DISTRACTION AND WORKLOAD
DRIVING ON THE A10 RING ROAD AROUND AMSTERDAM

Marika Hoedemaeker, Jeroen Hogema, Jasper Pauwelussen
TNO Human Factors
Kampweg 5, 3769 DE Soesterberg
Phone: +31 346 356 262
Marika.hoedemaeker@tno.nl

ABSTRACT

A simulator study was performed to establish the effects of motorway environment complexity on driver distraction and workload. In this study environment complexity refers to the visual complexity of static objects on or next to the road and in its vicinity (e.g. traffic signs, buildings, advertisements…). It does not include traffic density or traffic state. It was hypothesized that a complex road environment attracts attention of the driver more than a simple environment and therefore leads to a higher driver workload.

We compared two situations that represented the extremes regarding environment complexity (simple versus complex) of the A10 ring road around Amsterdam, which has been modelled in the simulator based on a photographic realistic representation. We concluded that although the simple and complex version of the A10 ring road differed substantially in environment complexity, no effects on workload were found as measured by objective secondary task measures. It appeared that participants were able to neglect distraction by the visual complex environment and that environmental complexity does not directly influence workload.

KEYWORDS
Driving simulator, environment complexity, distraction, workload, secondary task, Peripheral Detection Task (PDT)

INTRODUCTION

There are many external factors that influence the workload of a driver (see [1]):

- Macro traffic circumstances, like traffic density, intensity and speed.
- Micro traffic circumstances, like manoeuvring (e.g. overtaking), regulating (e.g. time headway). These factors are influenced by the driver, but are also forced by the other traffic participants.
- Weather, sight and road surface circumstances.
- Features of the road, like number and width of driving lanes, road markings and road environment.

The work presented here focuses on environment complexity. This term refers to static elements on or above the road (e.g., signs, gantries, dynamic route information panels), directly adjacent to the road (road furniture, advertisements), or near the road but still in the field of view of drivers (e.g. buildings). The environment complexity does not encompass traffic density or traffic conditions: these factors were kept constant in our study.

The factor environment complexity (simple versus complex environment) was also studied by Horberry et al. [2]. They reported that subjective workload did not differ between simple and
complex environments. Only elderly drivers (> 60 years) showed effects in their driving behaviour: they decreased their speed when driving through a complex environment.
Patten et al. [3] studied the effect of route complexity by using the Peripheral Detection Task (PDT). The used a classification of route complexity that was based on task demand in terms of information processing and vehicle handling, distinguishing among three complexity levels (low, average, high). Besides complexity, the influence of driving experience was studied. A higher complexity was found to be related to longer reaction times. Inexperienced drivers did not show differences between average and high complexity, while experienced drivers did not show differences between low and average complexity.

According to [4] distraction and mental workload are strongly related, but they are not the same. Performance motivation and task engagement influence performance and consequently distraction but not workload; environment complexity and driver state influence mental workload but not distraction.

The current study focuses on the effects of environment complexity by comparing a simple and a complex version of the same road in terms of driver workload. A complex road environment presents a cluttered world full of information from which the driver has to distract the information necessary for this safe and efficient driving task. To be able to do this he has to suppress possible distraction from the non driving task related information, which increases his workload. It is hypothesized that a complex road environment attracts attention of the driver more than a simple environment and therefore leads to a higher driver workload. Performance on secondary tasks will be the main measure of workload.

METHOD

To allow full control over the elements in the environment, we performed our study in the high-fidelity moving base driving simulator of TNO Human Factors (see Figure 1).

![Figure 1 The TNO driving simulator.](image)

In the driving simulator, the participant was seated in a BMW 318i mock-up with automatic transmission, which was placed on a motion base with six degrees of freedom. The participant watched a large radial screen in front of the mock-up and two flat screens behind the mock-up on which the road and traffic environment was projected. An additional 34” LCD display was mounted in the rear of the mock-up to display the central rear view. The original mirrors were
used to let the subject look at the rear displays. The front projection had a field of view of 180° horizontal and 35° vertical. Also the sound of traffic in the environment and the sound of the car the participant was driving were presented.

In this driving simulator study, two versions of the same part of the A10 ring road around Amsterdam were compared. Data files describing the road geometry of the actual road were provided by the Ministry of Transport, Public Works and Water Management for this purpose.

1. A complex version, in which all traffic signs, variable message signs (VMS), Dynamic Route Information Pannels, Road furniture and buildings were realistically modelled based on real-life photography. Also road geometry, lane markings, guard rails and connecting roads were modelled (see Figure 2).

2. A simple version, in which all the above was taken away except for the road geometry, lane markings, guard rails and connecting roads (see Figure 3).

Figure 2 Impression of the complex version of the A10 in the TNO driving simulator.

Figure 3 Impression of the simple version of the A10 in the TNO driving simulator.
In the second part of the complex condition, a Work In Progress situation was added to further increase the workload of the traffic environment (see Figure 4). On this section all traffic was directed to the right lane, with a speed limit of 90 km/h; a barrier was placed on the left of the remaining lane, thus increasing the load of the lane keeping task.

The combinations of environment complexity and segment are summarised in Table 1

<table>
<thead>
<tr>
<th></th>
<th>Segment 1 (4.8 km)</th>
<th>Segment 2 (2.0 km)</th>
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<tbody>
<tr>
<td><strong>simple</strong></td>
<td>low environment complexity</td>
<td>low environment complexity</td>
</tr>
<tr>
<td><strong>complex</strong></td>
<td>high environment complexity</td>
<td>high environment complexity + Work in Progress</td>
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</table>

Figure 4 Work In Progress in the complex condition in the TNO driving simulator.

In both versions of the environment, traffic density was kept the same. The other traffic was driving with an average speed of 100 km/h, with slight fluctuations and with a high traffic density (all lanes were occupied). The goal of the other traffic was to give the participants hardly any chance to increase their speed above 100 km/h or to change lanes. The vehicles of the other traffic maintained a headway of 1 second with respect to the participant and with respect to each other. In this way we prohibited the participants to compensate for a higher workload by adapting their driving behaviour and we would keep the behaviour of the participants as comparable as possible (same speed, same driving lane). Only in the kilometre before the Work In Progress, where all traffic had to merge into the right lane, the speed decreased to 90 km/h.
Secondary tasks
Two secondary tasks were applied in this study, varied between participants.

- Peripheral Detection Task (PDT).
  This task was developed by TNO [5] [6]. The method has shown to be very sensitive for variations in workload caused by different driving situations. According to [4], the Peripheral Detection Task can be used for assessing distraction, because distraction affects readiness to respond and event detection, which are also important aspects of driving performance. The PDT hardly interferes with the performance of the primary driving task. The task functioned as follows: Participants wore a headband with a small LED light, mounted such that the LED was to the left and above the left eye, without obstructing the view of the participant on the road (see Figure 5). The stimulus (onset of the red led light) had an interval time of 3 to 5 seconds from the start of the previous stimulus. Participants were instructed to press a micro switch that was attached to the index finger of the dominant hand as soon as they saw the stimulus. The stimulus was presented for 1 second maximum and disappears as soon as the participant pressed the switch.

- Digit task.
  The digit task was a visual detection task based on [7]. By default, a neutral stimulus ‘00’ was presented on a display. Participants had to detect the target stimulus ‘99’. The numbers on the display were each 18mm high and 11 mm wide. The stimulus had an interval time of 3 to 8 seconds from the start of the previous stimulus. The stimulus is presented for 2 seconds maximum and disappears as soon the participant presses a small finger switch. The display was deliberately positioned such that the participants had to take their eyes off the road to be able to see what was on the display. To this end the display was placed on the ground of the car in front of the passenger seat, which was about 50° to the right and 45° down from the normal (straight ahead) viewing direction of the driver (see Figure 5). The response mechanism was the same as for the PDT, i.e., pressing a micro switch on the index finger of the dominant hand.

Figure 5: driver in the simulator wearing the PDT headband (left); monitor for the digit task (right).
The PDT as well as the digit task are visual detection tasks. The important difference between the tasks is that the PDT stimulus is always visible in the peripheral field of view of the driver, while the stimulus of the digit task can only be detected when the participant is actually looking (i.e. taking his eyes off the road). The digit task could be more suitable to measure ‘spare capacity’ because of the necessity to look away. This digit task might at the same time more interfering with the primary driving task.

Dependent variables
Workload of the participants was measured with secondary task performance measures, subjective measures and driving behaviour measures. The performance on these secondary tasks gives an indication of the spare capacity of the driver. Good performance means more resources left to be able to perform the task well and therefore a lower workload of the primary driving task compared to less well performance.

1. Secondary task measures
The performance measures on the secondary tasks consisted of the average reaction time and the percentage of missed stimuli.

2. Subjective measures
The Rating Scale Mental Effort (RSME) [8] is a one-dimensional scale ranging from 0 to 150. There were 9 verbal labels on the scale ranging from absolutely no effort to extreme effort. The position of these labels on the scale was such, that distances between labels reflect relative magnitude of the intervals. Participants give their rating by putting a mark on this scale indicating how effortful their task was. Compared to other techniques of measuring mental workload the RSME has been shown to be one of the more sensitive measures [9].

These measures give an indication of the amount of objective risk that is taken during different driving situations. Behavioural measures also provide insight in the way drivers might compensate for experienced workload (for instance because of performing a secondary task). Driving behaviour is therefore the result of a certain level of workload than the workload itself.
The behavioural measures were:
- average time headway (s)
- standard deviation of the lateral position (SDLP, m)

In total, 45 drivers participated in the experiment. They all had a driving experience of at least 5 years with more than 20,000 kilometres per year. Their ages varied between 25 and 60.

The following factors were included in the design.
- Environment complexity with two levels: simple and complex (varied within subjects).
- Segment with two levels: part 1 and part 2, varied within subjects. (Note that road works were present only in the part 2 of the complex environment).
- Secondary task with two levels: with and without secondary task as within subjects variable.
- Type of secondary task with two levels: PDT and digit task. This factor was varied between subjects.
Participants were instructed to drive swiftly (but safely). They were explicitly told to keep up with the other traffic and to avoid very large headways. This was done to create a setting where the driving task was considered as the primary task, thus providing the best possible situation for the secondary task measures to show effects of environment complexity. Before starting the actual experiment, the performance on the secondary tasks was measured in a baseline condition (i.e. while seated in the driving simulator, but standing still). Next, four experimental runs were conducted: simple and complex environment, combined with the factor secondary task (with and without). These four conditions could be presented in 16 possible orders. These were balanced over subjects. After the last experimental run, another baseline measurement for the secondary task was done.

RESULTS

Performance on secondary tasks

Reaction time
Average reaction time showed a significant effect of baseline versus driving \([F(1,43)=265.5, p<0.001]\). The averages were: 368 ms for baseline and 753 ms for driving. Also a significant effect of type of task was found \([F(1,43)=70.2, p<0.001]\). Averages: 430 ms PDT and 691 ms digit task. The interaction between both independent variables was also significant \([F(1,43)=102.9, p<0.001]\) (see Figure 6). A Tukey test on this interaction showed the following:
In the baseline condition no difference was found between PDT and digit task (averages 358 ms versus 378 ms). During driving a significant difference was found between PDT (503 ms) and digit task (1003 ms) \([p<0.001]\). For both task types the increase because of driving compared to baseline was significant \([both p<0.001]\).

![Figure 6 Average reaction time per task type.](image)

Percentage missed stimuli
The average percentage missed stimuli for driving and for baseline with both secondary tasks are shown in Figure 7. The data of this variable did not show a normal distribution: in the
baseline-condition average and standard deviation were almost zero. That is why these data were analyzed using a Wilcoxon-test to establish the main effect of driving of type of task. The results show that the percentage missed stimuli was lower when performing the PDT during baseline compared to driving \[p<0.001\]. The same is true for the digit task \[p<0.001\].

Hence, the pattern is the same for the reaction time as for the percentage missed stimuli: In the baseline measurements, there is no difference between the task types, while the effect of driving in the simulator shows a larger impact on the digit task than the PDT.

The results for the average reaction time per task type and segment for the simple and complex environment are shown in Figure 8. There was a significant effect for task type: For the PDT the average reaction time was smaller than for the digit task \[F(1,43)=106, p<0.001\]. The reaction time was for driving with
the PDT smaller than the reaction time for driving with the digit task, respectively 497 versus 962 ms.
There was a trend effect for segment \([F(1,43)=3.5, \ p<0.1]\); the average reaction time for segment 2 was smaller than for segment 1, respectively 706 versus 753 ms.

![Figure 8 Reaction time per task type and segment for both complexities.](image)

There was a significant effect for task type with respect to the percentage missed stimuli (see Figure 9) \([F(1,43)=10.8, \ p<0.01]\): The percentage missed stimuli was larger for the digit task than for the PDT, respectively 15% versus 5%. There were no other effects found.

![Figure 9 Percentage missed stimuli per task type and segments for both complexities.](image)
Summarizing, the results show that there is a difference between the secondary tasks PDT and the digit task: both the reaction times and the percentage of missed stimuli were larger for the digit task than for the PDT. However, neither the PDT nor the digit task showed an effect of Environment complexity or of Work In Progress.

Subjective workload

The ANOVA on the subjective measures, i.e. the RSME data, showed that there was a main effect of Environment complexity on the experienced workload \([F(1, 43)=21.8; p<0.001]\) (see Figure 10). The average workload was smaller for the simple environment than for the complex environment, respectively 39.3 versus 48.3. Furthermore, there was an effect for secondary task \([F(1, 43)=93.1; p<0.001]\). Without a secondary task the experienced workload was smaller than with a secondary task, respectively 33.2 versus 54.9. There was an effect of the 2-way interaction between the secondary task and the task type \([F(1, 43)=10.4; p<0.01]\). The post-hoc Tukey test showed that the increase of the workload was larger for driving with the digit task than for driving with the PDT \([p<0.001]\), the means on the RSME scale were respectively 46.8 and 63.1.

The participants experienced a larger workload when driving in the complex environment than when driving in the simple environment. Because the RSME was completed after the total run, i.e. segment 1 and 2 together, the subjective workload of the different segments, i.e. with and without Work In Progress in the complex environment, can not be distinguished. Furthermore, driving with a secondary task resulted in a larger subjective workload than driving without the secondary task. This effect was larger for the digit task than for the PDT.

Behavioral measure: Time Headway

In the analysis of time headways, only samples with a value below 5 seconds were included. Larger headway indicate that participants were not in a following situation, which means that they had decreased their speed considerably. Decreasing speed or increasing headways might be an indication of compensating for an increased workload, while participants were instructed to decrease secondary task performance when workload gets too high. 2% of all the
runs were considered as missing data, because the participants had not performed a proper car following task, i.e. time headways larger than 5 seconds. Because driving speed was restricted to the speed of the car in front (set to 100 km/h), it was not taken into account in the statistical analysis as a behavioural measure.

A significant effect of Environment complexity was found on average time headway. For the simple environment, the time headway was lower (1.18 s) than for the complex environment (1.63 s) \([F(1,43)=28.9, p<0.001]\). Also a significant effect of segment was found: the average headway was lower for segment 1, without road works (1.16 s) than for segment 2 which had with road works in the complex environment (1.65 s) \([F(1,43)=41.3, p<0.001]\). Also a significant interaction effect between Environment complexity and Segment was found \([F(1,43)=40.6, p<0.001]\). See Figure 11. Tukey post hoc tests showed the following:

- For the simple environment no difference was found between the segments.
- Within segment 1, there was no difference between the simple and complex environments.
- For the complex environment, THW was larger in segment 2 \([p<0.001]\), which is the road works zone.

![Figure 11 Average headway for Environment complexity and Segment.](image)

Summarizing, the driving behaviour results show that, as intended, possible effects of environment complexity were not compensated for in terms of time headway. The average time headway of participants was about the same as the 1.0 s time headway maintained by the simulated other vehicles in the environment. There is one exception: in the Work in Progress zone (segment 2 of the complex environment), a larger average THW was maintained.

### Standard deviation lateral position (SDLP)

The standard deviation of the lateral position (SDLP) was significantly different between Environment complexities \([F(1, 43)=5.8; p<0.05]\). SDLP was larger in the complex environment (0.28 m) compared to the simple environment (0.26 m). Also a main effect of segment was found \([F(1,43)=58.2; p<0.001]\). SDLP was larger in segment 2 (0.31 m) compared to segment 1 (0.23 m). Both effects are shown in Figure 12. Although the interaction
between segment and Environment complexity was not significant \( p < 0.12 \), it was shown by a post-hoc Tukey test that only in segment 2 the complex environment had a larger SDLP than the simple environment \( p < 0.05 \).

![Figure 12 Standard deviation lateral position as a function of segment and Environment complexity.](image)

The strong increase in SDLP in the complex environment can be attributed to the change in lateral position to the right lane because of the road works. Although this lane change was meant to take place before segment 2, it turned out that part of it still took place during segment 2. Furthermore, the SDLP was also larger in the complex environment in segment 2 compared to segment 1. It turned out that this was caused by a long gentle curve in the road in segment 2.

**DISCUSSION AND CONCLUSIONS**

There are different factors that could influence the driver workload. In this research we focussed on motorway environment complexity, which contained several elements: driving task related, e.g. traffic signs, and non-driving task related, e.g. advertisements and buildings.

An increase in driver workload can manifest itself in different ways. From the literature [10] it is known that an increase of driver workload often results in adaptation in driving behaviour, specifically a decrease of speed. The current study primarily aimed at measuring effects of driver workload by performance on secondary tasks. To enable measuring these effects one needs to avoid compensating for an increased workload in driving behaviour. Participants were therefore explicitly told to keep up with the other traffic and to avoid very large headways. This was done to create a setting for the secondary task measures to show effects of environment complexity.

The simple and complex environment differed substantially in environment complexity. In spite of this, the secondary task measured showed no workload effects. Against expectation, PDT and digit task results did not show effects for environment complexity or for work in progress. Despite the measures taken to avoid compensatory driving behaviour, it was found that time headway was larger in the work in progress zone (segment 2 of the complex environment). This can be interpreted as
compensatory behaviour of the drivers for an increase in complexity and workload. Possibly this
behavioural compensation caused the lack of effects on the secondary tasks.
Workload was not only measured with secondary tasks, but also with the subjective RSME (Rating
Scale Mental Effort). The results of this questionnaire show that drivers experienced more workload
when driving in the complex environment as compared to the simple environment.
Formally, the fact that we found no significant effect of environment complexity on the
secondary task measures does not prove that there is no effect. In the full report of this study
[11], where a more detailed analysis was performed, it was shown that secondary task
performance did reveal several effects. Infrastructure elements such as relatively sharp curves
or weaving sections did manifest themselves in the percentage of missed stimuli. Thus, if
there are effects of environment complexity that the current study did not reveal, they are
minor compared to these infrastructural effects.

It is concluded that in the experimental setting as applied here, a visual complex environment does not
increase driver workload. Drivers were able to distract information of the cluttered world of information
in order to drive safely and at the same time perform a secondary task. Only when the complex
environment includes complex interactions with the other traffic, as in the work in progress situation,
driver workload increases.

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REFERENCES


