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The effects of an interactive cognitive task (ICT) in suppressing fatigue symptoms in driving

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A B S T R A C T

Background: Prolonged drive on inter-urban, monotonous roads has the potential of causing a decrease in the general level of arousal leading to a state of underload and fatigue. This study examines the effectiveness of an interactive cognitive task (ICT) in delaying fatigue symptoms induced by underload conditions. The ICT is an auditory-motor task which is based on the basic principles of a knowledge game known as "Trivia".
Method: Ten participants took part in two experimental sessions of 140 min drive in a fixed-base simulator. In a within-subject counterbalanced design one session consisted of driving without ICT and the other included ICT operation. In the ICT session the game was activated after 60 min of driving.
Results: When activated, the ICT increased physiological indicators of arousal, increased subjective feelings of alertness, and improved driving performance. The physiological and driving performance measures revealed that the ICT activation had an immediate but localized influence on arousal. Post-drive questionnaires showed that in the ICT condition, the participants' level of motivation increased and their feelings of sleepiness decreased.
Conclusions: Engaging in cognitive tasks can counteract the effects of underload and increases driving safety as long as they are active. However, additional research is necessary to determine the effects of long term use.

1. Introduction

It is common to distinguish among three types of factors that are responsible for car accidents: (i) driver and other road users – the human factor, (ii) road – the infrastructure factor, and (iii) vehicle – the technology factor (Evans, 2004; Shinar, 2007). The human factor is the largest contributor to crashes, and fatigued driving is a significant human factor, accounting for as much as 3.6% of fatal crashes in the USA (Knipling & Wang, 1994; Wylie, Shultz, Miller, Mitler, & Mackie, 1996). Driver-reported coping strategies include opening the window, talking to a passengers and talking on the cellular phone (Oron-Gilad & Shinar, 2001), singing aloud, listening to the radio with high volume, and eating (Royal, 2003).

Throughout the years researchers evaluated various methods to handle fatigue, either by developing potential fatigue countermeasures or by evaluating the effectiveness of intuitive methods used by drivers to handle fatigued driving. There is no doubt that the best way to handle fatigued driving is by simply taking a nap. Naps have been shown to benefit performance and decrease sleepiness (Wylie et al., 1996). Nevertheless, drivers often feel that they cannot take this course of action, either because of scheduling problems or because it is not their habit (Drory, 1985; Wylie et al., 1996). Driving – which is often a repetitive task that requires sustained attention – can under certain circumstances be fatiguing even to a relatively wakeful driver (McCartt, Rohrbaugh, Hammer, & Fuller, 2000). When referring to fatigued driving one must distinguish

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between fatigue generated as a result of the driver's state (e.g. sleep deprivation) and fatigue caused by the driving task demands. Our work addresses the latter type of fatigue, which might need different coping strategies as apposed to fatigue caused by driver state (i.e. lack of sleep can be treated with sleep) (Desmond & Hancock, 2001; Oron-Gliad & Ronen, 2007; Thiffault & Bergeron, 2003).

A prolonged drive on an inter-urban, monotonous road has the potential of causing a decrease in the general level of arousal leading to an underload state. Dynamic models of stress and sustained performance (e.g. Hancock & Warm, 1989) based on the idea of adaptation to task demands, claim that drivers can compensate for task dynamics by using different types of cognitive strategies. The potential hazard of fatigue is a decrease in the range or efficiency of strategies related to task effort regulation (Desmond & Matthews, 1997). The underload state does not indicate lack of available mental resources to perform the task, but rather the lack of ability to regulate the amount of resources needed to do so (Desmond & Matthews, 1997). Hence an underload state caused by low rate and amount of stimulation, usually combined with decrease in motivation, can eventually result in misjudgment of resources needed to perform the task adequately (Oron-Gilad, Ronen, & Shinar, 2008). Another model proposed to explain the decrease in performance due to a state of underload is the malleable attentional resources theory (MART) which is based on attentional resource theory (Young & Stanton, 2002). The theory's main assumption is that we have a limited or fixed attentional resources capacity. Degradation in performance occurs when task attentional demands exceed resource capacity (Desmond & Matthews, 1997). The MART posits that the size of the resource pool can change in relatively short term as function of task demands as opposed to resource theory which claims fixed resources pool. Young and Stanton (2002) propose that a decrease in performance in underload conditions is due to shrinkage of available resources reservoirs.

Whether attentional resources shrink – as implicated by the MART – or accessibility to them is curtailed – as claimed by dynamic models of stress and sustained performance – the outcome is the same. Under certain conditions the driver can easily slip into a state of underload. If we assume that underload is the result of low levels of stimulation combined with low motivation, then a motivating secondary task that increases the cognitive load can help counter the effects of fatigue.

Verwey and Zaidel (1999) demonstrated that performing an attention demanding secondary task while driving, under certain driving conditions can increase alertness and task engagement. Driver responses obtained from surveys conducted by Maycock (1995); as cited by Verwey and Zaidel (1999) imply that when fatigued, drivers tend to engage in mental games, or any other task which will mentally challenge them. Most recently results of a study conducted in our laboratory, in which participants operated three different types of secondary tasks that vary in their cognitive demands, indicated that some cognitive tasks – especially ones that involve long term memory – may enable a driver to maintain alertness during a prolonged drive (Oron-Gilad et al., 2008).

When considering the choice of a non-mandatory driving related tasks, we should bear in mind that a useful secondary task should not demand too much of the driver's attentional so as not to distract him or her from the primary driving task, but demand enough attention to force the driver to maintain high levels of alertness (Drory, 1985). In selecting the type of secondary task we must also take into consideration the interest and motivation of the driver to perform this task. Desmond and Matthews (1997) found that fatigued drivers can improve performance for a relatively long period of time when they are strongly motivated.

In light of our past findings (Oron-Gilad et al., 2008) and the desire to use a motivating task, we focused the current evaluation on a variation of the well-known 'Trivia" game. The aim of the current research was therefore to develop, design and evaluate an advanced interactive cognitive task (ICT) that will counteract the effects of fatigue and enable the driver to increase or at least maintain an adequate level of alertness during a prolonged drive. The specific goals in this study – beyond that of comparing the ICT to a control condition – were to examine if the pattern of use of the ICT affects its utility; If it can be effective more than one time during the drive (or does it suffer from a rapid habituating effect); and if it's effects are multi-dimensional – impacting performance, physiologic, and subjective measures - or uni-dimensional?

2. Methods

2.1. Participants

Ten healthy male and female students (aged 23–30) with at least 5 years of driving experience participated in the study. All were non-smokers and moderate caffeine consumers (maximum of 1–3 cups of coffee per day), with body mass index (BMI) of 18.5–25 kg/m^2. They were paid for participation in the experiment and given a bonus upon succeeding in the ICT task.

2.2. Apparatus

An STI-SIM driving simulator (Systems Technology, Inc.) integrated into a full-size passenger car provided the driver with the look and feel of driving in a real car. The visual display of the road was projected on 3 $\times$ 3-m screen at a distance of 3 m from the driver's eyes, providing the driver with a true horizontal field of 40° on a scale of 1:1. Cameras placed inside the car monitored the driver's face, and his or her body movements. A 5-key response panel on the hub of the steering wheel served as the interface between the driver and the ICT.

2.2.1. Driving scenarios

Three different 140 min driving scenarios were designed. Previous studies in the simulator indicated that a drive of this duration was enough to induce fatigue symptoms. All three scenarios consisted of a two-lane mostly straight rural road, with a few curves, low traffic density, and desert scenery. The scenarios contained four randomly distributed unexpected events. The drivers were instructed to drive at the posted speed limit of 55 mph.

2.3. Dependent variables

2.4.1. Subjective measures

Perceived fatigue related to the driving task was assessed by Swedish occupational fatigue inventory (SOFI-20) (Åahsberg, 1998). The questionnaire consists of 20 Likert-type questions related to five dimensions (four questions for each dimension): physical discomfort, physical exertion, lack of energy, lack of motivation, and sleepiness. The SOFI was administered just before and immediately after driving and the difference scores of each subject in each of the five categories were analyzed. Following the drive, drivers also answered a questionnaire about their attitude and feelings toward the ICT, and its perceived effectiveness.

2.4.2. Performance measures

The driving performance measures included five parameters: average and standard deviation (SD) of the lane position, average and SD of speed, and SD of the steering wheel angle.

2.4.3. Physiological measures

ECG signals were recorded from two skin surface electrodes at a sampling rate of 500 Hz using an 'Atlas Researches Ltd.' polygraph located in the back seat of the car and connected to a PC by an optic fiber. *R* wave peaks were detected and marked using "MATLAB" software. After detection, *R*–*R* intervals were calculated and the total change in HRV was determined from the total spectrum between 0 and 0.4 Hz of the *R*–*R* power spectra.

2.4.4. ICT secondary task

The interactive cognitive task (ICT) is an auditory-motor task designed along the basic principles of a knowledge game known as "Trivia". Multiple choice questions were presented to the driver through speakers located in the rear of the car, and the subject responded by pressing one of four buttons placed on the ICT keyboard. To make the ICT interesting to the participants they could select questions from anyone of five themes: movies, sports, current events, general knowledge, and cuisine. Within each theme the questions were grouped into three levels of difficulty (based on an independent evaluation on a sample of students). In each theme the driver started from the easy questions and continued to the next level only after successfully completing the previous one.

2.5. Procedure and design

The design was a within-subject counterbalanced design. Each driver was asked to participate in three sessions. The first session was a learning and adaptation session in which the participants signed a consent form. They were then familiarized with the driving simulator, the driving scenario, the physiological monitoring equipment, and the subjective questionnaires. During this session the participants operated the ICT several times until they felt comfortable with its usage.

The next two sessions were experimental sessions consisting of (1) a treatment session using the ICT and (2) a control session without the ICT. In the ICT session, the ICT was activated twice during the drive for duration of 20 min each time; first after 60 min of driving and again after 100 min from the beginning of the drive. The order of the control and ICT sessions was counterbalanced across participants. Fig. 1 is a schematic illustration of the treatment session.

The participants received a list of instructions and limitations that they were to observe prior to the experiment. A day before the experiment participants were asked to get a good night sleep of 7–8 h and avoid alcohol consumption. The experiments were in the afternoon (14:00 till 17:00). On the day of the experiment the participants were instructed to avoid naps, consumption of any products containing caffeine, and intensive sport activity. Participants arrived at the lab at 14:00, filled out SOFI questionnaire, were connected to the physiological recording system and then sat inside the simulator car for 10 min (rest period) before driving. After the rest the subject started 140 min of driving. The drive was followed by another 10 min rest period in the car (during all this time, the participants were physiologically monitored). After the rest the subject got out of the car and filled out a SOFI questionnaire.

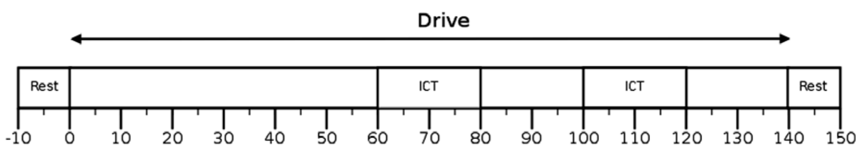

Fig. 1. The study protocol.

2.6. Data analysis

Each driving performance measure was analyzed using two-way-ANOVA for repeated measures (period × treatment) followed by post hoc Fisher LSD pair-wise comparisons to identify the source of significant effects. For each dimension in the subjective questionnaire the difference score between the level reported after the drive and the level reported before the drive was first calculated. The difference scores were analyzed using one-way-ANOVAs for repeated measures, also followed by post hoc Fisher LSD pair-wise comparisons. Heart rate variability was calculated for 16 consecutive periods in each session: "rest" before the drive, "baseline" period in the beginning of the drive, thirteen blocks of 10 min long driving periods, and "recovery" in the car after driving. Heart rate variability was normalized for each session separately according to the "baseline" that was given a score of 100%. The normalized scores were analyzed using a two-way-ANOVA for repeated measures (period × treatment).

3. Results

3.1. Driving performance measures

The within-subject analyses compared the difference in performance measures between identical road segments in the ICT sessions and the control sessions. In general we expected driving performance to deteriorate with time-on-task, and we hypothesized that the ICT will mitigate this deterioration.

Lane position variability decreased significantly with the ICT [$F(1,63) = 20.85$, $p < .001$], and the effects on the standard deviation of lane position are illustrated in Fig. 2. Standard deviation of the lane position was lower in both ICT 20 min periods of operation – after 60 min of driving and after 100 min of driving – than in control sessions (without ICT treatment) during same time periods. Thus, drivers were much more stable in maintaining their lane position while using the ICT (and possibly even in its anticipation), than in the control session.

3.1.1. Speed variability

A repeated measures two-way analysis of variance on treatment and time on the standard deviation of speed yielded significant main effects for the two independent variables and their interaction. The effect of the first ICT activation was significant [$F(1,63) = 30.11$, $p < .001$] but delayed: the difference between the control and ICT conditions reached significance only after the first ICT was terminated. The interaction with time-on-task shows that the effect was greater and appeared during the second activation of the ICT [$F(6,63) = 3.02$, $p = .01$]. A significant effect of time-on-task [$F(6,63) = 5.25$, $p = .01$] reflected the expected general decrease in participants' ability to stabilize their speed over time These results are presented in Fig. 3.

3.1.2. Steering wheel angle

The two-way ANOVA on the standard deviation of steering wheel angle yielded a significant main effect for the treatment variable. The standard deviation was lower in the second ICT 20 min period of operation (after 100 min of driving) than in control session during same period [$F(1,63) = 7.63$, $p = .01$]. This effect is presented in Fig. 4.

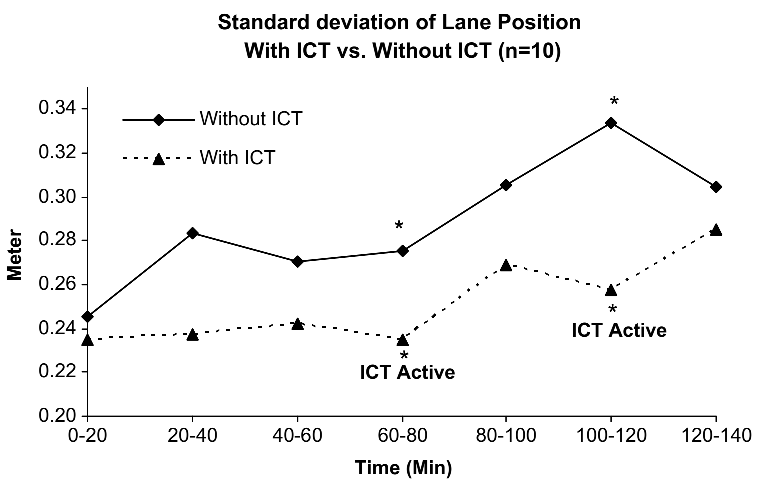

Fig. 2. The effect of ICT on the standard deviation of lane position (in feet).

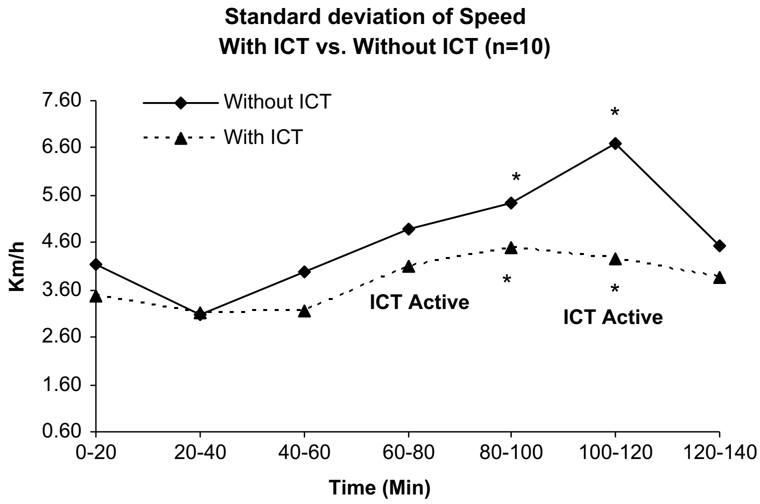

Fig. 3. The effect of ICT on the standard deviation of speed (in mph).

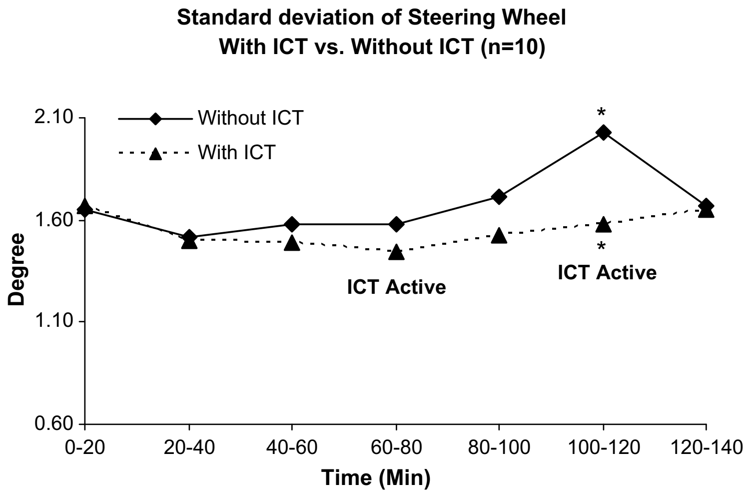

Fig. 4. The effects of ICT on the standard deviation of steering wheel angle (in degrees).

3.2. Subjective measures

One-way ANOVA of the effects of treatment yielded a significant result for the "*lack of motivation*" and "*sleepiness*" categories. "*Lack of motivation*" and "*sleepiness*" were significantly greater in the control sessions (without ICT treatment) than in the ICT sessions [$F(1,9) = 8.38$, $p = .02$ and $F(1,9) = 5.74$, $p = .04$, respectively]. These results are illustrated in Fig. 5.

3.3. Physiological measures

Heart rate variability (*HRV*) was used to assess levels of mental fatigue, arousal and alertness. An increase in demand is typically associated with a total heart rate variability decrease, while increase of HRV correlates with relaxation, time-on-task and fatigue (de Waard, 1996; Malik, 1996; Mulder, 1992; Stein, Bosner, Kleiger, & Conger, 1993).

The HRV measurements were standardized for each driver relative to the first 10 min of the drive. The two-way ANOVA on the HRV yielded a significant main effect for the time-on-task. In both control and ICT sessions HRV was significantly lower during the rest period prior to the drive than in the recovery period after the drive [$F(15,141) = 2.11$, $p = .01$]. Post-hoc test (Fisher LSD) showed that HRV was lower during second ICT 20 min period of operation (after 100 min of driving) than at the same period during in the control session ($p = .006$). These effects of time-on-task and ICT are illustrated in Fig. 6, where it can be seen that the two conditions were nearly identical throughout the drive except at the time when the ICT was employed in the treatment but not in the control condition.

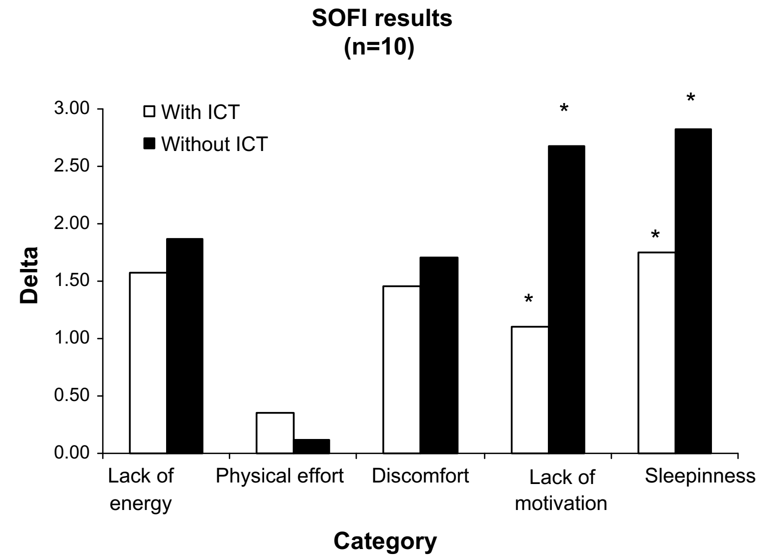

Fig. 5. The effect of ICT on the SOFI dimensions of fatigue.

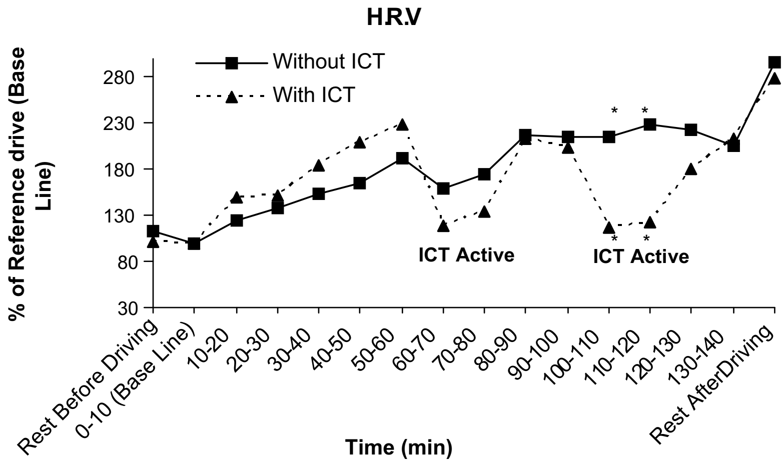

Fig. 6. The effects of ICT on relative heart rate variability.

3.4. ICT performance measures

The ICT task included questions from three ascending levels of difficulty. The results presented in Table 1 are consistent with the validation process; the average response time (RT) was significantly effected by the level of difficulty [$F(2,27) = 25.42$, $p = .00$], and the average percent of correct responses significantly decreased at each level (Friedman ANOVA Chi-square ($N = 10$, df = 2) = 20.00 $p = .00005$) (see Table 1).

Table 1
ICT performance results

Difficulty levels	Average RT (s)	Percentage of success
Easy	16.9 (2.0)	91 (7)
Medium	21.0 (2.2)	67 (9)
Hard	24.2 (2.8)	38 (12)

Values in parenthesis are standard deviations.

4. Discussion

The results of this study consistently support the main hypothesis and show a positive effect of the ICT in all three types of measurements: driving performance, subjective feelings, and physiological measures. In addition, the gradual increase in HRV over time in the control sessions indicates that 2 h and 20 min of driving simulation, can generate a monotonous fatiguing situation.

A detailed observation of the physiological and performance measures reveals that the ICT activation had an immediate but localized influence on the levels of alertness, indicated by a decrease in HRV coupled with a decrease in variability of the lane position, speed, and steering wheel corrections. These effects were even stronger during the second activation of the ICT relative to the control condition at this point in the drive. In general, the ICT effects dissipated immediately after its completion, demonstrating that the effect of the ICT was highly localized. Once the ICT intervention ended the physiological and driving measures deteriorated, and performance in the ICT and control conditions were similar.

A significant practical issue for a fatigue countermeasure is the willingness of the driver to use it (Oron-Gilad et al., 2008). In this sense the ICT is particularly attractive because it had positive effects on the reported level of motivation and the feelings of sleepiness, as reflected in the SOFI questionnaires results. However, the increased motivation to drive may also be counterproductive because it may induce drivers to drive when they would otherwise stop to rest. Still, given many people's inclination to continue driving while fatigue this may be a positive effect, as most of the participants reported that it was easier to complete the drive while using the ICT, and that they were motivated to succeed in the ICT task.

From a theoretical perspective, our results support models of underload, which claim that driving fatigue is the result of low levels of stimulation combined with low motivation (Desmond & Matthews, 1997; Young & Stanton, 2002). Our findings regarding the effectiveness of a secondary task as a means to manipulate drivers' work load are consistent with previous studies on driving fatigue (Oron-Gilad et al., 2008; Verwey & Zaidel, 1999) and illustrate that by adding a motivating secondary task that increases the cognitive load we can help counter the effects of fatigue and improve performance on the primary driving task at least as long as the driver is engaged in the ICT task. Still unknown are the long term usage effects of such ICTs.

5. Conclusions

The current study demonstrated that a motivating cognitive stimulation while driving has the potential to suppress fatigue symptoms caused by underload driving conditions. All three types of measurements that were used supported the hypothesis that the use of ICT temporarily increases alertness as long as it was activated. ICTs can have a significant role in eliminating hazardous situations caused by underload, and their benefits may increase with the advent of in-vehicle systems that relieve the drivers of more and more components of the driving task (such as adaptive cruise control, hazard detection, and lane monitoring/correcting systems). It therefore remains to be tested whether or not the ICTs compensate for potential boredom effects and have a benefit when combined with emerging techniques such as keeping the driver in the loop by decreasing the levels of automation afforded by new in-vehicle technologies.

In addition, this research provides experimental evidence that engaging in a cognitive task in underload situations does not interfere with the primary task of driving. As a result the drivers can successfully perform both tasks simultaneously. Perhaps more importantly, we did not find any immediate evidence of fatigue after-effect in the wake of the ICT. Finally, the drivers' subjective impressions also supported the benefits of the ICT, by showing that it increased drivers' motivation and decreased their sense of sleepiness, lending the ICT potentially important face validity that should help in implementing it as an attractive fatigue countermeasure.

This experiment established a platform for using ICT as a potential countermeasure. In order to convert this system into a practical and reliable on-board fatigue countermeasure additional research questions must be answered. For example, how effective is the system in repetitive usage? Is there an optimal duration and timing for its use? Would it be equally effective on other driver populations such as older drivers or professional drivers? These issues will be addressed in future research.

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