HUMAN FACTORS, 1994, 36(2), 298–314

Driver Fatigue

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Psychological fatigue is defined as a subjectively experienced disinclination to continue performing the task at hand. It generally impairs human efficiency when individuals continue working after they have become aware of their fatigue. It does not depend on energy expenditure and cannot be measured simply in terms of performance impairment. The interacting causal contributions to fatigue are the length of continuous work spells and daily duty periods, time available for rest and continuous sleep, and the arrangement of duty, rest, and sleep periods within each 24-h cycle. Empirical evidence for the separate and combined effects of these factors on fatigue, performance decrement, and accident risk are briefly reviewed, and the implications of these findings for driving and road safety are considered, with particular reference to the professional driver. This study shows that fatigue is insufficiently recognized and reported as a cause of road accidents and that its effects stem largely from prolonged and irregular working hours, rather than simply from time spent at the wheel.

INTRODUCTION

The aim of this paper is to consider the sources and implications of fatigue for the vehicle driver, not to address the more restricted question of fatigue caused solely by performing the task of driving. As this paper attempts to demonstrate, this broader aim is important for the health and safety of the private and professional driver alike.

Unfortunately, the literature is not particularly helpful in defining the term *fatigue.* Many introductions to the subject simply state that fatigue is a complex phenomenon that is difficult to define precisely. In a broad sense, the term is used to imply a diminished capacity for work; that is, it tends to be defined in terms of its consequences rather than its causes. There is, however, a general recognition that fatigue results not only from prolonged activity but also from psychological, socioeconomic, and environmental factors that affect mind and body. These views suggest that a more precise definition of driving fatigue may arise from an initial consideration of the effects of fatigue in general, followed by a review of its causal factors and of their relationship to the task and environmental conditions under which driving is commonly performed.

FATIGUE VERSUS IMPAIRMENT

A broad distinction may be made between psychological and physiological effects of fatigue. In their detailed study of the subject, however, Bartley and Chute (1947) held strongly to the view that the term *fatigue* should be used to identify only the psychological aspects of the phenomenon, which they

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distinguished clearly from physiological impairment. They pointed out that unlike impairment, psychological fatigue is always directly experienced. They also found that the measurable pattern of deterioration and recovery associated with physiological impairment is not necessarily mirrored by subjectively experienced fatigue. Indeed, one effect can occur in the apparent absence of the other. Thus an individual may not feel fatigued but may nevertheless perform poorly under adverse conditions. Alternatively, performance may be adequate, but the individual experiences extreme tiredness or discomfort. The latter sensations may be localized in specific parts of the body, whereas, as Bartley and Chute asserted, fatigue can be experienced only generally by the individual. Furthermore, psychological fatigue does not depend on energy expenditure, as appears to be the case with physiological impairment.

As further support for their claim that fatigue is purely a psychological phenomenon, Barley and Chute pointed to the evidence that fatigue is a personal experience, a function of the individual's aspirations, achievements, self-evaluations, and present and previous circumstances. Hence there is no simple relationship between the personal experience of fatigue and an individual's prevailing working conditions. Fatigue does, however, appear to be cumulative in the sense that if it is experienced under one particular set of conditions, it is likely to be experienced when similar conditions recur. The personal nature of fatigue is emphasized by the finding that it can result from conflict. For example, fatigue can occur when an individual cannot meet self-imposed or externally imposed performance goals but is forced to continue working under adverse conditions by a sense of duty and/or the need to safeguard the lives of others.

Bartley and Chute's extreme position has failed to persuade physiologists to substitute *impairment* for the term *muscular fatigue*, which is broadly seen to result from two types of work demand: dynamic muscular work, in which tension and relaxation of the muscles occur rhythmically, and static muscular work, in which the muscles remain in a state of increased tension in order to sustain a particular bodily posture. The different effects of these two types of muscular work have been described by Grandjean (1969). In brief, dynamic muscular fatigue will occur when the energy requirement of exercise exceeds the available oxygen supply and when lactic acid accumulates in the muscle fibers. With appropriate pacing of the work, however, a steady state may be reached in which recovery balances breakdown and serious fatigue effects are not experienced or are long delayed. Such a steady state is difficult to achieve with static muscular work because recovery depends on the relaxation of muscle tension, which may be followed by stiffness and/or pain. The potential effects of both types of muscular fatigue can impair the performance of ongoing perceptual-motor tasks, and static muscular fatigue in particular may distract the individual from the attentional and cognitive demands of the task at hand.

Although the effects of static and dynamic muscular work are more measurable and have a more lawful relationship to energy expenditure than does psychological fatigue, it is unclear whether these effects occur in the muscle itself or in the central nervous system. Hence it is difficult to accept the distinction made by Bartley and Chute (1947) between fatigue and impairment. It is, however, possible to accept the working hypothesis that subjective aspects of the fatigue phenomenon are emphasized in many well-designed dynamic tasks. For instance, driving requires physical demands that are normally well within the driver's capability and allows occasional rest pauses and limited postural changes. Yet it also demands sustained attention and readiness to respond to changing, often unpredictable, inputs.

PERFORMANCE DECREMENT

Changes in performance over time have increasingly concerned psychologists, as the nature of work (including driving) has changed from activities requiring considerable physical effort to ones requiring greater cognitive effort, such as sustained vigilance, selective attention, complex decision making, and the occasional exercise of largely automatized perceptual-motor control skills.

Much of the initial psychological research on fatigue was dictated by wartime demands. Of particular relevance to this paper is the research conducted on fatigue among aircrews during long flights. Summarizing much of this work, Bartlett (1948) reported that the principal early signs of skill fatigue were (a) inaccurate timing of control movements, leading to a loss of smoothness in manipulating the vehicle's controls; (b) a tendency to require larger-than-normal changes of stimuli before responding; (c) an apparent retraction of the normal span of anticipation; and (d) a heightened sensitivity to bodily changes, manifested largely in more aggressive responses toward other people but also toward the vehicle and its control equipment.

This analysis of skill breakdown was followed by many years of independent research on the different decrements in performance reported by Bartlett (1948, 1953) and his coworkers, rather than on these fatigue effects as a whole. The introduction of information theory to psychology (Quastler, 1955), however, led to the view of a human being as a single information channel having limited capacity. Given the ability to calculate the informational demands of a task over time, it was thus possible, in theory, to quantify fatigue in terms of a reduction in information-processing capacity. In cases in which tasks did not permit precise calculations of informational load on the operator, it was assumed that fatigue could be quantified in terms of changes in the operator's "reserve capacity." A set of techniques was developed from the broader field of mental workload methodology to index such changes by scoring the operator's performance on a secondary task that was designed to occupy reserve capacity (Ogden, Levine, and Eisner, 1979). Timing errors could thus be related to the temporal structure of informational demands on a task and to the individual's capacity for meeting that demand.

This approach to the study of fatigue was less than successful for two main reasons. First, individuals can, to some extent, offset any decrement in information-processing capacity by altering their work strategies (Sperandio, 1978; Welford, 1978). Second, the use of secondary task techniques provides individuals with extratask stimulation, which usually acts to offset effects of fatigue on alertness and capacity (Brown, 1978).

SUBJECTIVE EXPERIENCE

Getting individuals to introspect about their symptoms of fatigue has a long history, but the findings of such studies have often been treated with suspicion on the grounds that fatigue both impairs the capacity for introspection and changes the tendency to report symptoms. The latter possibility, at least, has been countered by the use of systematic data collection techniques that constrain the frequency of reporting symptoms while structuring the individual's response categories and simplifying the method of responding. Such techniques include the checklist approach, in which individuals simply identify their symptoms from a verbalized list (for example, "unable to concentrate" or "lacking patience"). Responses can be categorized into factors reflecting decrements in attention, perception, decision, skill, and so on. Yoshitake (1978) used this technique to identify the specific patterns of fatigue factors associated with different types of work. A more sophisticated approach is to represent possible fatigue symptoms as a set of bipolar dimensions (alert/drowsy, active/inert, etc.) used in analogue form (e.g., as horizontal lines, 100 mm long, printed on a response sheet). This permits the researcher to interpret important factors in fatigue development from the data, rather than imposing them on the individual via verbalization of questionnaire items. Herbert, Johnes, and Doré (1976) showed that these analogue scales can be useful in exploring, for example, the subjective feelings resulting from disruption of sleep.

All such techniques, whether used in before/after studies or applied within the working period, have the disadvantage that the added stimulation provided by completing the questionnaire may actually offset the subjective experience of fatigue. Perhaps a simpler and more direct approach in this field, as demonstrated by Nelson (1981), is to ask individuals to report when they feel like stopping a particular activity. The researcher would then be fairly certain that if workers were forced to continue, fatigue symptoms would produce conflict between perceived task demands and perceived coping ability, even if there were no overt indications of physiological impairment or performance decrement.

SUMMARY VIEWS ON FATIGUE

As already stated, Bartley and Chute (1947) reserved the term *fatigue* for the subjective experience of symptoms during prolonged working, regardless of the origins of those symptoms. Cameron (1974) has a broader view of the phenomenon, conceptualizing fatigue as a generalized response to stress experienced over time. In other words, he appears to view fatigue not only as the experience of symptoms associated with continuous work but also as the individual's experience of his or her own ability to cope with the stressful demands that are responsible for those symptoms. Brown (1985) supported this view and has related the subjective experience of fatigue to the fact that human behavior is both adaptive and purposive. Given sufficient motivation, operators can respond with greater effort to the demand for continuous working, and they may maintain that effort over long periods. This enhanced responding may consist of the mobilization of resources to meet the challenge of a stimulating task, or it may result from concentrated attempts to stave off boredom in monotonous tasks. Hence fatigue is seen to result not only from the need to cope satisfactorily with a demanding mental workload but also from the need for continued preparedness to cope with occasional and perhaps unpredictable demands on attentional, perceptual, or decision skills. This latter source of fatigue confirms the view that physiological impairment may be a major contributory factor in certain fatigue experiences, but it is not a necessary determinant of the phenomenon.

For all practical purposes, fatigue may be conceptualized as the subjective experience of individuals who are obliged, for whatever reason, to continue working beyond the point at which they are confident of performing their task efficiently. The experience of fatigue may therefore be regarded as feedback from a variety of behavioral and physiological sources and as having a protective function, in that it predisposes the individual's response toward recovery and the avoidance of further stress. If stress cannot be avoided and the individual has to continue working at the task, performance may continue to be effective—but at an increasing cost in terms of experienced fatigue—until a point is reached at which performance begins to break down. (See Hobfall, 1989, for a model of stress called *conservation of resources*.) If a work-rest ratio inappropriate to the nature of the work is established, the rest allowance may not completely eliminate the subjective experience of fatigue resulting from previous work periods. These experiences thus accumulate over time until the individual is said to be chronically fatigued.

From these summary views, at least for the purpose of discussing tasks with a substantial cognitive component, such as driving, it seems sufficient to define fatigue as the subjectively experienced disinclination to continue performing the task at hand. From this definition it follows that fatigue will have adverse effects on efficiency, though not necessarily on effectiveness, when individuals continue working at the task after they have begun to experience fatigue.

WORKING ARRANGEMENTS AS DETERMINANTS OF FATIGUE

Fatigue will usually be a joint function of the nature of the task in question, the person's ability and motivation to perform that task satisfactorily under normal conditions, the perceived consequences of failing to continue performing the task satisfactorily under adverse conditions, and the provisions made for relieving the individual of responsibility for the task when its continued satisfactory performance is perceived to be in doubt. The last determinant of fatigue should take into account the former three factors, and consideration of all factors should result in working arrangements that minimize or even eliminate fatigue during a work spell and that prevent fatigue accumulating in its chronic form. These arrangements would be important for professional drivers, especially for heavy-goods vehicle drivers working long and irregular hours (see Hamelin, 1978, 1987). In order to achieve such a satisfactory state of affairs, it is necessary to understand the full implication of making long-term arrangements for human work.

Three main factors determine whether humans can continue performing work at an acceptable level in the long term: (a) the length of continuous work spells and daily duty periods; (b) the lengths of time away from work that are available for rest and for continuous sleep; and (c) the arrangement of duty, rest, and sleep periods within the 24-h cycle of daylight and darkness, which normally entrains individuals' circadian rhythms. For drivers who must work shifts or irregular hours over extended periods, the effects of these three factors are not independent. Nevertheless, it may be informative to consider them separately.

Duty Periods

If extended for too long, duty periods tend to produce *reactive inhibition*. As the term implies, this is simply a disinclination of the human brain to continue producing the same response over and over again to the same environmental stimulus. In simple tasks, this may result in the occasional occurrence of unusually long response times (termed *blocking*). For more complicated perceptual-motor skills, reactive inhibition may result in mistimed responses (doing the right thing at the wrong time) or the intrusion of inappropriate responses from other learned behavioral sequences (doing the wrong thing at the right time). Reason (1987) refers to these intrusions as "slips of action" in order to distinguish them from "mistakes," which are the result of inappropriate intentions. The former could also be viewed as a cognitive version of reactive inhibition. For very complex cognitive tasks involving a heavy memory load and concurrent processing of different streams of information (such as air traffic control or even route-finding in heavy city traffic), reactive inhibition may result in operators' "losing the picture," that is, becoming disoriented with respect to interacting task demands and their own response to them.

Whether these potential consequences of prolonged duty periods present a real problem in practice depends on the nature of the task being performed. Few tasks, even vehicle driving, are truly continuous in the sense that attention cannot be withdrawn from them at all. Most tasks permit voluntary or spontaneous rest pauses to be taken at well-chosen intervals (although the opportunities for doing so are clearly limited in many driving situations), and this is usually sufficient to prevent reactive inhibition from becoming a serious problem. Skilled individuals generally learn when and for how long they can withdraw their attention from a given task, either completely or selectively, and they can thus adapt their concentration so that satisfactory performance can be continued for long periods, or at least for the expected length of given duty periods. The question is, does driving require the kind of attention and concentration that would make the length of continuous driving periods and daily duty periods major considerations in any attempt to counter fatigue effects?

In general, expert opinion appears to suggest that a typical industrial 8-h period of duty, divided by typical rest and meal breaks, should have no adverse implications for the performance of drivers. Long-standing evidence suggests, however, that longer periods of duty not only impair task performance but are also accompanied by increases in sickness absences and accidents (Grandjean, 1969; Vernon, 1921). More recent evidence demonstrates that striking the appropriate balance between daily hours and weekly hours is important if fatigue effects are to be avoided. For example, Rosa, Wheeler, Warm, and Colligan (1985) showed that a 12-h/4-day week is more detrimental to performance and produces more self-reports of drowsiness and fatigue than does an 8-h/6-day week.

On balance, working for continuous duty periods of durations typical in industry should have no adverse implications for fatigue among professional drivers, provided excessive overtime is avoided.

Rest Pauses

Taking breaks before, during, and after a period of duty is necessary for a variety of biological reasons. Summarizing research findings of that time, Grandjean (1969) concluded that "From a medical point of view, for the majority a midday break of 45–60 minutes is sufficient for recovery from fatigue, provided that breaks of 10–15 minutes exist in the morning and afternoon for rest and light refreshments" (p. 82). Meal breaks have particularly important implications for fatigue. On the one hand, it has long been known (Haggard and Greenberg, 1935) that blood sugar declines to a low level about 3 to 4 h after eating a meal, often accompanied by sensations of fatigue and impaired efficiency. On the other hand, it has also long been accepted (Bjerner, Holm, and Swenson, 1955) that perception and decision making are temporarily impaired shortly after the midday meal break. Colquhoun (1971) and his coworker Blake (1967) termed this the *post-lunch dip*. However, Folkard and Monk (1985) reviewed evidence suggesting that this effect is not simply a function of digestion but is largely attributable to the phasing of endogenous biological rhythms.

In brief, rest pauses are known to have essential restorative functions, but it cannot be assumed that performance will inevitably be restored to its initial level when work recommences. The timing of breaks within each 24-h period, as well as within and around the duty period, seems important if human performance is to be maintained at the level demanded by certain tasks, especially those requiring alertness and sustained vigilance.

There is little evidence regarding the duration of rest pauses needed to maintain performance on these types of task. Most studies on the need for rest have involved physiologically demanding work, in which recovery from muscular fatigue is the major requirement. There is some evidence from studies of less physically demanding work that the restorative effect of rest pauses declines throughout a duty period. For example, Harris et al. (1972), in a study of fatigue and truck driving, found that the third of three-hourly rest breaks produced no evidence of physiological recovery, nor did it arrest an increasing trend in drivers' errors that occurred after about 9 h of work. In fact, psychophysiological indexes of alertness showed a further decline after the break. This emphasizes the fact that there can be no hard and fast rule about the duration of rest pauses set independently of the task being performed and the scheduling of duty hours. In practice, rest pauses seem to have resulted largely from the negotiation of sufficient free time for workers to complete, in relative comfort, the activity associated with the break.

Sleep Breaks

To alleviate and prevent longer-term fatigue, sleep breaks are a necessity, justifiable on the basis of both common sense and a long-published history of research on the subject. Although justice cannot be done to that vast literature here, the more important relevant points can be identified.

The need for sleep and the consequences of shortened sleep breaks were reviewed by Horne (1985), who pointed out that

> Human sleep seems to be governed by at least two mechanisms. One is an obligatory requirement, probably for tissue repair and restitution following the "wear and tear" of wakefulness. This restitution seems oriented towards the brain, as most other organs seem to obtain their restitution "on line" during wakefulness. The other is a more facilitatory ("facultative") sleep mechanism mostly under the influence of a sleep drive governed by circadian influences as well as behaviors such as habit and boredom. "Obligatory" sleep is primarily regulated by the length of prior wakefulness and occupies the first part of sleep, with the remaining sleep being made up mostly of facultative sleep. Consequently, tiredness due to shortened sleep may not be due to loss of restitutive benefit, but to the facultative sleep drive which manifests itself through a decline in motivation to perform at tasks, rather than through a failing of the inherent capacity to perform. This drive seems amenable to change, with this tiredness manageable by methods other than obtaining more sleep. Sleep loss which intrudes into obligatory sleep produces additional central nervous system (CNS) impairments. (P. 53)

Experts are still uncertain as to the precise need for sleep, but from Horne's view it follows that the longer the spell of duty, the more stressful the task, and the more hazardous the working conditions (i.e., the more wear and tear there is associated with wakefulness), the more restitutive sleep the individual will be obliged to take. If such stressful conditions have to be faced regularly, under a restricted sleep regimen, people can tolerate a certain amount of partial sleep deprivation and perform reasonably well; however, the limit of tolerance seems to be about 4 to 5 h of sleep per day (Naitoh, 1976; cited in Fröberg, 1985). However, this limit cannot be used in isolation as a criterion for setting "safe" periods of restricted sleep. Tilley and Wilkinson (1984) showed that "the effects of a restricted sleep regime on the composition of sleep are partly a function of the time of night to which sleep is restricted" (p. 406). This is further evidence that the deleterious effects of any one main factor in the working arrangements that control fatigue cannot be considered or manipulated independently of one or both of the other two factors. It is their interaction that is important in determining the presence and magnitude of fatigue effects.

Fröberg (1985) summarized evidence on the increase in *microsleeps* that occur with increasing duty time and loss of sleep. These periods of a few seconds of sleep result in the increased probability of human error (such as missing a crucial signal when driving in traffic). Furthermore, it has been shown that these very short sleeps do not have the recuperative value of normal sleep, that individuals still feel sleepy, and that their performance still degrades, even though there may be a large number of microsleeps. Longer naps may be beneficial to performance, even though there is a tendency toward even greater deterioration of performance immediately after a short period of sleep (referred to as *sleep inertia*). Again, the restorative efficiency of a nap depends on the time of day at which it is taken as well as its duration.

As might be expected, performance of tasks that are long, familiar, monotonous, uninteresting, and complex deteriorates more than that of short, novel, variable, interesting, and simple tasks when they have to be performed under conditions of (partial) sleep deprivation. This has serious implications for the maintenance of vigilance by sleepy drivers. In a direct study of vigilance performance, Horne, Anderson, and Wilkinson (1983) demonstrated that sleep deprivation produced a progressive impairment in the ability to discriminate signals. They were able to identify the specific effect of sleep loss by subjecting their data to an analysis based on signal detection theory. By showing that sleep deprivation largely impaired perceptual sensitivity, which may be taken as a measure of "cerebral capacity," Horne et al. interpreted their findings as a demonstration that sleep has a mainly restitutive function. Note that the decline in perceptual sensitivity that accompanied sleep deprivation in their study was confined, for the most part, to the usual sleep period.

In brief, as Horne (1985) pointed out, it is still not clear whether these sleep effects are simply a withdrawal response from a demanding day or the result of an increasing need for brain restitution. What is clear from a variety of studies is that one cannot assess the effect of sleep independently of the time at which it is taken, the individual's normal routine, and the social context in which the individual operates.

Circadian Rhythms

Circadian rhythms in human arousal and performance appear to be of crucial importance for any assessment of fatigue effects on safety arising from an individual's working arrangements. The effects of circadian rhythms on human performance have been researched for more than 30 years, and these studies have developed into the independent science of chronobiology. Coverage of the practical implications of circadian rhythms for irregular and abnormal hours of working is provided by Rutenfranz, Knauth, and Colquhoun (1976), Colquhoun and Rutenfranz (1980), Folkard and Monk (1985), Folkard (1987), Åkerstedt (1988), and Folkard et al. (1993). The main conclusion from this work is that there is not a single performance rhythm, but many. Different types of performance rhythm seem to adjust to irregular or abnormal working hours in different ways (see Craig, Davies, and Matthews, 1987). Perfect adaptation of human performance to irregular or abnormal working hours is difficult, if not impossible, to achieve. The extent to which performance is impaired is a function of several interacting factors, including individual characteristics, domestic circumstances, and environmental conditions. The practical end result of these interacting factors, as Mitler et al. (1988) pointed out, is that human medical and performance catastrophies are far more likely to occur between 1:00 and 8:00 a.m., with a secondary period of vulnerability between approximately 2:00 and 6:00 p.m.

This brief overview of circadian effects on human activity emphasizes the fact that issues such as duty hours, rest and sleep, and shiftwork arrangements need to be considered in combination if any conclusion is to be reached on the importance of fatigue in road safety and on the justification for regulating professional drivers' working hours in order to limit fatigue and maximize safety. The following section brings these various issues together in a specific consideration of fatigue and driving.

DRIVING FATIGUE

In his comprehensive review of research specific to driving fatigue, McDonald (1984) found that disappointingly few conclusions could validly be drawn. This was largely because most of the studies were one-of-a-kind experiments, in which subjects unused to prolonged driving performed in only one driving session, under conditions of motivation and distraction that did not match those usually found in real life. In many cases the influence of circadian variations in activation and performance was confounded with time-on-task effects (e.g., Herbert and Jaynes, 1964). In other studies, researchers attempted to measure performance decrements by the use of short tests presented to the driver at intervals during the work spell (e.g., Brown, Simmonds, and Tickner, 1967; Brown, Tickner and Simmonds, 1966), thus tending to offset any adverse effects resulting from depressed levels of alertness. As McDonald pointed out, most driving fatigue experiments have confounded a whole range of personal, environmental, and task-related factors; researchers then attempted to search their data for evidence of a relationship between performance decrements and time spent driving. Researchers have frequently attempted to develop a reliable measure of this time-dependent fatigue, and they have ignored the other contributory factors in real-life prolonged driving tasks.

The more relevant studies suggest that vehicle control skills are little affected by fatigue. This would be expected because such skills are automatized, or overlearned, and thus resistant to change arising from any impairment of higher-level cognitive functioning. McDonald (1984) reviewed a series of studies that purported to show decrements in various perceptual-motor skills associated with steering control and speed tracking. Although some of this work demonstrated changes in the nature and effect of the driver's steering response, it is difficult to know whether such changes in, say, lane drift, reflect a deterioration that is causally implicated in road accidents or whether they reflect the adaptation of drivers' criteria to continued work demands.

For example, Fuller (1981) showed that the time *headway* adopted by drivers changed significantly over an 11-h working day and over the 4 days of his experimental test period. However, there was no evidence of an increase in riskiness among his drivers. On the contrary, they exhibited more caution when following other vehicles during later work shifts, as if they were adjusting their perceived abilities to the task and the environmental conditions. This finding appears to conflict with the report by Brown, Tickner, and Simmonds (1970) of an increase in risky overtaking maneuvers during a 12-h spell of driving. However, even this result may be interpreted as an adaptation to the task by subjects who were unaccustomed to driving for 12 h in one day.

In general, there is little evidence that the decision and response components of perceptual-motor skills are impaired by one-off periods of self-paced driving for up to 11 h during normal waking hours of the day (with meal breaks) or when that schedule is repeated for a minimum of four days. Nevertheless, the possibility that some drivers will suffer performance decrements in decision and skill cannot be ruled out. This is particularly relevant when continued driving impairs self-perception and breaks down one's ability to adapt to task demands.

The vast literature on vigilance supports the expectancy of a deterioration in perceptual skills during prolonged driving. The evidence from field studies, however, is inconclusive. This is largely because the tests used to measure drivers' vigilance have been artificial; that is, using extratask signals and responses and the presence of the experimenter in the test vehicle may itself have been an arousing stimulus. Riemersma, Biesta, and Wildervanck (1977) found a marked increase in errors over an 8-h drive when subjects were asked to report each 20-mile (32-km) change in the vehicle's odometer reading (a semitask-related demand). Näätänen and Summala (1976) also reported a decline in drivers' detections of certain road signs over a 257-km journey. Both findings, however, may be interpreted as evidence that greater concentration on important task features develops over time; that is, attention selectivity increases, which reflects an adaptation of visual search behavior to perceived changes in perceptual ability. Only when this self-regulatory process breaks down will prolonged driving become hazardous. It cannot be predicted from the evidence when this is likely to occur in terms of elapsed driving time. It can, however, be predicted that it is more likely to occur if driving is prolonged into the individual's normal sleeping period, with the risk being greatest at around 4:00 a.m. It can also be predicted that risk from perceptual error is greatest when task and environmental demands are low, such as on a sparsely trafficked highway. Michon and Wertheim (1978) reported that, under such conditions, a driver's visual sampling behavior may cease to be dictated by road and traffic demands and instead may be determined increasingly by internal oculomotor programs based on the experienced predictability of road and traffic events. This is clearly a dangerous state of affairs.

Evidence suggests that driving fatigue need not be a problem if drivers are able to match their own speed to traffic demands, within legal constraints; take rest pauses when desired; refrain from driving during that part of the 24-h cycle when they would normally be sleeping; and stop driving before they feel uncertain of coping with the task. If any of these criteria is relaxed, then fatigue could be dangerous. Nelson's research (1981) showed that people are sensitive to the changes in their performance incurred from prolonged driving, and they can use these changes to predict the point at which they should stop driving. Fatigue problems arise when something disrupts this self-regulatory process. One source of disruption is the pressure to complete a journey for commercial reasons. Hence fatigue is potentially a problem in the haulage and public transport industries, which will be discussed in the next section.

FATIGUE AND THE PROFESSIONAL DRIVER

Drivers of heavy-goods vehicles (HGV) and some drivers of public service vehicles (PSV) regularly deliver freight and passengers, respectively, over long distances. As discussed earlier, these drivers may be seriously at risk from fatigue effects because they are not free to determine their own work schedules and because their job-demands often involve irregular hours of work. It follows that, in attempting to reach a given destination, they may continue to drive beyond the point at which they feel (or actually are) capable of dealing effectively with road and traffic demands. In addition, their irregular shifts will force them occasionally to continue driving during troughs in their circadian rhythm of physiological activation, so that performance may decline to suboptimal levels. Irregular work schedules will also curtail the periods available for continuous rest and sleep. Furthermore, shiftwork may require these drivers to take daytime sleep under social and environmental conditions that are not conducive to rest. Finally, their driving cabs are likely to cause other stressors that interact with fatigue, such as heat, noise, and vibration. The importance of factors such as these was demonstrated by Storie's (1984) study of motorway accidents among 2000 HGV and PSV drivers. Fatigue seemed implicated in 11% of their accidents, though 62% of accidents occurred after they had driven less than 100 miles that day. Clearly, time spent driving on the day of the accident was not a major contributory factor.

Growing evidence suggests that this group of drivers presents an increasing problem for road safety (e.g., see Fuller, 1980; McDonald, 1980; Miller and Mackie, 1980). O'Hanlon (1978) noted that accidents attributed to drivers being asleep or fatigued are second only to those attributed to alcohol among the causal factors identified in road accidents in California. Much of the American evidence on truck and bus driver fatigue was reviewed at length by Mackie and Miller (1978). Although they investigated different types of truck operation, a clear finding was that irregular driving schedules produced greater subjective fatigue, physiological stress, and performance degradation than did regular hours of work. Fatigue effects became evident after about 8 h on regular schedules and considerably earlier when work was irregular. "Sleeper" operations (involving a two-man crew, one taking rest in the cab) showed earlier and greater signs of subjective fatigue and performance degradation than did "relay" driving (individual drivers handing over their freight to others). Sleeper driver performance was strongly affected by the time of day. Harris (1977) reported that twice as many truck accidents as expected happened in the second half of trips. The number of single-vehicle accidents was nearly 2.5 times greater than expected between midnight and 8:00 a.m., with accidents attributed to drivers dozing at the wheel occurring almost 3.5 times more frequently than expected. On the basis of electroencephalogram records, Lecret (1978) produced more evidence of sleepiness among drivers who distributed their work over 18-h periods than she did among drivers who worked regular daily hours.

Hamelin (1987) reported a similar pattern of accidents among French truck drivers. Accident risk increased throughout the normal day; that is, it was low up to noon, showed a small and transient peak between noon and 2:00 p.m., and then rose virtually linearly to a high peak between midnight and 2:00 a.m. before falling away again. The risk rate at this high peak was around 2.5 times the daily average. Hamelin highlighted the fact that relative risk rate is lower during some periods of high traffic density, such as the morning commuting hours of 6:00 to 10:00 a.m., than it is during periods of relatively light traffic, such as 10:00 p.m. to 4:00 a.m. Hamelin also pointed out that relative risk rate is slightly higher than average at the beginning of a daily duty period, and remains fairly stable for duty periods of up to about 12 h, but then rises to a high peak for duty periods exceeding 12 h. At this high peak, the risk of accident involvement is twice the daily average. The start-up effect agrees with a finding reported by Pokorny, Blom, and Van Leeuwen (1981) that bus drivers had a slightly higher risk of accident involvement when resuming work after a break, especially if they were on an early morning shift. Hamelin noted that the difference between high and low risk rates within the age groups surveyed in his study was greater among drivers over the age of 30 years. He attributed this to lower strength resources of drivers over 30, which limit their ability to compensate for fatigue effects once they have accumulated a certain number of duty hours or during the more difficult night driving hours. This age effect was also reported by Harris et al. (1972), who found that truck drivers over the age of 45 benefited less than younger drivers from rest breaks taken toward the latter part of their daily duty period. Kaneko and Jovanis (1992), however, found no evidence that a driver's age mediated the relationship between accident risk and working patterns. Their study of data from actual truck operations revealed that risk increased to a maximum after 9 h of driving and that accident risk was highest during the period from midnight to 10:00 a.m.

A special case of fatigue causation among drivers may be associated with sleep disorders. Aldrich (1989) presented evidence of higher accident rates among narcoleptics (who chronically have difficulty in remaining awake) and apneics (whose breathing is impaired during sleep). The incidence of sleep-related accidents among apneics was found to be lower than among narcoleptics, but apneics represent a potentially more serious problem for road safety because of their greater numbers. An additional problem is that apneics may not be fully aware of their problem. As with certain other hypersomnolent individuals, they may not recognize that they are becoming sleepy, and they may get no warning of acute sleep "attacks." They will therefore find it difficult or impossible to compensate adequately for their condition.

Although this may represent a problem among private motorists, one might expect it to be of little importance for professional drivers—presumably, they would become aware of their medical condition as they attempted to work long and irregular hours, causing them to consider withdrawal from the job. However, Horne (1992) found evidence that long-distance truck drivers seem particularly vulnerable to obesity, which is known to exacerbate the problem of sleep apnea. Therefore, a significant fatigue problem may exist among HGV drivers who become apneic as a result of occupationally related obesity at a stage in their career when they are reluctant to give up professional driving.

CONCLUSIONS

The magnitude of the road safety problem presented by fatigue is unreliably specified by accident statistics. To quote from Lauber and Kayten's (1988) keynote address to the Association of Professional Sleep Societies:

> Although . . . we have investigated many accidents in which sleep loss, sleep disorders, fatigue, and circadian factors are clearly implicated, I don't think we have the foggiest notion of the true prevalence of these factors in transportation system accidents. One of the most perplexing problems our accident investigators face is how to determine what role, if any, fatigue played in a specific accident. Unlike metal fatigue, human fatigue generally leaves no telltale signs and we can only infer its presence from circumstantial evidence. (p. 503)

In consequence, official accident statistics may attribute as few as 2% of road accidents to fatigue. However, more detailed studies of truck and bus drivers' accidents (e.g., by McDonald, 1984; O'Hanlon, 1978; and Storie, 1984) suggest that drivers are asleep at the wheel in at least 10% of collisions. For single-vehicle accidents, these and other studies suggest that fatigue is the principal contributory factor in at least 25% of the total. Clearly a more effective and reliable method of identifying the causal contributions of fatigue in road accident reporting systems is needed.

Driving fatigue is not determined simply by time spent at the wheel. Time on task per se appears to have a relatively small effect on accident risk when daily work periods are shorter than 11 h, especially when driving is restricted to normal daily work times. However, accident risk may double when duty periods exceed 12 h.

Circadian rhythms of physiological activation have a profound effect on drivers' relative accident risk. These rhythms have associated bimodal troughs in alertness: a major one in the early morning hours and a subsidiary one in the early afternoon. These troughs produce a substantial increase in accident risk during the early morning (variously reported as lying somewhere between 2.5 times the daily average risk rate and about 10 times the midmorning or early-evening rate), with a smaller increase in risk during the early afternoon.

Loss or disturbance of sleep exacerbates the effect of fatigue on driving. This contributory factor interacts with circadian rhythmicity and with time on task. Contributions to driving fatigue from sleep loss or disturbance will be a function largely of irregular working hours among professional drivers and of commercial pressures on them to complete a journey, even when they are feeling excessively fatigued, which may tempt them to exceed their legally permitted hours of driving (see McDonald, 1981).

Special cases of sleep contributions to fatigue are represented by narcoleptics and apneics. These groups present a potentially serious problem for road safety in general, largely because of their numbers but partly because they may be unaware of their problem or of the occurrence of acute "sleep attacks." Few narcoleptics and apneics might be expected among the professional driver population, because of self-selection. However, obesity exacerbates apnea and appears to be an occupational hazard among HGV drivers. Thus apnea may represent a fatigue problem for experienced drivers who are reluctant to change their job in midcareer.

Although fatigue is associated with prolonged duty periods and irregular working hours, individuals differ in the extent to which it affects their accident involvement. There is some evidence of an age effect, as drivers over 45 years of age are more susceptible to fatigue than younger drivers. There is also limited evidence (Hamelin, 1987) that professional drivers experienced in working under difficult task and social conditions acquire specific know-how that enables them to better manage their job demands and compensate for some fatigue effects. Thus, although their overall accident risk may be higher than that of drivers working under less-demanding conditions, experienced professional drivers appear to have the ability to deal adequately with certain critical accident-provoking situations that entrap less experienced drivers.

Current statutory regulations on European professional drivers' work hours inadequately safeguard against fatigue influences on accident risk. This is largely because the regulations specify only three parameters: the maximum number of hours a person may drive before taking a break, the maximum number of hours a person may drive per day, and the minimum number of hours a person may rest or sleep per day. The regulations take little account of the time since sleep or the time of day at which driving may begin or end. This shortfall in legislative protection of road users from fatigue effects has been expounded in the scientific literature for many years (e.g., see Brown, 1982; Hamelin, 1978, 1987; Horne, 1992; McDonald, 1984; O'Hanlon, 1981). However, the scientific evidence for this shortfall may have been overridden by commercial pressure to retain maximal flexibility in the scheduling of haulage operations.

Lauber and Kayten (1988) pointed out that although researchers lack quantitative evidence to support the role that sleep, circadian rhythms, and prolonged working play in transportation system safety, they have enough qualitative evidence to recognize the serious shortcomings in public policy on the subject, as reflected, for example, in the nature and enforcement of regulations governing operator duty hours and rest periods. Lauber and Kayten attributed these shortcomings largely to ignorance and misunderstanding of fatigue causation among public-policy makers. One widely held misperception that Lauber and Kayten identified is the notion that overcoming the effects of insufficient rest and sleep is simply a matter of motivation. Because there is no empirical support for such a belief, it is essential that the control of fatigue effects on road safety not be left solely in the hands of individual drivers or their employers.

Fatigue is a subjective experience distinguishable from physiological impairment. The latter represents only a minor source of fatigue from the task of driving modern vehicles, although static muscular fatigue may produce occasional distraction or irritation if driving periods are unduly prolonged. It is important, for two main reasons, to limit the definition of fatigue to the subjective experience of tiredness and a disinclination to continue performing the current task. McDonald (1984) pointed out that to rely solely on an operational definition of fatigue (in terms of overt behavioral or physiological phenomena or conditions of exposure) is to change the meaning of the word *fatigue* as it is used in modern language. He also pointed out that in a task like driving, the drivers' own appraisal of their performance and psychological state will determine whether they will continue driving or stop and take a rest when they feel drowsy. In other words, it is their reaction to their experiences and feelings that determine their safety. Hence, countermeasures protecting drivers against the effects of fatigue will be successful only if they are based on a sound understanding of drivers' subjective experiences of fatigue symptoms.

Fatigue is generally experienced as a disinclination to continue performing the task at hand. It may occasionally be experienced as an increased tendency to make errors of omission or commission. For experienced drivers, any errors of commission made during a work spell will probably be exhibited initially as slips of action (e.g., engaging an inappropriate gear or driving to a familiar but wrong destination). As fatigue progressively impairs performance, errors may appear more in the form of mistakes (e.g., misjudging braking distance at traffic lights, or attempting to overtake another vehicle when there is insufficient time to complete the maneuver).

For drivers in general and for professional drivers in particular, the subjective experience of fatigue involves conflict between the desire to rest and the inclination (or perceived commercial pressure) to continue driving to their planned destination. Drivers who experience severe fatigue yet persist in completing their planned journey do so at the expense of increasing stress, which itself compounds accident risk.

The main effect of fatigue is a progressive withdrawal of attention from road and traffic demands. This may be general, impairing both vehicle control and collision avoidance ability, or selective, impairing collision avoidance ability but leaving vehicle control virtually intact. In either case, the withdrawal of attention will be involuntary and difficult, if not impossible, to resist.

Probably the most frequent cause of general attentional impairment is the eye closure that accompanies sleepiness. However, undemanding road and traffic conditions may progressively and subconsciously redirect a driver's attention toward inner thought processes. This may happen even if a driver is not feeling tired and is gazing at the external scene. In other words, driving fatigue is a partial function of prevailing task, road, and traffic demands (see Brown, 1988). There is also circumstantial evidence for a third state of inattention, said to be causally associated with exposure to highly repetitive and predictable visual demands, in which visual sampling of the environment gradually becomes determined by an expectancy of unchanging task demands and associated internal programs for oculomotor control, rather than by actual current and upcoming task demands (see Brown, 1991). Individuals so affected have been described as "driving without awareness" (DWA) because they are apparently oblivious to impending collisions and, like most experienced and alert drivers, will implement routine steering corrections without conscious intervention.

Whereas the onset of sleepiness is usually experienced by drivers who are fatigued—a condition for which remedial action can be taken—the onset of attentional switching to inner thought processes, or of DWA, may be sufficiently insidious that drivers are unaware of their impaired state and hence in no position to remedy it. The sensitivity of drivers afflicted with either of these conditions is not clear. Anecdotal evidence suggests that drivers engaged in inner thoughts are aware of having been distracted by these thoughts when their attention is redirected to the road and traffic scene. DWA drivers, by contrast, appear to have absolutely no recall of events that occurred during their period of unawareness when they come out of their trance-like state. Therefore, it can be assumed that drivers who are merely distracted by thought processes will reliably respond to conspicuous environmental stimuli (such as hazard warnings, brake lights, etc.). However, the attention of DWA drivers will not be captured as readily, perhaps because they are fixating too close to the front of their vehicles. This is a phenomenon that has been observed among pilots flying at high altitudes and is referred to by aviation physicians as *empty field myopia.* The relative contributions to road accidents from sleepiness, inwardly directed attention, and DWA are unknown. However, inner thoughts and DWA would be expected to selectively increase the probability of rear-end collisions, whereas sleepiness would also increase the probability of involvement in single-vehicle ran-off-road accidents.

Drivers who are experiencing fatigue are likely to obtain only temporary benefits from self-initiated attempts to restimulate alertness (e.g., by conversing with passengers, listening to the radio, or stopping for a coffee or a short walk). These techniques seem to offer some relief during the early afternoon trough in alertness, but they are unlikely to provide lasting benefits when fatigue is experienced during the early morning. Therefore the only real solution to driving fatigue is to leave the road, stop driving, and sleep.

Given this limited ability of individual drivers to compensate for experienced fatigue and the commercial pressures on professional drivers to complete their journey, it follows that road-user safety can be adequately protected from fatigue-related influences only by appropriate, externally imposed control of drivers' working schedules. This would aim to limit not only the duration of continuous driving periods but also the extent to which duty hours could be distributed over the 24 h of each day and the regularity of such duty hours from day to day. As mentioned earlier, such control is not adequately provided by existing, poorly conceived legislation.

ACKNOWLEDGMENTS

This paper is a shortened version of an unpublished review, *Fatigue & Driving*, prepared in January 1992 by the

author for the Medical Commission on Accident Prevention and the U.K. Department of Transport.

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Date received: July 31, 1992
Date accepted: February 26, 1993