Measuring Driver Visual Distraction with a Peripheral Detection Task

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Abstract

In order to design safe vehicles it is important to be able to evaluate in-vehicle systems to determine how distracting they are for people to use while driving. The Peripheral Detection Task (PDT) is a method for measuring the amount of driver mental workload and visual distraction in road vehicles. It is a secondary task measure where drivers must respond to random targets presented in their peripheral view. As drivers become distracted they respond slower and miss more of the PDT targets. This study aimed to test if the PDT is useful for measuring driver mental workload and visual distraction from in-vehicle information systems in the real road-traffic environment.

Thirteen participants drove on a motorway and country road and performed different tasks (change CD, tune radio and backward counting). The dependent measures were PDT reaction time, hit rate, subjective mental workload and heart rate variability.

The PDT reaction time and hit rate measures revealed significant differences between the different tasks. Mean reaction times were slowest for the backward counting task on the country road. The hit rates were best for the baseline driving on both roads and worst for the CD changing task. No significant difference was found between the motorway and the country road for the PDT. It is concluded that the PDT is a good tool for measuring visual distraction and mental workload in a real car. More research is needed to validate the use of the PDT across a wider range of driving and in-vehicle tasks.

Keywords: cognitive tunneling, driver workload, secondary task, and visual distraction.

Introduction

Different kinds of systems inside the vehicle, for example audio systems, can compromise safety if they distract too much of the driver's visual attention away from the road (e.g., Wierwille, 1993). In order to design safe vehicles it is important to be able to evaluate in-vehicle systems to determine how distracting they are for people to use while driving. This study concerns one specific method for measuring the amount of driver mental workload and visual distraction in road vehicles.

Miura (1996) investigated driver reaction times to spots of light presented at different horizontal angles on the windscreen. He reported that driver reaction times increased with the complexity of the driving task (higher traffic density). Also, it was observed that increases in reaction time were associated with a decrease in the size of the driver's visual field. Williams (1985, 1995) conducted experiments that found similar results and has described this effect as visual tunneling. Others have suggested that this process reflect cognitive rather than visual tunneling. Dirkin and Hancock (1985) argue that the narrowing field of view is attentional rather than perceptual.

van Winsum et al. (1999) developed a method to exploit this cognitive tunneling effect in order to measure driver workload. This method is called the Peripheral Detection Task (PDT). It is a secondary task measure of mental workload and visual distraction. With the PDT, drivers must respond to random targets presented in their peripheral view. The idea is that when primary driving task demands increase, drivers will respond slower and miss more of the PDT targets. The PDT should also be able to indicate when drivers are visually distracted away from the forward view (e.g., when talking with a passenger or tuning their car radio).

Simulator studies of driver support systems have found the PDT to be sensitive to variations in driver workload (van Winsum et al., 1999; Burns et al., 2000). The present study aimed to test if the PDT is useful for measuring driver mental workload and visual distraction from in-vehicle information systems in the real road-traffic environment.

Method

Participants

There were 13 participants in this study, six men and seven women aged between 24-44 years. They had held a valid driver license for between 4 and 26 years. Six participants wore glasses or lenses while driving. Data from two participants (men) could not be used since their response data was corrupted. This left 11 participants with complete data for the analysis.

Equipment

The PDT presents a small red target light on the windscreen in the driver's perifoveal field of view. The target is an LED reflection on the windscreen (see Figure 1). The reflections appear as a heads-up display (HUD). The HUD target is located at a horizontal angle of approximately 11-23 degrees to the left of the driver's forward view and at a vertical angle of approximately 2-4 degrees above the horizon. The target appears within this area; one of 23 LEDs in the rack is illuminated. The targets appear with a random variation between 3-6 seconds. It lasts for one second and the response is possible from 200 milliseconds after onset until 2 seconds, otherwise it is considered a miss. Drivers respond to the targets by pressing a small button attached to their left index finger.

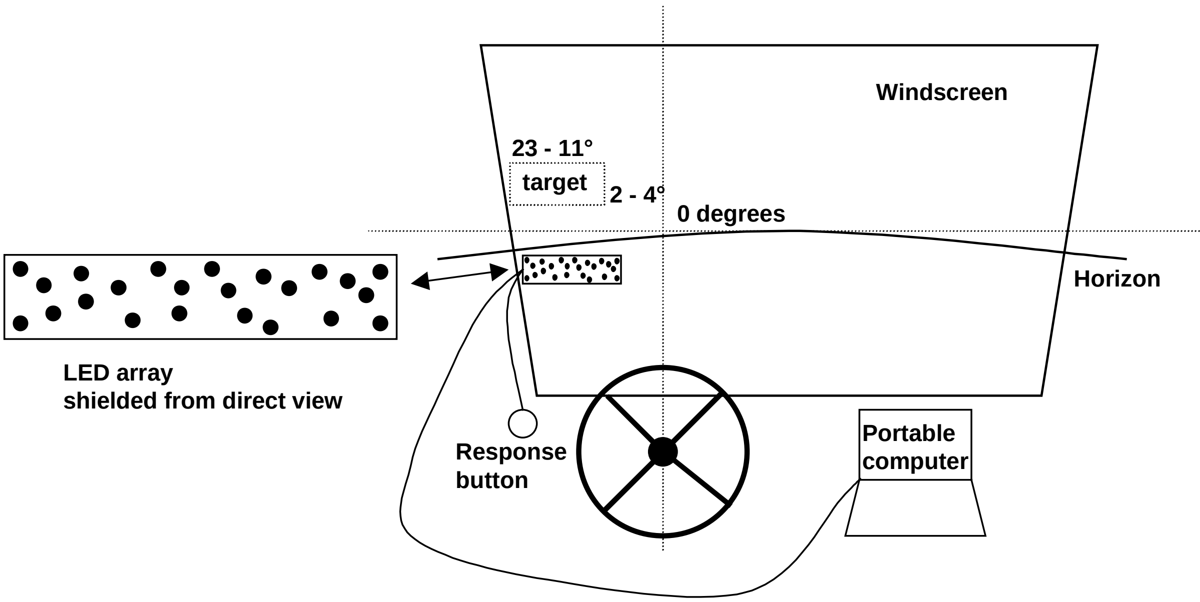

Figure 1. The Peripheral Detection Task Hardware.

The electrocardiograph (ECG) signals were taken with an ambulatory monitoring device (Embla™). The 0.1 hz component of heart rate variability (HRV) was obtained using the analysis software Somnologica™. The 0.1 hz component of HRV was extracted since it has been associated to mental effort (Mulder et al., 1973). Less variability or lower values of this measure indicate more mental effort.

The Rating Scale Mental Effort (RSME) was used to rate subjective workload. This is a single scale that consists of a line that runs from 0-150 mm, where every 10-mm is marked (Zijlstra & Van Doorn, 1985). Along this line statements related to the invested effort are given.

Procedure

The participants were first given the test instructions and the PDT was explained. After this the ECG equipment was connected. This was followed by a 5-minute rest period to collect baseline data for the ECG. The participants were instructed where to drive. The test vehicle was a Volvo S80. The road trial started with a familiarization/practice drive. The next part was on a motorway and the last part was on a 2-lane undivided road with a number of traffic lights. Participants were asked to perform the tasks at set points along the route.

An unbalanced repeated measures design was used. The independent variables were road type/speed, motorway (110 km/h) and country road (90 km/h) and task, embedded or cognitive. The embedded tasks were to determine the tuned frequency on the radio and manually select a specific radio station (Task 1, Radio), and turn on the CD-player and play a specific track on a specific CD, for example, track 3 on CD 1 (Task 3, CD). The cognitive task used was a backward counting task, for example 568-7 (Task 2, Counting).

The dependent measures were heart rate variability, subjective mental effort, PDT reaction time and target hit rate. The HRV and PDT performance were recorded throughout the drive. The RSME was completed after each road section. PDT performance was summarized over 30-second intervals surrounding the tasks. The baseline performance was recorded over a 5-minute period so that a sufficient amount of data could be collected to calculate the power of the mental workload component of the HRV by Fourier transform.

Results

An analysis of variance (ANOVA) was calculated to determine if there were any effects of the road (2) or task conditions (4) on PDT reaction times. There was a near significant interaction between task and road type [$F(3, 24) = 2.62$; $p < 0.07$]. Reaction time performance was particularly slow for the counting task on the country road (see Figure 2). There was a significant main effect for task [$F(3, 24) = 16.26$; $p < 0.0001$], but not for road type.

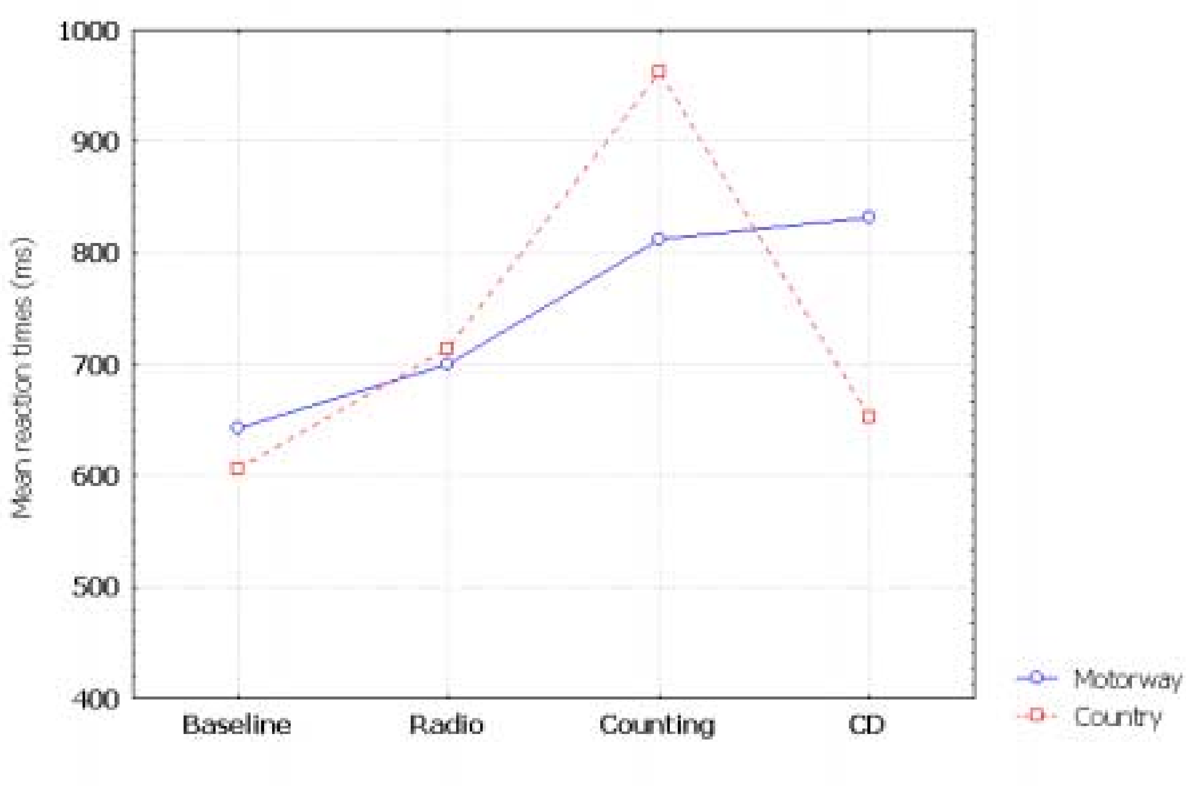

Figure 2. Mean reaction times for the PDT by task and road.

Table 1 shows the mean reaction time and standard deviation for the tasks and baselines. Post-hoc comparisons (Tukey HSD) showed a significant difference in mean reaction times with the baseline being significantly faster than the counting task and the CD task on the motorway. On the country road, the counting task had significantly slower reaction times than the other tasks and baseline. No gender differences were found for the mean reaction times.

Table 1. Mean (M) and standard deviation (SD) in mean reaction PDT reaction times for the different tasks.

RT in milliseconds	**Baseline M (SD)**	**Radio M (SD)**	**Counting M(SD)**	**CD M (SD)**
Motorway	643 (143)	700 (165)	812 (234)	832 (288)
Country	606 (138)	714 (190)	962 (279)	653 (209)

Figure 3 shows the mean hit rates for the PDT between task and baseline for the different roads. The distribution of hit rates (hits/total) was significantly skewed for some of the tasks and unsuitable for a parametric analysis. Friedman's non-parametric analysis found a significant difference ($p < 0.0001$) in the hit rates among the different tasks for both roads. Table 2 shows the means and standard deviations for the PDT hit rates over the different tasks and roads.

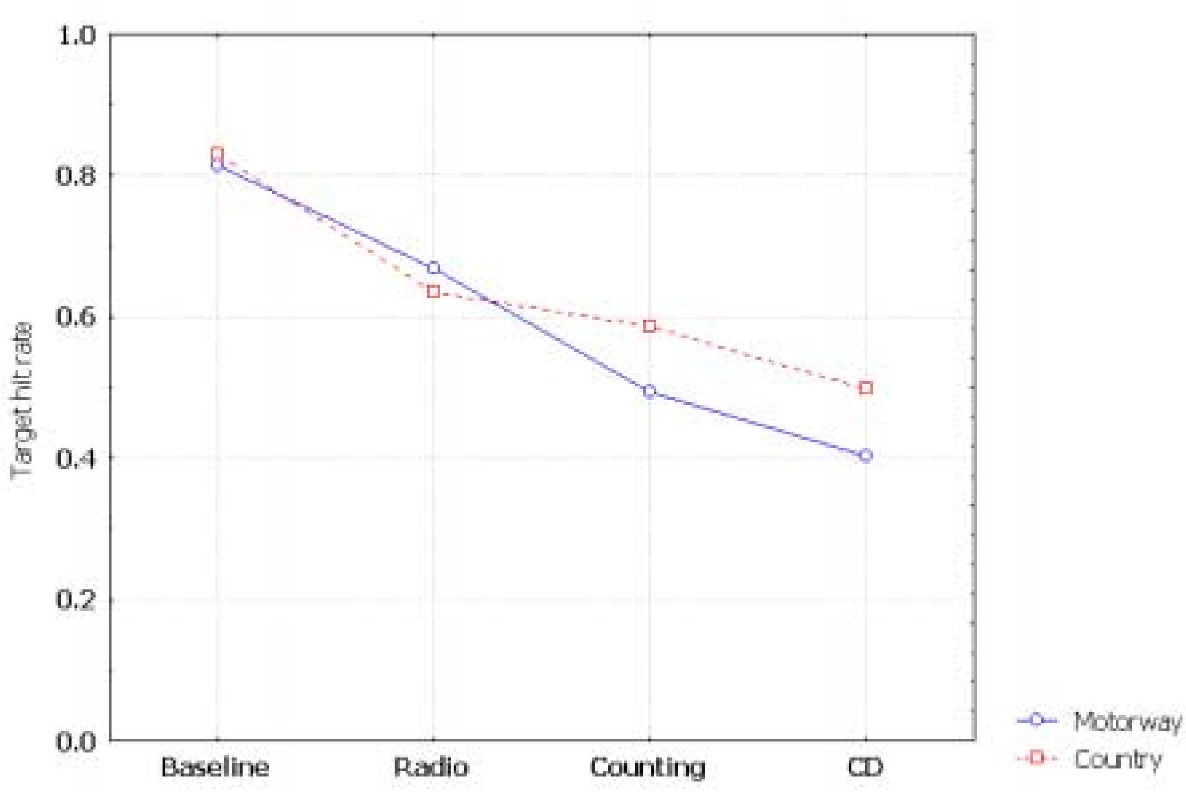

Figure 3. Hit rates for the PDT by task and road.

A Wilcoxon test was used to examine specific task comparisons. Significantly more targets were missed during the three tasks than for the baseline driving on the motorway and country roads. More targets were also missed during the CD task on the motorway than during the radio task ($p < 0.01$, Z = 2.85) and counting task ($p < 0.05$, Z = 2.19). No significant gender differences in PDT hit rates were found.

Table 2. Mean (M) and standard deviation (ST) in PDT hit rates for the different tasks.

Hits per targets	**Baseline M (SD)**	**Radio M (SD)**	**Counting M (SD)**	**CD M (SD)**
Motorway	.81 (.17)	.67 (.19)	.49 (.25)	.40 (19)
Country	.83 (.17)	.64 (.29)	.59 (.32)	.50 (.29)

A significant difference was found in the 0.1 Hz component of heart rate variability across the parked, motorway and country roads [$F(2, 20) = 6.81$; $p < 0.01$]. Post-hoc analysis indicated that there was significantly less mean variability when driving on the country road than when sitting parked (i.e., more mental workload). There were no significant differences found among the mean RSME ratings.

Discussion

The results indicated that the peripheral detection task (PDT) is a sensitive measure of the distraction from in-vehicle tasks while driving on real roads and using a small sample of subjects. The PDT reaction time and hit rate measures revealed significant differences between the different tasks. Mean reaction times were slowest for the backward counting task on the country road. The hit rates were best for the baseline driving on both roads and worst for the CD task.

No significant difference was found between the motorway and the country road for the PDT. Both of the baseline road sections were straight roads with light traffic and good weather. These are situations when a driver should be able to easily detect the PDT targets. Performance should have been optimal and no differences could really be expected in these circumstances. Although the HRV was sensitive to a difference, neither the PDT nor the RSME indicated one.

Sensitivity to different in-vehicle tasks is not the only criterion for a good measure of driver distraction. The measure should also have some construct validity. van Winsum et al. (1999) argues that the PDT has a functional correspondence with potential roadside objects. The location where the stimuli are presented corresponds with the position of pedestrians or road signs. If more PDT targets are missed because the driver is distracted, it may be assumed that under similar circumstances more road signs, pedestrians or other relevant objects may also be missed.

A potential advantage of the PDT is that it might be used to define some absolute criterion for driver distraction. For example, the use of an in-vehicle system must not give PDT hit rates of less than 65% and reaction times slower than 800 ms. Alternatively, a composite of measure of PDT reaction time and hit rate performance could be used (e.g., % hit rate/RT). The challenge will be to establish these ‘unsafe’ PDT performance values.

It is interesting to note the differences in the results between this road study and the simulator studies using the PDT (van Winsum et al., 1999; Burns, et al., 2000). Both of these simulator studies had much higher hit rates (> 95%) and faster reaction times (< 600 ms)on the PDT than for the baselines. This could have occurred because driving the simulator was easier (e.g., less traffic and no rear-view mirrors) and did not involve real hazards.

Another criterion for a good measure of driver distraction is intrusiveness. Does the measure interfere with or change normal driving? This is a difficult question to answer without looking at driving performance with and without the PDT. It certainly adds to driver workload, but from the passenger's perspective it did not seem to have a noticeably bad effect on participants' driving. The participants were asked to provide their opinion of the PDT. All thought it was acceptable to perform while driving. Some found it a bit difficult at the start of their driving, but none considered it too difficult. Others reported having pressed the switch for false alarms such as a red car or traffic light. This is interesting because it shows that there is some correspondence between the PDT targets and real events.

The PDT is also a good tool for measuring driver workload because data collection is fully automated. No additional analysis and data processing are required after the study has been run. Furthermore, the cost of the hardware is negligible with the exception of the data-logging computer.

Some problems with the implementation were found during the trial. The HUD was difficult to see on occasions, especially in bright sunlight. Larger LEDs with a higher intensity should eliminate this problem. Another problem was the difficulty in getting a consistent location of the image for all subjects because it changed with each participant's height and sitting position. A better system for adjusting the alignment of the HUD is required.

In conclusion, the PDT is a good tool for measuring visual distraction and mental workload in a real car. However, more research is needed to validate the use of the PDT across a wider range of driving and in-vehicle tasks. It would also be valuable to include some performance measures when validating the PDT in future research, for example recording vehicle speed and lane tracking.

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