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Drivers' inability to assess their level of alertness on monotonous highways

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Abstract

Decline of alertness constitutes a normal physiological phenomenon but could be aggravated when drivers operate in monotonous environments, even in rested individuals. Driving performance is impaired and this increases crash risk due to inattention. This paper aims to show that road characteristics - namely road design (road geometry) and road side variability (signage and buildings) – influence subjective assessment of alertness by drivers. This study used a driving simulator to investigate the drivers' ability to subjectively detect periods of time when their alertness is importantly reduced by varying road geometry and road environment. Driver's EEG activity is recorded as a reference to evaluate objectively driver's alertness and is compared to self-reported alertness by participants. Twenty-five participants drove on four different scenarios (varying road design and road environment monotony) for forty minutes. It was observed that participants were significantly more accurate in their assessment before the driving task as compared to after (90% versus 60%). Errors in assessment were largely underestimations of their real alertness rather than overestimations. The ability to detect low alertness as assessed with an EEG was highly dependent on the road monotony. Scenarios with low roadside variability resulted in high overestimation of the real alertness, which was not observed on monotonous road design. The findings have consequences for road safety and suggest that countermeasures to lapses of alertness cannot rely solely on self-assessment from drivers and road design should reduce environments with low variability.

INTRODUCTION

Despite an extensive literature on fatigue its negative effects on performance and safety, fatigue remains a major safety concern in settings such as road transportation. The two main contributing factors to crashes related to driver's operational situation are an overload situation and a monotonous situation (Yamakoshi, Rolfe, Yamakoshi, & Hirose, 2009). Monotonous tasks have been identified as particularly vulnerable performance decrements related to fatigue (Williamson et al., 2011). Monotonous driving arises during regular driving on a daily commuter route, or during long periods of motorway/rural-road travel at constant speed. Monotonous driving is associated with loss of task directed effort and poorer alertness and performance as a result (Matthews & Desmond, 2002).

The design of highways tends to over-simplify the driving task. On such roads, driving is mainly a lane-keeping task. A lane keeping task is not cognitively stimulating and can cause the driver to suffer from an alertness decrement after less than 20 minutes (Thiffault & Bergeron, 2003b). Driving behaviour is consequently impaired and drivers are then more likely to be involved in road crashes due to potentially slow reaction times or lack of reaction to unpredictable events. This is particularly dangerous on highways where the speed limit is high. This contributes to making inattention the most important contributor (27%) to fatal and

hospitalisation crashes in 2003 in Queensland, Australia (Queensland Transport, 2005). While effective countermeasures to early signs of fatigue exist (such as resting after a period of time), no research has focused on the decreased alertness that was observed during driving tasks performed on monotonous roads. Resting does not seem to be a promising intervention to avoid the decrement of alertness on monotonous highways since effects of monotony are observed with non fatigued drivers. Therefore other countermeasures should be investigated. The first step in designing an intervention to reduce risks of reduced alertness on monotonous highways is to understand whether drivers are able to detect their lapses in alertness on such roads. The aim of this study is to assess the ability of drivers to assess their alertness while driving on various types of highways in order to reduce crashes due to reduced alertness on highways.

This study focuses on two road characteristics that result in alertness decrement on highways: (i) the road design (road geometry) and (ii) the roadside environment (signage, buildings and traffic). This study also aims at assessing the effects of personality traits (sensation seeking level) on the accuracy of alertness estimates since high sensation seekers are more likely to suffer from monotonous driving conditions.

This paper will first introduce the background of the research, and then provide a description of the experimental design. Then the results of the ability of drivers to assess their alertness will be reported. The last part of this paper will discuss the implications of the results of this analysis.

1. Background

1.1 Monotony and driving

Monotony has been conceptualised as the result of constant, highly repetitive or highly predictive stimuli. However, such a definition is not sufficient to derive all the characteristics of monotony. The environment in which the task is performed can influence performance as much as the monotony of the task itself (Thiffault & Bergeron, 2003b).

Recently, monotony has been conceptualised as a construct with two dimensions that relate to characteristics of the task proper and the environment in which the task is carried out (Michael, 2010). This distinction is particularly relevant in the case of driving. The driving task is mainly a vigilance task, for which the task demand varies according to the location of the driving (city, rural or highway) and the traffic (cars and traffic lights). The task complexity increases as the driver has to perform more actions (indicating, checking other lanes and mirrors, changing gear and steering wheel movement). Conversely, rural area environments are monotonous (repeated trees and straight road design leading to low variability of stimuli) and the driving task demands are reduced.

Monotony has a psychological effect on the driver (Scerbo, 1998). Monotony impacts the driver's alertness and consequently results in lapses in vigilance. In fact, the driver experiences a loss of interest in performing the driving task, which can occur quite rapidly. Such impairment occurs more frequently in monotonous environments, especially highways at night (Thiffault & Bergeron, 2003b). This decrement in alertness can be observed through the driver's brain activity. Undeniably this mental state results in increasing EEG theta and alpha frequencies rhythms (Lal & Craig, 2005; Steele, Cutmore, James, & Rakotonirainy, 2004). This results in a state of low level of alertness to external stimulation (Tejero & Cholz, 2002) and the incapacity to react to infrequent sudden relevant traffic events, hence increasing crash risk.

Performing both a monotonous task and driving in a monotonous environment have consequences on the driver's ability to drive. The driver may quickly lose the motivation to perform the task and then become less alert under such conditions. Such effects have been detected in simulator experiment as early as 20 to 25 minutes (Peiris, Jones, Davidson, Carroll, & Bones, 2006; Thiffault & Bergeron, 2003b). Nevertheless, drivers react differently to declines in alertness. This is also observed with driving performance in a monotonous environment (Thiffault & Bergeron, 2003b). The experiment by Oron-Gilad, Ronen, & Shinar (2008) shows that underload situations such as monotonous situations lead to fatigue symptoms and impaired driving performance although the drivers were neither tired nor sleep deprived prior to the driving task.

1.2 Effects of sensation seeking level

There is some variability between individuals' capacity to sustain vigilance. The profile of drivers more likely to be involved in vigilance-related crashes have been determined in a simulator experiment (Thiffault & Bergeron, 2003a). Sensation seeking drivers need varied, complex stimuli and experiences. They take physical and social risks to reach such experiences. This sensation seeking level can be more or less developed but leads to risk taking driving, and negative reactions to monotonous driving (Zuckerman, 1994). Sensation seeking seems to be a good indicator of the driver's ability to focus on a monotonous task (Thiffault & Bergeron, 2003a).

1.3 Objective level of alertness

The most reliable and reproducible way to measure the alertness of a driver driving is to use an EEG (Lal & Craig, 2005; Pollock, Schneider, & Lyness, 1991; Tomarken, Davidson, Wheeler, & Kinney, 1992). EEG signals are analysed in the frequency domain, and four different bands contain the information: α , β , θ and δ . The most reliable method to measure

alertness variation is to use the following algorithm: $\frac{\theta + \alpha}{\beta}$. When increasing, this ratio between slow and fast wave activities indicates a decrement of alertness (Bastien, Ladouceur, & Campbell, 2000; Lal, Craig, Boord, Kirkup, & Nguyen, 2003).

1.4 Self-reported level of alertness

Self-reported measures of alertness have been used in studies investigating effects of fatigue (particularly through sleep deprivation) and have provided contradictory results (Schmidt et al., 2009). Particularly there is a considerable variability in individual abilities to recognise their level of alertness (Horne & Baulk, 2004; Kaplan, Itoi, & Dement, 2007). No research has focused on monotonous driving, and particularly on the two dimensions presented before. Nevertheless it has been observed that in the particular case of monotonous tasks, individual ratings of alertness do not provide consistent results with the accurate alertness of the person (Fell & Black, 1997; Horne & Baulk, 1995).

2. Methods

2.1 Participants

A stratified random sampling approach was used to obtain a representative population of licensed drivers (for at least two years), regular drivers from different age groups (as per categories used in road safety i.e. 18-24, 25-59 and 60+). The 60+ category was not targeted in this study due to vision impairments and possible circadian and cognitive functioning changes related to ageing (Blatter & Cajochen, 2007).

Twenty-five subjects aged between 18 and 49 (mean age = 29.1 years, SD = 8.3) volunteered for this study. Thirty participants were expected to drive in this experiment but five subjects were removed from the sample due to motion sickness which occurred during training on the driving simulator.

Young drivers were recruited from Queensland University of Technology (QUT). Other participants were selected from staff at QUT and the general community. Participants had had their licence for a minimum of two years and drove a minimum of three days per week similar to previous research (Campagne, Pebayle, & Muzet, 2005). All subjects provided written consent for this study which was approved by QUT ethics committee. Participants were paid AUS \$80 for completing the four driving sessions; students undertaking the first year psychology subject received course credit for their participation.

2.2 Experimental design

Four different scenarios were designed to vary the two dimensions of monotony in driving context (road design and the roadside environment). In each experiment, the participants were asked to drive and follow road rules for approximately 40 minutes. Each participant is tested on each scenario (repeated measures design). The task load is reduced and creates task monotony:

- driving consists of following a lane (no itinerary involved) at constant speed (60 kilometres per hour), without having to stop the car (no red traffic lights or other stops) or to press the brakes frequently (no T intersections or perpendicular turns)
- no manual gear changes were required
- no use of indicators was required
- low traffic conditions.

Only stimuli are varied in the four scenarios (see Table 1 and Figure 1). Scenario 1 is characterised by low road design variability and a low roadside variability. Roadside variability is changed to high for scenario 2, while road design variability is increased for scenario 3. Scenario 4 is done with both road design and roadside variability high.

	Roadside variability	
	low	high
Road design variability	low	Scenario 1
	high	Scenario 3
		Scenario 2
		Scenario 4

Table 1 – The 4 experiment scenarios

Road geometry is varied through the curvature of the road as well as its altitude. In the road design with low variability, the road is essentially straight or with little curves and flat. Such a

design is appropriate to model highways and some rural roads. Reduced speed is chosen to have similar task demands in the different scenarios. In the road design with high variability, the road is a sequence of small straight sections, significant curves and hills. This models urban roads and some rural roads.

The roadside design reflects areas where most fatigue related crashes occur. The roadside environment is varied in terms of road signs frequency and variability and scenery (desert with bushes along the road, urban highway, rural road with houses, farms, industries, etc.).

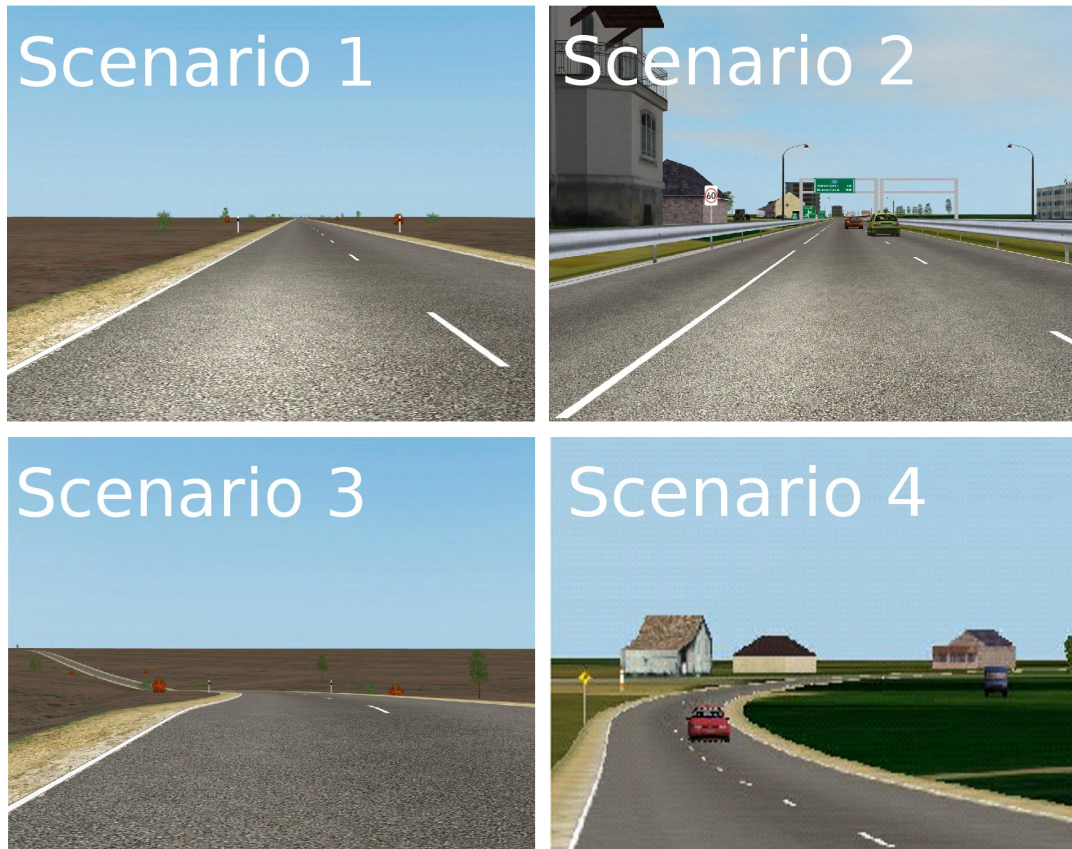


Figure 1 – Screenshots of the 4 scenarios

2.3 Procedure

Participants were tested individually in a quiet room in four sessions lasting approximately one hour per session. Each participant drives in one of the four scenarios (randomly assigned) in the simulator once a week for four weeks at a fixed testing time. Testing times are scheduled at 9am, 11am, 1pm and 3pm. Each participant chooses a testing time for which they feel they are the most alert.

A short practice is performed to familiarise participants with the driving task on the simulator permitting the setting up of sensors for the experiment at the same time. EEG baseline data are recorded prior to the driving task, with eyes open and the screen displaying the driving scenario. Next, participants performed their scenario and at the end of the experiment they answer questions about their level of alertness to check for the absence of fatigue effect. Participants are also asked not to consume alcohol 12 hours prior to the experiment.

2.4 Materials

2.4.1 Driving Interface

Experimentation was conducted on the driving on the static simulator Scanner from OKTAL. The road and environment were developed to fit the study requirements in terms of monotony. The participant sat in front of a screen where the Scanner simulator is played by a RGB video projector. The participant's head is situated at a distance of approximately 1.5 m from the screen, which has a width of 1.7 m. Consequently, the field of view is limited to 30 degrees to either side. The simulator displays a view from the inside of the vehicle with a speedometer. The participant drives the simulator using a modified computer steering wheel which provides force feedback and a two pedal set (brake and accelerator only). Five speakers reproduce the acoustics environment of inside a car.

2.4.2 Sensors

Data related to the driver's alertness are collected with the Bioradio 150 equipped with EEG electrodes.

2.4.3 Self-reported alertness level

Before and after each driving task, participants also rated their subjective alertness on a five point Likert scale, from very low alertness (1) to very high alertness (5) with a moderately alert level (3).

2.4.4 Softwares

Data extraction was performed with Matlab version 7.4.0.287. Particularly, the EEGLAB v6.03b has been used to analyse raw EEG data. Statistical modelling was performed with the software R version 2.5.0.

2.5 Data analysis

2.5.1 Extraction of Objective alertness measures

Driver alertness is assessed through analysis of data collected with the EEG. EEG data is collected at 7 different positions on the scalp (O1, O2, T5, T6, P3, P4 and F3) following the International 10-20 Electrode Placement System at 80 Hz and are divided into 1 second epochs. Epochs with too high/low values (threshold $\pm 75 \mu V$), linear trends, improbable data and/or abnormally distributed data are rejected. A 4-term Blackman-Harris window and a 0.5Hz cut-off high-pass filter were also used to reduce low frequency artefacts. Fast Fourier

Transform (FFT) is performed and this provided α , β , θ and δ band activities. $\frac{\theta + \alpha}{\beta}$ is

computed for each selected epoch. The baseline is used to obtain the range of values of the participant prior to driving. Values above two standard deviations are categorised as high.

The proportion of high level of the algorithm $\frac{\theta + \alpha}{\beta}$ (the higher the proportion, the lower the alertness) is computed during the first and last five minutes of the driving task.

2.5.2 Comparison between objective and subjective measures of alertness

The proportion of high level of $\frac{\theta + \alpha}{\beta}$ is a continuum and has to be classified in five folds like the self-reported alertness estimates. It is hypothesised that both objective and subjective levels of alertness have the same distribution, and therefore the thresholds for categorising objective data are computed so that the proportions of values in the five categories are similar to the ones observed for the self-reported assessments. Once the objective alertness is categorised, it is possible to compare self-reported alertness to alertness as measured with the EEG by computing the absolute difference between these levels. We categorise the differences Δ as follows:

- $\Delta = 0$ good estimation
- $\Delta = 1$ close estimation
- $\Delta > 1$ estimation far away from true level

Three different analyses are performed in this study. First the accuracy of the self-reported estimates is investigated, with a particular interest in the influence of the sensation seeking level of participants. Then estimates far away from the true alertness are further investigated in order to determine whether errors are mainly under- or over-estimations. Influence of the road design, roadside and sensation seeking level are also investigated in this analysis. Finally the ability of participants to detect low levels of alertness (levels 1 and 2 combined) is studied with respect to the road design, roadside and sensation seeking level.

These analyses are performed with the use of Generalised Linear Mixed Models (GLMMs) to take into account the correlation between repeated measures on the same participant (longitudinal study). GLMMs from a binomial family are fitted for each analysis in order to obtain the effects of the different factors (road design, roadside and sensation seeking level) on the proportion of (i) accurate self-reported estimates, (ii) under- and over-estimations and (iii) accurate detections of reduced levels of alertness. Statistical significance of the results is assessed with a p-value threshold of 0.05.

3. Results

Objective and self-reported levels of alertness were similar in 15% of the cases in this study, both before and after completion of the driving task (see Table 1). This value was independent of the time of the estimate (before or after the drive) and the sensation seeking level of the participant. Average and low sensation seekers were similar in their ability to assess their alertness. Before the driving task, 74% of the subjective estimates were close to the objective one, resulting in reasonable estimates 89% of the time. Such accuracy supports the methodology used to categorise continuous alertness levels obtained from the EEG. This accuracy decreases after the driving task, with 43% of close estimations, i.e. 58% of reasonable estimates. High sensation seekers were 20% less accurate than the average sensation seekers, both before and after the driving task. Hence their estimates were far away from the objective alertness measure in 31% (respectively 62%) of the reports before (respectively after) the driving task.

Table 1 : Comparison of the accuracy of the self-reported alertness before and after the driving session

		good	close	far away
Before driving	avg/low SS		74%	11%
	high SS		54%	31%
After driving	avg/low SS	15%	43%	42%
	high SS		23%	62%

avg: average

Misjudgements of the alertness level were largely due to underestimations (see Table 2). Before the experiment was conducted, 65% of the estimates were lower than the real level of alertness. After the experiment, almost all estimates were underestimated. Roadside variability changed slightly (but statistically significantly) the proportion of underestimations of alertness (99% for low roadside variability and 97% for high roadside variability). These results were not dependent on the sensation seeking level of participants. The main effect is therefore the simulated driving task rather than the variability in the design of the scenarios.

Table 2 : Misjudgements: probability of underestimation

	Before driving[†]	After driving
Scenario 1 and 3 (low roadside variability)	65%	99%
Scenario 2 and 4 (high roadside variability)		97%

[†] independent of scenario

The most interesting analysis in terms of road safety is to assess whether drivers are able to detect the periods of reduced alertness. Only 2% of these lapses were detected by the participants of this study (see Table 3). This result was independent of the road scenario. However, large differences are observed between scenarios in terms of the level of errors in the subjective estimations. Participants were much more likely to be accurate (good or close estimate) in detecting lapses in alertness during the scenarios with high roadside variability (scenarios 2 and 4 with 100% and 80%) compared to scenarios with low roadside variability (scenarios 1 and 3 with 24% and 17%). Therefore scenarios with low roadside variability resulted in high over-estimation of the real alertness (76% and 83% for scenarios 1 and 3). Such difference was not observed for road design monotony.

Table 3 : Accuracy of the subjective estimation of alertness classified as low with the EEG

	good	close	far away
Scenario 1	2%	22%	76%
Scenario 2		98%	0%
Scenario 3		15%	83%
Scenario 4		78%	20%

4. Discussion

Our results demonstrate useful relationships between driver's self assessment and the driving conditions. Monotonous driving conditions on highways led drivers to feel bored while performing the driving task. This can be inferred from the much higher inaccuracy of self-reported alertness after the driving task when compared to the estimates before driving. On a driving simulator, they assess their alertness as low after such driving conditions. Such estimates are lower than what is observed with an objective measurement of alertness with the EEG. This is also confirmed by the feedback we received from participants at the end of the driving task. This shows that drivers are unable to assess reliably their alertness while driving on highways. Furthermore most of the lapses in alertness were not detected by the participants we had on the driving simulator. This is of concern in terms of road safety, since drivers are not aware of moments when they should not drive. They cannot assess reliably the safe duration task on monotonous highways. It is therefore inappropriate to rely on drivers to assess their own level of alertness while driving on monotonous highways. Hence, most self-assessed estimates would be too low and would be equivalent to false alarms. Many dangerous alertness impairments would also be missed by drivers.

Variations in the accuracy of the self-reported measures of alertness have been observed for the different scenarios. Roadside environment appears to have a stronger effect on the

accuracy than the road design. Road environment with rare buildings and traffic led to large overestimations of the driver's alertness with 80% of the worse levels of alertness missed. This was a lot less observed for road design, with only 10% of the estimates being far away from the alertness estimate obtained with the EEG. This is of concern in terms of road safety in countries like Australia, where many highways have desert-like scenery with low traffic. The impossibility to make such monotonous scenery more appealing to drivers, constant monitoring of driver's alertness may be required in order to reduce the road toll due to fatigue on monotonous highways.

Another result from this study is that personality traits, and particularly sensation seeking level, influence the level of accuracy of self-reported alertness. While no difference was observed between average and low sensation seekers, high sensation seekers have a tendency to rate inaccurately their alertness. For both groups self-assessment of alertness became less accurate after the driving task. It highlights their lack of motivation to perform a long monotonous driving task on highways. After completion of the driving task, only 40% of the alertness estimates from high sensation seekers are accurate (compared to 60% for average sensation seekers). Therefore high sensation seekers combine (i) a higher likelihood to have their alertness impaired on monotonous roads (Thiffault & Bergeron, 2003b) and (ii) a reduced ability to assess their real level of alertness while driving. Highways with monotonous scenery are therefore of particular concern for high sensation seeking drivers. These results suggest that alertness of drivers (particularly high sensation seeking professional drivers since professional drivers are the most exposed to alertness decrements on such monotonous highways) should be monitored objectively and in real-time in countries like Australia.

This research suggests that other approaches and countermeasures are necessary to reduce the occurrences of crashes on monotonous roads due to reduced alertness. Particularly, technological solutions might provide better information to drivers about their level of alertness. Issues remain related to which sensors to implement in the car as well as the amount of false alarms and alertness impairment miss-detection from such systems, which are known to alter drivers' trust toward technological devices. Nevertheless, such approach appears to be the most likely to have an impact on road safety due to the fast development of affordable sensors that can be deployed in cars and the theoretical developments in biomathematical models of fatigue.

CONCLUSION

This simulation study confirms the difficulty that drivers have in assessing their alertness while driving. The accuracy of alertness estimates decreases during the driving task, and results in low accuracy. High sensation seekers are less accurate than others and this is of concern since they have a higher chance of being less alert during monotonous driving. Errors in the alertness estimates are mainly due to underestimations, which mean that real lapses in alertness are missed. The ability to detect lapses in alertness is shown to depend on the road monotony in this experiment, and particularly to the roadside environment. Low roadside variability results in high proportions of over-estimations of alertness during lapses of alertness, which is not observed with the road design factor. This study underlines the difficulty for drivers to detect their lapses in alertness while driving on Australian highways, many of which are characterised by desert-like scenery. The development of countermeasures cannot focus on driver's estimates of alertness and needs to take advantage of the recent developments of technology that made it possible to assess objectively the level of alertness of performance of drivers in real-time.

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