

## Sustained Attention and Hypovigilance: The Effect of Environmental Monotony on Continuous Task Performance and Implications for Road Safety

Michael, Rebecca<sup>1</sup> & Meuter, Renata<sup>2</sup>

*Centre for Accident Research and Road Safety – Queensland (CARRS-Q)<sup>1</sup>  
School of Psychology and Counselling<sup>2</sup>, Queensland University of Technology (QUT)*

### ABSTRACT

While driver hypovigilance is often attributed to fatigue, it is more frequent in monotonous road environments, suggesting that monotony of task (requiring simple, under-demanding responses) and/or environment (containing highly repetitive, predictable stimuli) plays an important role. We report an experimental study designed to disentangle the characteristics and effects of monotony from those of time on task and fatigue, using a series of short vigilance tasks. Task monotony was manipulated through changes in target probability ( $p(\text{monotonous}) = 0.11$  vs.  $p(\text{non-monotonous}) = 0.50$ ), while environmental monotony was manipulated through stimulus variation. Results revealed that performance, as indexed by accuracy and response times (RTs), was significantly worse in a monotonous context versus non-monotonous context. Furthermore, performance decrements emerged early in the vigilance task (within 4.3mins) and were consistent over the course of the experiment, suggesting that monotony effects are independent of time on task and fatigue. Experimental manipulations of monotonous contexts revealed that both task demands and stimulus variability are independent moderating factors of sustained attention, with improved performance in conditions of increased task demands and stimulus variability. Implications for road safety are discussed.

### INTRODUCTION

Driving is a highly demanding task, requiring sustained attention to maintain a good level of performance and to avoid crashes. Reductions in vigilance (hypovigilance) while driving result in poor driving performance and are commonly attributed to fatigue. Hypovigilance is more frequent in monotonous road environments (Thiffault & Bergeron, 2003a), suggesting an important role for monotony (of task or environment) in generating hypovigilance. However, the independent effect of monotony on hypovigilance remains largely ignored. Instead monotony is typically regarded only as a unidimensional task characteristic and used to facilitate fatigue in experimental situations. The underlying assumption appears to be that monotony directly causes fatigue and the associated symptoms.

In the driving arena there is indirect support for this position. Driver fatigue is estimated to contribute to 20-30% of all road accidents in Australia (Commonwealth of Australia, 2000, cited in Lal & Craig, 2001a). The contribution of fatigue is greater in rural areas (Haworth, 1998) and accounts for an estimated 30% of all fatal accidents on rural roads (Fell, 1995). However, Fell and Black (1997) reported that 27% of city drivers involved in fatigue-related road accidents or incidents subjectively claimed that they were *not tired* prior to the incident and a further 35% felt only marginally tired. Importantly, most of these drivers were travelling along well known routes. In rural areas, where driving conditions are arguably more monotonous, 45% of drivers reported that they were not at all tired prior to the incidents ascribed to fatigue. Furthermore, drowsiness, a key indicator of fatigue, has been found to not be a reliable measure of an individual's alertness under monotonous conditions (Kerr, 1991; Vespa, Wiley, Mitler, & Schultz, 1998).

This pattern of findings raises the possibility that the monotony of the driving environment, containing repetitive or highly familiar, predictable stimuli, produces the decrements in alertness and vigilance leading to crashes, quite independent of drowsiness and fatigue. Despite this, little research has been directed towards studying the characteristics and effects of monotony.

Consequently, there remains an absence of consistent evidence explaining the relationship between monotony and fatigue and the resultant hypovigilance that manifests itself in poor driving performance and crashes (Thiffault & Bergeron, 2003a).

### *Characterising monotony*

Driving is in essence a vigilance task, involving largely automatic processes. To study the effects of monotony on driver fatigue, the driving task is usually constructed as prolonged driving on roads containing constant or highly repetitive stimulation. It is important to note that driver fatigue research has largely not interrogated the concept of monotony and tends to conceptualise it as a unidimensional task characteristic (monotonous driving task), despite the fact that it is largely exogenous environmental characteristics (such as road design and road side stimuli) that are being manipulated to vary monotony. Accordingly, we propose that monotony is a multidimensional construct that relates to characteristics of both the environment and the task itself. Monotony is studied here using a computerised vigilance task.

Patterns of contextual stimuli are important in determining environmental monotony. Repetitive stimuli are widely acknowledged as being monotonous and associated with reduced attention and performance (Thiffault & Bergeron, 2003a; Straussberger, Schafer, & Kallus, 2004). Conversely, Wertheim (1978; 1991) suggests that it is the predictability of environmental stimuli (such as road geography and roadside stimuli), not the repetitiveness, that determines monotony. In highly predictable environments, the oculomotor system shifts from attentive to inattentive, resulting in an increasing dependence on the extra-retinal feedback system (mental schemas of what probable visual stimuli should be present) to respond to the environment. Dependence on the extra-retinal feedback system in predictable, monotonous environments results in highly automated responses which impair ability to respond to unexpected events. Consistent with Wertheim's theory, the oculomotor theory of attention proposes that oculomotor activity is directly related to attentional processes (Wright & Ward, 1998). In relation to monotony, reduced oculomotor activity, such as might occur when fixating on the road ahead, may inhibit an individual's ability to respond to unexpected visual events. The distinction between repetitive and predictable stimuli and the role of oculomotor activity in vigilance and performance in monotonous environments remains largely unexplored and will therefore be examined experimentally in this study.

Task demand, the complexity of a task, also appears to be an important factor related to monotony. Research from the vigilance field and rail industry suggests that low task demand contributes to cognitive underload which results in reduced alertness and error prone performance (Grandjean, Baschera, Martin, & Weber, 1977; Wild & Stinson, 1983). This proposition is supported by arousal theory of vigilance which attributes poor performance in monotonous tasks to a lack of necessary stimulation to maintain performance (Smit, Eling, & Coenen, 2004). Related to arousal theory, habituation theory goes further to suggest that cognitive underload, elicited by repetitive patterns of stimuli, reduces arousal which results in habituated, or automated, responses (Mackworth, 1969). Accordingly, we will examine the effect of task demands on vigilance and performance in varying monotonous contexts and whether increased stimulus variability increases cognitive load sufficient to improve performance.

Although environmental and task monotony appear to be highly correlated, this may not necessarily always be the case. To illustrate, driving on an urban freeway exposes the driver to a highly variable array of environmental stimuli but the operational processes of the task itself remain monotonous. We will explore the independent contribution of environmental and task monotony to the formation of a monotonous context.

### *Monotony and time on task*

Wertheim (1991) and others maintain that tasks requiring sustained attention (such as driving), for prolonged periods in highly predictable or repetitive (arguably more monotonous) environments, result in effects similar to those of fatigue. Notably these effects include drowsiness and hypovigilance (Campagne, Pebayle, & Muzet, 2004; Cerezuela, Tejero, Cholí, Chisvert, & Monteagudo, 2004; Lal & Craig, 2001b; Thiffault & Bergeron, 2003a; Straussberger et al., 2004; Verwey & Zaidel, 2000), with drowsiness considered one of the most robust indicators of fatigue (Dinges, 1995). Consistent herewith, studies in the rail and aviation industries have found that operator fatigue and hypovigilance arise from prolonged monotonous tasks (Edkins & Pollock, 1997; Kerr, 1991; Straussberger et al., 2004; Sussman & Copen, 2000). However, the use of prolonged tasks and fatigue measures to index hypovigilance in monotonous contexts obscures the exact relationship between monotony, fatigue and sustained attention (Thiffault & Bergeron, 2003a) and, importantly, fails to isolate the effects of (task and/or environmental) monotony from those of fatigue.

There is some evidence for early manifestations of hypovigilance on monotonous roads (see Brookhuis & de Ward, 1993; Richardson, 1995; van de Hulst, Meijman, & Rothengatter, 2001). Consistent with driving research, vigilance studies have found performance differences between monotonous and non-monotonous contexts in tasks of less than 5 minutes duration (Brandt, Stemmer, & Rakotonirainy, 2004; Meuter, Rakotonirainy, Johns, Tran, & Wagner, 2005). The early emergence of monotony effects is evident in a wide range of vigilance contexts including simulated radar monitoring tasks (Straussberger et al., 2004), simulated industry monitoring tasks (Johansson, Cavalini, & Pettersson, 1996), and locomotive operation (Edkins & Pollock, 1997), suggesting that the effect of monotony on vigilance is not dependent on time on task. These effects can occur when individuals are well rested, suggesting that fatigue is not always a contributing factor (Sussman & Copen, 2000). With the aim of clarifying the relationship between monotony, fatigue and hypovigilance, we will examine whether monotony effects can emerge early in a task which will point to the nature of any connection with fatigue.

### *Implications for road safety*

Current safety countermeasures aimed at maintaining driver alertness focus on reducing fatigue. Drivers are encouraged to take rest stops during prolonged driving and they are educated to recognise the early signs of fatigue, such as drowsiness (Haworth, 1998). Yet we have discussed evidence suggesting that, in monotonous environments, reduced driving performance can emerge early in the driving task and may not be accompanied by symptoms such as drowsiness. It remains to be determined how best to recover from monotony-specific hypovigilance and what the effect of different environmental or task ruptures might be. Contrary to the predicted effects of fatigue, data from van der Hulst et al. (2001) suggest performance *recovery* in fatigued drivers on a second monotonous task (rural driving) following highly demanding city driving. Thus changes to environmental monotony or task demands may improve driving performance. As stated, the effect of changes to environmental monotony on vigilance and performance will be explored in this study.

### *Aims*

Here we examined whether hypovigilance can emerge as a consequence of task and/or environmental monotony, independent of the effects of fatigue and time on task, in a computerised vigilance task. To this end, characteristics of environmental monotony were manipulated by systematically varying stimulus characteristics in a computerised sustained attention task, while controlling task characteristics (i.e., task monotony). Specifically, the effects of stimulus variability, stimulus change, and stimulus location were explored. Changes in stimulus variability equated to environmental variability in a driving setting, stimulus change modelled environmental change, while changes in

stimulus location allowed the evaluation of the effects of actively shifting vision and attention around one's environment.

In the past, generalisation of findings from laboratory vigilance studies to operational settings has been hampered by the use of experimental tasks that differ from the operational task on a number of dimensions. To improve generalisation of results, Davies and Parasuraman (1977) suggest that the tasks share similar characteristics. To this end, the basic task selected was adapted from Robertson, Manly, Andrade, Baddely, and Yiend (1997), also successfully used by Meuter et al. (2005), and involved rapidly responding to a continuous stream of simple stimuli, while constantly vigilant for the occurrence of a pre-defined, infrequently occurring target stimulus. In this type of task, target detection accuracy and RTs are used to index performance with higher accuracy indicating a higher level of sustained attention. Accordingly to Robertson et al., RTs are predictive of target accuracy with slower RTs associated with increased accuracy, indicating a non-automated response. Unlike traditional vigilance tasks - requiring responses to targets only - this is a continuous performance task not dissimilar to the process of driving (where the driver must make constant task adjustments while remaining vigilant for infrequently occurring critical events, such as braking suddenly to avoid collision). Consistent with previous observations, we expect better performance in non-monotonous than monotonous contexts. Furthermore, if hypovigilance related to monotony is independent of fatigue and time on task, we expect early emergence of measurable reductions in performance in monotonous contexts that remain consistent when observed over time. According to previous research and theoretical predictions, we expect greater environmental stimulus variability, stimulus change and moving stimulus location to be associated with better performance.

## METHOD

### *Participants*

Fifty seven students at an Australian university, 11 males and 46 females (mean age = 23.29 years, SD = 9.11), volunteered to participate in this study. Students undertaking the first year psychology subject received course credit for their participation.

### *Materials*

Six adaptations of a continuous sustained attention to response task (SART) (Robertson et al., 1997) were used. The conditions varied in level of monotony, stimulus variation, and location of stimulus appearance. Each condition took 4.3 minutes to complete.

*Baseline conditions.* Both a monotonous and non-monotonous baseline condition were used. In each condition 225 single digits (ranging from 1-9) were randomly displayed for 250 ms on a computer screen, with an inter-stimulus interval of 1150ms. The target stimulus to which responses were to be withheld was the number '3'. Task monotony was manipulated by changing the target probability. The monotonous condition was characterised by a low target probability ( $p(\text{target})=0.11$ ), resulting in an automated response mode. The non-monotonous condition was characterised by a markedly higher target probability ( $p(\text{target})=0.5$ ), resulting in a non-automatic response mode. Task monotony was lower in the non-monotonous condition due to the increased number of target digits (and associated reduced response predictability).

*Experimental conditions.* Four experimental conditions were used. In each, target probability was maintained at the level of the monotonous condition ( $p(\text{target})=0.11$ ) while the stimuli presented were varied systematically to manipulate environmental monotony, as follows. The No Change condition was identical to monotonous baseline condition and used digits as stimuli. In the Stimulus Change condition, the stimuli changed to letters (A-I), with as target the letter C. In the Increased Variability condition, the stimuli changed from digits (1-9) to a combination of letters and symbols (totalling 25 different stimuli), with as target the letter C. In the Moving Stimulus condition, on approximately a

third of the trials, the stimuli were presented in one of 6 positions towards the edge of the computer screen.

### *Procedure*

Participants were tested individually in a quiet room, between 9 and 3 pm<sup>1</sup>, in a session lasting approximately 45 min. They were allocated randomly to one of four groups, each of which performed five short vigilance tasks, as follows. Each group completed, in order, the baseline monotonous and non-monotonous task, followed by one of the experimental conditions. There was then a repetition of the baseline monotonous and non-monotonous tasks, presented in counterbalanced order.

Prior to each condition, participants received written instructions on the computer screen. The instructions asked them to respond as quickly and accurately as possible to all stimuli, but to withhold responses to the target stimulus. On completion, participants filled out five short questionnaires. These formed part of a larger study and will not be further described here.

### *Design and Analysis*

Hypovigilance was measured using response errors to targets as well as RTs. A mixed design was used, allowing for the evaluation of the effects of context manipulation on vigilance. Any independent contribution of fatigue was evaluated by comparing performance in monotonous and non-monotonous conditions before and after the intervening experimental condition.

## RESULTS

To evaluate the effect of monotonous and non-monotonous contexts on sustained attention, both RTs to non-targets and accuracy scores were used. Recall that there were four groups of participants, differing only in the experimental context following the first monotonous and non-monotonous contexts. The repeat occurrence of the monotonous and non-monotonous contexts was counterbalanced (Order of Presentation). A recording error resulted in this repeat occurrence not being registered for the Increased Variability group. A mixed design Analysis of Variance (ANOVA) was conducted separately on both performance measures, with Order of Presentation and Group (No Change, Stimulus Change and Moving Presentation) as between subject factors, and Task Context (Monotonous vs. Non-Monotonous) and Task Order (before or after the intervening experimental context) as the within subject factors. No effect for Order of Presentation was found. Accordingly, all analyses presented here were collapsed across this factor. A further mixed design ANOVA was conducted for each performance measure, with Context (first monotonous vs. experimental) as the within-subjects factor and Group (all four groups) as the between subject factor. All planned pairwise comparisons were carried out using Bonferroni corrections (at  $\alpha = .05$ ). Unless relevant to the aims of this study, only significant results are discussed.

### *Monotony effects in relation to time on task and fatigue*

To determine whether monotony effects could emerge early on task, independently of fatigue, RTs and accuracy associated with performance in monotonous and non-monotonous contexts were compared at two different time periods (before and after an intervening experimental context) for the No Change, Stimulus Change and Moving Presentation groups.

### *Response times.*

Mean of median RTs associated with non-target identification in monotonous and non-monotonous contexts (both before and after the intervening experimental contexts) are shown in Figure 1 (Panel A).

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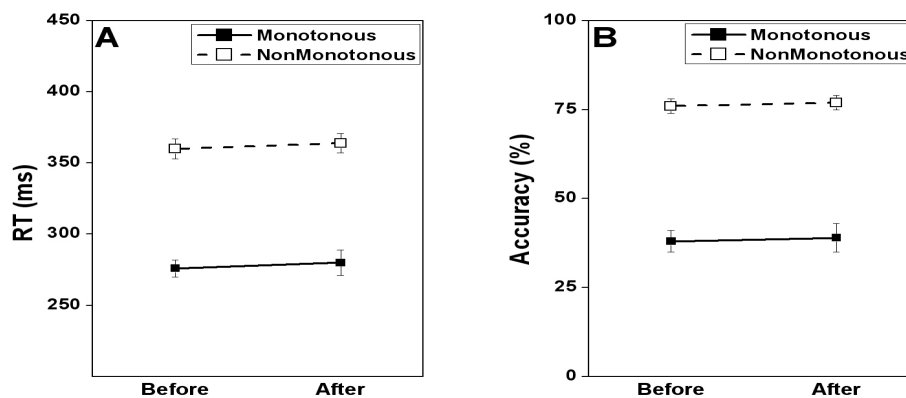
<sup>1</sup> The possible impact of circadian variations will be analysed separately and are not reported in this paper.

RTs in the monotonous contexts were measurably faster than those in the non-monotonous contexts,  $F(1,43) = 290.12$ , Wilk's  $\lambda = .129$ ,  $p < .001$ . The lack of a Task Context X Task Order interaction ( $F < 1$ ) suggests that RTs were not affected by fatigue.

The Task Order X Group interaction was marginally significant,  $F(2,43) = 3.20$ , Wilk's  $\lambda = .871$ ,  $p = .051$ . This effect reflected the fact that Stimulus Change group was measurably faster on their repeat performance,  $p < .05$ .

There was no Group main effect,  $F < 1$ , and no Task Context X Group interaction,  $F(2,43) = 2.69$ , n.s.

Figure 1. Panel A shows mean of median RT to non-targets (ms), plotted separately with respect to Task Context (monotonous vs. non-monotonous) and Task Order (before vs. after). In panel B accurately withheld responses to targets (%) are plotted separately with respect to Task Context (monotonous vs. non-monotonous) and Task Order before (before vs. after).



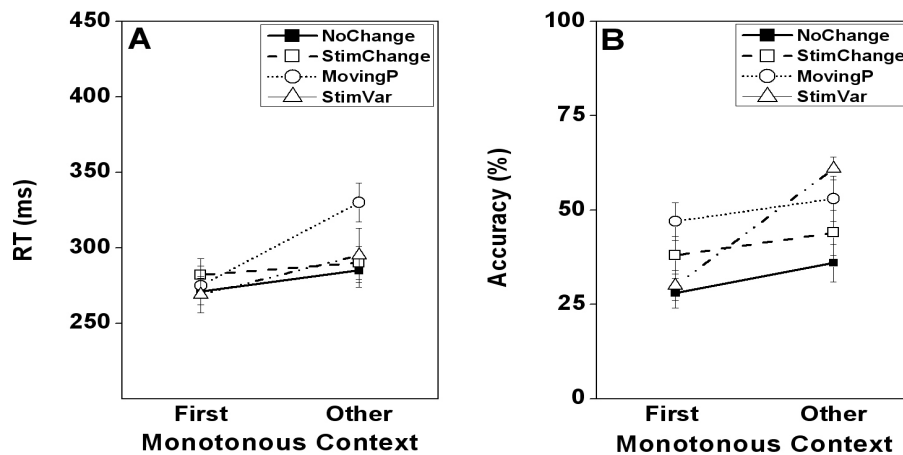
Accuracy.

Accurately withheld responses (%) to the target digit three are shown in Figure 1 (Panel B). As with the RTs, there was a significant main effect for Task Context,  $F(1,43) = 425.99$ , Wilk's  $\lambda = .092$ ,  $p < .001$ , with markedly more target correctly identified in the non-monotonous context. There was no Task Context X Task Order interaction, consistent with a negligible impact of fatigue on performance. A significant Group X Task Context interaction,  $F(2,43) = 4.99$ , Wilk's  $\lambda = .812$ ,  $p < .05$ , reflected the observation that the Moving Presentation group was more accurate than the No Change group in the monotonous contexts only. The differing patterns for RTs and accuracy argue against any explanation in terms of a speed-accuracy trade-off.

*The effect of changes in monotonous contexts*

To determine the characteristics of monotonous contexts that contribute to reduced performance and hypovigilance, the stimulus characteristics of the monotonous context were varied systematically (No Change, Stimulus Change, Moving Presentation, Increased Variability), while maintaining task demands (i.e., the same number of targets occurred). It was thus possible to directly compare the effect of changes in context on the ability to sustain attention. Performance in the first monotonous context was compared directly with that in the experimental context. Recall that the experimental context for the No Change group involved an identical monotonous task.

Figure 2. Panel A shows the mean of median RT to non-targets (ms), plotted separately with respect to Experimental Group and Context (Monotonous Context vs. Manipulated Context). Accurately withheld responses to targets (%) are plotted separately with respect to Experimental Group and Context Monotonous Context vs. Manipulated Context) in panel B.



### Response times.

A mixed ANOVA on RTs associated with non-target identification revealed a significant main effect for Context,  $F(1,53) = 42.09$ , Wilk's  $\lambda = .557$ ,  $p < .001$ , with RTs overall measurably slower in the first monotonous context (see Figure 2, Panel A). There was a significant Context X Group interaction,  $F(3,53) = 8.02$ , Wilk's  $\lambda = .688$ ,  $p < .001$ . Planned comparisons revealed that RTs in the Moving Presentation and Increased Variability groups only were significantly slower in the experimental context, indicative of non-automated responses both when target location varied and when stimulus variability increased in the monotonous context. Also, performance in the Moving Presentation group was significantly better than that of the No Change group suggesting a difference in baseline performance between these two groups.

### Accuracy.

As with the RTs, there was a significant main effect for Context when considering accuracy,  $F(1, 53) = 27.31$ , Wilk's  $\lambda = .660$ ,  $p < .001$ , with responses correctly withheld to a lower number of targets overall in the monotonous context (see Figure 2, Panel B). There was a significant Context X Group interaction,  $F(3, 53) = 5.90$ , Wilk's  $\lambda = .750$ ,  $p < .05$ . Planned comparisons revealed that participants performed at a greater level of accuracy to targets in the Increased Variability context than in the monotonous context,  $p < .001$ .

## DISCUSSION

The results of this study indicate that monotony affects sustained attention, with hypovigilance and associated performance worse in monotonous than in non-monotonous contexts. This finding is consistent with previous experimental and applied research examining the effect of monotony on sustained attention (e.g. Cerezuela et al., 2004; Straussberger et al., 2004). Critically, performance decrements emerged early in the task (within 4.3 mins) and remained consistent over the course of the experiment (21.5 mins), suggesting that monotony effects can operate independent of time on task and fatigue.

Much of the fatigue literature argues that monotonous tasks need to be prolonged for hypovigilance to occur, and that the observed performance decrements are indicative of fatigue. Our results refute this proposition. Instead, they strongly suggest that the prolonged nature of any task conducted in a monotonous context may mask monotony effects. We contend that, as a consequence, any performance decrements may be falsely attributed to and/or confounded by fatigue.

In support of our contention, we have demonstrated that monotony (in an experimental setting) results in hypovigilance and poor performance, quite independent of fatigue and time on task.

Central to furthering our understanding of how monotony affects vigilance (and performance) is the identification of the defining characteristics of a monotonous context. In our baseline conditions, the monotonous context was characterised by both the repeated occurrence of a small range of stimuli and low task demand (highly repetitive response mode because of infrequent targets). The non-monotonous context was equally limited in stimulus variation but was characterised by higher task demand: The greater target frequency did not afford a repetitive response mode. Performance differences between the contexts support our proposition that monotony is not a unidimensional construct. Within these contexts, which differed only in target frequency, it is reasonable to attribute worse performance in the monotonous context to low task demands associated with infrequently occurring targets. However, the experimental manipulation of monotonous contexts suggests differently. Performance was significantly improved when stimulus variability was increased (i.e., was less repetitive), even if target probability remained the same. The observation that a physical change of stimuli (from digits to letters), while maintaining the same low level stimulus variability and target probability, did not positively impact on performance further suggests that what appears to be critical is for the stimuli to exhibit a high degree of variability, thus decreasing repetitiveness.

In summary then, low task demands and low stimulus variability combine to form a monotonous context characterised by hypovigilance and poor task performance. However, variations to task demand and stimulus variability have been found to independently affect performance suggesting that monotony is a multidimensional construct that relates to both task monotony (associated with the task itself) and environmental monotony (related to characteristics of the stimulus).

How the nature of the stimuli relates to task demands, affecting vigilance in monotonous contexts, remains to be disentangled. Clearly, increased target probability in the non-monotonous context resulted in increased task demand. The processes underlying this increase however remain unclear. It is conceivable that repetitive stimuli in the monotonous context resulted in an automated response mode that physiologically decreased the ability to detect targets (Mackworth, 1969). While this habituation explanation would account for improved performance observed with increased stimulus variability, it is inconsistent with the performance difference between the baseline monotonous and non-monotonous contexts that contained equally repetitive stimuli. Warm (1977) points to another explanation, suggesting that sources of stimulus uncertainty (associated with what the stimulus will be, when it will occur and where it will occur) may affect vigilance performance. Thus the greater uncertainty associated with the response required in the non-monotonous context may have resulted in a higher level of vigilance and subsequent performance. Uncertainty regarding the nature of the stimulus when stimulus variability increased may have had a similar effect. The concept of stimulus uncertainty also explains the slower responses when stimuli occurred at random locations, resulting in a more cautious response mode.

#### *Implications for road safety*

Our findings are consistent with the existing driving research investigating monotony effects and indicate marked performance decrements that are not accompanied by drowsiness and fatigue. Further research should be conducted in a driving setting, specifically focusing on the differential effects of varying levels of task and environmental monotony. In so doing, not only will the relationship between monotony, time on task, and fatigue be further disentangled but, in addition, useful information on the value of short vigilance tasks (like the SART) in predicting driving performance in monotonous contexts will be provided to the road transport industry. If poor driving performance is found to emerge early and independent of fatigue when driving in monotonous contexts, future research should aim to identify monotony-specific countermeasures and to evaluate the effectiveness of fatigue countermeasures, such as rest and recovery, on reducing monotony effects.



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