A Driving Simulator Test of an Alertness Device

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Abstract

A simulator study investigated whether drivers' alertness, in drowsiness inducing conditions, can be maintained by a game-like system, a gamebox. Drowsiness was assessed by self-rating, blinking rate and eye closures. Mental effort was assessed by the NASA-TLX scale and by a physiological measure - the 0.1 Hz component of heart rate. Driving quality and safety were assessed by lane position and steering movements, a TLC (time-to-line crossing) measure, and by the occurrence of safety related driving errors - solid line crossings, driving off the pavement incidents and accidents.

When driving with the game device, drivers reported lower degrees of drowsiness and fewer instances of sleep episodes. Eye closures were in agreement with the subjective reports by drivers. Compared to a control condition, driving with the device resulted in fewer accidents and incidents and these occurred later in the session. The quality of vehicle control deteriorated over the course of the session, but less so in the gamebox condition. The gamebox benefited to some extent all drivers, but more so drivers who generally considered themselves very susceptible to drowsiness.

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Introduction

Drowsiness and traffic accidents

There is a broad consensus that the conditions associated with drowsiness accidents are long hours of driving in monotonous road conditions and when driving interferes with regular hours of sleep and, therefore, fatigue and drowsiness accidents typically occur during late night hours and on inter-urban roads. Estimates of fatigue, sleepiness, or drowsiness involvement in accidents range from 1% to 4% involvement rate estimated from general police databases to 10 - 25% or even higher when based on "in-depth" accident investigations or on clinical studies (Horne and Reyner 1995).

Drivers' experience with drowsiness

Drivers are usually quite aware of their drowsiness state and many have experienced driving in that condition. They can also recall instances of falling asleep behind the wheel.

In the UK, a national survey of car drivers (Maycock 1995) revealed that 29% of them have had at least one experience of a serious drowsiness episode during the last year. About ten percent reported on having been involved, due to drowsiness, in an accident in the last three years, mostly at night and on inter-urban roads. Essentially similar results were reported by McCartt *et al.* , (1995), based on a survey of drivers in New York state.

While drivers are generally aware of becoming drowsy, their ability to accurately monitor progressive, or momentary, shifts in their condition is often limited (e.g., Seko, Kataoka, and Senoo 1995, Skipper and Wierwille 1986, Wylie *et al.* 1996). Most commonly, drivers' own assessment of the decline in their alertness was found to lag behind objective indicators of drowsiness. The implication of this bias is that drivers might not invest sufficient effort in staying alert, or they over-estimate the success of their efforts and, therefore, continue driving beyond their capabilities.

The nature of alerting devices

In-vehicle alerting devices to counteract driver drowsiness can be divided into two general categories. The first includes those designed for detection of drowsiness followed by a warning and, in more advanced concepts, followed by intervention. In the second category are devices which are designed for maintaining alertness by some form of activation of the driver throughout the trip. This approach can be traced to interpretation of drowsiness as reflecting, in part, lowered arousal due to lack of stimulation. Accordingly, it was hoped that the drowsiness condition might be counteracted by presenting operators with additional stimulation.

In the context of driving research, the presence of an additional task is usually considered a "secondary task" (or "subsidiary task") which is presumed to "load" drivers and perhaps even create a task "over-load" situation. It is employed for two purposes: (a) to load drivers in order to measure their remaining attention or processing capacity in various driving situations (e.g., Verwey and Veltman 1996) and, (b) to investigate the effect of the subsidiary activity itself, such as the use of a cellular phone or listening to traffic information, on the quality of driving (e.g., Verwey 1996).

However, monotonous driving, especially at night and on rural roads, is a situation better described as an "under-load" situation with, possibly, lower arousal due to drowsiness or predictive stimulation (Wertheim 1991). Here, an attention demanding "secondary task" might increase the general level of arousal and improve performance. More generally, activities additional to driving might be detrimental in busy driving situations but beneficial when driving in under-load situations.

Wierwille *et al.* (1994) found that a secondary task requiring a simple yes / no response every 15 seconds tended to reduce drowsiness and to improve vehicle control measures. The findings were tentative due to a small number of drivers and the rather demanding schedule of the task. Fairbanks, Fahey and Wierwille (1995) report on further testing of secondary task stimuli as an alertness maintenance device (after drowsiness was detected), with generally disappointing results.

Everyday evidence for the use of additional tasks to maintain driver alertness comes from anecdotal evidence and driver survey data (e.g., Maycock 1995, McBain 1970) which suggest that drivers engage in a variety of self-initiated activities in order to maintain alertness. Very common are the use of radio, pre-recorded media, and conversing with passengers - if present. Some drivers prefer talk programs or educational programs over music because such programs are more interesting, more mentally challenging, or give them a better sense of "a person talking to them". With the spread of cellular phones (or CB radio in some countries) many drivers find it helpful (and useful) to communicate with other people on the road or elsewhere. Other drivers engage in mental games or exercises to keep alert and pass the time. For example, simple counting and calculating games, creating lists of words by certain rules, solving anagrams, or interacting with a language teaching program on tape. There is practically no research on the effectiveness of drivers' own methods for alertness maintaining, and whether the methods could be optimized and taught to others.

The purpose of the study

The purpose of the present study was to examine whether mental activity encouraged by a game-like task, during a monotonous long drive, could reduce degradation of safe driving performance caused by drowsiness and fatigue. It was our conviction that in order to avoid interference with driving and to be motivating, the mental task had to be interesting, self paced, used at will, and not overly difficult. Drivers should be able to adapt the complexity of the task to their abilities and to the demands of the driving task. To reduce interference with driving, the task should not overly involve the visual channel or interfere with hand operation (Verwey 1996).

The additional task in the present study was incorporated in a gamebox which contained twelve activities (i.e., games) varying in type, complexity and potential challenge. Activities could be selected and initiated at will and interaction between the driver and the device was via speech.

The hypothesized effect of the gamebox on driving performance could be due to a reduction in drowsiness and a generally increased level of alertness; or it could be an indirect product of drivers being motivated to invest more effort in keeping a safe level of performance. To investigate this issue, effort investment was assessed with both subjective and physiological measures.

METHOD

An overview of the experiment

Twenty six drivers drove a monotonous rural road for 2 hours and 15 min in a fixed-base driving simulator. They were pre-selected to have either a high or low tendency to get drowsy during long trips at night. Each driver drove the route twice, about four to seven days apart, during one of three different night shifts while not having slept before the drive. In a control condition, drivers had to just drive the route. In an alertness-aided condition, drivers were provided with an "alertness maintenance device" (a gamebox) with which they could interact at will.

The experimental design is a mixed, repeated measures design on 2 aiding conditions, and a 3 x 2 factorial on shift and driver type. Order of repetition was counter-balanced across all other conditions. Time-on-task was added as an independent variable to some analyses.

A data acquisition system collected a video record of drivers' face and eyes, various physiological measures, and selected vehicle performance measures. From these it was possible to determine the progression of drowsiness over time, the frequency of serious driving incidents and their behavioral precursors, and the effect that the gamebox had on drowsiness and quality of driving.

Participants

Drivers were selected on the basis of a telephone screening interview. Their age range was 25 to 49 years, (mean of each group: 38). They had their license for at least five years (average 17 years). There were 12 female and 14 male drivers. None used medication that could affect driving performance. Drivers were paid for their participation. They were promised a bonus for safe driving which, in practice, everybody received.

Dependent variables.

The main dependent variables were driving performance measures, driver drowsiness measures - blinking, eye closure, and self-rating of sleepiness on a 7-key scale every 25-35 min.-, driver mental effort, and the extent of using the gamebox.

Subjective mental workload was assessed with the NASA-TLX scale (Hart, S.G. and Staveland, L.E. 1988). The physiological measure of mental effort was the 0.1 Hz component of the heart rate variability (Mulder 1980). This measure has been frequently used to assess effort in cognitively demanding tasks where it was suspected that operators might be overloaded but some studies also assessed underload situations (e.g., Egelund 1982). The application here is to indicate mental effort in an underload situation where sleepiness must be resisted..

Apparatus and scenario

The experiment took place in a fixed base driving simulator at the TNO Human Factors Research Institute. The road was a two lane, 7.2 m wide road where the legal speed limit is 80 kph. The road curved gently through a flat rural landscape and day sight-distance was generally 800 m. Scenery was similar throughout the drive and included road markings, kilometer posts (with no numbers), scattered trees and shrubs and some outline of topographical features. Light conditions simulated an early dawn and vehicles had their lights on. The scenario embedded some situations and traffic events which require more attention from drivers: sharp curves; oncoming cars; parked cars; and slow moving vehicles;

Procedure

On the night of participating in the study, drivers had a regular day of activity without having any sleep before arriving to the laboratory. Coffee and alcohol were not allowed after 18:00. Upon arrival, hours before their driving time, they filled out consent forms and questionnaires and waited in a special area, provided with beverages, light snacks, magazines and audio-visual media.

After being fitted with the physiological sensors, participants were instructed about the use of the simulator car, the location and use of the alertness rating box, and the nature of the task. They were asked to drive safely in the way they would normally do. At the conclusion of the driving session, each driver filled out a post-drive questionnaire and was taken home by taxi.

RESULTS

Drowsiness measures

Has the gamebox affected subjective drowsiness and effort?

In- vehicle ratings (Figure 1) shows that on a scale from 0 (fully alert) to 6 (very sleepy), drowsiness increased monotonically with time-on-task [$F(4,72)=60.4$, $p<.001$]. The analysis also confirmed the success of the experimental manipulation of task difficulty and of the two types of drivers (the detailed analyses of these variables are reported elsewhere).

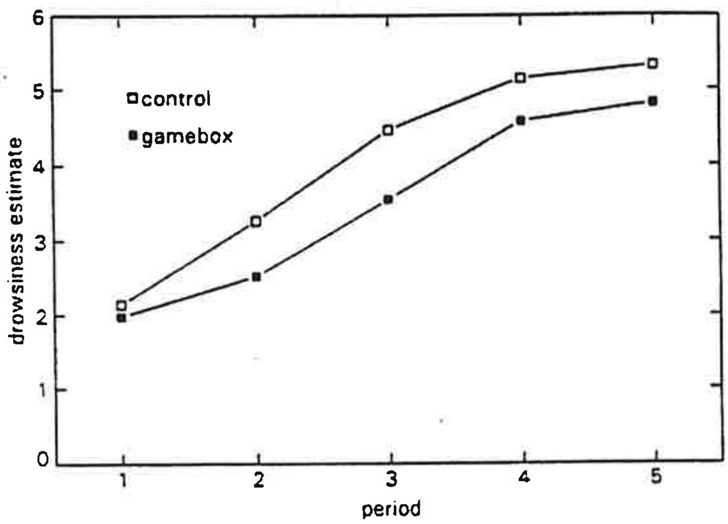

Fig.1 Selfreported drowsiness during the session.

Drivers thought they had actually fallen asleep 4.7 times, on the average, in the control condition and 1.0 time in the gamebox condition [$\chi^2(1) = 59.7$, $p<.001$]. Falling asleep was experienced by 17 out of 25 drivers in the control condition and by 9 out of 25 drivers in the gamebox condition, [$\chi^2(1) = 5.1$, $p<.05$].

TLX ratings given immediately after the drive with respect to the early and the last part of the drive, showed a significant early / late effect and a shift effect. Gamebox / control conditions did not differ significantly.

The physiological indicator of effort (the 0.10 Hz component of the heart rate signal) was also sensitive to time-on-task - effort went down with time [$F(8,72)=3.07$, $p<.01$] - but did not distinguish between control and gamebox conditions.

Has the gamebox affected blinking and eye closures?

We observed several instances of very obvious sleepiness as expressed in yawning, frequent blinking, drooping face, blank staring, long eye closures, head nodding, and other symptoms of drowsiness and the effort to fight it off. For quantitative analysis we used only blinking and longer eye closures as indicators of drowsiness.

A loglinear analysis of eye blink frequency (summed across drivers and excluding closures longer than 1 s) showed that more blinks occurred in the gamebox condition than in the control condition [frequencies per driver per 3 min period: gamebox: 64.6, control: 58.4; $\chi^2(1) = 41.0$, $p<.001$]. Long eye closures (i.e., > 1 s) did not occur in the first three min periods. A log-linear analysis on closure frequencies in the late period showed more closures in the control than in the gamebox condition [frequencies per driver per 3 min period: control: 2.1, gamebox: 1.3; $\chi^2(1) = 4.6$, $p<.05$].

The data suggest that the experimental manipulations were successful in inducing drowsiness. The frequency of long eye closures appears to be the most reliable indicator of driver drowsiness. It is not that blinking is not affected by drowsiness but that the changes in blinking are more complex. For example, Seko, Kataoka, and Senoo (1995) present records of blinks, in drowsy drivers, which change in duration, frequency and regularity. Episodes of long closures as well as long staring with no blinking, complicate the pattern even more.

Has the gamebox averted driving errors?

This section will discuss three types of errors. First, *accidents* are those events in which the vehicle left the road (i.e., the asphalt) entirely. Second, *incidents* entail all events in which the vehicle left the road with two wheels, and, third, *crossing events* are those events in which solid lane edge marks (left and right) were crossed but the road was not left. Care was taken not to double-count events.

These observable events were counted automatically from the vehicle performance data in the simulator, and their exact location registered. Analyses of all data records (including ratings, heart rate, and blinks reported earlier) were halted at the accident location. Visual inspection of the video records confirmed that in most cases, performance following an accident only got worse, indicating that the accidents had indeed been caused by extreme levels of drowsiness.

Table 1 presents the occurrence and timing of accidents, incidents, and crossing events in the two conditions, and the proportion of drivers involved in these unsafe events.

Table 1 Accidents, incidents, and crossing events in two conditions.

measure	control	gamebox
no. of drivers with an accident	6 (23%)	2 (8%)
mean time to accident	87 min.	103 min.
no. of drivers with an incident	10 (38%)	7 (28%)
mean number of incidents per incident-driver	4.6	3.0
mean time to first incident	83 min.	94 min.
no. of drivers with crossing events	10 (40%)	6 (24%)
mean number of crossing events per driver	3.9	3.7
mean time to first crossing	64 min.	79 min.
number of drivers with any event	15 (58%)	8 (32%)
total number of events	81	45
mean number of events across all drivers	3.2	1.8

Table 1 clearly shows that there is an advantage for the gamebox condition on all measures of driver errors. Compared to the control condition, fewer drivers in the gamebox condition ended up with an accident, incidents, and solid line crossings and it took longer for the first of these events to occur. The control condition had about twice as many incidents and crossings than the gamebox condition. All accident events took place in the second half of the driving session. The frequency of incidents and crossing events was higher in the later periods of the drive.

While some of the differences appear small, they are all very consistent, and by and large statistically significant. It should be noted that events were not equally distributed amongst drivers. A total of 14 drivers had accidents or incidents; 12 drivers had none.

This pattern of results suggests a performance degradation process in which increased drowsiness generates more crossing errors which lead into more serious incidents and, eventually, to an accident.

DISCUSSION

The results clearly demonstrate that the gamebox counteracted the normal performance deterioration in driving which is typical for monotonous driving. It reduced the numbers of accident, incidents and crossing events and it delayed the onset of errors. The positive impact on performance measures is supported by the effects on the various indicators for drowsiness - subjective reports of drowsiness and of sleep episodes during and after the drive, and longer eye closures.

The fact that the mental activity associated with interacting with the gamebox counteracted performance deterioration, suggests that the lack of attentional resources in normal monotonous driving is caused by a lack of mental activity - after all lane keeping is a largely automatic task. This notion is confirmed by Lisper *et al.*'s (1986) finding that inexperienced drivers, for whom lane keeping is probably less automated (Verwey, 1993), had less difficulty in staying awake than experienced drivers in the same condition.

Subjective effort ratings increased with time-on-task while the 0.1 Hz component suggested a reduction in effort. This divergence, between subjective measures of effort and the 0.1 Hz component, suggests that the 0.1 Hz measure here reflects the actual drowsiness state while subjective effort is a measure of "doing one's best" to maintain performance at an acceptable level. In studies with high workload, physiological state is probably affected directly by doing one's best, and consequently the physiological and subjective effort measures are similar. But, as our data suggest, in underload conditions where the natural tendency to become drowsy is strong, a divergence between the two effort indicators can occur.

Even drivers who did not commit serious errors exhibited increased drowsiness and degraded performance as a function of time on task or shift. Their reduced performance, however, stayed within safety bounds. It is quite possible that longer periods of driving or other fatiguing factors would push their performance out of bounds too. Some drivers, by virtue of their personality, constitution, or experience, are likely more than others to succumb to drowsiness, and are less able to fight off its effects. They are aware of this tendency and are willing, even eager, to make use of procedures and devices which promise a reduction in drowsiness.

Many drivers reported finding the device helpful and supported the concept of the device. The device, despite its technical limitations, benefited to some extent all drivers, and even more so those drivers who needed the help most. The device was utilized in different ways by different drivers. Some hardly turned it on; some interacted with it during a large part of the session; most operated it occasionally, for various periods of times. Sometimes drivers used it while still appearing (and self-rating themselves) quite alert; at other times they activated it when they felt very drowsy.

Many driving situations induce loss of alertness and could benefit from using the alerting concept. Actual design issues such as the nature of mental activities, the interface with drivers and possibly connection with detection systems, need to be investigated before optimal devices can be developed.

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