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Monotony of road environment and driver fatigue: a simulator study

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Abstract

Studies have shown that drowsiness and hypovigilance frequently occur during highway driving and that they may have serious implications in terms of accident causation. This paper focuses on the task induced factors that are involved in the development of these phenomena. A driving simulator study was conducted in order to evaluate the impact of the monotony of roadside visual stimulation using a steering wheel movement (SWM) analysis procedure. Fifty-six male subjects each drove during two different 40-min periods. In one case, roadside visual stimuli were essentially repetitive and monotonous, while in the other one, the environment contained disparate visual elements aiming to disrupt monotony without changing road geometry. Subject's driving performance was compared across these conditions in order to determine whether disruptions of monotony can have a positive effect and help alleviate driver fatigue. Results reveal an early time-on-task effect on driving performance for both driving periods and more frequent large SWM when driving in the more monotonous road environment, which implies greater fatigue and vigilance decrements. Implications in terms of environmental countermeasures for driver fatigue are discussed.

Keywords: Fatigue; Drowsiness; Vigilance; Monotony; Road accidents; Prevention

1. Introduction

Hypovigilance and fatigue have been regarded for a long time as probable causes of road accidents. While there is an impressive amount of literature covering the problem of vigilance and its implications to transport operations, increasing attention has recently been focused on driver fatigue and drowsy driving. Even if research has not yet determined precise contributions of these factors in motor vehicle crashes, there is an emerging consensus among researchers that they represent major road safety hazards.

Different definitions of concepts such as vigilance, fatigue, arousal and activation may bring a certain confusion in the understanding of these phenomena. It is therefore important to clarify their significance in the present context. The research literature underscores two broad conceptions of vigilance: one related to the physiological processes underlying alertness or wakefulness, the other related to information processing and sustained attention. Fatigue, on the other hand, is a general term which relates to both physiological and psychological processes. Generally speaking, fatigue reflects a decreased capacity to perform, along with the subjective states which are associated with decreased performance (Lyznicki et al., 1998). According to Dinges (1995), vigilance decrement is the most robust effect of fatigue and sleepiness. In the current study, fatigue will be defined as a general psychophysiological state which diminishes the ability of the individual to perform the driving task by altering alertness and vigilance. Vigilance, on the other hand, will designate the ability to maintain sustained attention within the road environment. Other concepts that are potentially misinterpreted are the notions of activation and arousal, since they are often used interchangeably to designate energy mobilization. Activation will be used here to refer to the tonic maintenance of alertness over long periods of time and arousal to short-acting, task-induced phasic changes, as defined by Pribram and McGuiness (1975).

The review of the theoretical and experimental literature presented below is organized as follows: the general causes of fatigue and drowsy driving are first summarized and a distinction is made between endogenous and exogenous (task-induced) factors. The focus is then oriented toward task-induced factors and the impact of monotony and ruptures of monotony on drivers' fatigue are more closely analyzed.

1.1. The causes of fatigue and drowsy driving

Several factors can account for fatigue and drowsy driving. Different physiological and psychophysiological

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processes can be linked to fluctuations of activation, arousal, alertness and vigilance. Although numerous parameters of a given driving situation can have an effect on these processes, the very complex and systemic nature of human functioning renders it difficult to isolate them precisely. However, as Smiley (1998) observes, not all variables can be controlled or examined in any single study. Indeed, experimental studies examining fatigue and driving usually try to isolate causal factors in order to gain a better understanding of their contribution to the problem.

Most previous studies have examined factors that influence the basic preparation state of the organism when performing the driving task. In a review of these factors, Smiley (1998) identified long hours, time of day and sleep-related problems, not only as major contributors to fatigue, but also as potential sources of corrective measures aiming to prevent fatigue-related road accidents. Long hours spent driving, referred to as the *time-on-task* effect, is known to produce fatigue and a deterioration of driving performance, although degradation can occur during the very early stages of a driving or vigilance task. Summala and Mikkola (1994) observed that 60% of fatal sleep-related accidents in Finland occurred within the first hour of driving. The 24 h physiological circadian rhythm, or *time-of-day* effect, is another major factor that accounts for fatigue. There is a more important proportion of sleep-related accidents during the early morning hours: 2:00–6:00 a.m. and to a lesser extent during the afternoon period: 2:00–4:00 p.m. (Pack et al., 1995). Sleep-related factors such as sleep deficit, sleep fragmentation and sleep apnea also increase accident risk.

It is important to note that the above factors are all associated with basal fluctuations of the physiological parameters that determine the level of alertness. However, other physiological processes must be considered as well. Indeed, two broad categories of factors can influence the physiological states that underlie alertness and vigilance: endogenous and exogenous factors (Cabon et al., 1996; Thiffault and Bergeron, 1997).

Endogenous factors affect the basic preparation state of the individual when performing the driving task. They are associated with long term fluctuations of alertness that emanate *from within* the organism. The main endogenous factors include the circadian variations associated with time of day, the fatigue generated with the duration of the task and sleep-related problems. Long hours, late night or mid-afternoon driving periods, as well as sleep deficits, are good examples of widely studied endogenous precursors that are detrimental to driving performance, since they are directly associated with tonic variations of physiological activation.

However, the characteristics of road geometry and roadside environment, including other factors that define the driving task, can have an impact on driving performance by affecting arousal, alertness and information processing. An under-demanding monotonous road environment with low traffic density can produce fluctuations of arousal that decrease alertness and vigilance. Such performance deterioration, which is induced by under load, may be as important as what is observed during over-demanding crowded urban expressway situations, when arousal is risen to a point where the driving performance is negatively affected. These task-induced factors can be labeled as "exogenous", because they stem from the individual's interactions with the road environment. Like endogenous factors, exogenous factors may produce physiological reactions that influence alertness and vigilance.

The traditional approach to the study of fatigue and driving is largely oriented towards sleep research and endogenous fluctuation of alertness. This research orientation has produced important insights in our understanding of how time of day, long hours and sleep-related problems can affect alertness and driving performance. It has provided a strong basis for the formulation of recommendations for driving practices, such as limiting driving during circadian low points and encouraging the screening and treatment of drivers suffering from sleep apnea (Smiley, 1998). These studies have also provided insight into the management of sleep and rest that has benefited the performance, comfort and health of shift workers of transport operation systems.

While this approach is fundamental, an ergonomic analysis of the driving task that includes exogenous factors represents an important complement. Psychophysiology and cognitive ergonomy form the basis of an interactionist perspective that enables an *in depth* analysis of each driving situation, accounting for both endogenous and exogenous factors that can alter alertness and vigilance. The basic state of alertness of the organism is the primary source of information but it will, in any case, be modified by what the person is doing and under which conditions. Endogenous and exogenous factors interact continuously and it is their joint influence that determines alertness and vigilance at any given point during driving. For example, monotony may exacerbate the impact of late night driving, whilst overloaded roadside environments may generate arousal levels that counteract this effect. This implies that the characteristics of both the driving task and road environment are essential when examining alertness and vigilance. According to Desmond and Matthews (1997), the disappointing effectiveness of in-vehicle fatigue countermeasures could be attributable to a failure to consider the variation of fatigue effects across task demands. They observe that these devices should take into account this task-specific nature of fatigue.

The ecological approach to fatigue research implies the same kind of reasoning. In this context, fatigue emerges as a function of the driver/environment relationship in a particular driving environment. As Nelson (1997) says: "... it (fatigue) is no longer regarded solely as something within the brain ..., it depends of what you are, what you are doing and where you are doing it". Nelson observes that highway design, and especially the lack of stimulation, can play a role in fatigue-related accidents. He recommends that education should be oriented toward teaching how conditions in the environment can influence the development of fatigue-related symptoms.

1.2. Task induced fatigue: the impact of monotony

Almost every study examining driver fatigue suggests that it is more frequent on monotonous road environments such as highways. In a consensus statement from the International Conference on Work Hours, Sleepiness and Accident, it was acknowledged that highway night drivers were particularly vulnerable to sleep-related accidents (Åkerstedt et al., 1994). While comparing self-reported driving fatigue in the US and Norway, Sagberg (1999) suggests that the higher prevalence of self reported drowsy driving found in the US may be due to differences in road geometry, design and environment, as well as exposure. He argues that the risk of falling asleep is higher on straight, monotonous roads in situations of low traffic, where boredom is likely to occur. This type of roads is more common in the US than in Norway.

Horne and Reyner (1995) found that sleep was involved in 23% of accidents occurring on monotonous motorways. Survey data from Maycock (1995, see Brown, 1997) also suggest that tiredness is a contributory factor in 20% of accidents on motorways. Fell (1994) estimates that sleepiness accounts for 30% of fatal crashes on rural roads. McCartt et al. (1996) report that 40% of sleep-related accidents occur on highways or expressways. For Shaffer (1993, see Dinges, 1995), sleep-related accidents may be common on long stretches of motorways, and may account for at least 40% of fatal accidents. In a driving simulation study, Desmond and Matthews (1996) observed that driving performance decreases faster on straight road sections than on curves.

Monotony is usually defined with reference to the sensory stimulation that is present in a specific situation. According to McBain (1970), a situation is said to be monotonous when the stimuli remain unchanged or changing in a predictable manner. For O'Hanlon (1980, see Cabon, 1992), monotony refers to a situation where sensory stimulation is constant or highly repetitive. Wertheim (1991) observes that the concept of monotony can be defined as a lack of alerting stimulation. In his view, the alerting potential corresponds to the amount as well as the variation of stimulation and to its importance for the perceiver. Generally, lower amounts and lower variations of stimulation should lead to lower arousal. While this is true in laboratory settings, Wertheim points out that it is not necessarily the case in real life driving. He argues that drivers do not become less alert in reduced visibility conditions such as when fog occurs. For him, it is not only the monotony of road conditions that has an impact on driving performance, but rather its predictability.

Cabon (1992) observes that two different concepts can be associated with monotony: the monotony of the task and the monotonous state. The former concept refers to simple actions taking place in a repetitive manner over long periods of time, while the latter reflects a combination of physiological and psychological changes that affects the operator performing a monotonous task. The physiological changes correspond to tonic variations of the autonomic nervous system, which is associated with an increase of parasympatic activity leading to a drop in activation. Thorevskij et al. (1984, see Cabon, 1992) observed an increase of EEG theta and alpha rhythms under monotonous conditions. For these authors, alpha rhythms indicate a decrease of vigilance and theta rhythms reveal signs of a stress response.

Psychological reactions to monotony consist mainly of feelings of boredom and drowsiness coupled with loss of interest of performing the task at hand. Stress can also be related to these conditions. The dynamic model of stress and sustained attention views underload, as well as overload, as stressors to which one has to adapt (Hancock and Warm, 1989). As Cabon observes, the stress associated with monotonous situations produces accentuated fatigue which causes other psychological problems that are observed in populations performing monotonous tasks.

Lowering physiological activation can also affect information processing by altering vigilance. The ability to maintain sustained attention on a signal source over a prolonged period of time tends to decrease with activation and wakefulness. As O'Hanlon and Kelly (1977) observed, driving in a monotonous environment can be viewed as a vigilance task. Thus, vigilance decrement can account for performance impairment, and may play an important role in vehicle accidents (Harris, 1977). Dinges (1995) also establishes an association between sleepiness and sustained attention. According to him, vigilance decrement represents the strongest effect of fatigue. He stresses that the ability of maintaining visual vigilance and reacting quickly decreases with increased levels of sleepiness, which could increase the risk of accidents that are usually attributed to driver inattention.

The effect of road environment monotony on fatigue can be discussed in many ways. For Bartley (1970, see Nilsson et al., 1997) fatigue is "an experience of tiredness, dislike of present activity and unwillingness to continue". For Brown (1994) it is a "disinclination to continue performing the task at hand" and a "progressive withdrawal of attention from road and traffic demands". This disinclination is more likely to occur in low demanding roads when attention is redirected toward inner thought processes.

Arousal theory suggests that performance is poor when arousal is either weak or very strong (see Davies and Parasuraman, 1982). Accordingly, fatigue, which results from the under-arousal induced from prolonged rural highway driving, may be responsible for the occurrence of driving accidents (Kenny, 1995). This view is compatible with the dynamic model of stress and sustained attention (Hancock and Warm, 1989; Milosevic, 1997). While the individual is usually able to compensate for variations in moderate levels of workload, fatigue would impair the ability to match efforts to extreme task demands by reducing the efficiency of strategies available for the regulation of effort.

Habituation theory provides another view of how monotonous stimulation can alter vigilance and alertness

(Mackworth, 1969). Accordingly, the central nervous system tends to *habituate* its reactions to repetitive stimulation. The desynchronization of brain activity tends to diminish and eventually disappear after repeated presentation of the same stimuli, as shown by Sharpless and Jasper (1956, see Davies and Parasuraman, 1982). Mackworth argues that the repetitive nature of sensory stimulation under monotonous conditions would habituate the neural response and thereby explain the progressive decline in detection rate found over time during vigilance tasks. Moreover, she observed that a sudden change in the presentation of the stimulation leads to dishabituation, or the immediate restoration of the response. As Davies and Parasuraman (1982) point out, the habituation theory of sustained attention has not yet received empirical support, apart from Mackworth's own work. However, the habituation process and the orienting response (OR)—a concept which can be related to dishabituation—are well-established phenomena in psychophysiological science.

Habituation and OR can be summarized as follow. The first presentation of a stimulus, or the presence of a novel or incongruous stimulus in the environment, leads to increased arousal and a mobilization of attention. After several repetitions of the stimulus, the response tends to decrease and disappear. However, a change in stimulus leads to a reappearance of the response, with a corresponding increase of arousal and attention. Applying these general processes to the driving task implies that the presence of repeated stimuli on a monotonous environment could act on driver fatigue by decreasing arousal and one's attention to the road. On the other hand, a change in stimulation, or the presence of a novel or incongruous stimuli, could lead to temporary increases of arousal and attention.

The ecological perspective provides another interesting explanation of the impact of monotony on fatigue. According to Nelson (1997), straight flat roadways with little variations in landscape content may be seen as *deficiency hazards*, where chronic deficiency of sensory stimulation can reduce arousal to dangerously low levels, causing inattention and drowsiness. Here, the reduction of arousal is attributed to monotonous environments depicting *panoramic* sceneries in which environmental hazards can easily be identified, leading to a sense of security and a state of relaxation. These effects may be contrasted to those produced by *vista* views, where visual perception is partly restricted, preventing the individual to assess completely the presence of every object and situation that is relevant to security. The perceptual blocking caused by curves, hills or trees, for instance, would have the effect of adding interest to the landscape, thereby reducing the effects of boredom and monotony.

The term *highway hypnosis* has also been used to explain the occurrence of accidents on monotonous roadways. Shor and Thackray (1970) describe this phenomenon as "the tendency of the automobile driver to become drowsy and to fall asleep during monotonous, uneventful highway driving". Wertheim (1978) first proposed an explanation based on the fact that oculo-motor control shifts from "attentive" to "intentive" modes under very predictable visual environment. Having a cognitive significance and an effect on cortical arousal, the shift from one mode to another "could influence several psychological functions which are crucial for the task of driving".

In 1991, Wertheim suggested a new explanation of highway hypnosis based on the theory of controlled versus automatic attention. These two types of attention underlie different modes for task performance. Controlled performance is closely related to perceptual and kinesthetic feed-back, which can only be achieved by investing effort, allowing for variations in levels of alertness. However, after experience and training, skilled performance becomes possible and the shift is made toward automatic processes where external feed-back is no longer essential. Performance under the automated mode relies mainly on internal motor programs and since very little external feed-back is needed, very little effort can be invested, reducing the possibility to increase alertness at will. This situation can lead to a decrease in alertness and arousal, as shown by an increase in brain alpha activity. In other words, the driving task is too easy on highly predictable roads. The performance becomes automatic, which puts a restriction on the need for feed-back, reducing the investment of effort that could lead to an increase of arousal. Given the under-reliance of external error feed-back during automated performance, drivers may fail to act on slowly developing error such as steering bias or changes in the speed of surrounding vehicles (Kerr, 1991).

Another important driving research construct is the driving without attention mode (DWAM) concept, which is similar to highway hypnosis (Kerr, 1991). DWAM often occurs when individuals have difficulties remembering the experiential details that occur during long driving periods. Under monotonous road conditions, attention and control would shift from external to internal events. Since the driver becomes less aware of what is happening in the environment, his driving performance tends to rely on an internal schema of the driving activity.

There are many theoretical explanations for the effect of monotony on alertness, vigilance and fatigue. Some accounts, such as arousal theory and the dynamic model of stress and sustained attention, have an observable physiological basis. Other accounts, based on the notions of habituation, highway hypnosis and DWAM, however, contain interesting propositions that should be considered as well. Nelson's (1997) ecological perspective also offers a very pertinent conceptual framework for a systemic understanding of drivers fatigue. This transactionist perspective emphasizes the fact that the nature of the driver/environment relationship has a fundamental impact on alertness and vigilance, and that task induced, or exogenous factors, have to be considered in conjunction with endogenous factors in a general analysis of this phenomenon. This view is consistent with the dynamics of physiological processes that are inherent in arousal, alertness and sustained attention. It is also congruous with a cognitive ergonomic analysis of the problem of driver fatigue.

Although a critical analysis of these theories is not the scope of this paper, the following general points are worth underscoring. Monotony is said to have an impact on alertness, or wakefulness, by inducing decreases in arousal. This decrease of alertness would impair information processing and driving performance by altering the capacity of the driver to remain vigilant. Subjective factors such as boredom and a dislike of driving would favor a displacement of attention from the driving task to inner thought processes. Ruptures of monotony should have a positive effect on driving performance by allowing a temporary restoration of alertness and vigilance.

This last proposition has practical implications that lead to the consideration of environmental countermeasures to driver fatigue. For example, Brown (1991) suggested that it could be beneficial to integrate novelty and variety into the drivers task and environment. According to Nelson (1997), partial perceptual restrictions render the landscape more interesting and lessens boredom and monotony. Shor and Thackray (1970) acknowledge that highway engineers build highways so as to induce mild stress and perceptual novelty in order to help ward off drowsiness. McBain (1970) recommends that monotony may be decreased by increasing activity and subjective variety in the environment by “the introduction of irrelevancies to the task at hand”. Ingwersen (1995) found that most fatigue accidents occur on high-quality routes in Australia. He observes that high quality pavement conditions combined with limited environmental distractions are likely to contribute to the development of highway hypnosis. Moses (1995) points out that visual stimulation can be used as countermeasures to combat driver fatigue. He suggests that road designers, landscape architects and traffic engineers could increase the level of visual stimulation of particular road sections by including curves in the road’s design and kilometer pegs that stimulate subsequent peg search, as well as mental calculations that can enhance alertness. He suggest the possibility of involving landscaping as a means to provide interesting scenery that can serve to intrigue the driver. Gårder (1995) proposes that drowsy driving can be reduced by design efforts in highway engineering. This may be done by building roads “with shorter tangents, rhythmic alignments and appealing vistas at irregular but short distances”. He also refers to the installation of artificial “eye-openers”, such as art exhibits along the road, an initiative which, he claims, has already been used in France.

These proposals all assume that road monotony has a negative effect on alertness and vigilance and that ruptures of monotony could help ward off driver fatigue, at least temporarily. However the impact of the landscape monotony, as well as the effect of ruptures of monotony on driver fatigue and vigilance, have yet to be systematically evaluated. De Waard et al. (1995) performed a study which examined the effects of raising mental workload by testing infra structural changes on driving performance. The results show that drivers adapt to these constraints by decreasing their speed. This is a good indication that road layout and road environment can have significant effects on drivers information processing and driving performance. However, it would be pertinent to study these phenomena under low demanding monotonous conditions.

The concept of monotony is troublesome because it can relate to the nature, quantity or variation of the stimulation (Wertheim, 1991). A road environment can be described as monotonous, because it contains little sensory stimulation. Since low sensory stimulation leads to low arousal, this type of monotony could play a role in driver fatigue. A road environment could also be described as monotonous because of the repetitive aspect of stimulation. On the basis of the habituation process, low variation could lead to decreases in arousal, inducing driving fatigue. Thus, low sensory stimulation and low stimulus variation can be considered as two forms of monotony, both having an impact on arousal and alertness. However, given their inter relatedness, the reciprocal effects of repetition and low perceptual stimulation may be hard to disentangle. Low sensory stimulation over time tends also to be repetitive.

Ruptures of monotony should nonetheless be beneficial. It could serve to increase the amount of stimulation or to induce variability. However, questions arise regarding the form that these ruptures or “events” should take. For instance, does simple variation in the rhythm of sensory stimulation have an effect? Would the addition of visual stimuli in the environment be sufficient to reduce driver fatigue? What would be the relative importance of the form and the meaning of these stimuli for the driver?

1.3. Aims

The objective of this exploratory study is to evaluate the impact of the monotony of road environment on driver fatigue. Driving performance on a driving simulator is closely analyzed on two different monotonous road conditions, each characterized by a different visual scenery. While one scenery is repetitive, the other contains diverse contextual stimuli that are intended to interrupt monotony. Comparing the subjects’ driving performance in these two monotonous environments will provide useful data regarding the utility of environmental countermeasures against driving fatigue.

2. Method

2.1. Participants

Fifty-six male university students participated in the experiment. All had a valid driving license since at least 2 years. The mean age is 24. Each participant received monetary compensation for their involvement in the experiment.

2.2. Material

The Université de Montréal simulator that was used in this study is a fixed-based driving simulator composed of a complete automobile, fully functional pedals and dashboard, and a large screen showing highway images projected by an RGB projector. Simulated highways have been designed using actual Canadian geometric route design standards. The images are generated by Silicon Graphic computers. During a simulation test, the location and speed of the vehicle on the *x*, *y* and *z* axes are recorded. A potentiometer attached to the steering column allows detailed recording of steering wheel movements (SWM). Room temperature is controlled. Each subject was required to complete questionnaires assessing various factors that may have affected test performance (recent meals, consumption of psychoactive substances, amount and quality of sleep the preceding night, etc.) as well as driving habits and preferences. A Likert scale was created to measure the subjective level of alertness (SA).

2.3. Procedure

All subjects were tested during the afternoon *post-lunch dip* period, which is associated with a peak for daytime sleep-related accidents. Participants arrived at the laboratory at 13:00. At 13:20, they drove for a 5-min period in order to familiarize themselves to the simulator. They were then tested for SA and completed a first 40 min driving period starting at 13:30. At 14:10, they were tested again for SA, after which they were given a 15-min break and invited for an outdoor walk. This break was intended to diminish as much as possible the fatigue effect of the first driving period. Subjects walked up and down a four story stairway, leading to variations in physiological activation which, according to the literature, should help ward off the fatigue effects of a monotonous driving period. A second 40-min drive started at 14:25. At 15:05 the last SA measure was recorded and they were accompanied to a quiet office where they completed research questionnaires. The order of the two experimental periods was randomly counterbalanced across subjects.

2.4. The task

The driving task was the same for the two 40-min driving periods. Only the road environment differed. The subjects were required to drive in the center of the right lane on a straight two-lane rural highway. They were told to steer the car at a fixed speed and as straight as possible, as they would in a natural setting. This speed was chosen solely on the basis of the sensory experience it produced on the simulator. Subjects could see their speed on the dashboard speedometer. Light side winds, pushing the car to the right side of the road, were added to the simulation in order to create variations in lateral position. The choice of making the wind push from the left to the right was made on the basis that natural roads are designed with a curved banking to allow draining. This creates a tendency to deviate to the right if one is driving in the right lane. These wind gusts were of unequal force and they were randomly distributed at every 10 s intervals during the driving period. The same total force of wind was applied to the car at every 10 s interval, but it was impossible for the subjects to habituate to the wind, since there was no wind pattern. This task is very sensitive to attentional decreases.

Three different road scenarios were used. Each scenario involved the same road geometry and flat environment. Only the scenery was varied across road type. In the first scenery, which was used for the familiarization period, the roadside environment contained nothing but grass. The second scenery (road A) presented pairs of pine trees, one tree on each side of the road, which passed by the driver at the rate of one pair per second at a speed of 130 km/h. Pairs of trees were visible to the point of the horizon. The third scenery (road B) was intended to be monotonous but without the repetitive environment of road A. Road B thus included visual stimuli representing elements that are likely to be seen in a rural setting. It was bordered by infrequent random trees, houses and farms. There were occasional pedestrians on the roadside and in the fields. Three road signs indicating the "Montréal–Laval–Québec" direction overhung the road. On three occasions, the vehicle drove over a flat metal structured covered bridge that crossed a large blue river. The vehicle also passed over three flat overpasses that were bordered by removable concrete sections. There was also, on three occasions, a route merging on the right side of the highway. These *events* were considered as natural elements that would interrupt driver monotony. These elements were not suppose to induce any lateral or speed variations.

2.5. Dependent variables

In this study, driver fatigue is observed on the basis of driving performance. Straight line driving can be construed as a vigilance task (Brookhuis, 1995; Wertheim, 1978). The driver is asked to maintain attention to the upcoming road in order to detect lane deviations. Once a deviation is detected, the driver corrects the car's trajectory with SWM. In general, if the driver is alert and vigilant, the road deviations will be detected early and negotiated by small SWM. However, it has been shown that with decreased alertness and vigilance due to fatigue, the driver does not respond as well to lane deviations: that is, the driver loses perceptual sensitivity to small deviations and/or his reaction time tends to increase. As a result, he makes larger SWM in order to correct larger lane deviations. Hence, the effect of fatigue on driving can be observed by the standard deviation of lateral position (SDLP), as well as the mean amplitude of SWM, frequency analysis of larger SWM, and the standard deviation of steering wheel movements (SDSWM). Numerous studies have used these variables (De Waard et al., 1995; Elling and Sherman, 1994; Planque et al., 1991; Stein, 1995; Summala et al., 1999; Verwey and Zaidel, 1999, etc.), which have been cross-validated with physiological measures of alertness and vigilance (Brookhuis and De Waard, 1993; Chaput et al., 1990; De Waard and Brookhuis, 1991; Fairclough, 1997). According to Brookhuis and De Waard (1993), cross-validation of physiological and behavioral measures such as SWM has demonstrated that it is feasible to develop monitoring devices on the basis of vehicle parameters alone. Brown (1997), points out that the deterioration in steering skills is the most valid and accessible measure of drowsiness that accompanies driver fatigue. It has to be acknowledged, however, that if most authors agree that steering behavior provides good indicators of driver fatigue, "there is still little consensus on the exact details of how steering activity should be captured and quantified" (Fairclough, 1997). In other words, even if studies concur to say that these measures are accurate, the use of steering behavior to study driver fatigue remains exploratory.

The dependent variables examined in this study were performance measures of steering behavior, lateral position and speed. All dependent variables were measured across 5 min blocks, resulting in eight scores per driving period. Steering behavior data was measured in several ways. The SDSWM measure was calculated for each block, the mean amplitude of the SWM per block was also recorded, as well as the frequency of small (1–5°), large (6–10°) and extreme (more than 10°) SWM. The SDLP was also computed, but these data were not examined in the analysis due to problems inherent to the configuration of certain visual roadside stimuli of road B. Subjects had a marked tendency to deviate to the middle of the road due to the presence of pedestrians on the roadside and narrow bridges which they had to cross. Hence, even if these elements were not components of the road per se, they created significant deviations in the lateral driving alignment, which contaminated the measures. It was thus decided not to consider SDLP in the analysis. Speed related measures were computed but they did not show any significant variability. Subjective alertness was recorded on a five point Likert-type scale at the beginning and the end of each driving period.

3. Results

Separate repeated measures ANOVA and a trend analysis were performed on each SWM variable in order to evaluate the effect of time (eight blocks) and road environment (repetitive roadside stimuli: road A, versus variable roadside stimuli: road B).

3.1. Time-on-task effect

Significant results were obtained for the SWM measures for the time-on-task effect. There was a clear transformation of SWM over time. Fig. 1 shows that the mean amplitude of SWM increases over time for both periods ($P < 0.001$). This result is important because it indicates that there was indeed an effect of fatigue on steering behavior, with greater fatigue being related to more pronounced steering movements, which is consistent with previous studies (Elling and Sherman, 1994; Planque et al., 1991). Accordingly, the frequency of smaller SWM (from 1 to 5°) decreases significantly over time ($P < 0.001$) and there was a marked increase in the frequency of large SWM, ranging from 6 to 10° ($P < 0.001$), but mainly on road A, as can be seen in Fig. 2. The fatigue-related changes in SWM were also apparent for increases in SDSWM ($P < 0.002$), as it is shown in Fig. 3. After an important decrease between the first and the second block, which can be attributed to task familiarization and a tendency to bring the vehicle towards the center

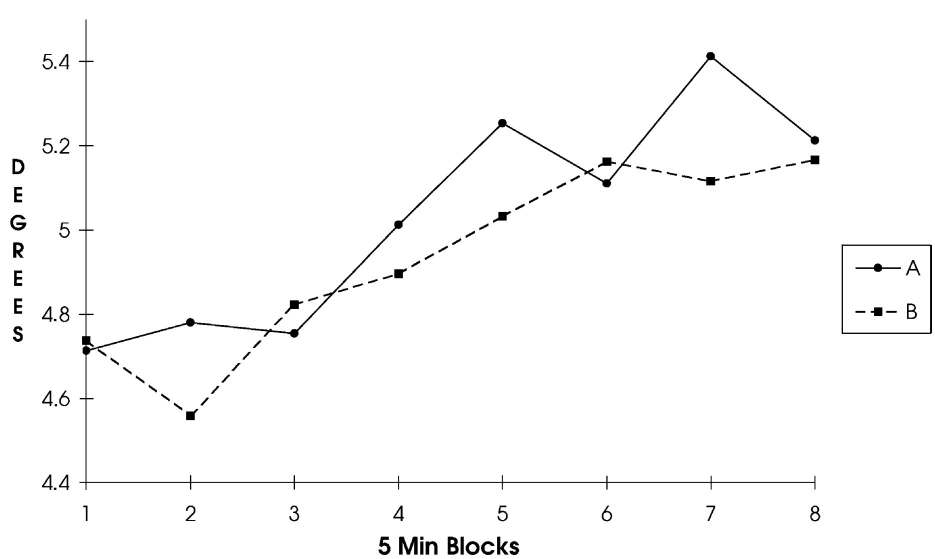

Fig. 1. Mean amplitude of steering wheel movements.

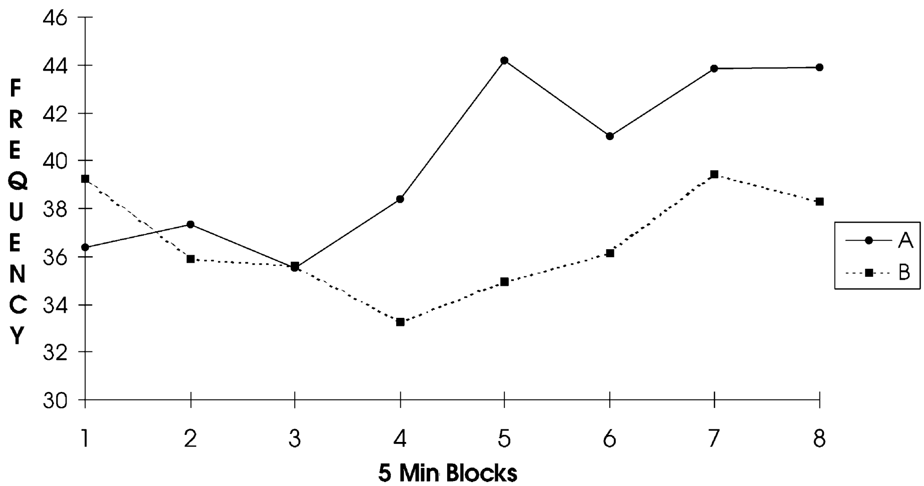

Fig. 2. Frequency of large steering wheel movements (6–10°).

of the driving lane, there is an increase of SDSWM levels that mirrors the changes of the mean amplitude of the SWM. A Trend analysis of the data shows that the transformations are linear for the mean amplitude of SWM ($P < 0.001$), the frequency of large SWM ($P < 0.008$) and for the SDSWM, when the first bloc is taken out of the data ($P < 0.001$).

Significant results were obtained with time-on-task on the subjective alertness measure. Subjects expressed lower level of alertness after both driving periods than before ($P < 0.001$). The difference between both periods, however, is not significant.

3.2. The effect of monotony

The main objective of this study was to observe the impact of environmental monotony on driving fatigue. To do so, driving performance was evaluated on a straight monotonous road as a function of two types of scenery, one characterized by repetitive visual information, the other containing contextual visual information intended to interrupt monotony. An increase of SWM amplitude occurred as a function of the time-on-task effect, suggesting that the frequency of large steering movements can be used in order to detect the presence of fatigue. While this inference is based on the empirical observations of this particular study, it is also supported by other research, as was shown earlier.

Fig. 1 illustrates the mean amplitude of SWM for both driving periods. While the SWM amplitude for road A is somewhat larger than for road B, the difference it is not significant ($P < 0.391$). However, Fig. 3 shows that this tendency is also present for the SDSWM measure. While still not being statistically significant ($P < 0.198$), the difference in SDSWM for each road type goes in the same direction than the SWM amplitude. In both cases, the values are higher for road A than for road B. A more robust difference between both driving periods was however found when the frequency of larger SWM are compared. Fig. 2 indicates that subjects made large SWM more frequently when driving on road

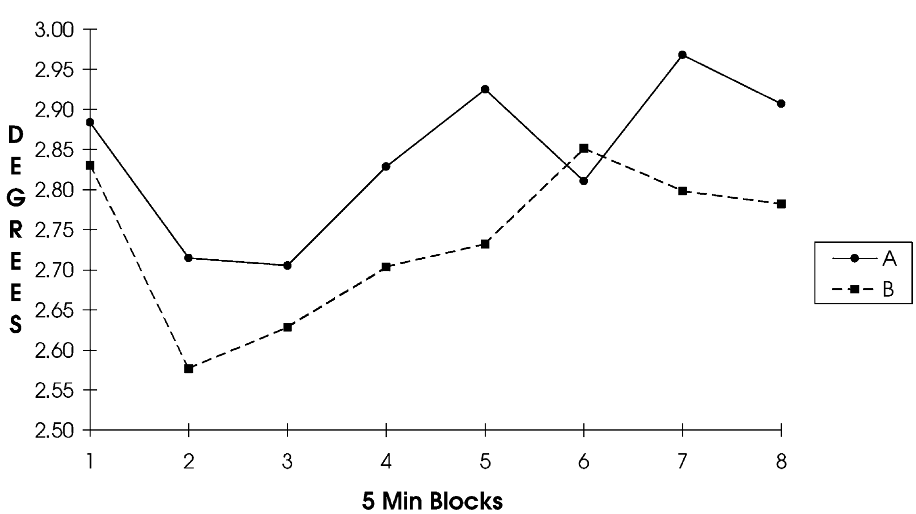

Fig. 3. Standard deviation of steering wheel movements.

A than on road B ($P < 0.049$). It is important to note that the interaction effect between the time and monotony factors is marginal on this variable ($P < 0.062$). According to Tukey (1991), a statistical level of less that 0.15 can be considered as an indication of a significant tendency. This is particularly true in an exploratory research. Hence, the data do suggest that the linear functions of roads A and B are somewhat different. Nevertheless, there is a significant impact of monotony on the frequency of large movements, even if the interaction effect between time and road type is only marginal.

4. Discussion

There are two main results to be considered in the current study. First, there is a consistent time-on-task effect on each dependent variable and second, there is a general tendency that shows a small difference in subject's steering behavior between both driving periods.

4.1. Time-on-task

The results associated with the time-on-task effect imply the presence of several fatigue-related processes for the driving tests that were used, and indicates that the amplitude of SWM tends to increase with experienced fatigue during driving. The correspondence between SDSWM and the amplitude measures used here reinforces the fact that these variables measure the same underlying phenomenon and that this phenomenon is fatigue-related, as was observed in above-mentioned previous studies.

Another important observation in relation with the time-on-task effect is that the impact of fatigue is robust and appears quite early during each driving session, with a marked peak occurring during block 5, that is, between the 20 and 25 min of driving. These results are of significant importance to the understanding of the time-on-task effect because drowsiness is usually characterized as appearing after more prolonged driving periods. Even if the current study involved a driving simulator, which generally yields greater sensory deprivation than real life driving, it indicates that fatigue is likely to manifest itself quite rapidly under driving conditions where the driver receives little sensory stimulation. This reinforces the finding that the nature of the driving environment impacts on the development of driver fatigue, and should be taken into account when studying or evoking the time-on-task effect. It also implies that the nature of the driving environment should be considered when making recommendations regarding the duration of safe driving periods for long distance drives.

4.2. The effect of monotony

The analyses of road type suggests that stimulus repetition had a different effect on driver fatigue than when monotony was periodically interrupted. Even if they are not always statistically significant, these differences show a general tendency that should be taken into account when interpreting the results. A significant difference was observed however between roads A and B when the frequencies of large steering movements (6–10°) were considered ($P < 0.049$). Fig. 2 shows that subjects made large SWM more frequently while driving on road A than on road B. Although the interaction between the time and period factors is only marginal, it is interesting to note that the peak effect of block 5 is more pronounced for road A. Hence, while these data do not underscore large differences in the evolution of the time-on-task effect between both driving periods, they indicate nonetheless an impact of monotony on the frequency of larger SWM, which implies a greater effect of fatigue on steering performance.

It is important to specify that the monotony factor was only moderately varied in the current study. Recall that roads A and B were in fact the same road with different types of scenery, each representing monotonous environments devoid of vehicles, curves or hills. Given that a small difference in monotonous stimuli had a small but significant effect on driving performance, greater stimulus variability could have had a more pronounced impact. Non-natural or unexpected stimuli, stimuli with strong target value or stimuli that call upon more complex cognitive functions, would have likely generated a greater variability in driving performance.

It has been acknowledged that road safety is multidimensional in nature. This assertion is very meaningful when human factors are considered. Because of its very complex and systemic organization, human functioning is influenced by an enormous variety of parameters. Consequently, countermeasures aimed at changing driving behavior must also be construed as being multidimensional. Efforts to reduce DWI are good examples of multidimensional countermeasures that have proven to be efficient.

Preventing measures aiming to limit the damage of fatigue-related problems should follow the same rational and approach the problem on different (i.e. multidimensional) levels. The physiological and psychophysiological processes underlying the fatigue phenomena show that different classes of factors may affect alertness at any given point in time during driving. As it was indicated earlier, they can be construed as either endogenous or exogenous. We believe that interventions should be oriented toward both these classes of factors.

At the present time, multiple countermeasures are being developed in order to reduce driver fatigue. Most of these are oriented toward dealing with endogenous factors associated with fatigue such as the time of day circadian variation, the fatigue generated with time-on-task and sleep related problems. Limiting long hours and late night driving, as well as screening and treating professional drivers with sleep problems, are good examples of such countermeasures. Other measures aim at detecting driver fatigue and at “waking up” sleepy drivers.

While these countermeasures are of fundamental importance, they do not address the problem of the exogenous causes of driver fatigue, which occurs when alertness decreases when the nature of the driving task is under-demanding or monotonous. We believe that these factors could also serve as targets for the implementation of countermeasures, and that this approach should be viewed as a complement to what is currently being undertaken. For instance, since the identification of "black spots" in fatigue-related accidents usually shows that these road environments are under-stimulating, low demanding and monotonous, environmental countermeasures could be used at these locations or road segments in order to diminish the impact of monotony. While the use of rumble strips on highways and in-vehicle devices is useful to wake up sleepy drivers, the literature shows that many fatigue-related problems occur when the driver has not fallen asleep (Dinges, 1995; Lyznicki et al., 1998). Hence, it would be of practical importance to try to prevent the build up of drowsiness by alleviating the impact of under-stimulation on certain highway segments where these accidents do occur.

These considerations are not all new. As was shown earlier, efforts have already been made by engineers in order to add mild stressors and perceptual novelty on certain highways to help ward off drowsiness (Moses, 1995; Shor and Thackray, 1970). While it should be important to consider the phenomenon of under-stimulation and monotony in the design of future highways, we also believe, considering the results of the present study, that roadside visual stimulation could be used in order to alleviate fatigue and drowsiness on existing road infrastructures.

The results of this exploratory study suggest that fatigue is likely to manifest itself very early when driving in low demanding road environments. It also suggests that roadside visual stimulation have an impact on driving fatigue and that interruptions of monotony may alleviate the build up of drowsiness when driving on highly repetitive or very under-stimulating road environments. However, future research should assess the impact of interruptions of monotony that are more pronounced than those examined in the present study. It is important to verify if stronger ruptures of monotony do indeed have a greater impact on driver fatigue and if so, systematically determine the nature of the visual stimulation that should be used along roadsides. The size, color, intensity, shape and the content of such visual stimulation are some of the critical dimensions that should be targeted.

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