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Driver experience and cognitive workload in different traffic environments

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Abstract

How do levels of cognitive workload differ between experienced and inexperienced drivers? In this study we explored cognitive workload and driver experience, using a secondary task method, the peripheral detection task (PDT) in a field study. The main results showed a large and statistically significant difference in cognitive workload levels between experienced and inexperienced drivers. Inexperienced, low mileage drivers had on average approximately 250 milliseconds (ms) longer reaction times to a peripheral stimulus, than the experienced drivers. It would, therefore, appear that drivers with better training and experience were able to automate the driving task more effectively than their less experienced counterparts in accordance with theoretical psychological models. It has been suggested that increased training and experience may provide attention resource savings that can benefit the driver in handling new or unexpected traffic situations.

Keywords: Cognitive workload; PDT; Driver experience

1. Introduction

Do levels of cognitive workload whilst driving differ between experienced and inexperienced drivers? The idea that an inexperienced operator or, as in this case, an inexperienced driver, would experience higher levels of cognitive workload when operating a machine/system is not new (Sweller, 1993; Sweller et al., 1998; Wickens and Hollands, 2000). It also fits Rasmussen's (1980, 1987) theoretical model of human behaviour. However, showing the extent and importance of the difference between experienced and inexperienced drivers, using objective/quantitative measures is less well explored and is therefore the focus of the present study.

The importance of measuring the workload of non-professional drivers lies in the bigger picture of workload research and the applicability of workload research for drivers with a more 'average' or modest driving experience. We studied experienced, professional drivers, because they would normally have more training and experience than 'average' drivers and therefore, from a scientific point of view, should have less 'noise' in the workload data. However, when generalising workload results, there is a great benefit in knowing the relative 'distance' between experienced and professionally trained drivers and drivers who have little or only modest driving experience but who were not unqualified or novice drivers.

In theoretical terms, Rasmussen (1987) suggested in his model of human control and behaviour (the skill–rule–knowledge-based framework) that during training in a particular task, such as driving, control moves from the knowledge or rule-based levels towards the skill-based level, resulting in the reduction in mental/cognitive workload required for the operations involved in the driving task and, thereby, inherently accommodating a larger amount of available attention that can be allocated to other tasks or operations. The level of available attention the driver has at any given moment is partly dependent on the driver's prioritisation between different tasks, whether primary or secondary. The driver's prioritisation between tasks is intrinsically linked to the aspect of distraction.

The term *driver distraction* implies that drivers do things that are not primarily relevant to the driving task (driving safely) and that this reduces the available attention that would otherwise be needed for driving safely. The problem of driver distraction for traffic safety must, in part, lie in the limitations of human attention resources and how the attention is allocated (prioritised) by humans in their management of the different tasks, whether they are primary-task related (driving) or not. The allocation of

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mental resources, *attention*, is associated to the different levels of driver (cognitive) workload (Wickens and Hollands, 2000; De Waard, 1996; Patten et al., 2004). Workload is defined as the amount of information-processing resources used per time unit, for task performance (Wickens and Hollands, 2000; De Waard, 1996).

In terms of visual search patterns, distinct differences were noticeable between novice and experienced drivers, and especially so in situations that were particularly demanding (Chapman et al., 2002). Chapman and Underwood (1998) suggested that the duration of eye fixation, whilst driving, represents the time spent processing hazard-related information in the road scene. Moreover, newly qualified drivers appeared, in Chapman and Underwood's study, to be more affected by increased complexity than the experienced drivers. Several studies have noted narrower visual search patterns among novice drivers (cf. Chapman and Underwood, 1998; Mourant and Rockwell, 1972; Crundall and Underwood, 1998) but do not explore the element of workload and inexperience as an effect of this narrowed search pattern. These studies have, however, focused more on the lack of skill which are evident when the subjects are untrained novice drivers (cf. Chapman et al., 2002). Mourant and Rockwell's field study (1972) at an early stage clearly differentiated between experienced and novice drivers when studying their visual search patterns. In contrast to the experienced drivers, the novice drivers tended to fixate their gaze to a small area not far ahead of the vehicle. Novice drivers also used their mirrors less frequently, and on the motorway sections made pursuit eye movements whilst the experienced drivers only glanced. Mourant and Rockwell (1972), furthermore, suggest that the visual acquisition process of novice drivers was unskilled and overloaded.

Underwood et al. (2003) in their laboratory study found, inter alia, that experienced drivers had better recall than novice drivers. They also noted that as skill and experience increases, drivers increase their sampling of events from their immediate traffic scene, they also sampled from more locations in their traffic scene. Similar results were reported by Crundall et al. (2003). In a more elaborate and earlier study by Crundall and Underwood (1998), novice and experienced drivers' distribution of visual attention was studied during exposure to different levels of cognitive workload. Crundall and Underwood induced different levels of complexity with different road traffic environments. As with other studies in this field, the main dependent variable was the visual search strategies of the participants. Crundall and Underwood found that experienced drivers select visual strategies according to the complexity of the road traffic environment and that novice drivers' visual search strategies were inflexible to changes in (visual) demand.

Lee and Triggs (1976) found that increased environmental complexity during driving affected the detection of peripherally presented stimuli negatively. Later, Miura (1986, 1999) demonstrated that task demand rather than visual complexity affected eye movement patterns as well as sensitivity to stimuli in the drivers' visual periphery. Chan and Courtney (1993, 1996, 2000) demonstrated that variations in cognitive demand also affect sensitivity in the visual periphery at a constant level of perceptual load in the foveal field. Handy et al.'s (2001) study of perceptual workload and visuocortical processing indicated, inter alia, that increasing foveal target detection, i.e. increasing the visual workload, such as driving in an information-rich environment (e.g. a busy high street with delivery trucks, cyclists, pedestrians, children, crossing traffic, etc., all in close proximity to each other), decreases the residual attention capacity available for allocating to parafoveal stimuli.

The peripheral detection task (PDT) method has been used in several field and high fidelity simulator studies and shown itself to be a sensitive measure of cognitive workload, especially where visual demand is high such as in driving (Martens and Van Winsum, 1999, 2000; Harms and Patten, 2001, 2003; Olsson and Burns, 2000; Patten et al., 2004; Kircher et al., 2004; Crundall et al., 1999). Another advantage of the PDT method is its continuousness. Unlike more traditional reaction time measures (often used for evaluating situation awareness), such as brake-reaction time, they are only really ecologically valid for a few 'situations' because the participants quickly learn that certain 'events' or 'situations' will at some stage pop up. The PDT method in contrast, also by being a secondary task, is in the background throughout the entire experiment. Large quantities of data can be collected and baseline or reference data (within-subject design) are easily included in the experimental design. Furthermore, the measurement of available cognitive resources also provides a more valid reflection of the driving task and its demands on the driver.

1.1. Purpose

The main purpose of this study was to evaluate the effect of driver experience on workload demand using a secondary task method, the PDT, in a real-life driving context. An additional objective of this study was to evaluate the effects of route complexity on the secondary task being used (i.e. PDT) when comparing two driver groups. Here the focus was on the ability of drivers to cope with different levels of additional cognitive or mental workload introduced through primary task complexity variations. In this way, the *competition* over mental attention resources increases as an effect of the level of driver experience and route complexity.

2. Method

2.1. Participants

Participants were recruited from newspaper advertisements and compensated approximately €75 euros (including travel expenses to and from the study site). This compensation was for 1 h of briefing, donning of physiology electrodes, 5–10 min of familiarisation with the study apparatus and approximately 1 h of actual experimentation. A total of 79 participants were recruited for this study with 40 of these participants in the "high mileage", experienced driver group and 39 in the "low mileage", inexperienced group.

The selection criteria for the participants in the 'high mileage', experienced driver group were that they were required to be professional drivers, and had held a professional driver's licence for at least 3 years, aged from 21 to 60 years, a minimum annual mileage of 15,000 km in the last year, and were very familiar with the town where the experiment was held. There were 40 participants who completed the experiment for the high mileage driver group; however, due to incorrect classification of 2 participants and 1 participant who disregarded the task, there were only 37 participants, 29 males and 8 females, who successfully completed the experiment for the 'high mileage' driver group. Their average age was 39.9 years; their age range was from 22 to 59 years; the average annual mileage was 47,200 km. If the participants were not sure about the exact mileage they had to state their estimated minimum annual mileage.

The selection criteria for the participants in the 'low mileage', inexperienced driver group were that they were non-professional drivers, with a maximum estimated annual mileage of 15,000 km and who had little or no experience of driving in Linköping town centre. There were 39 participants who completed the experiment for the high mileage driver group; however, due to incorrect classification of 1 participant, there were only 38 participants who successfully completed the experiment for the low mileage group. There were 20 male and 18 female drivers; their average age was 32.9 years; their age range was from 19 to 56 years; the average annual mileage was 9900 km. These participants were not to be novice drivers (as there are other mechanisms in play when considering workload, etc., such as fundamental vehicle handling skills and also learning rates are likely to be inhomogeneous), merely modestly experienced, low mileage, qualified drivers. This driver group, due to their modest driving habits, had some difficulty in estimating their annual mileage. When in doubt, they were asked to estimate their maximum annual mileage.

Based on the elimination of participants from each group as previously stated, a total of 75 participants were actually used for the subsequent analyses. All participants were Swedes or fluent in the Swedish language. This was important since the audio guidance from the navigation systems used in the study was in Swedish.

2.2. Equipment and materials

An instrumented vehicle was used in this field study; a Volvo 850S, 2.5 l engine, manual gearbox and the model year was 1996. The Volvo, an estate (or station wagon) version was, for the driver, apparently quite ordinary. The driver could not see any of the video cameras mounted in the car; they were concealed and also very small. All of the data collection equipment was in the boot of the Volvo. Data were collected in the vehicle at a rate of 5 Hz and stored in an onboard laptop computer. The vehicle's cruise control was disabled.

The PDT method is an indirect measure of workload and measures cognitive workload by evaluating reaction times to secondary-task stimuli. In this case a visual stimulus was in the form of a light emitting diode (LED), placed in the peripheral area of the driver's line of forward sight. The PDT equipment comprised a display with six red LEDs set in a display panel, a modified micro-switch with increased depression feedback and a computer unit for control, calibration of settings and data logging.

One diode at a time was illuminated, the selection of which was random. The interval between illuminations of the LED signal was between 3 and 5 s, also at random within that range. The period of illumination was a maximum of 2 s unless the participant extinguished the LED signal by depressing the micro-switch. The light signals from the LED were reflected up onto the left-hand side of the windscreen in the form of a head-up display. The PDT LEDs had a light intensity of 8.2 cd, a projection angle of $\pm 3^{\circ}$ and a wavelength of 660 nm (red). The LED reflections appeared approximately 6.8–21.8° left of the centre of the steering wheel and approximately 3.8–5.3° elevated above the car console. The participants' performance was recorded in the form of PDT miss rate and their reaction times in milliseconds (ms). The PDT data were synchronised with all the instrumented-vehicle data (e.g. speed, steering wheel angle, distance travelled, etc.).

For greater generality, we used two navigation systems with equal voice and visual message presentation on different screens. The size and location of the systems used were typical for the navigation systems commonly available on the market. The number of participants between the two systems and the two driver groups was evenly balanced (20 low mileage and 18 high mileage participants used the small system; 18 low mileage and 19 high mileage participants used the large navigation system). Both systems gave exactly the same auditory guiding information and used the same digital map information. The main differences between the two navigation systems were that the 'small' system, a VDO Dayton MS4200, had a smaller, monochrome display and only basic indicator shapes for roads and intersections for route guidance and was placed in the car audio rack. The 'large' system, a VDO Dayton MS5000, had a colour monitor with larger route and driving information available. Their position in the vehicle was also different. Fig. 1 shows the two navigation systems as installed in the instrumented vehicle.

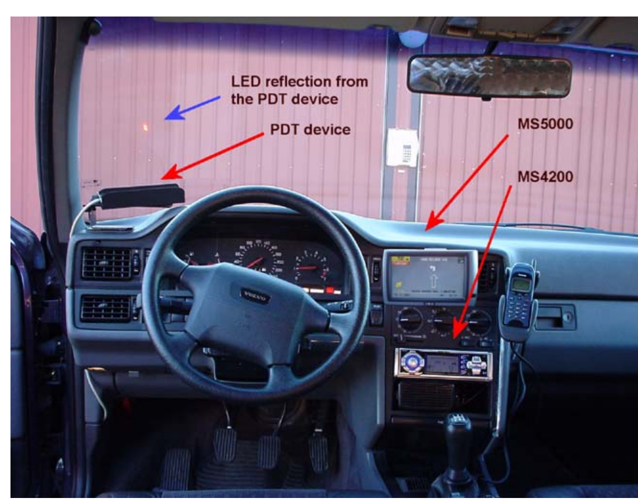

Fig. 1. An interior view of the instrumented vehicle. The two navigation systems are pointed out with arrows (MS4200 and MS5000). The PDT is also visible on the left-hand side of the windscreen. During the experiments only one navigation system was installed at a time.

Note, however, that during the experiment, only one navigation system was installed and operational at a time.

The small navigation system was positioned 36 cm to the right of the centre of the steering wheel (horizontally), and 21 cm below the centre of the speedometer (vertically). The screen was turned 7° horizontally and 18° vertically to the driver. The large navigation system was positioned 32 cm to the right from the centre of the steering wheel (horizontally), and 4 cm below the centre of the speedometer (vertically). The screen was turned 7° horizontally and 5° vertically to the driver. The vertical distance between the two navigation systems was 17 cm. All distance measurements relate to the centre of the screen of the navigation systems.

2.3. Procedure and design

All participants were instructed about the experiment and signed informed-consent forms regarding their liability and responsibilities when driving. Video footage consent forms were procured post-experimentally.

The participants were further instructed to drive as they would 'usually' do, but to keep in mind their legal responsibilities regarding traffic violations. The participants were prepared with physiology electrodes prior to driving (not reported). Training was also provided for the PDT. All adjustments of seats, mirrors, cabin temperature and seat belts were done before leaving the Swedish National Road and Transport Research Institute (VTI) garage. This familiarisation phase typically took about 5–10 min. Finally, the participants were instructed to prioritise the driving task first and respond to the light signals of the PDT diodes second.

Throughout the entire journey, a VTI technician was present in the test vehicle, sitting behind the driver. His role was to coordinate the navigation route inputs, to follow the design protocol, to attach electronic markers to the vehicle data at predetermined points, to administer the NASA-RTLX subjective workload protocols and to deal with any problems. The participants were instructed to have no contact with the technician during the driving task.

The PDT was used in this study to evaluate the participants' workload whilst driving. The PDT task required the participants to react to a light stimulus (the LED) that appeared in the participants' periphery (in respect to the main driving focal point—straight ahead) and the light stimulus was illuminated for 2 s. The participants reacted by depressing the micro-switch attached to the left index finger. The LED is, upon depression, subsequently extinguished. If the response was classified as 'correct' (response within 2 s) the reaction time was recorded in milliseconds, otherwise the response was recorded as a late or missed response.

The use of navigation systems, per se, was a means to an end and not a primary objective in itself. The automated driving instruction provided by the navigation system provided us with the means to create an equal task, in its structure, for the two driver groups with a realistic (driving) task for the participating drivers. The drivers had no prior knowledge of the planned test route. The participants received visual and auditory route guidance instructions from only the navigation system.

The route was 8.6 km long and extended from the western periphery to the centre of the town of Linköping, which has about 130,000 inhabitants. The selected urban environment consisted of sections with low to high complexity and the drive took approximately 40 min to complete. This included stops for NASA-RTLX and navigation system programming but did not include time for familiarisation which was done prior to departure. The weather conditions ranged from sunny to rainy; however, the roads were never icy or snowy. The speed limit was 50 km/h along the whole route.

The taxonomy by Fastenmeier (1995) was used to define and select road sections with a certain complexity. Each high/high complexity section had at least five turns which were considered to have high demands on information processing and high demands on vehicle handling, hence the term high/high. A simplified description of the three levels of route complexity used in this study is provided below.

The classification of route complexity:

(1) High demands on information processing/high demands on vehicle handling (high/high complexity): typical examples from this group of situations occur when driving within city centre environments.
(2) High demands on information processing/low demands on vehicle handling (high/low) and low demands on information processing/high demands on vehicle handling (low/high) (medium complexity): typical examples from this group of situations occur at intersections regulated by road signs and where the driver has right of way, and at intersections regulated by traffic lights.
(3) Low demands on information processing/low demands on vehicle handling (low/low complexity): typical examples from this group of situations occur in urban and rural areas and on motorways where 'free driving' is possible.

There were five stops on the route, where the technician programmed the next destination in the navigation systems. During the stops, which took approximately 25 s each, the drivers were asked not to look at the navigation system screen, to prevent them from seeing the next destination. The route included two high/high complexity sections, three medium and two low/low complexity sections. The order of the route complexity was low/low, medium, high/high, medium, high/high, medium and low/low with the participants returning to their point of departure, i.e. the VTI garage. Stop number 1 was after approximately 1800 m, stop 2 was after approximately 2500 m, stop 3 was after approximately 4300 m, stop 4 was after approximately 5100 m and stop 5 was after approximately 5900 m. The final stop was at the journey's point of origin. The location of these stops was dictated by the need to reprogram the GPS guided navigation system in order to facilitate an exact adherence to the planned route.

The study's setup comprised a 2×3 experimental design (two driver groups and three levels of route complexity). The dependent variables reported in this study were PDT reaction times and

PDT miss rates. The independent variables were driving experience (two groups) and traffic environment complexity (three levels). The route, which was a circuit in a real city centre, comprised seven segments (low/low, medium, high/high, medium, high/high, medium and low/low) and to counter the order of route complexity, the seven segments were condensed into their respective levels of route complexity. The distances travelled for each level of route complexity were all approximately equal.

3. Results

The sections of road where the drivers inadvertently left the designated route were excluded from the analyses; they were few in number and short in duration and did not affect the overall data. The parts where the driver was stopped in order to reprogram the navigation system were also excluded from the analyses. After resuming the drive after such a stop, 2 s of data were excluded, since this time was needed by the driver to regain normal cruising speed.

The PDT reaction times and the PDT miss rates are in a sense two sides of the same coin. Therefore, any individual miss rate greater than two-thirds on a route complexity section (66%) was deemed to involve a potential bias for the corresponding PDT reaction time. These particular PDT reaction times were therefore omitted from the analysis to avoid potential biases in the reaction time results. The corresponding miss rate values were, however, retained.

The main results of the study are shown in Figs. 2 and 3. In Fig. 2, there is a clear and statistically significant effect of the relative level of driver experience on the PDT reaction times. Low mileage drivers had on average approximately 250 ms ($\bar{X} = 245.67$ ms) longer reaction times than the high mileage drivers. All statistical analyses were performed using a standard SPSS (11.0) software package.

The analysis of variance between the two navigation systems (small and large) for traffic environment complexity was not significant; the low/low traffic environment complexity PDT reaction times and PDT miss rates, respectively ($F_{(1,73)} = 1.168$, p = n.s.; $F_{(1,73)} = 0.788$, p = n.s.); the medium traffic environment complexity PDT reaction times and PDT miss rates, respectively ($F_{(1,71)} = 0.013$, p = n.s.; $F_{(1,73)} = 0.105$, p = n.s.); the high/high traffic environment complexity PDT reaction times and PDT miss rates, respectively ($F_{(1,72)} = 0.47$, p = n.s.; $F_{(1,73)} = 0.212$, p = n.s.). The data sets for the navigation systems were condensed into one set for the following analyses. These results were also consistent with a previous, unpublished study using the same type of navigation systems (Kircher et al., unpublished).

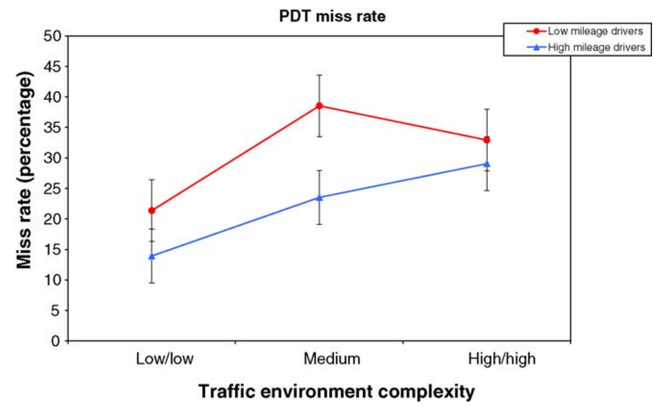

Fig. 3. A line chart, including standard error of mean bars, illustrating the mean PDT miss rate, as a percentage rate, over three levels of traffic environment complexity and for two driver groups.

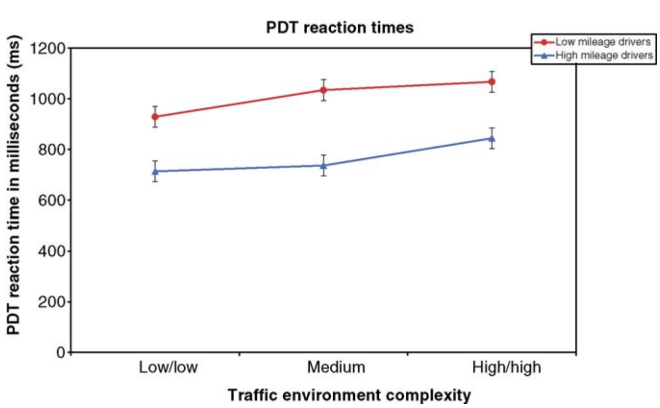

Fig. 2. A line chart, including standard error of mean bars, illustrating the mean PDT reaction times over three levels of traffic environment complexity and for two driver groups. The reaction times are in milliseconds (ms).

For the PDT reaction times, the main effect of traffic environment complexity was significant in a 2 × 3 repeated ANOVA ($F_{(2,142)} = 41.683$, $p < 0.001$). Mauchly's test of sphericity was not significant; therefore, the univariate results are reported. The main effect of driver experience (high mileage and low mileage driver groups) was also significant ($F_{(1,71)} = 56.944$, $p < 0.001$). The traffic environment complexity by driver experience interaction was significant ($F_{(2,142)} = 3.694$, $p = 0.027$).

In post hoc analysis, using the Bonferroni approach (α/c), to control the familywise error rate (FW), α decreased from 0.05 to 0.008 (FW = 0.05/6 = 0.0083). The analysis of the effect of route complexity (cf. Fig. 2) used paired t-test analyses on the PDT reaction time measure of cognitive workload. We interestingly found that the difference in the mean PDT reaction times between low/low and medium traffic environment complexity was statistically significant for the low mileage drivers ($t = -3.991$, d.f. 37, $p < 0.001$), but not for the experienced drivers ($t = -1.895$, d.f. 34, p = n.s.). The difference in mean PDT reaction times between the medium complexity and the high/high complexity route sections was, however, significant for the experienced driver group ($t = -6.572$, d.f. 34, $p < 0.001$), but not for the low mileage drivers ($t = -1.567$, d.f. 37, p = n.s.). The difference between the low/low and the high/high complexity traffic environments was significant for the low mileage drivers ($t = -5.443$, d.f. 37, $p < 0.001$) and for the experienced drivers ($t = -8.613$, d.f. 35, $p < 0.001$). The mean and standard deviation values are reported in Table 1 for the respective driver groups and the three levels of traffic environment complexity.

In additional post hoc analysis of the driver groups for PDT reaction times, using the Bonferroni approach (α/c), to control the familywise error rate, α decreased from 0.05 to 0.017 (FW = 0.05/3 = 0.017). The difference between the mean PDT reaction time for low mileage drivers (929 ms) and high mileage

Table 1
Mean and standard deviation values for the PDT reaction times (PDTms) and miss rates (missed PDT responses) for the respective mileage groups and traffic complexity conditions (low/low, medium and high/high)

Mileage groups	PDTms			Missed PDT response		
	Low/low	Medium	High/high	Low/low	Medium	High/high
Low mileage drivers						
Mean	928.986	1034.432	1067.135	0.214	0.385	0.329
N	38	38	38	38	38	38
Standard deviation	179.848	182.347	191.165	0.143	0.128	0.155
High mileage drivers						
Mean	713.313	736.322	844.477	0.139	0.235	0.291
N	37	35	36	37	37	37
Standard deviation	132.254	124.028	136.956	0.105	0.179	0.169
Total						
Mean	822.587	891.503	958.815	0.177	0.311	0.310
N	75	73	74	75	75	75
Standard deviation	190.960	216.423	200.175	0.130	0.171	0.163

drivers (713 ms) in the low/low complexity traffic environment was statistically significant ($F_{(1,73)} = 34.852, p < 0.001$). The difference between the mean PDT reaction time for low mileage drivers (1034 ms) and high mileage drivers (736 ms) in the medium complexity traffic environment was statistically significant ($F_{(1,71)} = 65.568$, $p < 0.001$). The difference between the mean PDT reaction time for low mileage drivers (1067 ms) and high mileage drivers (844 ms) in the high/high complexity traffic environment was also statistically significant ($F_{(1,72)} = 32.852$, $p < 0.001$).

In Fig. 3, there is also a clear effect of the level of driver experience on the mean PDT miss rate. The main effects of traffic environment complexity and driver experience were statistically significant as shown in the following analyses.

For the PDT miss rates, Mauchly's test of sphericity was significant and therefore the Pillai's Trace multivariate results were reported. The main effect of traffic environment complexity was significant (Pillai's Trace = 0.648, $F_{(2,72)} = 66.283$, $p < 0.001$). The main effect of driver experience (high mileage and low mileage driver groups) was also significant ($F_{(1,73)} = 7.688$, $p = 0.007$). The traffic environment complexity by driver experience interaction was significant (Pillai's Trace = 0.354, $F_{(2,72)} = 19.687$, $p < 0.001$).

In post hoc analysis, using the Bonferroni approach (α/c), to control the familywise error rate, α was moved (FW = 0.05/6 = 0.0083). In the paired t-test analyses of the effect of route complexity (cf. Fig. 3), using the PDT miss rate as the primary measure, we found that the difference in the mean PDT miss rates for the low mileage drivers was statistically significant between low/low and medium traffic environment complexity ($t = -10.531$, d.f. 37, $p < 0.001$), and between medium and high/high ($t = 6.770$, d.f. 37, $p < 0.001$). The differences in the mean PDT miss rates for the high mileage drivers were also statistically significant between low/low and medium ($t = -5.467$, d.f. 36, $p < 0.001$), and between medium and high/high ($t = -3.379$, d.f. 36, $p = 0.002$).

In additional post hoc analysis of the driver groups for PDT miss rates, using the Bonferroni approach (α/c), to control the familywise error rate, α decreased from 0.05 to 0.017 (FW = 0.05/3 = 0.017). The difference between the mean PDT miss rates for low mileage drivers (21%) and high mileage drivers (14%) in the low/low complexity traffic environment was statistically significant ($F_{(1,73)} = 6.608, p = 0.01$). The difference between the mean PDT miss rates for low mileage drivers (39%) and high mileage drivers (24%) in the medium complexity traffic environment was statistically significant ($F_{(1,73)} = 17.575$, $p < 0.001$). The difference between the mean PDT miss rates for low mileage drivers (33%) and high mileage drivers (29%) in the high/high complexity traffic environment was not statistically significant ($F_{(1,73)} = 1.064$, p = n.s.).

4. Discussion

The main results of this study showed a large and statistically significant difference in the cognitive workload between the two driver groups. The differences in mean PDT reaction times between the two driver groups were significant for each of the road sections (low/low, medium and high/high). Low mileage drivers had approximately 250 ms longer mean reaction times than the high mileage drivers.

An interesting aspect of the PDT reaction time data was that the low mileage drivers' reaction time performance did not significantly differ when comparing performance between the medium and the high/high traffic environment complexity sections. The high mileage drivers' performance did, however, noticeably deteriorate from the medium to the high/high traffic environment complexity. Moreover, the opposite of this situation is found for the two driver groups from the low/low to the medium complexity sections. A possible explanation of this pattern in the PDT data is that the high mileage drivers generally had a better ability to chunk information and decrease their levels of cognitive workload and also experienced the low/low and medium sections as having a relatively similarly low workload burden. The high/high complexity was, however, noticeably more taxing for the experienced drivers. When comparing the two driver groups, it is evident that the high mileage drivers' level of cognitive workload is much less in all of the traffic complexity sections than the low mileage drivers.

This shows how drivers with better training and experience are able to automate their driving more effectively than their less experienced counterparts. Ipso facto, the more experienced drivers had more available mental resources that could be allocated to peripheral information. In line with this, the visual/cognitive tunnelling effect appears to be greater for the less experienced, low mileage driving group when directly compared to the experienced drivers doing the same task.

The size and location of the navigation systems used did not significantly add to the level of complexity when driving in this study, as also was the case in an earlier, unpublished report using the same type of navigation systems (Kircher et al., unpublished). The data sets for the two navigation systems were therefore condensed into one set for the main analyses. The auditory guidance information from the navigation systems was identical, thus suggesting that the participants focused primarily on the auditory information provided. The visually displayed information was secondary and had a supportive or strengthening function for the auditory conveyed information. This would explain, in part, the lack of differences found between the two navigation systems used in this study.

When drawing on theory (cf. Rasmussen, 1980, 1987) it leads us to verification of the view that increased experience reduces the driver's mental workload. This may be especially so for novice drivers in the process of learning to drive, when everything that is required for driving safely has to be acquired cognitively (formal and informal rules, traffic scenarios, etc.) and as motor skills (vehicle handling, controls, etc.). However, even experienced drivers will experience greater cognitive workload when encountering new situations (e.g. driving in new cities in foreign countries). This study, using objective or quantitative cognitive workload measures, supports this theoretical conjecture on workload and experience. Additionally, with respect to the PDT method and the use of reaction times, it is important to be able to map the relative difference or distance in reaction times between well-trained and experienced drivers with more modestly experienced, average drivers. Such knowledge will have consequences for analyses of accidents in which attention failures played a role, illustrating the applicability of PDT data in traffic research.

The results of this study are also in line with the view that there are safety benefits to be gained for drivers in maintaining a regular level of driving experience. This is because training and experience reduce the driver's cognitive workload and increase the level of available attention resources where limitations of attention resource allocation are dimensional for the human capability for safe driving (cf. Broadbent, 1958, 1982; Baddeley, 1976; Wickens and Liu, 1988; Debecker and Desmedt, 1970; Wickens and Hollands, 2000).

The NASA-RTLX results were inconclusive with no significant differences. The indices were not sensitive enough in the present study to measure changes or differences in cognitive workload. It is possible that more frequent ratings or another, perhaps simpler subjective workload index, may have been more effective.

The PDT miss rate data are an indication of the quality of the corresponding reaction time data. Where there is a PDT miss, there will be no PDT reaction time for that particular stimulus. There is usually a certain percentage of missed stimuli for each participant, depending on the complexity of the primary task, and this is reflected in the mean PDT miss rate. With correct responses to the PDT stimulus, the reaction times are recorded and reflected as a mean PDT reaction time for the respective condition and participant. However, if there is a very large number of misses, the mean reaction time will comprise of a smaller number of correct responses. This could lead to biases in the data for that participant and condition. Therefore, we deemed it prudent to have a cut-off point for the mean PDT reaction time data for a traffic complexity section, whose corresponding miss rate data were greater than two-thirds (66%). The miss rate data were, however, retained because an increase in the PDT miss rate is also an indication of the reduction in the drivers' available attention in the different experimental conditions.

In future research, it would be of great interest to observe inexperienced, low mileage drivers and also novice drivers under longer periods of high workload where a waning of cognitive resources may well occur more rapidly. This intermittent level of driving experience, i.e. where manual driving skills are relatively developed but experience of driving and development of rule-based strategies for traffic scenarios are less well developed, is of interest for driver-training professionals, licensing authorities and accident epidemiologists.

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References

Baddeley, A.D., 1976. The Psychology of Memory. Basic Books, New York.

Broadbent, D.E., 1958. Perception and Communication. Pergamon, London.

Broadbent, D.E., 1982. Task combination and selective intake of information. Acta Psychol. 50, 223–290.

Chan, A.H.S., Courtney, A.J., 1993. Effects of cognitive foveal load on a peripheral single-target detection task. Percept. Mot. Skills 77, 515–533.

Chan, A.H.S., Courtney, A.J., 1996. Foveal acuity and search performance: a review. Int. J. Ind. Ergon. 18, 113–119.

Chan, A.H.S., Courtney, A.J., 2000. Effects of object size and inter-object spacing on peripheral object detection. Int. J. Ind. Ergon. 25, 359–366.

Chapman, P., Underwood, G., 1998. Visual search of driving situations: danger and experience. Perception 27, 951–964.

Chapman, P., Underwood, G., Roberts, K., 2002. Visual search patterns in trained and untrained novice drivers. Transportation Res. Part F 5, 157–167.

Crundall, D.E., Underwood, G., 1998. Effects of experience and processing demands on visual information acquisition in drivers. Ergonomics 41 (4), 448–458.

Crundall, D., Chapman, P., Phelps, N., Underwood, G., 2003. Eye movements and hazard perception in police pursuit and emergency response driving. J. Exp. Psychol. 9 (3), 163–174.

Crundall, D., Underwood, G., Chapman, P., 1999. Peripheral detection rates in drivers. In: Gale, A., et al. (Eds.), Vision in Vehicles VII. Elsevier Science Publishers, Amsterdam, pp. 261–269.

Debecker, J., Desmedt, J.E., 1970. Maximum capacity for sequential one-bit auditory decisions. J. Exp. Psychol. 83 (3), 366–372.

De Waard, D., 1996. The measurement of drivers' mental workload. Ph.D. Thesis. University of Groningen, Traffic Research Centre, Haren, The Netherlands.

Fastenmeier, W. (1995). Die Verkehrssituation als Analyseeinheit im Verkehrssystem. In: Fastenmeier, W. (Hrsg.), Autofahrer und Verkehrssituation. Verlag TÜV Rheinland, Köln, pp. 27–78.

Handy, T.C., Solitani, M., Mangun, G.R., 2001. Perceptual load and visuocortical processing: event-related potentials reveal sensory-level selection. Psychol. Sci. 12 (3), 213–218.

Harms, L., Patten, C., 2001. Measuring distraction from navigation instructions in professional drivers—a field study with the peripheral detection task. In: Proceedings from 9th International Conference of Vision in Vehicles, Brisbane. Elsevier Science Ltd., Exeter.

Harms, L., Patten, C., 2003. Peripheral detection task as a measure of driver distraction. A study of memory-based versus system-based navigation in a built-up area. Transportation Res. Part F 6, 23–36.

Kircher, A., Östlund, J., Patten, C., Nilsson, L. PDT as a Workload Measure in Driving—The Swedish Experience, unpublished report.

Kircher, A., Törnros, J., Vogel, K., Nilsson, L., Bolling, A., Patten, C., Malmström, T., Ceci, R., 2004. Mobile Telephone Simulator Study. VTI Meddelande 969A, Linköping.

Lee, P.J.N., Triggs, T.J., 1976. The effect of driving demand and roadway environment on peripheral visual detections. In: ARRB Proceedings, vol. 8. ARRB, Australia, pp. 7–12.

Martens, M., Van Winsum, W., 1999. Activation Criteria and Warning Strategies: Driving Simulator Results. IN-ARTE Project (TR4014), ID 7.1. TNO Human Factors Research Institute, Soesterberg, unpublished technical report.

Martens, M., Van Winsum, W., 2000. Measuring Distraction—The Peripheral Detection Task. TNO Human Factors Research Institute, Soesterberg, www-nrd.nhtsa.dot.gov/departments/nrd-13/driver-distraction/PDF/34.PDF.

Miura, T., 1986. Coping with situational demand: a study of eye movements and peripheral vision performance. In: Gale, A., et al. (Eds.), Vision in Vehicles. North Holland, Amsterdam, pp. 205–217.

Miura, T., July 1999. Behaviour orientated vision: the two dimensional and three dimensional attention characteristics. In: The Sixth ATR Symposium on Face and Object Recognition. ATR, pp. 43–44.

Mourant, R.R., Rockwell, T.H., 1972. Strategies of visual search by novice and experienced drivers. Hum. Factors 14, 325–335.

Olsson, S., Burns, P., 2000. Measuring driver visual distraction with a peripheral detection task. In: NHTSA Driver Distraction Forum on the World Wide Web., www-nrd.nhtsa.dot.gov/departments/nrd-13/driver-distraction/PDF/6.PDF.

Patten, C.J.D., Kircher, A., Östlund, J., Nilsson, L., 2004. Using mobile telephones: cognitive workload and attention resource allocation. Accid. Anal. Prev. 36, 341–350.

Rasmussen, J., 1980. What can be learnt from human error reports? In: Duncan, K., Gruneberg, M., Wallis, D. (Eds.), Changes in Working Life. John Wiley & Sons, Chichester.

Rasmussen, J., 1987. Cognitive control and human error mechanisms. In: Rasmussen, J., Duncan, K., Leplat, J. (Eds.), New Technology and Human Error. John Wiley & Sons, Chichester.

Sweller, J., 1993. Some cognitive processes and their consequences for the organisation and presentation of information. Aust. J. Psychol. 45, 1–8.

Sweller, J., van Merrienboer, J.J.G., Paas, F.G.W.C., 1998. Cognitive architecture and instructional design. Educ. Psychol. Rev. 10, 251–296.

Underwood, G., Chapman, P., Berger, Z., Crundall, D., 2003. Driving experience, attentional focusing, and the recall of recently inspected events. Transportation Res. Part F 6, 289–304.

Wickens, C.D., Hollands, J.G., 2000. Engineering Psychology and Human Performance, third ed. Prentice Hall, Upper Saddle River, NJ.

Wickens, C.D., Liu, Y., 1988. Codes and modalities in multiple resources: a success and a qualification. Hum. Factors 30, 599–616.