boards, a network of stationary units at various locations along all roads, and a receiver unit on each vehicle.

Another form of crash avoidance system is an automatic braking system. These usually involve on-car radar which measures the distance to the car in front, a comparator which compares this information with vehicle speed and safe limits, and automatic braking which is activated when safe limits have been violated (Clorfeine, 1973). The problem of false alarms from such a system is reduced if harmonic radar is used (Shefer and Klensch, 1973) but probably not eliminated. Such false alarms could be dangerous in high-speed traffic and have considerable nuisance value at other times. An alternative is to have on-car radar, a comparator and a driver warning system, rather than automatic braking. This system is part of Clorfeine's concept of Driver Alert and Inhibition.

STIMULANTS

Many drivers believe that stimulants (particularly caffeine) will reduce fatigue in driving (Prokop and Prokop, 1955 in Nairn, 1987). Arousal theories of fatigue predict that stimulants will reduce fatigue levels because they act to increase arousal (Eysenck, 1963 in Warburton and Wesnes, 1978).

Caffeine

Cameron (cited in Vondra, 1977, p. 118) advises that "caffeine - in coffee, strong tea and cola drinks - will help keep you awake, but only for a limited time". Lisper, Tornros and van Loon (1981) report lower reaction times to an auditory detection secondary task during three hours of driving with caffeine administration. It is not possible to draw strong conclusions from this study because only six subjects were used and large individual differences exist in both driving behaviour and drug effects (Smiley, 1986).

Amvhetamines

The use of amphetamines by truck drivers is thought to be widespread yet few estimates are available. Guinn (1983) conducted a study of drug use among drivers of perishable goods trucks in an area of Texas. One of the questions was "How often in the past year have you used drugs (except vitamins, aspirin, No-Doz(R) and similar over-the-counter preparations) for the purpose of remaining awake and alert while trucking?" Only 19.6% of the 112 subjects responded that they never used drugs for this purpose. Drugs were used "rarely" by 17.9%, "sometimes" by

33.9%, "often" by 18.8% and "all the time" by 9.8% of his sample of truck drivers. Guinn did not ask for specific drugs to be identified but it is likely that the majority of drugs taken for the purpose of remaining awake, excluding caffeine, would be amphetamines.

Stimulant drugs (e.g., amphetamines) have been shown in the laboratory to improve tracking, concentration and attention (Schroeder, Collins and Elam, 1974; Blum, Stern and Melville, 1964; Wenzel and Rutledge, 1962; Strasser and Muller-Limroth, 1973; all in Seppala, Linnoila and Mattila, 1979). The degree of enhancement is usually greater in fatigued subjects and in simple rather than complex tasks. The effect is usually not large unless subjects are deprived of sleep (Hurst, 1976). Whilst this suggests that they function to counteract fatigue, their use in driving is contraindicated by findings that they increase risk taking (Baumler, 1975 in Seppala et al., 1979).

The effects of dosages within the clinical range need to be distinguished from dosages related to abuse of amphetamines. Seppala et al. point out that there are no studies of the effects of acute withdrawal or chronic use of these drugs on driving skills. Anecdotal evidence suggests that severe exhaustion may result from acute withdrawal and paranoid psychotic reactions may accompany chronic use.

Hurst (1971) warns that there is little epidemiological evidence concerning the role of amphetamines in crash causation and that this must result in caution in recommendations about the use of amphetamines as a fatigue countermeasure. He concludes

I do not recommend that amphetamines be doled out indiscriminately to fatigued or intoxicated drivers....Once in a very great while, the circumstances may arise when someone who is sleepy, or has been drinking, suddenly finds that he must drive. In such instances, I do not believe that the use of amphetamine-type stimulants is contraindicated by the known facts. But of course, this matter may be of little practical importance, since it would seem very difficult to legalize use of amphetamines for driving only under such unique circumstances. (p. 12)

It seems that Hurst is recommending amphetamines for rare instances of fatigue. If most problems of fatigue occur regularly for truck drivers, then their use is contraindicated since abuse could develop. The small amount of epidemiological evidence available suggests that amphetamine abuse increases crash rates (Smart, Schmidt and Bateman, 1969).

Smokina and nicotine

Nicotine is a stimulant drug and many drivers report that smoking helps them to keep alert (Prokop and Prokop, 1955?). Empirical studies have been conducted to assess the relationship between smoking, nicotine and the maintenance of attention (e.g., Warburton and Wesnes, 1978; Wesnes and Warburton, 1978). Nicotine increases cholinergic functioning and electrocortical arousal which, it has been theorised, are implicated in the control of attention.

Wesnes and Warburton (1978) required subjects to perform a vigilance task which consisted of watching a clock to detect double movements of the hand for 80 minutes. Smokers who smoked during the experiment had a smaller vigilance deficit than non-smokers or deprived smokers. The results of other studies in which nicotine and herbal cigarettes were compared or in which nicotine was administered in tablet form gave further support to the claim that it was the nicotine, rather than the act of smoking which was responsible for maintaining attention.

An issue in regard to the effects of nicotine which is raised by Wesnes and Warburton (1978) is that of the effects on smokers and nonsmokers. It is possible that the beneficial effects of nicotine on vigilance are due to its intake returning nicotine-deprived smokers to a more "normal" state.

AUDITORY INPUT

When Prokop and Prokop (1955) asked drivers what steps they took to combat fatigue, many replied that they listened to the car radio. There is some experimental evidence from general and driving-related studies that this course of action is likely to be effective (Fagerstrom and Lisper, 1977; Hartley and Shirley, 1977; Hockey, 1970; Wilkinson, 1963).

The effect of loud noise on a driving-like task was studied by Hockey (1970). The high priority task was tracking and the secondary task was detection of lights arranged in a semi-circle in front of the subject. Loud noise improved frontal detection but led to deteriorations in peripheral detection. The deterioration over time (fatigue effects) in tracking were less during the loud noise.

The use of noise as a fatigue countermeasure gains support from studies of the effect of noise under conditions of sleep deprivation. The effects of noise and sleep deprivation seem to be antagonistic. Under conditions of loud continuous noise, individuals with a total sleep loss make fewer errors when a loud noise is present (Wilkinson, 1963). Hartley and Shirley (1977) demonstrated that partial sleep loss led subjects to perform more riskily in a visual detection task whereas noise led to more cautious responding. The combination of sleep loss and noise cancelled out the effects of the individual variable's effects on criterion placement. Similar effects on criterion placement were shown with fatigue in a vigilance task and noise (Broadbent and Gregory, 1965). In addition, noise seems to have a more positive effect on early morning performance (Blake, 1971 cited in Jones, 1983; Mullin and Corcoran, 1977).

The difference in the effects of sleep deprivation and noise seem to be in the pattern of performance, rather than an overall difference in efficiency (Hockey, 1973). Using a multisource monitoring task Hockey (1973) demonstrated that loud noise increased sampling of the source associated with high fault probability while sleep loss resulted in a reduction of sampling of the high probability source.

Fagerstrom and Lisper (1977) showed that listening to the car radio reduced the slowing of reaction times that occurred after several hours driving. But the benefit was not of a constant magnitude for all subjects: it was greater for subjects classified as extroverts than those classified as introverts. This finding serves as a reminder that characteristics of the driver must be considered in the both the evaluation of levels of fatigue and the development of countermeasures.

SUMMARY

Two types of educational countermeasures were proposed: teaching drivers to recognise the signs of fatigue and teaching attention maintenance strategies to actively "fight" fatigue. No details of implementation or evaluation of these countermeasures are available.

Legislation to limit the length and distribution of hours of work is widespread but better design of log books, including time stamping of fuel receipts and bills of lading would make detection of violation of these regulations easier. Field fatigue tests and incidental driving performance tests are two enforcement strategies which should be explored.

Countermeasures which involve changes to road design may be expensive and take a long time to implement. However, these may be useful if confined to particular areas which have a record of a large number of fatigue-related crashes.

Subsidiary reaction time devices have been shown to be effective as fatigue monitors. Some authorities have expressed concern about fatigue monitors, that they may encourage drivers to drive for longer periods. At present there is no empirical evidence to support or deny this claim.

Laboratory studies show that stimulants may have short term benefits in counteracting fatigue but they may increase driver risk taking. In the long term, addiction to amphetamines may develop with possible consequent bizarre behaviour and problems of withdrawal. The Federal Office of Road Safety is opposed to the use of stimulants.

Both anecdotal reports and published research suggest that auditory input in the form of a car radio may be helpful in counteracting fatigue.

CHAPTER SEVEN

FURTHER RESEARCH

There are good prospects for progress in defining and alleviating the role of fatigue in road crashes. Such progress would involve further research in widely varying aspects of fatigue in driving: concepts and theories of fatigue, the nature of the fatigue-crash relationship and the development of countermeasures. Research in concepts and theories of fatigue and the fatigue-crash relationship are longer-term notions, not so directly related to the implementation of countermeasures but necessary to understand more about the relationships between fatigue, hours of service and driving performance.

CONCEPTS AND THEORIES

The lack of consensus and misunderstanding that plague the concept of fatigue should not prevent further research in this area but a clarification of the concept may enable progress via the synthesis of findings from widely varying studies.

There are'several issues regarding concepts and theories of fatigue which warrant further investigation. The first is the scope of the concept of fatigue. It is not clear as yet whether a general concept of fatigue is viable, or whether the effects of fatigue from different tasks differ so much in their specific effects as to make a general concept too vague to be of use.

The recent theories of fatigue which describe performance in terms of demand and effort (Schonpflug, 1983) seem to provide a firm basis for further research and conceptualisation in that they incorporate the interrelationship of fatigue and stress. Further research to examine these concepts in relation to driving, particularly in relation to Janssen's (1979, in Sanders, 1986) hierarchical model, could prove fruitful.

THE FATIGUE-CRASH RELATIONSHIP

Very few of the studies of the fatigue-crash relationship reported in Chapter Five were conducted in Australia. Several in-depth studies have been conducted in Australia but, as Hampson (1984) noted, these studies were prone to limitations of location and time sampling and are likely to have underestimated the contribution of fatigue to crashes in Australia. There is some evidence that the strength of the fatigue-crash relationship is greater for larger countries since distances travelled are greater (Beckett, Shea and Brenton, 1985) and for this reason Australian data are necessary. In fact the contribution of fatigue to road crashes may vary across areas of Australia. Until appropriate Australian studies are carried out speculation about such issues is all that is possible.

COUNTERMEASURES

In the body of this report a wide variety of fatigue countermeasures was identified. The countermeasures were generally under-evaluated, which resulted in difficulty in the judgement of which were most likely to be effective. However, a division of the countermeasures into those which have the potential to be implemented in the short-term (5 years) and those which are longer-term projects is possible. It can now be stated with confidence that prolonged hours of service (driving plus other duties), particularly by professional drivers, is an important cause of fatigue and that reduction of excessive driving hours and redistribution of hours over time of day should function as an effective countermeasure. The recent findings of over-representation of semi-trailer trucks in fatal crashes suggests that initially fatigue countermeasures should be aimed at this population. Yet the legal, industrial and economic factors which combine to affect hours of service are unlikely to be able to be changed in the short term. Such changes might be hastened by the results of an adequate Australian study of the fatigue-crash relationship but it does not seem possible to reduce and redistribute excessive hours of service in the short term. Attempting to enforce hours of service regulations does not seem a countermeasure likely to be successful because drivers will continue to find ways of largely neutralising enforcement strategies.

Those countermeasures which were judged to be likely to be most effective in the short term were fatigue monitors and education. The cost-benefit payoff for fatigue monitors is likely to be best for commercial vehicles but educational programmes should benefit all drivers. Yet the introduction of these countermeasures is not possible until further research is conducted. In the case of educational programmes designed to alert drivers to the dangers of fatigue and to teach attention maintenance techniques, studies to assess whether mass media campaigns or licensing programmes are more effective have not been conducted. Neither is it known over what length of time these countermeasures are likely to be effective.

Past research into the use of fatigue monitors suggests that they are effective in both monitoring and alerting functions but a number of issues need to be addressed before implementation of such devices. Previous studies were carefully controlled experiments and the experimenter was often in the vehicle with the subject. Thus it is not clear whether their effect is the same when a driver is travelling alone. Furthermore, the issue of interference with the proper functioning of the device by drivers who are legally required to use a monitor has not been considered. In addition there is the question of whether with continued use drivers become accustomed to the monitor and the effectiveness of the alerting signal is reduced. At least several techniques are available for monitoring the driver that warrant investigation, in both research and field environments. These include subsidiary reaction time devices and monitors of eye movements and eye closure.

Another type of countermeasure which warrants future research is field fatigue tests. These tests are suited to detecting unsafe levels of driver fatigue in the general driving population as they do not require the fitment costs of fatigue monitors. As we mentioned in Chapter Six, it seems likely that field sobriety tests which have been designed to identify alcohol intoxication could be adapted to identify fatigued drivers. The research needed to develop a field fatigue test would involve several steps. The first would be the fatiguing of a number of drivers by many hours of driving a car or a simulator. Performance on a battery of tasks including the tests of nystagmus, walking and balance which comprise field sobriety tests would then be assessed. Those tasks which distinguished fatigued from nonfatigued drivers could form the basis of a field fatigue test battery.

The countermeasures for which we have advocated further research vary in their scope of application and the length of the time period likely to be needed for development and implementation. Educational programmes and field fatigue tests are applicable to the general driving population but seem to be longer-term projects. Fatigue monitors have the potential for development and implementation in the short-term and should reduce the number of fatigue-related crashes in the segment of the driving population that is most at risk, drivers of commercial vehicles.

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