**Human Machine Interface And the**
**Safety of Traffic in Europe**
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# Deliverable 2

## *- HMI and Safety-Related Driver Performance -*

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# Executive Summary


The aim of HASTE is to develop methodologies and guidelines for the assessment of In-Vehicle Information Systems (IVIS). The intention is to devise an assessment regime that is independent of the design of an IVIS and that is based on an evaluation of driving performance while using the system as compared with driving performance when not using the system (baseline driving). The ambition is to provide an assessment regime which:

- Is technology-independent;
- Has safety-related criteria;
- Is cost effective;
- Is appropriate for any system design; and
- Is validated through real-world testing.

The objective of the experiments in this Workpackage (WP2) was to investigate the impact of IVIS task load on driving performance and safety. To achieve this, two surrogate IVISs (S-IVISs) were created, one representing cognitive load and the other visual load. Using these S-IVISs, it was possible to vary secondary task load systematically. Separate assessments of the effects on driving of the different types of task load were carried out, with as clean a distinction as possible between visual and cognitive load.

The objective was also to identify the advantages and disadvantages of the different assessment methods (laboratory, simulator, field), and finally to identify which road types and scenarios are the most productive for testing IVIS. Different groups of drivers were used and scenarios varied in accordance with the protocol and procedure for safety assessment of IVIS as outlined in Deliverable 1 (Roskam et al., 2002).

A very large set of experiments was conducted. But in one sense this was one very large multi-national unified and integrated experiment with a common goal, a common experimental protocol and common indicators. The effect of IVIS use in three distinct road categories — urban, rural, and motorway — was investigated. To do this, a total of 14 separate driving simulator experiments were conducted, with each participant experiencing only one type of S-IVIS. All seven driving simulators were used to investigate driving with both S-IVISs on a common rural road. For the most part, each simulator road type had three levels of difficultly with the most difficult being driving when some critical event was triggered (the motorway had only two levels of difficulty: without and with events).

For the field (real road) studies, both types of S-IVIS were included in the drives for each participant, with the order of S-IVIS tasks counterbalanced. This was because, for these studies, there was no issue with the drivers learning what might happen in the critical events, since none were staged — all the driving was done in natural settings. The three field studies used different combinations of the road types and all roadway types were completed in a single session.

The overall number of experiments, both simulator and field, was 17. A total of 527 participants were used.

A large number of indicators of driving performance, particularly related to longitudinal and lateral control, were collected. Also collected was information on secondary task

performance (acting as the Surrogate IVIS), both static (not driving) and dynamic (whilst driving). The indicators can be classified into:

- Self-reported driving performance
- Lateral control
- Longitudinal control, i.e. control of speed and distance to a lead vehicle
- Workload, such as physiological measures and gaze behaviour
- Expert observations of driving performance

Following the anaysis of this data, a meta-analysis was carried out to compare the various studies and to identify the most effective indicators. This meta-analysis was intended to single out the most powerful scenarios and to assist in showing which indicators could be dispensed with in subsequent work testing the methods in evaluating some real IVISs.

The major dimensions of the study, to some extent in order of importance, were:

- IVIS type, visual versus cognitive
  - Within IVIS type, IVIS level
  - Within IVIS type, Static IVIS performance versus Dynamic IVIS performance
- Simulator and Laboratory studies versus Field Studies
  - Simulator/Laboratory type
- Road category (urban, rural, motorway)
  - Within Road category, Road level
- "Average" drivers versus Elderly drivers
- UK drivers versus Portuguese drivers

Findings across these dimensions were:

**S-IVIS Type:** The two types of S-IVIS had quite different effects on driving performance. The visual task had pronounced effects in terms of steering and lateral behaviour. On the other hand, the cognitive task caused reduced lateral deviation; in other words it "improved" steering behaviour, though there was also a tendency for drivers to compensate for the task load by shifting away from the road edge. This "improvement" in steering behaviour was accompanied by an increase in glances focussed on the road ahead, at the expense of the periphery. There were indications in some of the results that the predominant negative effect of the cognitive task on driving performance was on longitudinal control in car following.

**S-IVIS level:** Drivers were not always able to manage the trade-off between primary and secondary task, and there were many indications of driving performance being poorest when the secondary task demand was the highest. The elderly drivers were particularly poor at this task management.

**Static S-IVIS Performance vs Dynamic Performance:** Generally, the studies found that there was an interaction between S-IVIS performance across the baseline (static) and three levels of dynamic situation (i.e. the three levels of road difficulty). This advocates the HASTE approach of requiring the driving context to be considered in assessing an IVIS. Static performance did not reliably predict dynamic performance.

**Simulator vs. Field:** The field studies tended to pick up somewhat different effects of the systems than the simulator studies. Additionally, it has not proved possible to test elderly drivers with the visual task due to simulator sickness. This shows the value of the field tests, but also suggests that the incorporation of some additional scenarios or tests in the simulator roads should be considered. These could perhaps take the form of detecting objects in the periphery or detecting changes in the peripheral scene.

**Simulator Type:** The broad conclusion is that the type of simulator or laboratory used in the assessment did not have an effect.

**Road Category:** In the simulator studies, the rural road was the most diagnostic and the motorway the least diagnostic, i.e. the effect sizes from the rural road were generally larger. The urban road did not pick up any additional information that was not provided by the rural road. This means that, for simulator and laboratory assessments, the rural road can be used as the sole road category in the later work of HASTE assessing real IVIS systems as well as in the final HASTE test procedure. In the field studies with the cognitive task, the motorway produced the only indicator with a consistent effect.

**Road Level:** Road level is an important factor. It will be sensible in the later work of the project to consider dispensing with the easiest level of the road.

**"Average" vs Elderly Drivers:** The findings have confirmed the hypothesis proposed in Deliverable 1 (Roskam et al., 2002), that there would be severe problems for elderly drivers in using IVIS while driving, particularly at higher levels of task demand.

**UK vs Portugal:** The controlled comparison of the British and Portuguese showed the expected effect: the Portuguese drivers exhibited riskier driving behaviours. But, reassuringly, the analysis revealed there was no interaction effect of the "country" factor. In other words, results obtained with Portuguese drivers should be as reliable as those obtained with drivers from northern Europe.

As regards **methodology,** the results obtained form this very large set of studies confirm some of the initial decisions made in formulating the HASTE approach. There was clear value to the focus on *dynamic* evaluation, i.e. of looking at interaction with an IVIS while driving and of identifying the effects of that interaction on driving. Static testing cannot predict how an IVIS will affect steering behaviour or interaction with other road users. The different road levels proved their worth, particularly levels 2 and 3 of the rural road. There is also clear value to the inclusion of events (road level 3), but there is also some scope for improving the events so that the drivers are less able to adapt to their occurrence, by for example slowing down as the lead vehicle comes closer to them.

There may also be scope for the inclusion of peripheral detection tasks (PDTs) in the driving task, in order to gain a better understanding of drivers' ability to assimilate information in the periphery, which is crucial to safety.

The results also confirm the value of using a very large number of indicators. Some of these indicators have turned out to be non-diagnostic and therefore can be abandoned in the next phase of the project. Others have turned out to be superfluous in that what they reveal overlaps with the diagnosis provided by other indicators. The meta-analysis has helped to sift through the indicators and test environments to identify the most powerful ones.

Important **conclusions** from the studies are:

- The effect of the S-IVIS visual task on driving is very clear: increased distraction leads to problems in lateral control.

- The effect of the S-IVIS cognitive task is more complex, in that some driving parameters, particularly related to steering control and lateral position appear to improve. However, this improvement seems to be an artefact of greater concentration on the road straight ahead at the expense of information acquired from the periphery. Thought needs to be given to tasks or tests that might capture this loss of information acquisition from the periphery.

- Motorway driving in the various simulators and the laboratory was generally less diagnostic, than driving on other road types.

- Elderly drivers exhibited very risky driving while performing IVIS tasks

- The field studies provided some information that was not provided by the simulator assessments. The subsequent work in the project should consider simulator tasks that can provide analogous information.

# Disclaimer

The research reported herein was conducted under the European Commission Competitive and Sustainable Growth Programme. The project is being carried out by a consortium comprising: the Institute for Transport Studies, University of Leeds; TNO Human Factors Research Institute; the Swedish National Road and Transport Research Institute (VTI); Delft University of Technology; Volvo Technology Corporation; MIRA Ltd; Technical Research Centre of Finland (VTT); Universidade do Minho; and Transport Canada. The opinions, findings and conclusions expressed in this report are those of the authors alone and do not necessarily reflect those of the EC or of any organisation involved in the project.

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# List of Abbreviations

| | |
|---|---|
| IVIS | In Vehicle Information System |
| S-IVIS | Surrogate In Vehicle Information System |
| SLv | S-IVIS difficulty level. Four levels: Baseline (no task), 1, 2 and 3 |
| RLv | Road complexity level. In simulator rural road: 3 levels (straight, curved and event). In simulator motorway: 2 levels (normal and event). In |
| BL | BaseLine - refers to driving without S-IVIS |
| Cognitive task | One of the two S-IVIS: Auditory Continuous Memory Task |
| Visual task | One of the two S-IVIS: A motor visual S-IVIS task |
| Leeds | Institute for Transport Studies, University of Leeds, UK partner |
| Minho | Universidade do Minho, Portuguese partner |
| Delft | Delft University of Technology, Dutch partner |
| TC | Transport Canada, partner |
| TNO | Human Factors Research Institute, Dutch partner |
| VTEC | Volvo Technology Corporation, Swedish partner |
| VTI | Swedish National Road and Transport Research Institute, partner |
| VTT | Technical Research Centre of Finland, project |

For list and definitions of driving performance and workload measures, see *Appendix 1*

# 1. Introduction

## 1.1. In-Vehicle Information Systems and Safety

The introduction of in-vehicle information systems (IVIS), such as navigation systems, into the market offers some real benefits. With such systems, drivers may be able to find their way to their destination more easily and more efficiently. Driving safety, particularly as compared with using a map while driving for route-finding, may be improved and distance travelled reduced with consequent reduction in exposure to risk. There may also be less chance, with a well designed navigation system, of abrupt manoeuvres and of the driver changing his/her mind in mid-manoeuvre.

However, there are also safety risks from the new systems. The interface may be poorly designed, drivers may fixate on displayed information, screens may be cluttered, the timing of information may be inappropriate (not soon enough, arriving at a time when the driver is heavily loaded, etc.), menu navigation may be difficult, information entry may be demanding and so on. In addition, not all new systems are ones that are relevant to the driving task. Drivers increasingly feel a need to receive non-driving-related information and to communicate while driving. As early as 1999, 68% of Finnish drivers admitted using a mobile phone while driving, and 50% of those who used a phone acknowledged that they had got into dangerous situations from phone use (Lamble, Rajalin & Summala, 2002). Beyond the mobile phone, there is the growth of other communication functions, represented by the concept of the "office on wheels".

There is no lack of *guidance* on how to design a safe system, although since the guidance is not compulsory there is no legal obligation to follow it and no mechanism for ensuring compliance. Another problem is that many of the devices used in vehicles are not necessarily intended or designed for in-vehicle use — this is the problem of the so-called "nomad" system. The various checklists, codes of practice and statement of principle, including the European Statement of Principles on Human Machine Interface, are reviewed in Carsten and Nilsson (2001). However, there is currently a lack of an assessment regime for assessing the quality of the design of a particular system, and still less of an assessment regime that relates the usage of system (or of a particular function of a system) to safety while driving. The HASTE project is intended to address that need.

## 1.2. The HASTE Project

The aim of HASTE is to develop methodologies and guidelines for the assessment of In-Vehicle Information Systems. The intention is to devise an assessment regime that is independent of the design of an IVIS and that is based on an evaluation of driving performance while using the system as compared with driving performance when not using the system (baseline driving). Theoretically, it should be possible to test any IVIS, and indeed any information or communication system that can be used in a vehicle while driving, with the HASTE test regime. Indeed, it would even be possible to evaluate the design of, for example, the heating and ventilation system or the entertainment system in a vehicle, using the HASTE approach.

The ambition of HASTE is to provide an assessment regime which:

- Is technology-independent
- Has safety-related criteria
- Is cost effective
- Is appropriate for any system design
- Is validated through real-world testing

The theoretical schema behind the HASTE approach is illustrated in Figure 1. In-vehicle information systems can impose visual and/or cognitive loads on drivers. Such loads can be measured by glance behaviour and various indicators of workload. The effects of load can be manifested by changes in driving performance (e.g. reduced speed, greater lateral variability, decreased time-to-collision) and interference of perception and judgement of the traffic situation (i.e. reduced Situation Awareness). Reduced performance has a negative impact on safety, which could be measured, for example, by the increased risk of a conflict. All of this is influenced by the traffic environment and the current situation.

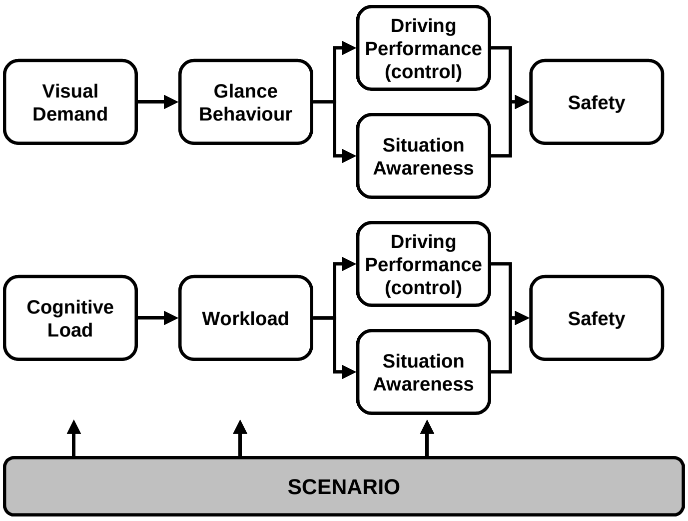



**Figure 1 – The HASTE approach**

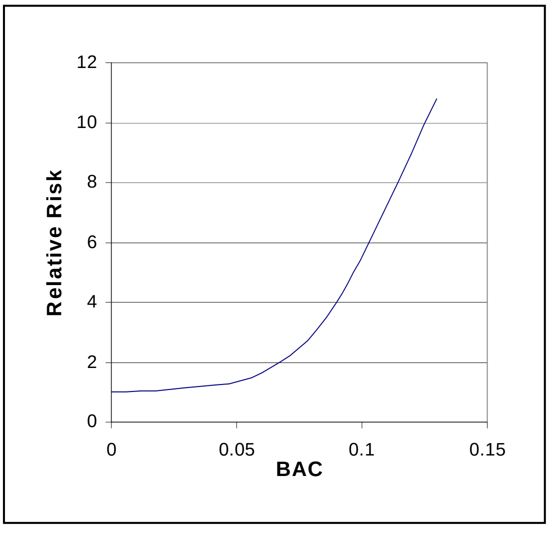
A further important theoretical underpinning of HASTE is the notion that secondary task load can impair driving and that most impairment-safety relationships are exponential in form. This can be illustrated by the well known relationship between blood alcohol and accident risk as shown in Figure 2. As a result, it has been hypothesised in HASTE that driving performance will deteriorate as secondary task load increases, and that while drivers may be able to compensate when the driving scenario is relatively easy, they will have far less capacity to do so in more complex and more demanding driving situations.

The work of HASTE began by designing the experimental procedures to be used. This work is documented in Deliverable 1 (Roskam et al., 2002). The next workpackage, reported here, is the work examining the impact of distraction on driving performance. This is designed to:

1. Identify the major impacts of distraction
2. Identify how driving performance changes as distraction increases
3. Test which features of the assessment are the most effective in diagnosis of (1) and (2).

The final stage of the work will be to apply the test regime which has been developed to the evaluation of real IVIS (WP3). The test regime will be further refined at this stage.

In order to carry out the work on the relationship between distraction and driving, the project identified a need to vary both primary and secondary task load in a systematic manner. Primary (driving) load was varied by using a variety of driving environments and, for the simulator and laboratory trials, varying driving difficulty within road type. Secondary task load was manipulated by means of the IVIS-like tasks that drivers were asked to perform. This led to the development and use of a "Surrogate IVIS" (in fact two Surrogate IVISs or S-IVISs, one for visual load and one for cognitive load) to create controlled distraction. These two S-IVISs were used in all the experiments described here.




*(from Hurst et al., 1994)*

**Figure 2 – Relative accident risk by blood-alcohol content**

## 1.3. Towards a Test Regime Identifying IVIS Safety Problems

A test regime for assessing the safety of an IVIS should have a number of qualities:

- It should be ***efficient*** — any unnecessary elaboration or duplication should be removed.
- It should be ***effective*** — the sample size (number of tests) needs to be sufficient to reveal differences between good and poor designs.
- It should be ***reliable*** — the tests, when repeated at different test sites or with different drivers, should produce similar results. This would argue in favour of using a driving simulator or laboratory environment, because in such an environment it is easier to control the conditions and situations encountered.
- It should be ***relevant*** — the criteria being used to assess the IVIS should be related to the safety of the driving task. Poor functionality or usability of a system in aspects that cannot be used while driving, e.g. use of a menu that is locked while the engine is running, might affect the user's impression of a system, but is not safety-relevant.
- It should be ***comprehensive*** — all important safety implications should be assessed. This argues in favour of using driving in a naturalistic environment, i.e. on real roads, as part of the test regime, since such driving is more likely to reveal unanticipated problems which might not be revealed in the more constrained environment of a simulator.

- It needs to be ***safe*** in that neither the test subject (driver) nor the test administrator (e.g. an observer in a test vehicle) should be exposed to improper risk.

Each of these aspects is discussed in more detail below.

**Efficiency:** parts of the test that provide no added value or are not diagnostic should be removed. To that end, the approach used in defining the test regime in HASTE has been to start out with a comprehensive assessment, covering for example all major road categories (urban, rural and motorway), with the intention of reducing that set where feasible. The work covered in this report details that comprehensive assessment. Equally, the approach allows the examination of whether field tests provide any added value over laboratory or simulator tests. The HASTE methodology also allows examination of how elaborate a simulator must be in order to be adequate for IVIS assessment. Because the HASTE partners have at their disposal a range of driving simulators from the VTI moving-base system at the top end to the Portuguese “laboratory” simulator at the simpler end, there is the possibility to assess whether different categories of simulator provide comparable results. Again, the work reported here, makes that comparison. Finally, it is also possible, with the HASTE methodology, to ascertain whether static use of an IVIS (i.e. not while driving) is equivalent to dynamic use of an IVIS (i.e. while driving) and whether static performance with the IVIS can be used to predict *driving* performance while using an IVIS. If static performance were found to predict driving performance, then it would be possible to dispense with the requirement to carry out the assessment while driving.

**Effectiveness:** there is no advantage in carrying out a study that is larger than necessary (this leads to unnecessary cost), but there is also a problem if an evaluation is too small to show significant effects (this can make the whole investigation pointless). In this set of studies, the dependent indicators collected have been analysed with regard to their effect size. This allows the selection of those conditions and those indicators where the effect size is relatively large. As a result, the required number of subjects to be used in a test can be limited appropriately.

**Reliability:** the protocol used in the experiments has been, as far as possible, common across all the sites. Common definitions were used for the various indicators (see Appendix 2), the S-IVISs used have been identical across the sites and, for the simulator and laboratory experiments, there have been common layouts and common event scenarios for each of the three road types — urban, rural and motorway. Virtually identical assessments of the effects of both the visual and cognitive S-IVIS when driving on rural roads were conducted at six sites on a range of driving simulators. Simulator driving on urban roads with both S-IVISs was evaluated at two sites, as was driving on rural roads. There was a particular concern about whether the data obtained from the Porto driving simulator used in the Minho experiment, which was the most simple simulator used in the project, would be the result of a "Portuguese driver effect" or the result of a simulator design effect. Therefore, a separate cross-cultural study was conducted on that simulator using British drivers recruited in Portugal and comparing their driving, with and without IVIS, with that of the Portuguese subjects. Overall, the study design enables comparison across a variety of simulators and comparison between simulator and real-road environments.

**Relevance** was inherent in the experiments. Visual load and cognitive load were identified in advance as the main sources of problems in interaction with an IVIS. In other words an IVIS can impose visual load by having a screen that is too cluttered or containing lots of confusing information, or it can impose cognitive load by requiring the driver to absorb complicated information (such as complex navigation instructions). It was also important to distinguish between the effects of the different types of task load that could be imposed by an IVIS. The surrogate tasks that were developed for use in the experiments were designed to be representative of the two different loads and so as to be as "pure" as possible in the type of load that they imposed. However, it must be conceded that in an ideal world the investigation would have been extended to manual tasks. This was not feasible for resource reasons.

Efforts have been made here to address the need for a **comprehensive** test regime that is relevant to real-world conditions and to variability among drivers. Of course, it is not feasible to include in an assessment every possible scenario that might be potentially relevant to driving with an IVIS. But the scenarios selected for the laboratory and simulator experiments were thought to be representative of the risky situations that might occur in real driving. In addition, the field tests were designed to complement the more controlled tests by revealing what might occur under naturalistic conditions. Finally, a specific investigation was carried out on the effects of IVIS on what had been identified in HASTE Deliverable 1 (Roskam et al., 2002) as the most important group of drivers requiring special attention, namely elderly drivers (defined as those aged 60 or more).

**Safety** was assured by limiting IVIS task load in the real-road drives as shown hypothetically in Figure 3. In fact three levels of each S-IVIS were tested in the simulator and laboratory environments, but the maximum level tested in the real-road drives was in most cases a level "2.5". This needs to be borne in mind when making comparisons between the effects of the most demanding S-IVISs in the different test environments.

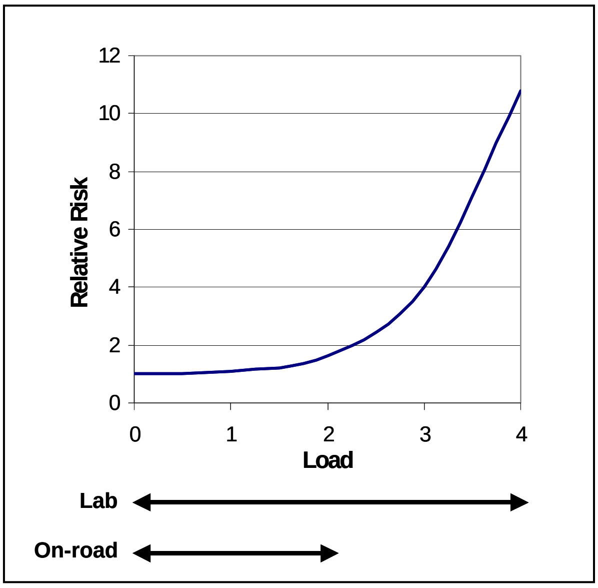



**Figure 3 – Hypothetical IVIS task load and appropriate test regime**

It needs to be reemphasised that the risk relationship shown in Figure 3 is completely hypothetical. Distraction, unlike alcohol impairment, is momentary (although it may carry on for some time after the direct interaction with the IVIS has finished). But most risk functions are exponential in shape, in that beyond some point safety deteriorates very quickly. One such example is the increase in accident risk rising with the proportion that a driver is exceeding the mean speed of traffic.

Of course, the test regime used here is far more elaborate than what will be proposed at the end of the project. A more reduced version will be applied in the subsequent testing of real IVISs. This subsequent testing will also provide an opportunity to refine the test regime. Where a particular element has not proven effective, it could be the case that the focus was inappropriate from the start. But it could also be the case that there were methodological or practical flaws in the way the element was applied. The later work in the project will provide an opportunity to remedy those flaws and also to focus on any counter-intuitive results that have been found.

## 1.4. Objectives of the WP2 Experiments

The objective of these experiments was to investigate the impact of IVIS task load on driving performance and safety. Task load was varied systematically and separate assessments carried out of different types of task load, with as clean a distinction as possible between visual and cognitive load. The objective was also to identify the advantages and disadvantages of the different assessment methods (laboratory, simulator, field), and finally to identify which road types and scenarios are most productive for testing IVIS. Different groups of drivers were used and scenarios varied in accordance with the protocol and procedure for safety assessment of IVIS as outlined in WP1. Relevant data were collected and adapted for the validation of the experimental protocol, and for subsequent risk analysis.

The results of WP2 were expected to be applications of scenarios, dependent variables and data analysis methods in simulator, laboratory and field experiments. It was expected that the resulting methods for assessing IVIS were to have the sensitivity and specificity to identify effects on driving that are safety-critical.

# 2. Common Methodology for IVIS Assessment

## 2.1. Methodological approach

The methodological approach was to impose cognitive and visual load on drivers using a range of artificial tasks. These were referred to as surrogate IVIS (S-IVIS), implying that this load would lead to an increased risk of an accident. The impact of risk on accidents is primarily related to driving performance, driver visual and cognitive attention, and driver mental workload.

In driving simulators and laboratories, the participants were exposed to highly controlled safety critical scenarios, as well as “normal” non-safety critical scenarios. In field trials, the level of visual and cognitive load could not be so high that driving was considered unsafe for to ethical and practical reasons. Two S-IVIS tasks were developed within HASTE (see *2.4 - Surrogate IVIS*); one visual and one cognitive. Each of these had three levels of difficulty in order to impose mild to severe distraction.

HASTE Deliverable 1 (Roskam et al., 2002) identified a set of parameters considered highly relevant for assessing the safety impact of IVIS. Of these, the following were chosen to be included in the experiments:

- scenario parameters
    - urban, rural and motorway environments
    - critical events, or road complexity level
    - junctions as a parameter of road infrastructure
- individual parameters
    - average and older drivers
    - nationality

To identify the most successful and relevant combination of driving scenarios, variables and assessment method, it was of high priority to cover all road types within laboratory, simulator and field experiments. It was also prioritised to cover more than one road complexity level within each road type. To cover both cognitive and visual distraction, both S-IVIS tasks were included within each road type and assessment method. It was also of high priority to include critical events in laboratory and simulators since it is most likely that the risk of an accident is highly increased if the driver is distracted. Older drivers were included in one simulator and one field trial, and junctions were also separately analysed in one field trial.

The listed parameters above were all highly relevant, not only to cover safety critical scenarios, but also since the experiments had to be representative for the driving situation in EU. However, this does not imply that comparisons can be made within the range of each parameter. For example, it may be difficult to compare between road types since driver behaviour is significantly restricted by the driving environment, which not necessarily has anything to do with driving performance or risk. However, the scenario parameters and individual parameters are most likely relevant regarding the impact of IVIS on driving performance and risk. It is thus realistic to assume that a final test regime will include several scenarios and driver groups, and also scenario-specific safety indicators and criteria. The specifications of scenarios are found in *2.6 - Road and Traffic Environments*, and the definitions of safety indicators in *2.7 - Indicators and Analysis*.

## 2.2. Participants

"Average" drivers were included in all experiments. Average drivers were defined in HASTE Deliverable 1 (Roskam et al., 2002) as:

- Age: 25-50 years
- Gender: Both male and female
- Total driving experience: between 10,000 – 1,000,000 kilometres

Elderly drivers were included in one simulator trial and one field trial. Elderly drivers were defined as of age 60+. All drivers were current license holders. All participants were paid.

## 2.3. Experimental design

### 2.3.1. Overview of experimental design

All combinations of road type and S-IVIS were covered at least twice in the simulator and field experiments, resulting in a total number of 12 experiments. All simulator experiments included a standard rural road (defined in *2.6.1.2 - Simulator rural road*). In the laboratory experiment both S-IVISs were used, but only the rural road was included (see Table 1 and Table 2). In all experiments, at least average drivers were included. The idea of this distribution was to have comparable experiments and to test reliability across simulators, and validity between simulators, laboratory and field trials. The field trial situation was considered to be the reference situation (see Figure 4). Of course, the comparability to the field experiments depended on the scenarios.

There was a separate baseline drive (without S-IVIS) for each road type. Baseline sections were not included in the experimental drive since it was assumed that the effect of S-IVIS could be present when S-IVIS was not active; thus a separate "clean" baseline drive was preferable. The order of experimental (with S-IVIS) and baseline drives was counterbalanced.

**Table 1 – Distribution of road types and S-IVIS tasks across partners in the field trials**

| Field Experiments | Urban | Rural | Motorway |
|---|---|---|---|
| **Visual task** | DELFT, VTT | DELFT , VTT | DELFT, VTI+Volvo |
| **Cognitive task** | VTT, Leeds | VTT, Leeds | VTI+Volvo, Leeds |

**Table 2 – Distribution of road types and S-IVIS tasks across partners in the simulator experiments**

| Simulator Experiments | Urban | Rural | Motorway |
|---|---|---|---|
| **Visual task** | TC, TNO | Leeds, VTI, Volvo, TC, TNO | VTI, Volvo |
| **Cognitive task** | TC, TNO | Leeds, VTI, Volvo, TC, TNO | VTI, Volvo |

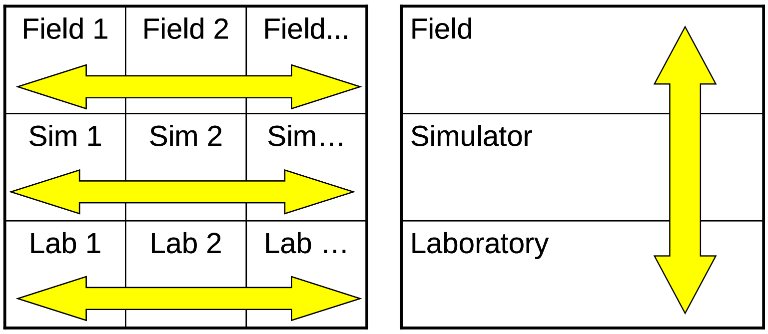



**Figure 4 – Strategy for testing reliability and validity**

### 2.3.2. Impact of S-IVIS on experimental design

S-IVIS complexity level (SLv) was a within-subjects factor. These levels were all included and counterbalanced in one single drive. In the simulators and the laboratory, every participant used only one of the two S-IVIS tasks due to the risk of learning and predicting the critical events; the number of drives along the same route had to be minimized. In the field trials, however, both S-IVIS could be included for each participant since no critical events were included. The order of S-IVIS tasks was counterbalanced.

There was a static S-IVIS test included for each participant in order to evaluate how the S-IVIS was prioritised as a dual task compared to single task. If performance on the S-IVIS task was the same in the single and dual task conditions and did not vary across driving difficulty, then there would be strong arguments for testing an IVIS without any need to resort to driving simulators or real-road driving. The static test would pick up any problems and thresholds could be set in terms of glance durations or task time.

### 2.3.3. Impact of Road Complexity on experimental design

In the simulator scenarios, up to three road complexity levels were included. The first level(s) corresponded to “normal” traffic conditions, whereas the highest level corresponded to a critical event requiring an immediate brake reaction by the driver. In one of the field trials two road complexity levels where included, where junction negotiations were included in the higher complexity level.

The critical events in the simulator and laboratory experiments had to be comparable within each experiment and road type with respect to the required driver reaction, e.g. brake reaction time. Therefore, a set of critical events for each road type was designed. Each participant drove twice on each road type (one baseline drive and one experimental drive). In order to limit the learning effects, two road sections were designed with separate sets of comparable critical events. These road sections were identical except for the critical events. In the field trials there was no problem with learning effects (with respect to driving task), since no critical events were included and since all participants were familiar with the routes that they drove.

### 2.3.4. Effect of Road Types on experimental design

In the simulator experiments, the standard rural road was driven first. The reason for this was twofold: the rural road was to be used for testing reliability between simulators.  It was therefore important for the drivers taking part to have had the same amount of experience when they drove on the rural road, i.e. just a practice session and the rural road driving. The second reason was that it was not an objective to conduct between road type comparisons, so that there was no requirement for the order of road types to be counterbalanced. In the field trials, there were no corresponding restrictions.

### 2.3.5. Factors and Levels

The experimental factors and number of included levels are listed in Table 3. Experiments on different road types and different age groups are considered separate experiments and are thus not included as factors.

**Table 3 – Factors and levels**

| Factor | Levels | Type |
|---|---|---|
| S-IVIS complexity level (SLv) | 4 (including baseline) | fixed |
| Road complexity level (RLv) | 3 (in Sim and Lab rural road)<br>2 (in Sim Motorway and Urban road)<br>1 or 2 (in field trials) | fixed |
| S-IVIS task (ST) | 2 (the cognitive task and the visual task) | fixed |
| Study object ($\alpha$) | N (number of participants, at least 24) | random |

A generic experimental design (Table 4) was developed for the simulator and laboratory experiments. The same design was to be adopted in the field trials to as large extent as possible. The factors in Table 4 were within-subject in all experiments. This design included three road complexity levels and four S-IVIS complexity levels. Nine activations of the S-IVIS were included in the experimental drive, evenly distributed over S-IVIS and road complexity levels. Since there was a separate baseline drive, there were three observations for each RLv in the baseline drive. The number of S-IVIS activations was either 6 or 9 in the field trials. The experimental design for each experiment is further described in each report in the following sections.

**Table 4 – Generic experimental design**

| | S-IVIS level | | | |
|---|---|---|---|---|
| **RLv** | **BL** | **SLv 1** | **SLv 2** | **SLv 3** |
| **RLv 1** | 3 | 1 | 1 | 1 |
| **RLv 2** | 3 | 1 | 1 | 1 |
| **Event** | 3 | 1 | 1 | 1 |

(BL=Baseline)

### 2.3.6. Overall Experimental Design in the Field Trials

Each partner used both S-IVIS tasks. The participants were all recruited from the local area and were thus familiar with the driving route. No standard route as in the simulator experiments was included in the field trials. The designs in the separate field trials varied from including only one road type but both S-IVIS tasks, to all three road types but only one S-IVIS task. Since each road type was included in two experiments, reliability could be tested to some extent, However there were some restrictions due to between-experiment differences.

The order of S-IVIS difficulty (SLv) and the order of baseline and experimental runs were counterbalanced. The order of road types was not counterbalanced.

## 2.4. Surrogate IVIS

### 2.4.1. Background

The operation of an IVIS can generate moments of high mental and physical workload for drivers. Whilst it is important to ensure that drivers use such in-vehicle systems efficiently, interference with the driving task must be kept to a minimum. For instance, to enable optimum driving performance, the secondary task should not overly compete with the drivers' visual or mental/cognitive workload. In addition, when considering a suitable IVIS, effort must be made to reduce the requirement for a manual response to this system, if and when this is necessary for the driving task.

Although several studies have examined the interaction between in-vehicle secondary tasks and driving performance (Radeborg, Briem, & Heman, 1999), there is an absence of data on the systematic relationship between increasing secondary task complexity and driver performance. In addition, the use of miscellaneous methodological techniques and the employment of different modes of input and variable response styles do not allow a satisfactory comparison across studies.

An important theoretical underpinning of HASTE was the notion that load from a secondary task can impair driving performance, and that most impairment-safety relationships are exponential in form. This can be illustrated by the well-known relationship between blood alcohol and accident risk, and has also been shown to apply to individual driver speed choice, as measured by the ratio of a driver's speed to mean traffic speed (Taylor, Lynam, & Baruya, 2000). For the HASTE project, a similar theoretical relationship was predicted between increasing secondary task load (difficulty) and relative risk, where BAC is replaced by task load (see Figure 2 and Figure 3). It was important to design secondary tasks that could be presented at different levels of load/difficulty, to study the effect of task load on driving impairment/safety - and therefore relative risk. It was also assumed that whilst a maximal increase in task load could be implemented in the laboratory and simulator studies, a lower level had to be used in the field experiments since it was expected that maximal task load could result in accidents.

In order to conduct a controlled experiment, and study the systematic effect of increasing task load on performance, it was necessary to establish how increasing load on a particular information processing system would subsequently influence driving performance. The difficulty with using any real IVIS for this purpose is that these systems may place a combination of cognitive, visual and motor demands on the driver at any one time. This would in turn cause problems when trying to establish exactly what sort of demand from an IVIS is affecting driver performance.

Therefore, the rationale behind devising a *surrogate* IVIS (S-IVIS) was to effectively 'separate out' the different demands from a real IVIS as much as possible, examining how *each* type of load affects driving performance[1]. In particular, we concentrated on the design of two surrogate systems; one that, as much as possible, would only require visual processing/demand - therefore requiring relatively little cognitive processing, and another that would be quite demanding in terms of cognitive/executive resources. In order to try and separate the 'visual' and 'cognitive' tasks further, the latter was presented auditorally.

[1] Clearly, the effect of multimodal and motor/manual information on driving is also important. However, resource limitations prevented these being addressed in this part of the HASTE work.

In the next two sections, we describe the steps taken to design these S-IVIS tasks, beginning with the results of a number of pilot studies for each system.

### 2.4.2. The Visual Task

The design of this task was based on visual search experiments frequently used in experimental psychology. According to Treisman's Feature Integration Theory (Treisman, 1988) the speed at which a visual target is identified within a display is affected by its visual similarity to other objects in that display. Visual search experiments have shown that unique features of a target object allow it to 'pop out' of the display, resulting in faster decision times. Difficulty in target identification will therefore increase as the non-target objects become more similar to the target in colour, shape and/or orientation. In addition, increasing the number of objects in a display is shown to increase reaction time to targets, but only when a target object must be recognised by a conjunction of features (e.g. colour and shape).

This information was therefore used to create a visual task that could be presented at different levels of difficulty, based on the number and visual characteristics of 'non-target objects'. Two pilot experiments were conducted on this task to test our hypotheses.

### 2.4.3. Visual task - pilot study 1

#### *2.4.3.1. Participants*

Thirty-five staff and students from the University of Leeds (16 male, 19 female) were paid £10 to take part in the study (mean age = 30.29, SD = 8.25).

#### *2.4.3.2. Design and Procedure*

The experiments were carried out on a PC using E-Prime software. E-Prime is a graphical experiment generator for Windows 95/98/ME and consists of a suite of applications to design, generate, run, collect data, edit and analyse data. The visual display for the visual task consisted of a 4x4 grid of black arrows, the direction of which was predetermined by the computer. The 'target' object was an up-facing arrow, the appearance and position of which in the 4x4 display was random. Any arrows in the down, left or right direction were therefore 'non-target' items. Table 5 shows an example of the all the displays used in the visual task.

Each display remained on the screen for 5 seconds or until a participant's response. The displays were presented randomly within a block of trials, and participants completed four blocks of forty trials. They were instructed to respond as quickly and accurately as possible, pressing the number '1' key on the keyboard if they observed the target upward arrow, and the number '2' key otherwise. Participants' performance was assessed by calculating the percentage of correct responses, percentage of errors and reaction time in each for the six levels of difficulty.

**Table 5 – Examples of the type of displays used in the visual task**

| Target Arrow | Present | Present | Present | Present | Absent | Absent | Absent | Absent |
|---|---|---|---|---|---|---|---|---|
| Direction of non-target arrow | 15 left | 15 right | 15 down | 15 mixed | 16 left | 16 right | 16 down | 16 mixed |
| Number of possible permutations | 16 | 16 | 16 | Many | 1 | 1 | 1 | Many |
| Example of display | ← ← ← ←<br>← ← ← ←<br>← ← ↑ ←<br>← ← ← ←<br>(a) | → → → →<br>→ → ↑ →<br>→ → → →<br>→ → → →<br>(b) | ↓ ↓ ↓ ↓<br>↓ ↓ ↓ ↓<br>↓ ↓ ↑ ↓<br>↓ ↓ ↓ ↓<br>(c) | ↓ → → ↓<br>→ → ↓ ↓<br>↓ → → →<br>→ ↑ → →<br>(d) | ← ← ← ←<br>← ← ← ←<br>← ← ← ←<br>← ← ← ←<br>(e) | → → → →<br>→ → → →<br>→ → → →<br>→ → → →<br>(f) | ↓ ↓ ↓ ↓<br>↓ ↓ ↓ ↓<br>↓ ↓ ↓ ↓<br>↓ ↓ ↓ ↓<br>(g) | ↓ ↓ → ↓<br>↓ → ↓ →<br>→ ↓ → ↓<br>← → ↓ →<br>(h) |
| Predicted Difficulty of Display | 1 | 1 | 3 | 5 | 2 | 2 | 4 | 6 |

Note: It was hypothesised that reaction time would be the best indicator of difficulty level in this task, since degree of visual attention required would depend on the ease at which subjects were able to identify the presence/absence of the target arrow. 1= Easiest level, 6= Most difficult level

### *2.4.3.3. Results*

The first block of 40 trials was considered a practice block. An average reaction time for the remaining three blocks was calculated for each of the 6 levels of difficulty, for each subject. Figure 5 shows the mean reaction time for each of the six conditions in the visual task. A one-way ANOVA showed a main effect of difficulty level: $F(5,209)=132.05$, $p< .001$), with paired comparisons showing a reliable difference in reaction times for difficulty levels 5 and 6, compared to all other levels ($p< .001$).

No formal analyses were carried out on the number of missed or percentage of correct responses in this task, since an exploration of the data revealed that subjects responded correctly around 95% of the time.

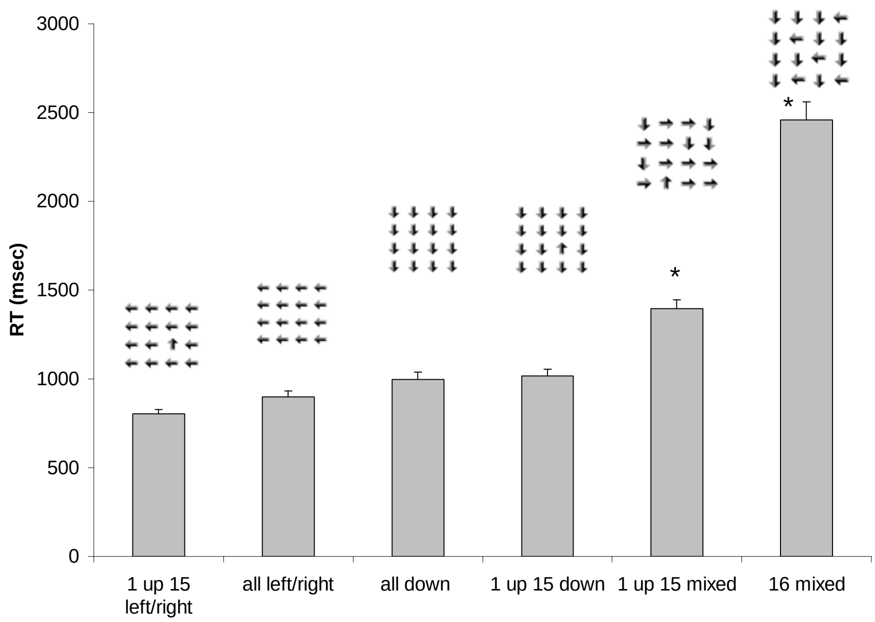



**Figure 5 – Mean reaction time for the six displays of the visual task (Pilot Study 1)**

#### 2.4.3.4. Discussion and Conclusions

The results of the first pilot study showed clearly that the visual task could be presented at different levels of difficulty, as revealed by the observed reaction time to each of the 6 display categories. However, a number of improvements to this task were required to create the S-IVIS task for the HASTE experiments. Firstly, in order to ensure that displays were present for the same amount of time for all subjects, the visual task was changed from a subject-paced to a system-paced task. Secondly, the 6 difficulty levels were combined to create 3 new levels, with the aim of creating difficulty levels that were sufficiently different from each other.

### 2.4.4. Visual task - pilot study 2

This pilot study was designed to test the effect of combining the displays used in pilot study 1 to create a system-paced version of the visual task, with three levels of difficulty.

#### 2.4.4.1. Participants

Six participants (mean age=26.17, SD = 4.62) volunteered for this short experiment, and were paid £5 on completion.

#### 2.4.4.2. Design and Procedure

To create three levels of difficulty, the 6 displays from Pilot Study 1 were used to form a 30 second ‘burst’ of six displays. As shown in Table 6, these 30 second bursts were created by combining a selection of displays from Pilot study 1. To ensure that the third level of difficulty required an adequately high degree of visual attention, the size of display for this level was increased from a 4x4 grid to a 6x6 grid.

**Table 6 – Displays used in the visual task Pilot Study 2**

| Size of Display | Predicted difficulty of display for Pilot 2 | Predicted difficulty of display in Pilot 1 | Quantity used for one ‘burst’ |
|---|---|---|---|
| 4x4 | Level 1 | 1 | 2 |
| | | 2 | 2 |
| | | 3 | 1 |
| | | 4 | 1 |
| | | 5 | 0 |
| | | 6 | 0 |
| 4x4 | Level 2 | 1 | 1 |
| | | 2 | 0 |
| | | 3 | 1 |
| | | 4 | 0 |
| | | 5 | 2 |
| | | 6 | 2 |
| 6x6 | Level 3 | 1 | 1 |
| | | 2 | 0 |
| | | 3 | 1 |
| | | 4 | 0 |
| | | 5 | 2 |
| | | 6 | 2 |

As in pilot study 1, participants were asked to respond as quickly and accurately as possible to each display, using numbers ‘1’ and ‘2’ on the keyboard. However, unlike the first pilot study, each display remained on the screen for 5 seconds, regardless of the speed at which they responded, creating a system-paced visual task. Participants completed 4 blocks of the visual task, and each block consisted of 60 trials.

### *2.4.4.3. Results*

As with pilot study 1, the first block was considered a practice block. Mean reaction time to each level of difficulty for the remaining three blocks was then compared using a one-way ANOVA. As shown in Figure 6, reaction time increased in a systematic manner from difficulty level 1 to 3 ($F(2,179) = 142.885$, $p<.001$).

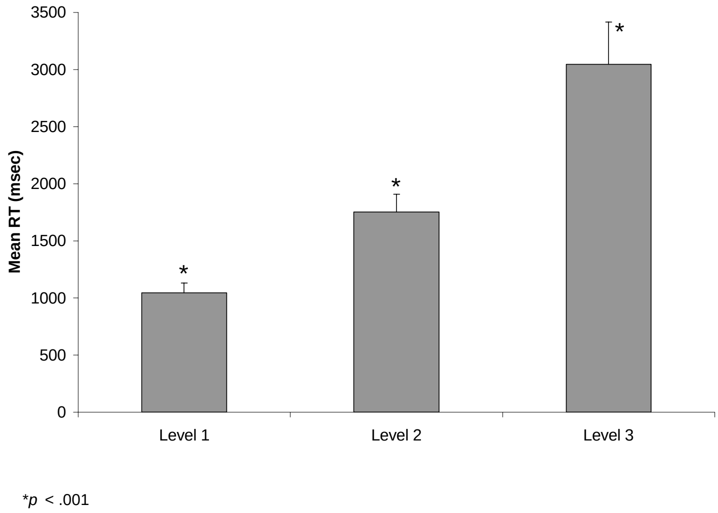



**Figure 6 – Mean reaction time in the visual task (Pilot Study 2)**

### *2.4.4.4. Discussion and Conclusions*

The main aim of this pilot study was to create a system-paced visual display task that required visual attention at varying degrees, as indicated by the accompanying reaction time. As shown in Figure 6, this objective was met, allowing the use of this task as a surrogate IVIS in the HASTE studies.

However, to allow the use of the visual task as an S-IVIS, the following minor modifications were made:

- The visual task was presented on a 6.4" X 6.4" LCD touch screen, positioned in a convenient location for each driving environment (see Figure 7 for an example).
- The start of each block of trials was system-controlled to coincide with the start of a particular driving event.
- An auditory signal was used at the start and end of each block to alert participants and avoid any unnecessary shift of their visual attention from the road, when there was no IVIS demand.
- Response to the task was achieved by pressing 'YES' or 'NO' on the LCD screen.

**Figure 7 – Position of touch screen display in VTT instrumented vehicle**

The visual S-IVIS task and LCD were then distributed to all HASTE partners for use in their driving environment. In the next section, results of pilot studies designed to create a 'cognitive' S-IVIS are outlined.

### 2.4.5. The Cognitive Task

This experiment was adapted from a visual version of the Continuous Memory Task, used by Veltman and Gaillard (1998). In this task, a series of target letters (A, AB, ABC, ABCD) were presented sequentially with non-target letters (E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T, U, V, W, X, Y, Z) on a computer screen. Participants were asked to press a button every time a target letter was presented, and the number of button depressions increased with the presentation of target letters. Once a target letter was presented more than three times, the tally was returned back to zero. Level of difficulty in this task increases by increasing the number of target letters that must be remembered in any one chain of letters. Load can be assessed by using either a manual or vocal response.

This task was deemed suitable for testing the effect of increasing cognitive load on performance. However, to distinguish between the visually presented the visual task s-IVIS and this task, an *auditory* version of the cognitive task was created, by replacing the letters with bursts of sound.

### 2.4.6. Cognitive task - pilot study 1

#### *2.4.6.1. Participants*

Thirty-five volunteers (16 male, 19 female) were recruited for this study (mean age = 30.29, SD = 8.25). Volunteers received £10 at the end of the test session.

#### *2.4.6.2. Design and Procedure*

The visually presented letters used by Veltman and Gaillard (1998) were replaced by bursts of complex sound that were about 320ms long. Complex sounds were used to reduce the use of verbal coding by participants, as much as possible. Four target sounds were chosen for their obvious distinction from one another, and a 320 ms burst of broadband noise was chosen as the non-target sound. The intensity of all sounds was normalised before presentation.

Each participant completed seventeen blocks of the task, with the first block considered as a practice session, and subsequently eliminated from the analysis. Each block contained a sequence of 10 or 20 sounds, presented randomly at a rate of 1 per second. The target sounds were introduced to participants at the start of each block, and they pressed the keyboard space bar to start each experimental block. The task was to keep a count of each target sound as it was presented, storing the response for each sound in a separate tally. Response was via the appropriate number on a keyboard. Each target sound was presented a maximum of three times within a block, although participants were not aware of this. The same target sounds were presented throughout the experiment, since the aim of the experiment was to test their ability to keep a tally of the sounds, rather than remembering if a particular sound belonged to the target list.

#### *2.4.6.3. Results*

As well as calculating the mean reaction time of correct responses, results were categorised and analysed as follows:

- % of correct responses–where the correct count was entered for a target sound
- % of false responses–where the incorrect count was entered for a target sound
- % of missed responses–where a response was not recorded for a target sound
- % of false positive responses–where a non-target sound was counted

Each response category was then treated to a 2 (list size: 10 sounds, 20 sounds) x 4 (target number) repeated measures ANOVA.

As might be expected, increasing the number of target sounds was found to lead to a greater number of missed, false positive and incorrect responses, and therefore reduced the number of correct responses. Reaction time to target sounds was not found to be affected by list length ($p$=.85) or number of target sounds ($p$=.09). These results are summarised in Table 7.

**Table 7 – Results of Pilot Study 1 (the cognitive task)**

| **Tests of within subjects effects** | **List Length** | | **Number of Target Sounds** | | **Interaction** | |
|---|---|---|---|---|---|---|
| | df | F | df | F | df | F |
| Percentage correct | 1,34 | 215.56*** | 3,102 | 25.337*** | 3,102 | 15.47*** |
| Percentage missed | 1,34 | 226.24*** | 3,102 | 28.32*** | 3,102 | 14.25*** |
| Percentage incorrect | 1,34 | 15.82*** | 3,102 | 4.91** | 3,102 | 3.83* |
| Percentage false positive | 1,34 | 3.45 | 3,102 | 2.71* | 3,102 | 1.66 |

*$p$<.05, **$p$<.001, ***$p$<.0001

As shown in Figure 8, increasing the list of sounds from 10 to 20 had a dramatic effect on accuracy; with many more missed responses in the latter condition (see Figure 9). In addition, increasing the number of target sounds produced a sharper drop in accuracy in the 10 sound list condition than in the 20 sound list condition.

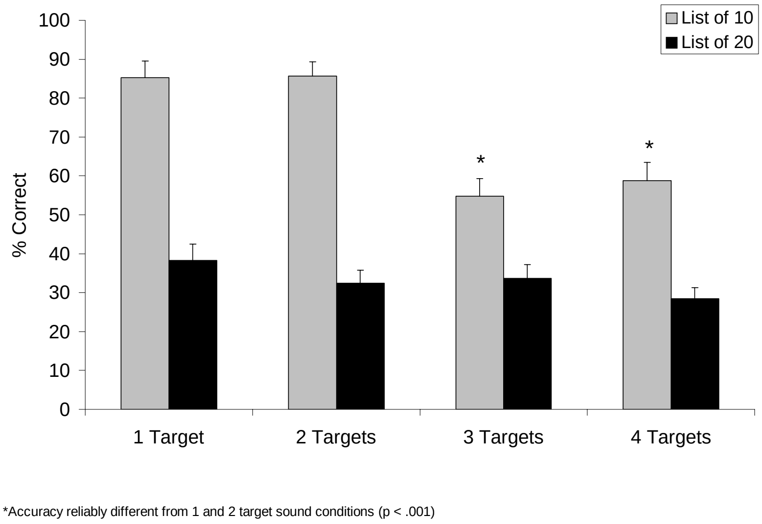



**Figure 8 – % correct responses in the cognitive task (Pilot Study 1)**

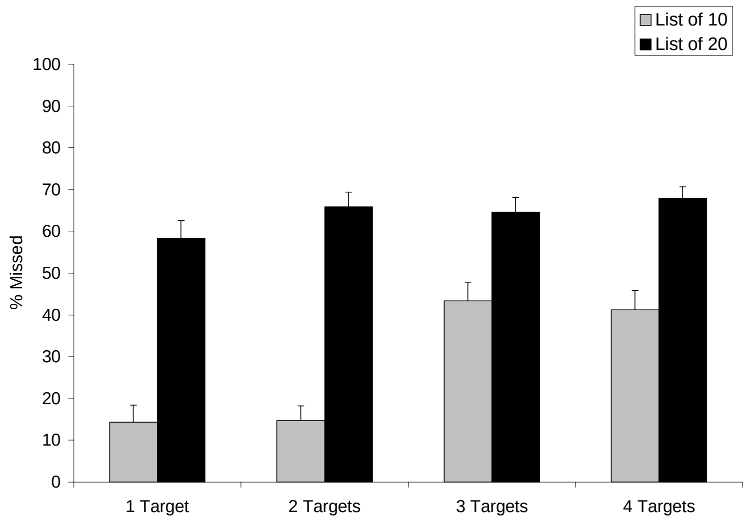



**Figure 9 – % missed responses in the cognitive task (Pilot Study 1)**

### *2.4.6.4. Discussion and Conclusions*

This cognitive task was created to examine the effect of increasing cognitive load (target sounds) on performance. Results showed a relatively systematic increase in difficulty, as revealed by the percentage of correct and missed responses. This was particularly evident when a list of ten sounds was presented. These preliminary findings gave some assurance that this task would act as a suitable surrogate IVIS.

However, one concern about this task was that quite a large number of responses were missed by participants, suggesting that presenting sounds at a rate of once a second may have been too fast. Also, unlike the visual version of the task, only one non-target sound was used in this experiment, which may have also created some spurious results. A further pilot study was therefore conducted to tackle these issues.

### 2.4.7. Cognitive task - pilot study 2

This pilot study continued to study the effect of increasing target sounds on accuracy. However, a larger number of non-target sounds were introduced in this study and sounds were presented at two different rates. Once again the study was carried out at a PC, i.e. statically, using the E-Prime software.

#### *2.4.7.1. Participants*

Nine volunteers (4 female, 5 male) from the University of Leeds staff and students participated in this experiment (mean age=29.11, SD=7.96). All volunteers received £10.

#### *2.4.7.2. Design and Procedure*

Four target sounds and ten non-target sound samples were chosen for this experiment (mean duration=161. 67 ± 27.49 msec). Sounds were presented at two different rates: one every 1.5 or one every 2 seconds, and the list of sounds presented was either 10 or 15 sounds long. As with pilot study 1, participants were alerted to their target sounds before the start of each block and pressed the keyboard space bar when they were ready to begin. Each participant completed a practice block, followed by twelve experimental blocks. In this pilot study, load increased from 2 to 3 to 4 target sounds.

As well as performing the cognitive task, they were asked to complete a computerised questionnaire, rating the distinction between each target sound and all non-target sounds. This measure was added to ensure that any error in the cognitive task was not related to confusions between target and non-target sounds.

#### *2.4.7.3. Results*

**Cognitive task:** Due to the small number of volunteers and the large number of variables in this experiment, formal statistical analyses were not conducted — it was clear that statistical reliability was not achievable. Results were once again categorised in terms of correct, missed, false and incorrect responses. The percentage of correct responses for each rate of presentation and list length are plotted in Figure 10. While response rate was relatively low, a clear pattern is seen, with an increase in the number of target sounds causing a reduction in accuracy. This systematic fall in accuracy is shown to be more prominent in the 15-sound-list condition, and when sounds are presented every two seconds.

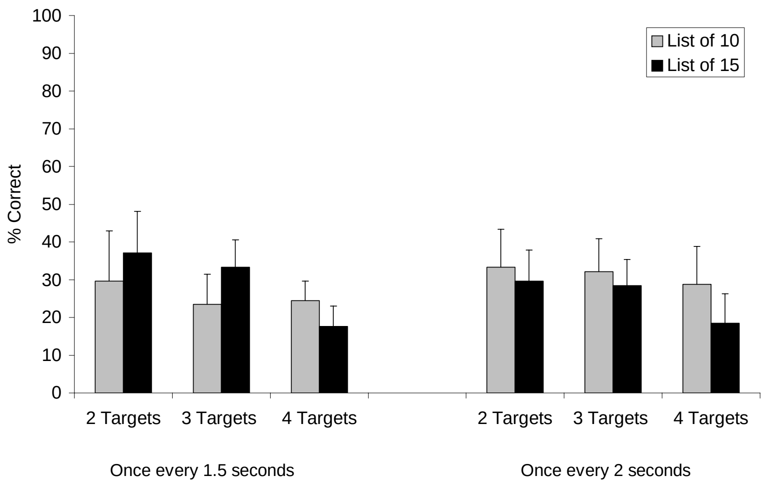



**Figure 10 – % correct responses in the cognitive task (Pilot Study 2)**

**Subjective questionnaire:** As outlined above, following completion of the cognitive task, participants were asked to decide how distinct each target sound was from each of the non-target sounds. An average rate of 6.32 ± 1.05 was scored for the four target sounds, using a scale of 1 (not very distinct) to 9 (very distinct). The distinction between a particular non-target sound and the first target sound was given a score of 3.1 and this non-target sound was therefore removed from forthcoming the cognitive task experiments.

#### *2.4.7.4. Discussion and Conclusions*

The two pilot studies described above were designed to test the feasibility of using an auditory version of the visual memory task as a S-IVIS task. The important criteria for this task were:

- An ability to present stimuli in a non-visual manner
- Evidence of a systematic rise in cognitive load, as witnessed by a fall in accuracy

Results from the above pilot studies confirm that these objectives were met by the designed cognitive task.

As with the visual task, a number of modifications were made to the final version of the cognitive task before distribution to all HASTE partners. These included:

- Presentation of sounds from speakers positioned in the driving environment.
- System-controlled start of each block to coincide with the start of a particular driving event.
- A vocal response to the task by participants to reduce any conflict a manual response may have caused to the driving task.[2]

## 2.5. Assessment Methods

In the HASTE project, fixed and moving base simulators are referred to as simulators. PC-based driving simulators with a PC-monitor and low cost steering and speed controls are referred to as laboratories. For the field experiments, instrumented vehicles were used for measuring driving behaviour. Overall, 5 simulators, 1 laboratory and 3 instrumented vehicles were used in the experiments.

### 2.5.1. Simulators and Laboratories

The main advantage of using driving simulators and laboratories for IVIS testing is the excellent prerequisites for experimental control. All drivers can be exposed to the same conditions. Also, a perfect replication of those conditions between baseline drives and experimental drives is possible. Thus, driving simulators and laboratories provide an excellent environment for experimental studies and possibilities to generate sufficient qualities and quantities of data at a reasonable cost.

The technical possibilities of the measurement of vehicle-related parameters, such as speed and lateral position of the own vehicle and other vehicles, and events in the traffic environment are much greater in simulators and laboratories than in real traffic. Another advantage is that the drivers can be forced beyond the limit of their capabilities of managing critical situations without being in any physical danger.

[2] A short pilot study in the laboratory confirmed no difference in performing the cognitive task between manual and vocal response.

The most important feature of a driving simulator is its behavioural validity. If the behavioural validity of a driving simulator has not been verified, it is questionable whether the simulator should serve as a research environment for IVIS testing. In the absence of behavioural validations, results obtained in a driving simulator should be interpreted with greatest caution, particularly if they are not in correspondence with general findings in similar or field studies. Laboratories, as defined in this project, are in general not validated. In this project, however, the comparisons made between field, simulator and laboratory studies partly serve as a validation of the simulators and laboratory.

The main advantages of laboratories compared to simulators are that low cost experiments and data sample systems can be implemented, and that it is possible to test a larger number of participants with lower research costs.

### 2.5.2. Field studies

The field studies performed with instrumented vehicles come as close to real life as possible. Not only does this mean real accident risk and high driver motivation, it also includes more unpredictable aspects such as behaviour of other traffic participants, adverse weather conditions, unexpected road constructions, etc. The test route may be fixed, but events are not under experimental control. To ensure safety, test vehicles are generally equipped with dual controls that can be operated by a driving instructor or experimenter. For a more complete discussion of advantages and disadvantages of field tests see Smiley and Brookhuis (1987) and de Waard (1996).

## 2.6. Road and Traffic Environments

### 2.6.1. Rural Road

#### *2.6.1.1. General description*

In principle these are all roads outside built-up areas. The speed limit can be 60, 80 or 100 km/h and oncoming traffic is common. The lane width is usually around 3 metres. The lanes are not divided and there is only one lane per direction. The specific characteristics of the rural road used in the field trials are described in the separate chapters in this deliverable. In the simulator and the laboratory, the same rural road and scenarios were implemented in order to test cross-site and cross-country reliability (see chapter 13 - Cross test site comparisons). This road is described below. Deviations from the description are reported in the separate chapters.

#### *2.6.1.2. Simulator rural road*

Two sections of rural road were designed. The characteristics of each road were the same, and are described in Table 8. All participants drove both rural roads (R1 and R2). However, the order of drives was counterbalanced, such that half (N=12) drove R1 before R2, and the other half drove R2 before R1. Similarly, R1 was driven as a baseline road by half of the participants, and in conjunction with the S-IVIS task by the other half (see Section 2 on experimental design for more details).

**Table 8 – Characteristics of the HASTE rural road**

| | |
|---|---|
| Speed limit | 96 km/h |
| Length | Just over 29 km |
| Total road width | 7.3 m |
| Number of Lanes | 2 (1 per direction of travel) |
| Lane width | 3.65 m |
| Shoulders | None |
| Verge | None |
| Minimum radius of Curvature | 510 m. |
| Exit | None |
| Connections | None |
| Junctions | 2 for each road |

Each road consisted of three repetitions of 3 driving scenarios, which were designed to vary in terms of workload and driving difficulty. These are referred to as sections of different road complexity level (RLv). These were:
**RLv1:** Straight roads, requiring minimal workload compared to other scenarios.
**RLv2:** Gentle s-shaped curves, which required some negotiation by the driver.
**RLv3:** Discrete critical events, which necessitated a major reduction of speed by the driver. As well as requiring a reasonable degree of interaction with the simulator and the lead car, this type of scenario was also thought to impose maximal driving difficulty, when compared to the other two scenario levels (see Figure **11** for an example).


The lead car comes to a stop, due to the presence of a lorry crossing in its path

**Figure 11 – Example of a rural road discrete event**

Each of the above scenarios was interspersed with ‘filler’ sections of road. To reduce learning, six ‘discrete events’ (scenario level 3) were created – with three events dedicated to each road. The order of scenarios was the same for each road type, as outlined in Table 9.

A lead car was introduced at the start of each rural road, and participants were instructed not to overtake this car. The lead car maintained three seconds headway with the simulator car *at the start* of each event, to allow maximum data collection, whilst ‘free driving’ was introduced during non-event/filler road sections.

**Table 9 – Order and description of scenarios for rural roads 1 and 2**

| Order of Scenarios | Road 1 | Road 2 |
|---|---|---|
| 1 | Straight | Straight |
| 2 | Discrete Event – *Sheep blocking the road* | Discrete Event – *Road works* |
| 3 | S-shaped Curve | S-shaped Curve |
| 4 | Discrete Event - *Crossing lorry* | Discrete Event – *Crossing car* |
| 5 | S-shaped Curve | S-shaped Curve |
| 6 | Straight | Straight |
| 7 | Straight | Straight |
| 8 | Discrete Event – *Emerging lorry* | Discrete Event – *Emerging car* |
| 9 | S-shaped Curve | S-shaped Curve |

### 2.6.2. Motorway

#### *2.6.2.1. General description*

In motorways, the directions of travel are divided, with at least two lanes per direction (plus hard shoulder). Speed limits are in general between 110 and 130 km/h and the lane width is generally 3.6 – 4.0 metres, not including the hard shoulder. In these experiments, there were two lanes per direction plus hard shoulder. An identical motorway was included in two simulators (VTI and Volvo) and is described below. The motorways included in the field trials are described in each experiment report, but follow this general description.

#### *2.6.2.2. Simulator motorway*

The motorway was 46 km long and had two driving lanes in each direction plus hard shoulder. The lane width was 3.75 metres. See Figure 12 below. The speed limit was 110 km/h. The road curvature was sampled from a road in Sweden. At predefined locations along the road, there were cars to be overtaken, and cars overtaking the participant. The road included two levels of complexity; normal driving and events. In the normal driving condition, there was random curvature, occasional overtaking cars and cars to be overtaken. The events were caused by other vehicles: on three occasions, other vehicles cut in front of the participant. These vehicles were either merging from slow travelling queues or overtaking the participant. The latter alternative involved the car braking. The cutting in and braking was trigged on predefined Time-to-Collision (TTC) values or Time Headway (HWT) values. The situations were then resolved on predefined TTC, HWT or Distance Headway (HWD) values in order to avoid collisions. The situations were resolved by accelerating the lead vehicle. The critical situations required the participants to react within two seconds. Otherwise, the situations were automatically resolved.

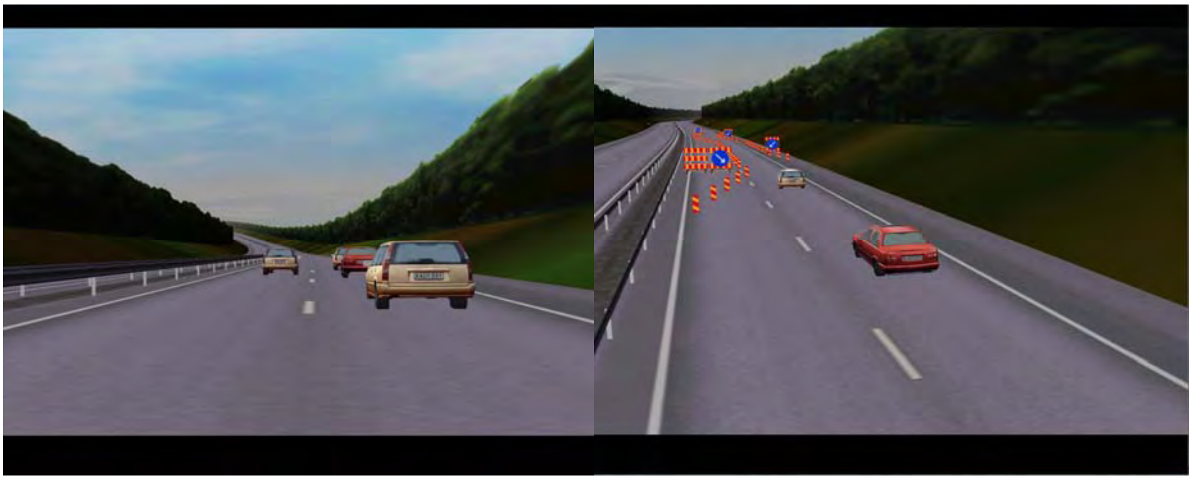


**Figure 12 – Motorway environment and roadwork event**

There were two motorway routes; one for the baseline run and one for the experimental run. They were identical except for the position and design of one of the events. See Table 10 for short descriptions of the motorway events. For example, in one motorway an 'overtaking event' could involve overtaking three vehicles while in the other only two vehicles were overtaken. Also, colours as well as types of vehicles were changed between the two motorways in order to make the second run on the same road type less predictable. Six critical events were designed and distributed with three critical events per motorway.

**Table 10 – The critical events on the motorway**

| Critical events: Motorway 1 | Critical events: Motorway 2 |
|---|---|
| Participant overtakes three vehicles, of which the second cuts in | Participant overtakes three vehicles, of which the second cuts in |
| Road works and vehicle cutting in | Subject overtakes four vehicles, of which the third cuts in |
| Three vehicles in left lane pass subject, of which the second cuts in | Three vehicles in left lane pass subject, of which the second cuts in |

### 2.6.3. Urban Road

There are different types of urban roads; from low to higher speed limit these could be characterised as

- 'woonerf' (Dutch design) where all traffic participants mix and the speed limit is 15 km/h
- area entrance roads; in the Netherlands and Germany these roads have a limit of 30 km/h or 50 km/h; narrow roads
- urban through roads, high traffic volume urban roads, speed limit 50 km/h (sometimes 70 km/h)

Urban roads were included in simulator experiments and field trials. The simulator urban roads had a speed limit of 50 km/h and included turning at intersections. The roads and scenarios are further described in the separate reports.

## 2.7. Indicators and Analysis

The analysis was divided into driving performance, workload data analysis and S-IVIS performance analysis. The purpose of the analysis of driving and workload data was to analyse the safety indicators' sensitivity to cognitive and visual/motor load. The purpose of the S-IVIS data analysis was to investigate how the drivers prioritised between the driving task and the S-IVIS task.

### 2.7.1. Common analysis method

The common analysis method was designed at VTI. A common analysis approach in all studies was necessary in order to generate comparable results between the experiments. Since the experimental design differed somewhat between simulator, laboratory and field experiments, the details of the analysis methods also had to differ. An example of such a detail was the number of road complexity levels. For the simulator/laboratory rural road experiments, however, the designs were identical and thus required identical analysis methods, as was also the case for the simulator motorway experiments. Univariate Analysis of Variance (ANOVA) and a 5% level of significance were used.

The analysis method was primarily designed for the most complex experiment; the simulator/laboratory rural road experiments. These experiments included three road complexity levels, of which the highest level consisted of critical events. The motorway and urban road simulator experiment included two road complexity levels. The field trials generally included only one road complexity level, but there were exceptions. In the less complex experiments, the levels of the included factors were less. The analysis method was, except for these deviations, identical to the one described here. Detailed analysis plans for the rural road simulator/laboratory experiments and the simulator motorway experiments are included in Appendix 4 and 5. Since the analysis plans for the field experiments and the simulator urban road experiments were individual, those plans are described in the individual experimental reports.

It was mandatory to include the factors of S-IVIS difficulty (4 levels) and road complexity (if included, 2 or 3 levels) in the analysis. Although different road types and not only one S-IVIS were included in the experiments, it was not mandatory to include these as factors in the analysis. In fact, there is little support for the comparability between S-IVIS tasks or road types. Therefore separate analyses for different road types and S-IVIS tasks were carried out.

In Appendix 3, detailed analysis designs and models for the different scenario setups are reported.

### 2.7.2. Indicators

The very purpose of WP2 is to test if those scenarios and indicators identified in WP1 successfully can be used for assessing IVIS, as stated in *2.1 - Methodological approach*. For classifying an indicator as successful, the indicator has to be

- sensitive to driving performance deterioration
- reliable between drivers, test sites and countries
- easy to implement
- cost effective, which of course relies on the previous criteria

The effects of IVIS on driving behaviour may not only result in an increased accident risk. The driver may, for example, compensate for the distraction by reducing speed, choosing to drive a less demanding route or increasing the distance to other road users. In the end, these actions may lead to less accident risk compared to when not using an IVIS. Therefore, in order to identify an indicator as reflecting driving performance, it has to be arguable that the indicated behavioural changes caused by the impact of the S-IVIS tasks lead to increased risk of accident.

All experiments had to include a set of mandatory measures – if possible. There was also a set of optional measures. All measures were strictly defined in order to avoid any between variations in the implementation of the measures. The selected measures and their definitions are found in Appendix 1 and Appendix 2. The measures were based on the outcome of WP1, where a large set of indicators of driving performance, workload and visual distraction were identified. These measures were based on automatic detection of e.g. travel speed and vehicle lateral position, observer ratings of driver performance, self-reported driving performance and detection of physiological parameters such as gaze angle and heart rate.

The indicators included in WP2 can be classified into

- Self reported driving performance
- Lateral control
- Longitudinal control, i.e. control of speed and distance to a lead vehicle
- Workload, such as physiological measures and gaze behaviour
- Observations of driving performance made by an accompanying expert observer

The *self reported driving performance* is a subjective rating of absolute driving performance made by the driver on a scale of 1 to 10. The scale is similar to many scales used in psychological tests, but have not been previously used in this form. The expert observer was defined as an experienced driver (a total mileage of at least 10 000 km and holder of a driving licence for at least five years), and also being experienced with driver behaviour and traffic safety research.

### 2.7.3. S-IVIS measures and analysis

It was important to analyse drivers' performance on the S-IVIS secondary task as well as their driving performance. The purpose of the S-IVIS analysis was to investigate how the drivers prioritised between the driving task and the S-IVIS task — for example, they might choose to reduce their effort on or even to drop the secondary task when driving became more demanding. In the description of the S-IVIS tasks (see section 2.4, Surrogate IVIS ), several performance indicators were defined. For the cognitive and visual tasks, the proportion of correct, missed and false responses were measured. For the visual task, response reaction time was also measured. The S-IVIS performance indicators were analysed using univariate ANOVA or repeated measures analysis. The effect of S-IVIS difficulty (SLv) in the driving condition was analysed; the factors included was SLv and road complexity level (RLv). Also a comparison between using the S-IVIS as a single task (static test) or dual task (during driving) was made. The factors included here was SLv and static/dual task (two levels).

# 3. Introduction to the separate reports

There is one report for each experiment (chapters 4 to 12) included in this deliverable. The reports all follow the same structure, and include the applicable parts of the following:

- Study title
- Test site
- Scenarios and participants
- S-IVIS evaluated
- Experimental design
- Procedure
- Measures and analysis method
- Results
  - Effects of the S-IVIS and road complexity in the different scenarios (mandatory)
  - Comparisons of effects between the visual task and cognitive task (optional)
  - Comparisons of effects between road types (optional)
  - Comparisons between drivers of different nationality (mandatory where applicable)
- Summary and conclusions
- Measures summary tables

The results are reported for different road types separately. Also, the results are reported for the cognitive task and the visual task separately. AT the end of each report there are tables including all measures that were collected. There is one table for each combination of road type and S-IVIS. In the tables, mean values, significant effects (5%) and post hoc tests for each safety/workload indicator are included. Due to space restrictions, only the abbreviations of the indicators are included, thus not the full names.

The data plots in the reports display the estimated marginal means (bars) and the 95% confidence intervals (whiskers) obtained from the statistical analysis.

# 4. The MINHO Laboratory Experiment

## 4.1. Test site

The laboratory experiments were performed in the laboratory (DriS) of the Faculty of Engineering of the University of Porto. The main core of DriS runs on a SGI Onyx Reality Engine 2 graphical workstation. This workstation holds the scene database, and performs the simulation and the computer graphics tasks. In these experiments, as can be observed in Figure 13, the driver views the image on a 21” monitor at a distance of 80 cm. The horizontal visual angle under these conditions was 27°. Experiments were performed with a spatial resolution of 1280x1024, and a temporal resolution of 18 frames per second. The driver interface was composed of a low cost kit of steering-wheel and pedals (brake and accelerator). Audio and dynamic feedback was not provided in these experiments. All the experimental work was recorded by a video camera.

**Figure 13 – Laboratory experiment site (Minho)**

An extra study was conducted for a comparison between British and Portuguese participants. The purpose of this extra study was to confirm whether, should the results obtained in the Minho laboratory differ from those obtained elsewhere, this was attributable to the different nature of the laboratory or to the different driving style of Portuguese drivers. The experiments were performed by a British test leader to avoid linguistic or cultural difficulties, with the support of the Portuguese test leaders. All the specifications and conditions of the Minho lab site were maintained in the cross-cultural lab study.

## 4.2. Scenarios and participants

The sample included 144 average drivers, i.e. holding a licence for at least 5 years and aged between 23-49 years. Their average age was 32 years (SD 7.35) and 77% of the sample was male. They had held their driving license on average for 12 years (SD 6.19) and had an average annual mileage of 23934 km (SD 16283).

The British sample included 24 average drivers, i.e. holding a licence for at least 5 years and aged between 25-49 years. The British participants were in Portugal on vacation or as residents. It was difficult to recruit British drivers in Portugal who had not been exposed to the Portuguese traffic conditions - although this would have been the preferred option. It is not known how much these British subjects have adapted their behaviour due to their Portuguese exposure.

The age of the British drivers was 33 years (SD 6.80) with an equal distribution of males and females. They had held their driving license on average for 14 years (SD 7.16) and had an average annual mileage of 17522 km (SD 6541). All the drivers had more driving experience in the UK when compared to their driving experience in Portugal (mean 4 years; SD 4.30).

The experimental route only included a rural scenario, already described in this document (two rural roads, with equivalent critical events – road 1 and 2). The speed limit was 90 km/h and the road was 30km in length. For the British drivers, the road was adapted for driving on the left hand side.

## 4.3. S-IVIS evaluated

Both of the S-IVIS were included: the visual task (72 participants) and the cognitive task (72 participants). The tasks and their difficulty levels were maintained according to the description in section 2.1 (the 24 S-IVIS files with the difficulty levels balanced were distributed for the subjects that performed each one of the S-IVIS).

Only the visual S-IVIS task was included in the experiment with the 24 British participants in the cross-cultural study. The task and its difficulty levels were maintained according to the description in section 2.1 (the 24 S-IVIS files with the difficulty levels balanced were distributed for each subject).

## 4.4. Experimental design

The experimental design followed the description already presented in this report.

## 4.5. Procedure

Before the experiment, all participants underwent a familiarisation period (driving, additional task and performance rating), where they drove with the same instructions used in the experiment. Drivers completed two runs on the rural road, one with the additional task (“experimental”) and one with only the driving task (“baseline”). The order in which each version of the rural road was presented was balanced. An S-IVIS single task condition (without driving) was performed and the order of this task, baseline and experimental was also balanced. After the S-IVIS blocks in the experimental road and at the corresponding points of the baseline road (9 points) the drivers were asked to rate their driving performance on a scale from 1 to 10. This assessment was triggered verbally by the test leader.

## 4.6. Measures and analysis method

The data were sampled at 10 Hz. The collected data allowed the calculation of all the mandatory measures – longitudinal control, lateral control and self reported driving performance related measures - already indicated in this document as well as some additional measures:

- minimum TTC
- SD distance headway
- SD time headway
- minimum distance headway
- minimum time headway
- minimum TLC
- minimum speed.

The variables related to lateral and longitudinal position were measured by taking the position of the driver as the reference (instead of a part of the vehicle as in most simulators). Also, for the calculation of the time-to-line-crossing measures, distance to the lane markings was measured from the location of the driver, thus not from the outer edges of any simulated front wheels. The driving and S-IVIS data obtained were analysed with the common method already described above, following the measures and steps defined for the rural road analysis.

In the cross-cultural study, the data for 24 British drivers was compared against 24 Portuguese drivers under the same experimental conditions (e.g., road, order of driving and S-IVIS counterbalancing). Repeated measures Anova and EMMEANS statement were used to discover statistically significant differences between the Portuguese and British data. Repeated measures Anova were performed to statistically evaluate effects of the S-IVIS and Road Complexity levels in the aggregated Portuguese and British data.

## 4.7. Results

### 4.7.1. Effects of the cognitive task in Rural Road driving

No interaction between the two independent variables S-IVIS difficulty level and Road complexity level was found for all dependent variables. Significant effects of S-IVIS difficulty level were only found for Mean Distance and Time Headway and Time Headway variation. The proportion of TLC minimum values less than one second was always zero and this variable was not taken into account with the cognitive task.

#### *4.7.1.1. Self reported driving performance*

A decrease in self reported driving performance (subj_r) was observed as the S-IVIS complexity level increased, with significant differences between baseline and the three S-IVIS difficulty levels, see Figure 14. This difference was also observed between the S-IVIS difficulty levels 1 and 3. So, the presence and the level of difficulty of S-IVIS are associated with poorer self-reported driving performance.

An effect of increasing Road complexity level was also observed. Drivers reported their performance was poorest in the critical events (mean.6.956) when compared with straight (mean.7.405) and curved (mean.7.281) sections.

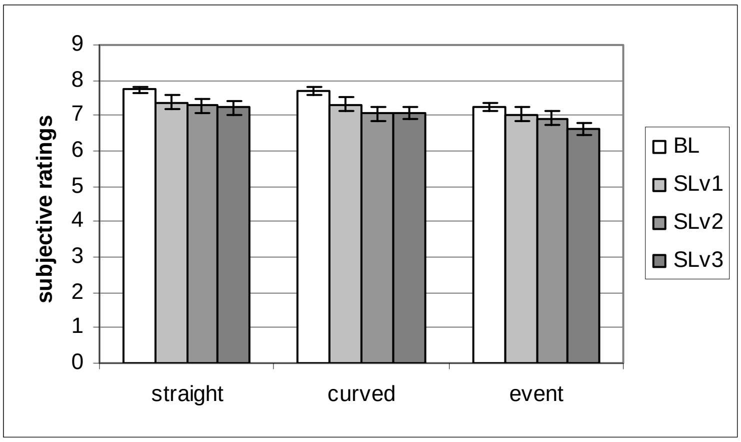



**Figure 14 – Self reported driving performance (subj_r), Cognitive task, Rural road**

#### *4.7.1.2. Longitudinal control*

A reliable effect of the cognitive task difficulty levels was observed on Headway related dependent variables during the event scenarios: time and distance headway (mn_hwt, mn_hwd) increased and the distance headway variation decreased (sd_hwd) with the presence of S-IVIS. The post hoc test revealed only a reliable difference between SLv3 and baseline for time and distance headway. For sd_hwd, a difference between SLv2 and BL was found. See Table 11, Figure 15 and Figure 16 for mean time and distance headway. These results could indicate a possible compensatory behaviour during the cognitive task, because the drivers' longitudinal control became more stable, with maintenance of greater distance and time headway. None of the other variables were reliable.

**Table 11 – Analysis of mean distance and time headway (mn_hwd, mn_hwt), Cognitive task, Rural road**

| | Mean values | | | | Effects | | | Post Hoc test | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 | |
| mn_hwd [m] | 29.05 | 29.81 | 30.62 | 31.317 | ✓ | n/a | n/a | BL | × | × | ✓ | event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| sd_hwt [s] | 0.501 | 0.452 | 0.43 | 0.446 | ✓ | n/a | n/a | BL | × | ✓ | × | event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |

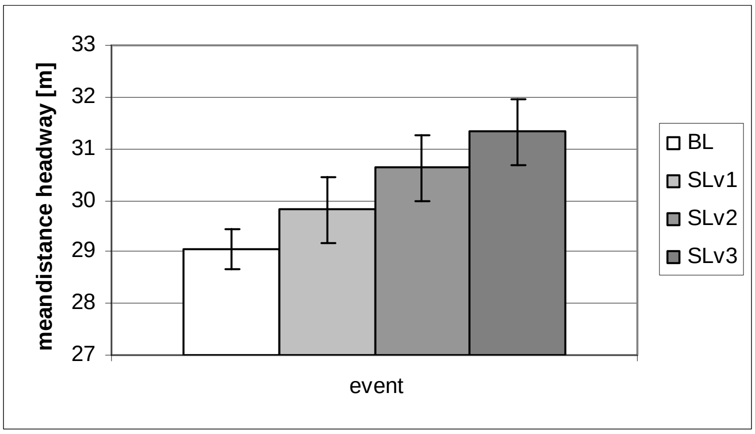



**Figure 15 – Mean distance headway (mn_hwd), Cognitive task, Rural road**

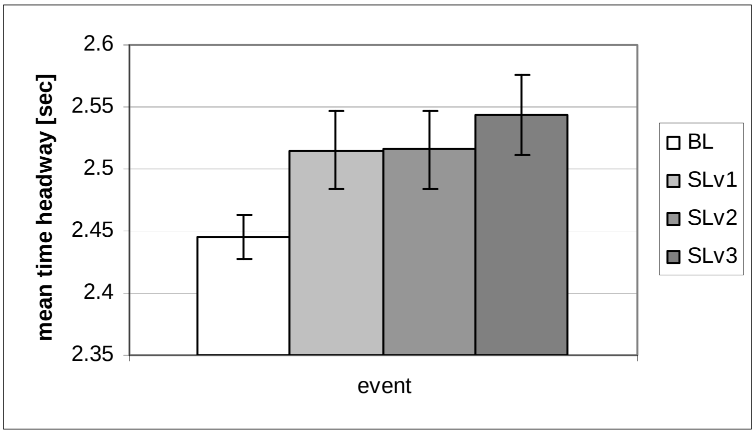



**Figure 16 – Mean time headway (mn_hwt), Cognitive task, Rural road**

#### *4.7.1.3. Lateral control*

A reliable effect of the cognitive task difficulty level was found for the dependent variables Lateral position variation (st_lp) and Reversal rate (rr_st1). In these two cases, the baseline was significantly different from levels 1, 2 and 3 (see Table 12).

Lateral position variation (st_lp) decreased as the cognitive task difficulty level increased (see Figure 17), indicating an improvement in lateral control performance. Statistical testing indicated increased Reversal rate (rr_st1) from baseline to experimental conditions, see Figure 18. ). It should also be noted that the mean values decreased (non-significantly) from SLv1 to SLv3.

**Table 12 – Analysis of lateral control measures, Cognitive task, Rural road**

| | Mean values | | | | Effects | | | Post Hoc test | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 | |
| st_lp [m] | 0.393 | 0.355 | 0.354 | 0.35 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ | straight, curved and event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| rr_st1 | 10.46 | 11.825 | 11.57 | 11.354 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ | straight, curved and event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |

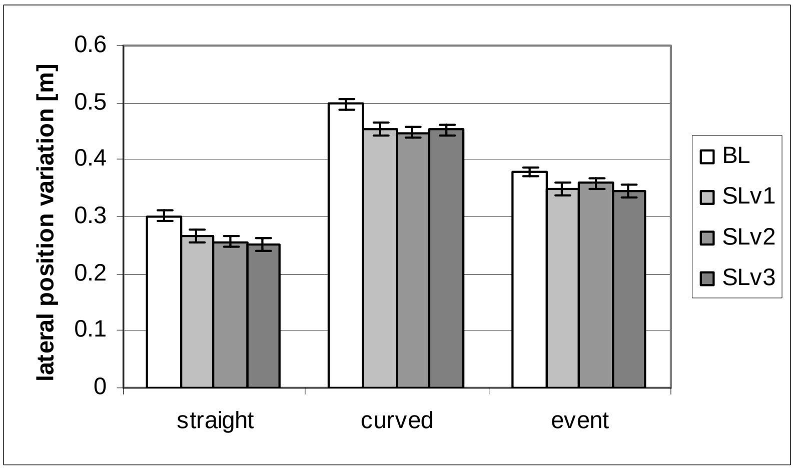



**Figure 17 – Lateral position variation (st_lp), Cognitive task, Rural road**

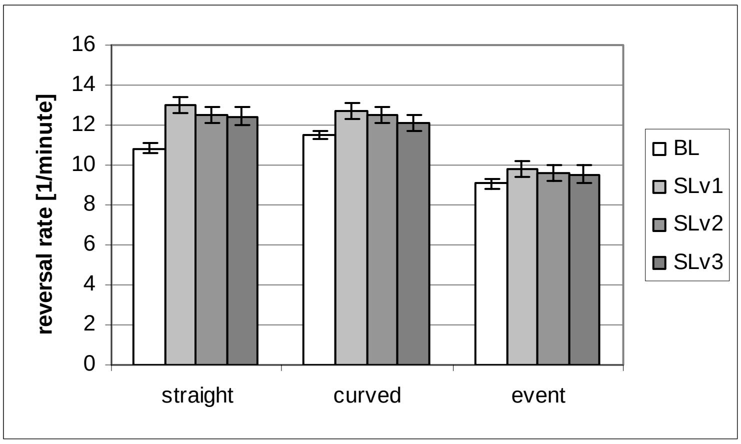



**Figure 18 – Reversal rate (rr_st1), Cognitive task, Rural road**

In terms of Road complexity levels, main effects were found on lateral position measures. Reversal rate in events (mean.9.504 1/minute) was significantly lower than in straight (mean.12.203 1/minute) and curved (mean.12.205 1/minute) sections, as can be observed in Figure 18. For Lateral position variation, all the levels were reliably different, reaching the highest value in the curved section. In these sections the lateral control was more difficult to maintain due to the road geometry.

Although the effect of the cognitive task difficulty level over the remaining dependent variables was not significant, some clear tendencies could be observed from means analysis. For example, average Lateral position increased as the cognitive task complexity level increased. Conversely, Lanex decreased when the cognitive task complexity level increased – these results suggest an improvement in lateral control during the performance of a cognitive secondary task.

### *4.7.1.4. S-IVIS performance*

Main effects of Road complexity and S-IVIS difficulty levels were found in the cognitive task analysis, as can be observed in Table 13 and Table 14. Looking at Figure 19 to Figure 21 it can be observed that the number of correct answers found in the baseline was reliably higher than the curved sections and events. Thus the cognitive task was found to have reliable effects, revealing a decrease in the number of correct answers as the task complexity increased.

**Table 13 – Analysis of Road complexity (4 Lvs), Cognitive task, Rural road**

| | Mean values | | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|
| Measure | BL | straight | curved | event | | straight | curved | event |
| Percentage of correct responses | 88.48 | 89.622 | 82.497 | 80.22 | BL | ✗ | ✓ | ✓ |
| | | | | | straight | | ✓ | ✓ |
| | | | | | curved | | | ✗ |
| Percentage of incorrect responses | 7.769 | 7.255 | 7.681 | 11.11 | BL | ✗ | ✗ | ✓ |
| | | | | | straight | | ✗ | ✗ |
| | | | | | curved | | | ✗ |
| Percentage of missed responses | 3.782 | 3.086 | 9.774 | 8.629 | BL | ✗ | ✓ | ✓ |
| | | | | | straight | | ✓ | ✓ |
| | | | | | curved | | | ✗ |
| Percentage of false response | 0.968 | 7.255 | 7.681 | 11.11 | BL | ✓ | ✓ | ✓ |
| | | | | | straight | | ✗ | ✓ |
| | | | | | curved | | | ✓ |

**Table 14 – Analysis of S-IVIS (3 Lvs), Cognitive task, Rural road**

| Measure | Mean values SLv1 | SLv2 | SLv3 | Post Hoc test | SLv1 | SLv2 | SLv3 |
|---|---|---|---|---|---|---|---|
| Percentage of correct responses | 89.935 | 85.43 | 80.252 | SLv1 | | ✓ | ✓ |
| | | | | SLv2 | | | ✓ |
| Percentage of incorrect responses | 5.684 | 8.132 | 11.542 | SLv1 | | ✓ | ✓ |
| | | | | SLv2 | | | ✓ |
| Percentage of missed responses | 4.394 | 6.373 | 8.188 | SLv1 | | × | ✓ |
| | | | | SLv2 | | | ✓ |
| Percentage of false response | 5.031 | 6.399 | 8.826 | SLv1 | | × | ✓ |
| | | | | SLv2 | | | ✓ |

The highest percentage of incorrect and misses answers was found on the highest S-IVIS and Road complexity levels, so as the demanding effort of the driving scenarios and S-IVIS task increased, the performance of this secondary task (the cognitive task) decreased. Regarding incorrect responses, reliable differences were found between baseline and events of Road complexity and between all the levels of S-IVIS. Missed responses reached higher levels in the curved sections and events (with reliable differences between these levels and the baseline and the straight sections). An increase in the number of target sounds increased the percentage of missed responses, as can be observed in the reliable differences between the level 3 (highest percentage) and the other levels of S-IVIS difficulty.

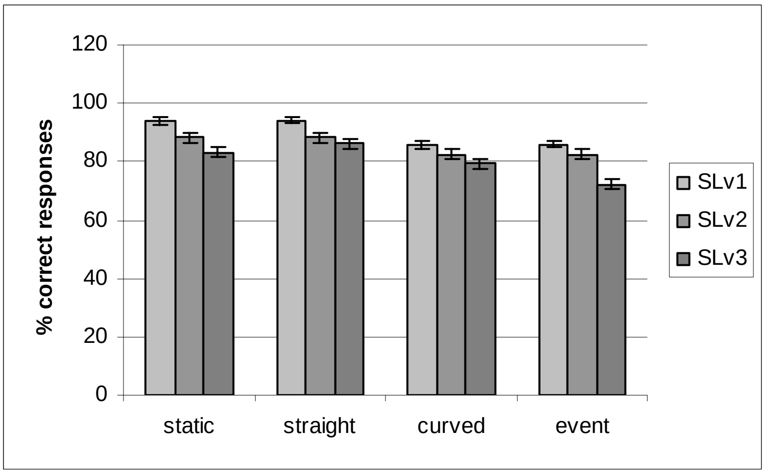



**Figure 19 – % correct responses by Road complexity and S-IVIS difficulty, Cognitive task, Rural road**

False responses were almost inexistent in the S-IVIS baseline and the percentage increased substantially as effect of the Road complexity levels and secondary task levels, as can be observed in Figure 22.

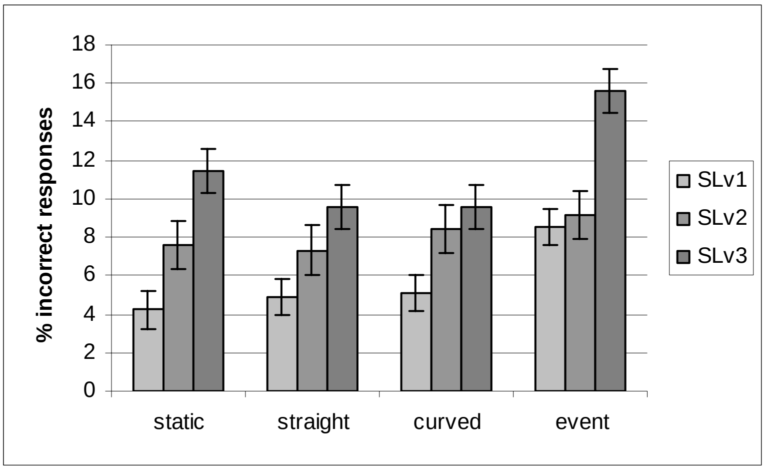



**Figure 20 – % incorrect responses by Road complexity and S-IVIS difficulty, Cognitive task, Rural road**

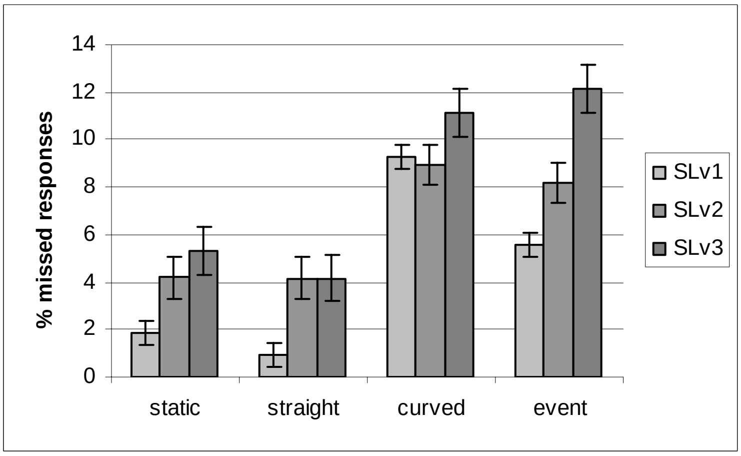



**Figure 21 – % missed responses by Road complexity and S-IVIS difficulty, Cognitive task, Rural road**

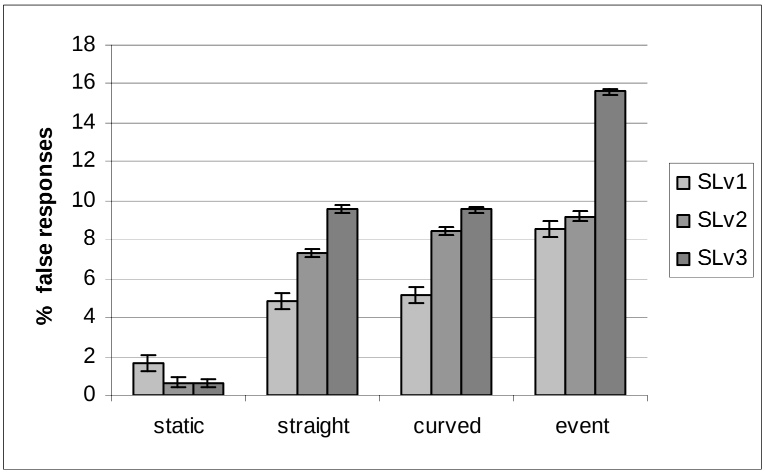



**Figure 22 – % false responses by Road complexity and S-IVIS difficulty, Cognitive task, Rural road**

## 4.7.2. Effects of the visual task in Rural Road driving

### *4.7.2.1. Self reported driving performance*

The self reported driving performance (subj_r) was lower in the experimental conditions (SLv1-3) compared to the baseline (see Table 15). No differences were found between the experimental levels. Subj_r was significantly lower in the curved road segments than in the other road complexity levels (see Figure 23).

**Table 15 – Analysis of self reported driving performance (subj_r), Visual task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 | |
| subj_r | 7.728 | 6.259 | 6.375 | 6.4 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ | straight, curved and event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |

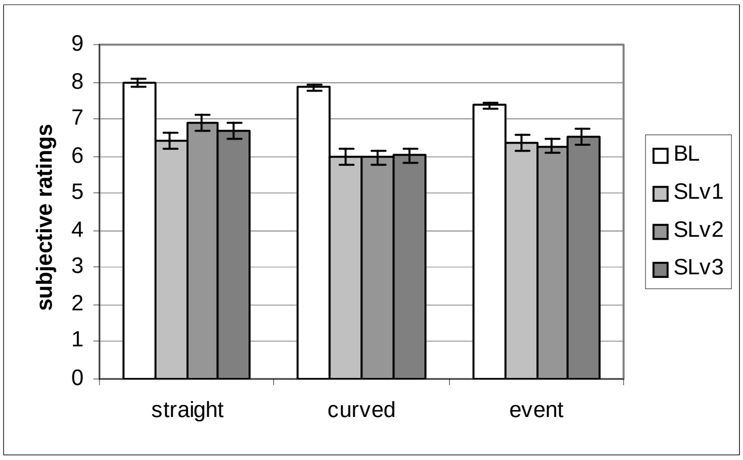



**Figure 23 – Self reported driving performance (subj_r), Visual task, Rural road**

### *4.7.2.2. Longitudinal control*

As shown in Table 16, mean speed (mn_sp) was reduced as an effect of the visual task - the experimental condition resulted in a reduction of 7 km/h compared to the baseline condition. The corresponding value for minimum speed (u_sp) was 11 km/h.

**Table 16 – Analysis of longitudinal measures on straight and curved sections, Visual task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 | |
| mn_sp [km/h] | 95.093 | 87.586 | 87.951 | 89.65 | ✓ | n/s | n/s | BL | ✓ | ✓ | ✓ | straight and curved |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| st_sp [km/h] | 2.017 | 6.259 | 5.386 | 5.269 | ✓ | n/s | n/s | BL | ✓ | ✓ | ✓ | straight and curved |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| mn_hwt [s] | 2.944 | 2.979 | 2.986 | 2.991 | ✓ | n/s | n/s | BL | × | ✓ | ✓ | straight and curved |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |

A reliable increase in speed variation (st_sp) was observed in the experimental levels 1, 2 and 3; when compared with the baseline performance, which represents poorer longitudinal control during the presentation of the secondary task. The reduction in speed could be an indicator of the major effort required to deal with the simultaneous tasks (i.e. drivers are compensating)

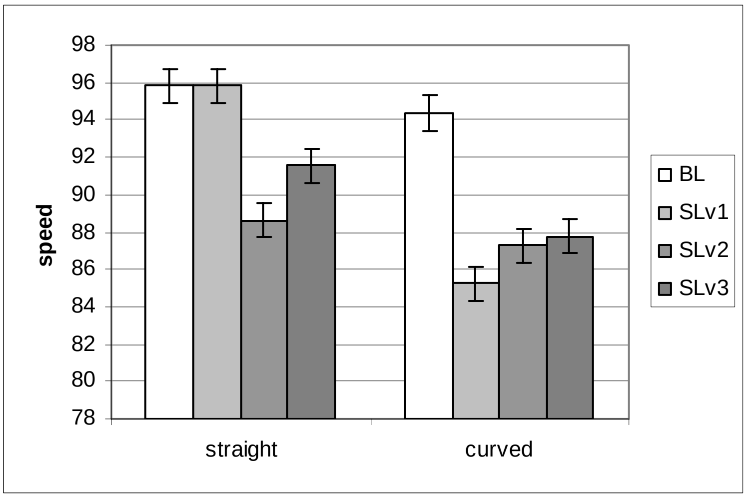



**Figure 24 – Mean speed (mn_sp), Visual task, Rural road**

Distance and time headway (mn_hwd, mn_hwt) increased with increased visual task difficulty in the straight and curved road sections. Regarding Distance headway, a significant variation was observed between the baseline, where the variation was higher, and level 3 of S-IVIS. The highest difference between average Distance headway occurred also between the baseline and levels 3. Significant differences in the Time headway were found between the baseline and the levels 1, 2 and 3 of S-IVIS, with an increase in the experimental levels, see Figure 25. The variation of Time headway decreased with the presence of the secondary task with a value of 0.041s in baseline and 0.018s, 0.017s, 0.009s for levels 1, 2 and 3, respectively.

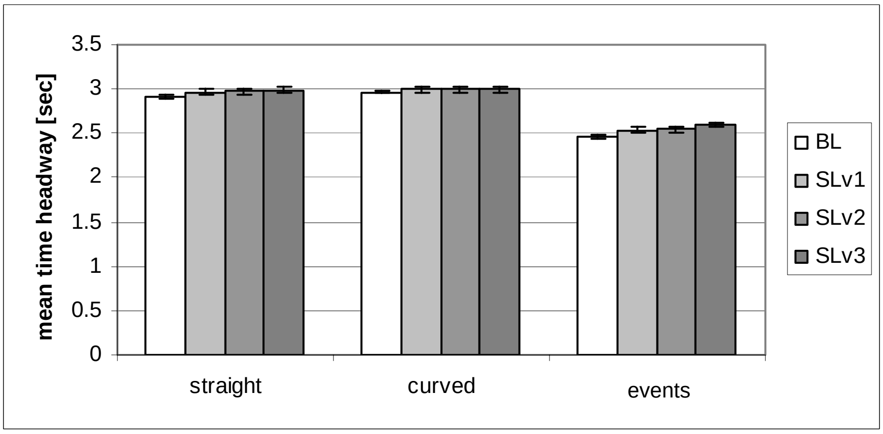



**Figure 25 – Mean time headway (mn_hwt), Visual task, Rural road**

In the event scenarios, the distance headway (mn_hwd) increased as an effect of the visual task (see Figure 26). A difference was, however, only found between the visual task SLv3 and baseline. Minimum distance headway (u_hwd) also increased as an effect of the visual task, although more pronounced than mn_hwd as differences were found between all experimental levels and baseline, see Table 17. The variation of distance headway (sd_hwd) decreased significantly with the presence of the secondary task. For the time headway measures, mn_hwt increased significantly - as proved equally sensitive as mn_hwd.

**Table 17 – Analysis of longitudinal control measures in the events, Visual task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 | |
| mn_hwd [m] | 29.049 | 29.81 | 30.623 | 31.32 | ✓ | n/a | n/a | BL | × | × | ✓ | event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| u_hwd [m] | 11.463 | 14.042 | 13.908 | 14.42 | ✓ | n/a | n/a | BL | ✓ | ✓ | ✓ | event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |

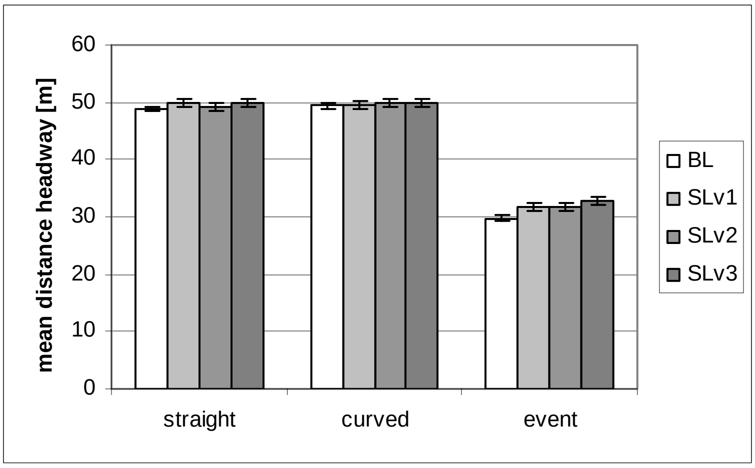



**Figure 26 – Mean distance headway (mn_hwd), Visual task, Rural road**

This increase in the Time and Distance headway with the presence of the S-IVIS can be interpreted as a direct result of the decrease of speed combined with compensatory behaviour due to higher levels of task load during the simultaneous performances, which can be interpreted as a risk indicator. The reduction in Headway variation supports this idea.

### *4.7.2.3. Lateral control*

Table 18 shows the effects of the visual task on lateral position variation (st_lp), reversal rate (rr_st1) and lanex (lnx).

**Table 18 – Analysis of lateral control measures, Visual task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 | |
| st_lp [m] | 0.414 | 0.523 | 0.509 | 0.502 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ | straight, curved and events |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| rr_st1 [1/minute] | 10.985 | 12.521 | 12.32 | 12.45 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ | straight, curved and events |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| lnx [%] | 1.789 | 5.478 | 5.562 | 4.775 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ | straight, curved and events |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |

The average lateral position (mn_lp) was shifted to the left as a result of the visual task (see Figure 27). The total shift was approximately 13 cm. The lateral position variation (st_lp), reversal rate (rr_st1) and lanex (lnx) were all increased as an effect of the visual task, indicating a degradation in lateral control performance and the increased need for corrective steering manoeuvres. No differences were however found between SLv1, 2 and 3.

Comparing Road complexity levels, effects were found for the average and variation of Lateral position. The average lateral position in the events was 0.33m less compared to in the straight section, and 0.38m less compared to the curved sections. The lateral position variation was highest in the curved sections and lowest in the straight sections. An effect of road complexity level was also found in the reversal rate, with the highest value in the curved sections, followed by straight sections and finally events (see Figure 28). The same results were found in Lanex (Figure 29). The curved sections were the most demanding road complexity level in terms of lateral control. The TLC measures were not affected by the visual task.

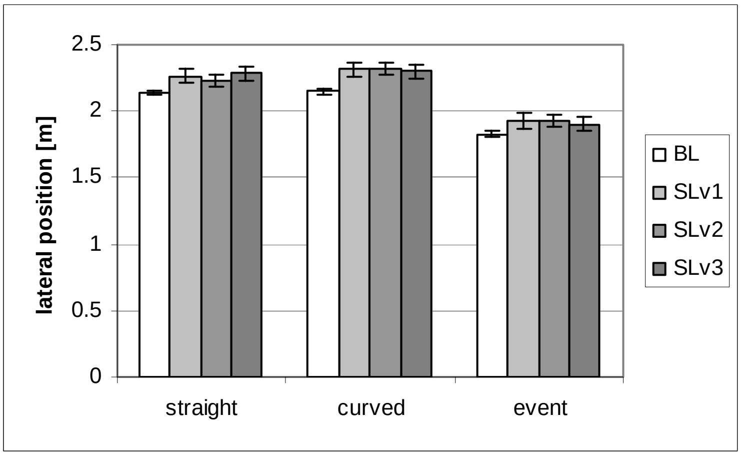



**Figure 27 – Lateral position (mn_lp), Visual task, Rural road**

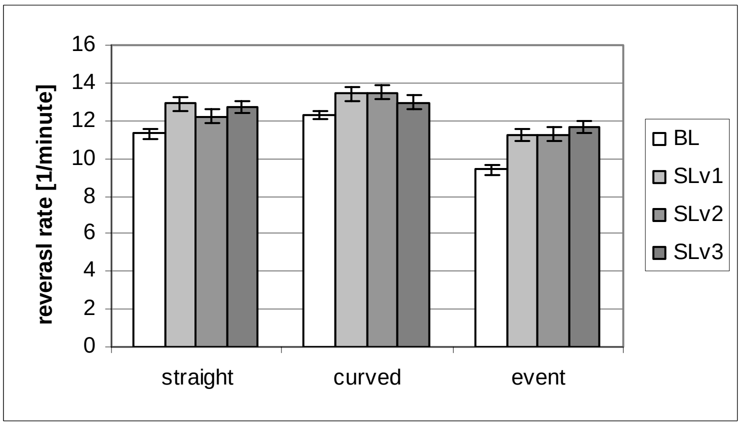



**Figure 28 – Reversal rate (rr_st1), Visual task, Rural road**

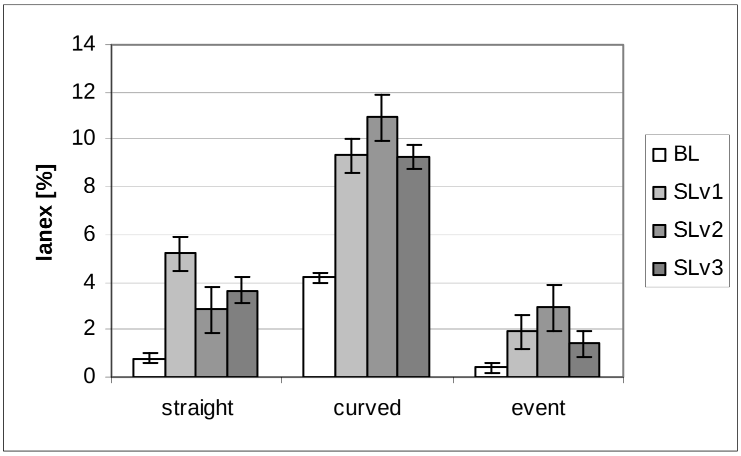



**Figure 29 – Lanex, Visual task, Rural road**

### *4.7.2.4. S-IVIS performance*

In the visual task analysis, interaction effects were found between the two variables: Road complexity and S-IVIS difficulty levels. The differences in performance between the four Road complexity levels were reliable (see Figure 30). The clearest variation was in the result of the single task (static) when compared with the other road complexity levels (see Table 19. Looking at Table 20, the differences in percentage of correct answers were not significant between the S-IVIS difficulty levels.

**Table 19 – Analysis of Road complexity (4 Lvs), Visual task, Rural road**

| | Mean values | | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|
| Measure | BL | straight | curved | events | | straight | curved | events |
| Percentage of correct responses | 95.421 | 85.03 | 81.79 | 76.16 | BL | ✓ | ✓ | ✓ |
| | | | | | straight | | ✓ | ✓ |
| | | | | | curved | | | ✓ |
| Percentage of incorrect responses | 2.985 | 5.556 | 6.714 | 5.865 | BL | ✓ | ✓ | ✓ |
| | | | | | straight | | ✗ | ✗ |
| | | | | | curved | | | ✗ |
| Percentage of missed responses | 1.595 | 9.337 | 12.115 | 18.21 | BL | ✓ | ✓ | ✓ |
| | | | | | straight | | ✓ | ✓ |
| | | | | | curved | | | ✓ |
| Mean Reaction time | 2.188 | 2.755 | 2.873 | 2.966 | BL | ✓ | ✓ | ✓ |
| | | | | | straight | | ✓ | ✓ |
| | | | | | curved | | | ✓ |

**Table 20 – Analysis of S-IVIS (3 Lvs), Visual task, Rural road**

| | Mean values | | | Post Hoc test | | |
|---|---|---|---|---|---|---|
| Measure | SLv1 | SLv2 | SLv3 | | SLv2 | SLv3 |
| Percentage of correct responses | 85.763 | 84.59 | 83.448 | SLv1 | ✗ | ✗ |
| | | | | SLv2 | | ✗ |
| Percentage of incorrect responses | 3.704 | 6.251 | 5.884 | SLv1 | ✓ | ✓ |
| | | | | SLv2 | | ✗ |
| Percentage of missed responses | 9.26 | 9.742 | 11.941 | SLv1 | ✗ | ✗ |
| | | | | SLv2 | | ✗ |
| Mean reaction time | 2.537 | 2.721 | 2.828 | SLv1 | ✗ | ✓ |
| | | | | SLv2 | | ✓ |

When Road complexity level increased, performance on the secondary task decreased, as can be observed in Figure 30, Figure 31 and Figure 32. Only a few errors and omissions were made on the static level, but this percentage increased reliably when compared with the dual task levels (straight, curved, event). The percentage of incorrect responses significantly increased when level 1 of –S-IVIS difficulty was compared with levels 2 and 3. There were no effects of S-IVIS difficulty levels on the percentage of missed responses. However, when differences between Road complexity levels were analysed, significant results were found between all the levels.

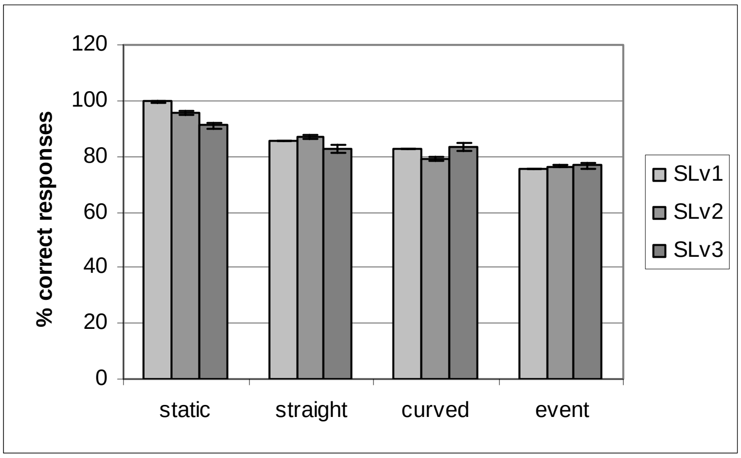



**Figure 30 – % correct responses by road complexity levels and S-IVIS difficulty, Visual task, Rural road**

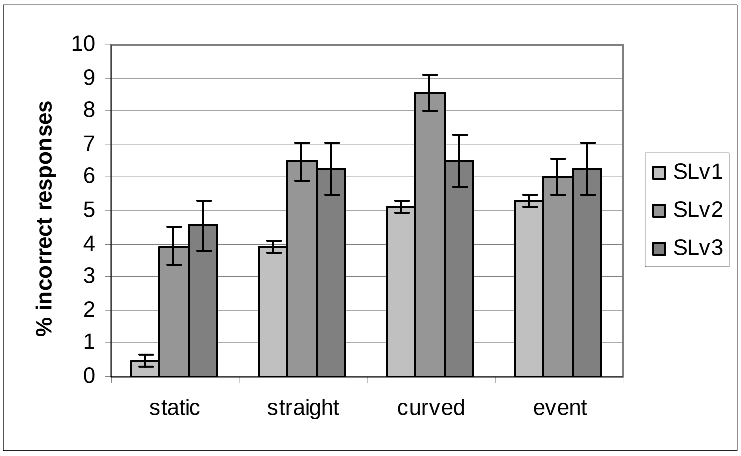



**Figure 31 – % incorrect responses by road complexity levels and S-IVIS difficulty, Visual task, Rural road**

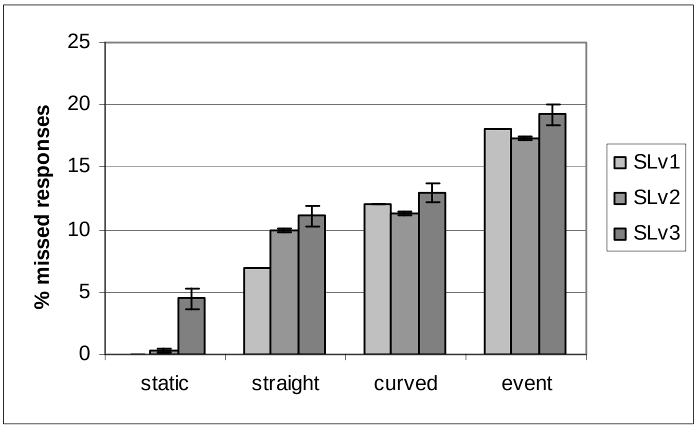



**Figure 32 – % missed responses by road complexity levels and S-IVIS difficulty, Visual task, Rural road**

Reaction time to the visual task increased in a systematic manner from baseline to events, with significant differences between all the levels of road complexity. So drivers' performance of the secondary task deteriorated with more demanding environments. The differences between visual task difficulty levels were more evident during the static task (see Figure 33), but significant differences were found only between the S-IVIS difficulty level 3 and the other two levels.

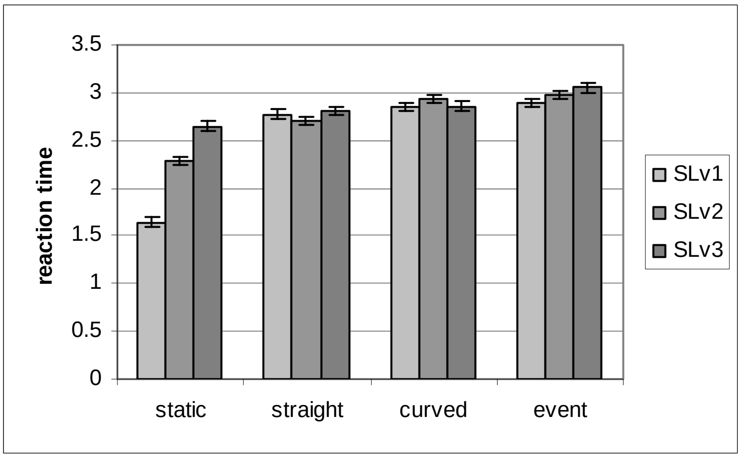



**Figure 33 – Mean reaction time by Road complexity levels and S-IVIS difficulty, Visual task, Rural road**

## 4.8. Comparison between British and Portuguese drivers

### 4.8.1. Effects of S-IVIS – the visual task (4 Lvl) in Rural Road driving

In this section, effects are analysed for British and Portuguese aggregated data. Significant interactions between the two independent variables S-IVIS difficulty level and Road complexity level were found for Lanex, self reported driving performance and Time exposed to TTC.

A significant effect of S-IVIS difficulty level was found for several variables: Speed variation, Minimum speed, Lanex, Reversal rate, Lateral position variation, Time exposed to

TTC, Minimum TLC, Mean distance headway, Time headway variation, Minimum time headway and Minimum TTC.

#### *4.8.1.1. Longitudinal control*

An effect of the visual task was found in some speed derivative measures. With the presence of the S-IVIS tasks, a decrease of 7.4 km/h in Minimum speed (u_sp) and an increase of 2.5 km/h on speed variation (st_sp) were observed (see Table 21). No differences were found between the experimental levels (SLv1-3).

When driving the straight and curved sections, the S-IVIS task was found to have an effect on Time exposed to TTC (tet). A significant increase was observed between the baseline (mean.0.878%) and all the levels of S-IVIS (1.484%, 1.805%, and 1.452% at levels 1, 2 and 3, respectively). The same pattern was found in the analysis of Road complexity effects: an increase in tet across straight, curved sections and events (mean.0.005%, 1.017%, and 3.193%, respectively). With more demanding driving environments and with the presence of a secondary task, the drivers had a tendency to increase tet. In the event situations, tet increased from 2.385% (se.0.256) in the baseline to 3.879% (se.0.501) with level 2 S-IVIS and 3.281% with level 3 S-IVIS(se.0.426). Mean TTC (mn_ttc) and minimum TTC (u_ttc) presented a reliable decrease with the presence of S-IVIS, as can be observed in Table 21. All of this indicated decreased levels of safety as secondary and primary task demand increases.

**Table 21 – Analysis of longitudinal control measures, Visual task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 | |
| | | | | | | | | BL | ✓ | ✓ | ✓ | |
| st_sp [km/h] | 1.7725 | 3.6295 | 4.5112 | 4.613 | ✓ | n/s | n/s | SLv1 | | × | × | straight and curved |
| | | | | | | | | SLv2 | | | × | |
| | | | | | | | | BL | ✓ | ✓ | × | |
| u_sp [km/h] | 73.259 | 66.547 | 64.29 | 66.74 | ✓ | n/s | n/s | SLv1 | | × | × | straight and curved |
| | | | | | | | | SLv2 | | | × | |
| | | | | | | | | BL | ✓ | ✓ | ✓ | |
| tet [%] | 0.8782 | 1.4836 | 1.8054 | 1.452 | ✓ | ✓ | × | SLv1 | | × | × | straight and curved |
| | | | | | | | | SLv2 | | | × | |
| | | | | | | | | BL | × | ✓ | ✓ | |
| tet [%] | 2.3854 | 3.225 | 3.8792 | 3.281 | ✓ | n/a | n/a | SLv1 | | × | × | event |
| | | | | | | | | SLv2 | | | × | |
| | | | | | | | | BL | ✓ | × | ✓ | |
| mn_hwd [m] | 30.787 | 34.248 | 32.697 | 33.49 | ✓ | n/a | n/a | SLv1 | | × | × | event |
| | | | | | | | | SLv2 | | | × | |
| | | | | | | | | BL | ✓ | × | ✓ | |
| sd_hwt [s] | 12.435 | 11.586 | 11.865 | 10.67 | ✓ | n/a | n/a | SLv1 | | × | × | event |
| | | | | | | | | SLv2 | | | × | |
| | | | | | | | | BL | ✓ | ✓ | ✓ | |
| u_ttc [s] | 7.1389 | 6.5833 | 5.9375 | 5.563 | ✓ | n/a | n/a | SLv1 | | ✓ | ✓ | event |
| | | | | | | | | SLv2 | | | × | |
| | | | | | | | | BL | × | ✓ | × | |
| mn_ttc [s] | 5.62 | 5.3226 | 4.9496 | 5.409 | ✓ | n/a | n/a | SLv1 | | × | × | event |
| | | | | | | | | SLv2 | | | × | |

Effects were observed in minimum time headway (u_hwt) and time headway variation (sd_hwt) between the baseline and the levels 1 and 3 of the experiment. The u_hwt had increased with the presence of S-IVIS from 12.373s (baseline) to 16.477s (level 3). The Variation of time headway (sd_hwt) presented a different pattern: this measure decreased with the introduction of an additional task, as shown in Table 21. In the baseline, a significant difference in Mean distance headway (mn_hwd) was found (mean.30.787m), when compared with the levels 1 and 3 of the experiment (mean.34.248m and 33.489m, respectively).

In events, Mean and Minimum TTC (mn_ttc, u_ttc) presented a significant decrease with the presence of S-IVIS. Mn_ttc decreased from 5.620s in the baseline to 5.323s, 4.950s and 5.409s in the S-IVIS difficulty levels 1, 2 and 3, respectively. U_ttc reached the lowest value in the S-IVIS difficulty level 3 (mean.5.563s) and the highest value in the baseline (mean.7.139s). The increase in time and distance headway with the presence of S-IVIS was accompanied by the reduction of TTC, that suggests that the cognitive effort involved in the secondary task performance may encourage drivers to maintain a stable longitudinal control.

The increase in Speed variation and in the Time exposed to TTC indicate a major risk when the S-IVIS was active. Also, the quality of longitudinal control decreased with the presence of the secondary task.

#### *4.8.1.2. Lateral control*

Lanex (lnx) increased with the presence of the S-IVIS from a baseline value of 0.970% to 3.116% in level 1, 3.665% in level 2 and 4.810% in level 3. In the Road complexity analysis, the highest value of lnx was obtained in curved sections (4.583%), and the lowest value corresponded to the events (1.624%). The results of the Minimum TLC (u_tlc) showed the same pattern: main effects of S-IVIS were observed in the decrease of this variable from 2.280s in the baseline to 1.771s in the S-IVIS difficulty level 2 and 1.582s in the S-IVIS difficulty level 3. Main effects of Road complexity were observed between all the levels and the lowest value of minimum TLC was also in the curved sections (mean.0.567s).

Analyses of lateral position derivative measures, presented in Table 22, showed an increase of Lateral position variation (st_lp), between the baseline (mean.0.352m) and all the levels of the experiment (mean.0.401m, 0.428m, 0.487m, respectively), as an effect of the presence of S-IVIS visual task. Regarding the Road complexity, the highest st_lp was observed in the events.

**Table 22 – Analysis of lateral control measures, Visual task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 | |
| st_lp [m] | 0.3517 | 0.4011 | 0.4282 | 0.487 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ | straight, curved and events |
| | | | | | | | | SLv1 | | × | ✓ | |
| | | | | | | | | SLv2 | | | × | |
| u_tlc [s] | 2.28 | 2.0567 | 1.7705 | 1.582 | ✓ | ✓ | × | BL | × | ✓ | ✓ | straight, curved and events |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| lnx [%] | 0.9699 | 3.1164 | 3.6649 | 4.81 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ | straight, curved and events |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| rr_st1 [1/minute] | 9.2528 | 10.518 | 10.682 | 11.25 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ | straight, curved and events |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |

Significant differences were found for average Reversal rate (rr_st1) between the baseline task (mean.9.253 1/min) and the levels 1 (mean.10.518 1/min), 2 (mean.10.682 1/min) and 3 (mean.11.254 1/min) of S-IVIS. The secondary task was more demanding, illustrated by the increase in the number of corrections of the steering wheel, which showed that there was increasing difficulty in keeping lateral control of the vehicle. This is supported by the effect seen of S-IVIS above the st_lp, already described.

The Reversal rate had a significant variation among the Road complexity levels, showing the lowest value in the curved sections, with increasing rates in the events section and higher values still in the straight sections.

As before, the fact that vehicle lateral control worsened with the presence of the S-IVIS was supported by increases in lane exceedences, increases in steering-wheel corrections and lateral position variation while the secondary task was performed.

### 4.8.2. Cross-cultural analysis

No interaction effects between S-IVIS difficulty level, Road complexity level and Nationality were found in any of the included measures. The results from the two groups were analysed using a repeated measures ANOVA with a between-subject factor of nationality.

#### *4.8.2.1. Longitudinal control*

British drivers' Mean speed (mn_sp) was reliably lower (mean.70.349 km/h, se.2.514) when compared with that of the Portuguese drivers (mean.77.653 km/h, se.2.514) but their speed variation was higher (Table 23). Minimum speed (u_sp) was significantly lower for Portuguese than for British drivers.

**Table 23 – Means and Main effects of Nationality for longitudinal control measures, Visual task, Rural road**

| | | Mean values | | Significant Effects |
|---|---|---|---|---|
| **Measure** | | Port | Brit | Nationality |
| **Mean speed (straight and curved)** | | 77.653 | 70.349 | ✓ |
| **Speed variation (straight and curved)** | | 2.794 | 4.469 | ✓ |
| **Minimum speed (events)** | | 0.894 | 1.801 | ✓ |
| **Time headway variation** | **straight and curved** | 0.509 | 0.528 | ✓ |
| | **events** | 12.521 | 10.759 | ✓ |
| **Mean time headway (events)** | | 2.471 | 2.693 | ✓ |
| **Mean distance headway (events)** | | 29.98 | 35.631 | ✓ |
| **Minimum time headway (events)** | | 12.175 | 17.121 | ✓ |
| **Minimum distance headway (events)** | | 0.499 | 0.367 | ✓ |

While Mean distance headway (mn_hwd) and Mean distance headway local minima (u_mn_hwd) were lower in the Portuguese sample, the Minimum distance headway (u_hwd) was higher (mean.0.499 m) when compared with the British sample (mean.0.367 m). Therefore the Portuguese drivers kept smaller distances to the lead vehicle, but the extreme minimum value was reached by the British sample.

In the Portuguese sample, Mean (mn_hwt) and Minimum time headway (u_hwt) were significantly lower compared to the British sample. In the straight and curved sections, Time headway variation (sd_hwt) in the Portuguese sample was 12.521s (se.0.524), the highest value, and in the British sample was 10.759s (se.0.524). For the events, this pattern of results was inverted: in the British sample the highest value of Time headway variation (mean.0.528s) was obtained compared to the Portuguese (mean.0.509s). Minimum TTC (u_ttc) was significantly different between the British and Portuguese studies: 5.854s and 6.757s, respectively.

#### *4.8.2.2. Lateral control*

Reliable differences between the two groups were found in some lateral control related measures: Lanex (lnx) and Lateral position (mn_lp), see Table 24. While the Portuguese drivers had an lnx of 5.406% (se.1.069), the British drivers obtained a lnx of 0.874% (se.1.069). The British drivers were found to have the lower mn_lp (British LP: 1.292m; Portuguese LP: 3.075m). Therefore Portuguese drivers kept a larger distance to the lateral lane marking, they crossed the lane boundary more. Reversal rate (rr_st1) was higher for the Portuguese (mean.10.807 1/min) compared with the British (10.047 1/min).

**Table 24 – Means and Main effects of Nationality for lateral control measures, Visual task, Rural road**

| | **Mean values** | | **Significant Effects** |
|---|---|---|---|
| **Measure** | Port | Brit | Nationality |
| **Lanex** | 5.406 | 0.874 | ✓ |
| **Lateral position** | 3.075 | 1.292 | ✓ |
| **Reversal rate** | 10.807 | 10.047 | ✓ |

## 4.9. Summary and conclusions

Effects of S-IVIS were found in the driving measures. Main effects were found between the baseline and the experimental drives, but not between the 3 difficulty levels of the secondary task. Grouping our driving related measures in general categories (longitudinal control, lateral control, self reported driving performance) - significant Main effects of the secondary task were found in all of them.

Regarding the lateral control related measures, lateral position was affected by the presence of both S-IVIS systems. Lateral position increased and Lateral position variation had decreased with the visual S-IVIS task. These changes were accompanied by an increased Lanex. So, the maintenance of the lateral control of the vehicle seems to be more difficult with the presence of the visual task, which can be considered a risk factor in a system's safety assessment.

The effects of the cognitive task were different: for the Lateral control variables, decreased Lateral position variation was found. Drivers are possibly adapting their behaviour to the cognitive in order to avoid significant changes in vehicle control.

Significant effects of both S-IVIS tasks were found for steering reversal rates. With the presence of the secondary task reversal rate increased, showing a tendency for steering corrections – the driver is less able to deal with the driving task with the presence of an additional task.

Speed related variables are sensitive measures to the assessment of visual S-IVIS task effects. While average Speed had decreased – a possible compensatory behaviour – an increase in Speed variation was observed. This could be considered as a risk factor because of the adaptation of the driving task and the responses to the environment, while the driver is simultaneously performing the visual task. During the performance of the cognitive task significant effects weren't found for the speed related measures. Nevertheless, a decrease in Speed variation was observed between the baseline and experimental (the cognitive task) period. This reduction in speed variation supports the idea that the drivers adopt an attitude of delay or sub-functioning in the process of decision-making and adaptation to the driving environment while performing a secondary cognitive task.

The analysis of the S-IVIS effects revealed significant differences in the headway measures. In both types of the secondary task an increase in the Time and Distance headway with the presence of the S-IVIS was observed. This is a result of the decrease in speed combined with compensatory behaviours due to higher levels of task load. In the same way, a reduction in Headway variation was observed when the visual and cognitive tasks were performed. The maintenance of Speed between baseline and experiment in the straight and curved road segments, during the experiments with the cognitive task, could be the explanation for the less significant effects of the headway variables, when compared with the visual task.

When the difficulty of the task was increased, the ratings of the driving performance quality decreased. But the general results pointed to positive perception in all the tasks (driving and S-IVIS) difficulty levels – all the average self reported driving performance had results higher than 5 in a scale from 1 to 10.

Integrating the driving and the S-IVIS analysis, it could be observed that the simultaneous tasks had induced a decrease in the results of both performances – the additional task had effects on the driving task and also its results had deteriorated between the static and experimental performance. The laboratory studies seems to indicate that a low cost methodology can produce valid results in systems assessment and in the validation of a safety test protocol, and therefore might be regarded as a promising evaluation approach.

Regarding the cross cultural study, significant differences between the British and Portuguese studies were found in headway, speed, lateral position and steering related measures. However, the direction of these differences was inconsistent. For example, for the speed related measures in the levels 1 and 2 of Road complexity, the British sample obtained the lowest mean speed but a highest speed variation; in the critical events the lowest minimum speed was found in the Portuguese sample. The same type of results were found in the headway related measures: in the road events, lowest minimum distance headway was found in the British sample, but the average mean distance headway was higher when compared to the Portuguese. It is thus difficult to highlight relevant differences in terms of driving risk or adaptation between the samples.

The S-IVIS effects analysis of the aggregated data (British and Portuguese) revealed the same measures as sensitive as the independent Portuguese lab study did, including:

- reduction in Speed; increase in Speed variation;
- increase of Headway; decrease of Headway variation;
- increase of Tet
- increase of Lanex
- increase of Lateral position and Lateral position variation.

These results can be thought of as risk indicators. A decrease in lateral and longitudinal control performance was observed, especially with the increase of Speed and Lateral position variation, Tet and Lanex when driving with a secondary task.

The highlighting of the same sensitive measures and the absence of interaction factors between Nationality and S-IVIS difficulty and Road complexity levels support the development of laboratory studies as a valid assessment methodology of IVIS, regardless of cultural differences. Therefore this approach supports the use of common parameters for the validation of a safety test protocol.

## 4.10. Measures summary tables

### 4.10.1. Cognitive task, Rural road

| | Mean values | | | | Effects | | | Post Hoc test | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 | |
| **Self reported driving performance** | | | | | | | | | | | | |
| subj_r | 7.551 | 7.241 | 7.093 | 6.972 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ | all |
| | | | | | | | | SLv1 | | × | ✓ | |
| | | | | | | | | SLv2 | | | × | |
| **Longitudinal control** | | | | | | | | | | | | |
| mn_sp [km/h] | 92.68 | 92.682 | 93.49 | 92.414 | n/s | | | | | | | straight and curved |
| mn_sp [km/h] | 41.98 | 41.398 | 41.73 | 42.81 | n/s | | | | | | | event |
| st_sp [km/h] | 6.702 | 6.568 | 6.367 | 6.527 | n/s | | | | | | | straight and curved |
| u_sp [km/h] | 2.449 | 2.396 | 2.228 | 2.234 | n/s | | | | | | | straight and curved |
| u_sp [km/h] | 6.402 | 6.291 | 6.979 | 7.008 | n/s | | | | | | | event |
| u_ttc [s] | 3.067 | 3.268 | 3.266 | 3.284 | n/s | | | | | | | event |
| mn_ttc [s] | 5.3 | 5.406 | 5.526 | 5.612 | n/s | | | | | | | event |
| pr_ttc [%] | 37.15 | 34.278 | 33.07 | 36.556 | n/s | | | | | | | event |
| tet [%] | 0.992 | 0.969 | 0.912 | 0.967 | n/s | | | | | | | straight and curved |
| tet [%] | 2.916 | 2.867 | 2.736 | 2.874 | n/s | | | | | | | event |
| mn_hwd [m] | 48.57 | 49.28 | 49.06 | 49.189 | n/s | | | | | | | straight and curved |
| mn_hwd [m] | 29.05 | 29.81 | 30.62 | 31.317 | ✓ | n/a | n/a | BL | × | × | ✓ | event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| u_mn_hwd [m] | 19.83 | 18.721 | 21.42 | 21.422 | n/s | | | | | | | event |
| pr_hwd [%] | 55.58 | 63.722 | 50.94 | 55.083 | n/s | | | | | | | event |
| sd_hwd [m] | 0.625 | 0.337 | 0.292 | 0.535 | n/s | | | | | | | straight and curved |
| sd_hwd [m] | 13.25 | 12.558 | 12.99 | 13.066 | n/s | | | | | | | event |
| u_hwd [m] | 10.43 | 11.599 | 11.42 | 11.884 | n/s | | | | | | | event |
| mn_hwt [s] | 2.922 | 2.966 | 2.946 | 2.942 | n/s | | | | | | | straght and curved |
| mn_hwt [s] | 2.445 | 2.515 | 2.516 | 2.544 | ✓ | n/a | n/a | BL | × | × | ✓ | event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| u_mn_hwt [s] | 1.408 | 1.433 | 1.563 | 1.521 | n/s | | | | | | | event |
| pr_hwt [%] | 16.47 | 13.652 | 14.6 | 10.75 | n/s | | | | | | | event |
| sd_hwt [s] | 0.059 | 0.028 | 0.041 | 0.048 | n/s | | | | | | | straight and curve |
| sd_hwt [s] | 0.501 | 0.452 | 0.43 | 0.446 | ✓ | n/a | n/a | BL | × | ✓ | × | event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| u_hwt [s] | 1.398 | 1.488 | 1.565 | 1.531 | n/s | | | | | | | event |
| rt_br [s] | 0.865 | 0.961 | 0.755 | 1.149 | n/s | | | | | | | event |
| **Lateral control** | | | | | | | | | | | | |
| mn_lp [m] | 1.947 | 1.958 | 1.972 | 1.976 | n/s | | | | | | | all |
| st_lp [m] | 0.393 | 0.355 | 0.354 | 0.35 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ | all |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| mn_tlc [s] | 1861 | 1525.4 | 1178 | 2564.4 | n/s | | | | | | | all |
| u_tlc [s] | 619.8 | 465.61 | 2.301 | 928.33 | n/s | | | | | | | all |
| pr_tlc [%] | 0 | 0 | 0 | 0 | n/s | | | | | | | not analysed |
| lnx [%] | 0.68 | 0.505 | 0.403 | 0.37 | n/s | | | | | | | all |
| rr_st1 | 10.46 | 11.825 | 11.57 | 11.354 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ | all |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |

### 4.10.2. Visual task, Rural road

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 | |
| **Self reported driving performance** | | | | | | | | | | | | |
| subj_r | 7.728 | 6.259 | 6.375 | 6.4 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ | |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| **Longitudinal control** | | | | | | | | | | | | |
| mn_sp [km/h] | 95.093 | 87.586 | 87.951 | 89.65 | ✓ | n/s | n/s | BL | ✓ | ✓ | ✓ | straight and curved |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| mn_sp [km/h] | 42.513 | 41.707 | 41.683 | 42.27 | n/s | | | | | | | event |
| st_sp [km/h] | 2.017 | 6.259 | 5.386 | 5.269 | ✓ | n/s | n/s | BL | ✓ | ✓ | ✓ | straight and curved |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| u_sp [km/h] | 90.493 | 77.341 | 79.574 | 80.6 | ✓ | n/s | n/s | BL | ✓ | ✓ | ✓ | straight and curved |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| u_sp [km/h] | 6.497 | 6.8 | 6.567 | 6.328 | n/s | | | | | | | event |
| u_ttc [s] | 3.036 | 3.347 | 2.981 | 2.909 | n/s | | | | | | | event |
| mn_ttc [s] | 5.307 | 5.307 | 5.127 | 5.418 | n/s | | | | | | | event |
| pr_ttc [%] | 33.387 | 41.485 | 42.126 | 37.87 | n/s | | | | | | | event |
| tet [%] | 0.936 | 1.176 | 1.25 | 1.059 | n/s | | | | | | | straight and curved |
| tet [%] | 2.81 | 3.528 | 3.75 | 3.176 | n/s | | | | | | | event |
| mn_hwd [m] | 49.145 | 49.667 | 49.479 | 49.99 | n/s | | | | | | | straight and curved |
| mn_hwd [m] | 29.049 | 29.81 | 30.623 | 31.32 | ✓ | n/a | n/a | BL | × | × | ✓ | event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| u_mn_hwd [m] | 1.533 | 1.395 | 1.533 | 1.447 | n/s | | | | | | | event |
| pr_hwd [%] | 57.45 | 51.921 | 52.224 | 47.25 | n/s | | | | | | | event |
| sd_hwd [m] | 0.31 | 0.144 | 0.155 | 0.018 | ✓ | n/s | n/s | BL | × | × | ✓ | straight and curved |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| sd_hwd [m] | 12.96 | 11.721 | 11.788 | 11.68 | ✓ | n/a | n/a | BL | ✓ | ✓ | ✓ | event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| u_hwd [m] | 11.463 | 14.042 | 13.908 | 14.42 | ✓ | n/a | n/a | BL | ✓ | ✓ | ✓ | event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| mn_hwt [s] | 2.944 | 2.979 | 2.986 | 2.991 | ✓ | n/s | n/s | BL | × | ✓ | ✓ | straight and curved |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| mn_hwt [s] | 2.467 | 2.536 | 2.548 | 2.597 | ✓ | n/a | n/a | BL | × | × | ✓ | event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| u_mn_hwt [s] | 1.396 | 1.449 | 1.423 | 1.494 | n/s | | | | | | | event |
| pr_hwt [%] | 15.123 | 18.287 | 18.75 | 17.36 | n/s | | | | | | | |
| sd_hwt [s] | 0.041 | 0.018 | 0.017 | 0.009 | ✓ | n/s | n/s | BL | × | ✓ | ✓ | straight and curved |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| sd_hwt [s] | 0.476 | 0.453 | 0.467 | 0.439 | n/s | | | | | | | event |
| rt_br [s] | 0.757 | 0.7317 | 0.726 | 0.715 | n/s | | | | | | | |
| **Lateral control** | | | | | | | | | | | | |
| mn_lp [m] | 2.038 | 2.169 | 2.153 | 2.162 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ | |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| st_lp [m] | 0.414 | 0.523 | 0.509 | 0.502 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ | |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| mn_tlc [s] | 1597.1 | 2571 | 1097.8 | 2177 | n/s | | | | | | | |
| u_tlc [s] | 465.36 | 927.5 | 1.947 | 1.762 | n/s | | | | | | | |
| pr_tlc [%] | 0 | 0 | 0.231 | 0 | n/s | | | | | | | |
| lnx [%] | 1.789 | 5.478 | 5.562 | 4.775 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ | |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | × | | × | |
| rr_st1 [1/minute] | 10.985 | 12.521 | 12.32 | 12.45 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ | |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |

### 4.10.3. Cross cultural comparison, Visual task

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 | |
| **Self reported driving performance** | | | | | | | | | | | | |
| subj_r | | | | | n/a | | | | | | | all |
| **Longitudinal control** | | | | | | | | | | | | |
| mn_sp [km/h] | 77.389 | 72.874 | 71.426 | 74.31 | n/s | | | | | | | straight and curved |
| mn_sp [km/h] | 41.3 | 41.567 | 41.747 | 41.41 | n/s | | | | | | | event |
| st_sp [km/h] | 1.7725 | 3.6295 | 4.5112 | 4.613 | ✓ | n/s | n/s | BL | ✓ | ✓ | ✓ | straight and curved |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| u_sp [km/h] | 73.259 | 66.547 | 64.29 | 66.74 | ✓ | n/s | n/s | BL | ✓ | ✓ | × | straight and curved |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| u_sp [km/h] | 1.2565 | 1.7145 | 1.1008 | 1.319 | n/s | | | | | | | event |
| u_ttc [s] | 7.1389 | 6.5833 | 5.9375 | 5.563 | ✓ | n/a | n/a | BL | ✓ | ✓ | ✓ | event |
| | | | | | | | | SLv1 | | ✓ | ✓ | |
| | | | | | | | | SLv2 | | | × | |
| mn_ttc [s] | 5.62 | 5.3226 | 4.9496 | 5.409 | ✓ | n/a | n/a | BL | × | ✓ | × | event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| pr_ttc [%] | | | | | | | | | | | | not analysed |
| tet [%] | 0.8782 | 1.4836 | 1.8054 | 1.452 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ | straight and curved |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| tet [%] | 2.3854 | 3.225 | 3.8792 | 3.281 | ✓ | n/a | n/a | BL | × | ✓ | ✓ | event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| mn_hwd [m] | 40.613 | 40.72 | 40.792 | 41.98 | n/s | | | | | | | straight and curved |
| mn_hwd [m] | 30.787 | 34.248 | 32.697 | 33.49 | ✓ | n/a | n/a | BL | ✓ | × | ✓ | event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| u_mn_hwd [m] | 21.189 | 22.622 | 19.69 | 22.2 | n/s | | | | | | | event |
| pr_hwd [%] | | | | | n/a | | | | | | | |
| sd_hwd [m] | 8.4335 | 8.5381 | 8.9533 | 7.827 | n/s | | | | | | | straight and curved |
| sd_hwd [m] | 3.2575 | 2.9983 | 2.8807 | 3.456 | n/s | | | | | | | event |
| u_hwd [m] | 0.4273 | 0.4073 | 0.4708 | 0.427 | n/s | | | | | | | event |
| mn_hwt [s] | 2.5549 | 2.5716 | 2.4823 | 2.628 | n/s | | | | | | | straight and curved |
| mn_hwt [s] | 2.5477 | 2.6248 | 2.5509 | 2.605 | n/s | | | | | | | event |
| u_mn_hwt [s] | 1.5452 | 1.4157 | 1.5209 | 1.491 | n/s | | | | | | | event |
| pr_hwt [%] | | | | | | | | | | | | not analysed |
| sd_hwt [s] | 0.5221 | 0.5181 | 0.5467 | 0.487 | n/s | | | | | | | straight and curved |
| sd_hwt [s] | 12.435 | 11.586 | 11.865 | 10.67 | ✓ | n/a | n/a | BL | ✓ | × | ✓ | event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| u_hwt [s] | 12.373 | 15.65 | 14.092 | 16.48 | ✓ | n/a | n/a | BL | ✓ | × | ✓ | event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| rt_br [s] | | | | | | | | | | | | not analysed |
| **Lateral control** | | | | | | | | | | | | |
| mn_lp [m] | 3.615 | 4.2293 | 4.0017 | 4.19 | n/s | | | | | | | |
| st_lp [m] | 0.3517 | 0.4011 | 0.4282 | 0.487 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ | straight, curved and events |
| | | | | | | | | SLv1 | | × | ✓ | |
| | | | | | | | | SLv2 | | | × | |
| mn_tlc [s] | 3.1619 | 2.7952 | 3.0038 | 2.647 | n/s | | | | | | | |
| u_tlc [s] | 2.28 | 2.0567 | 1.7705 | 1.582 | ✓ | ✓ | × | BL | × | ✓ | ✓ | straight, curved and events |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| pr_tlc [%] | | | | | n/a | | | | | | | |
| lnx [%] | 0.9699 | 3.1164 | 3.6649 | 4.81 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ | straight, curved and events |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| rr_st1 [1/minute] | 9.2528 | 10.518 | 10.682 | 11.25 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ | straight, curved and events |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |

# 5. The Leeds Simulator Experiment

## 5.1. Test site

The Leeds Driving Simulator is currently based on a complete Rover 216GTi with all of its basic controls and dashboard instrumentation still fully operational. On a 2.5m radius, cylindrical screen in front of the driver is projected a real-time, fully textured and anti-aliased, 3-D graphical scene of the virtual world. Realistic sounds of engine and other noises are generated by a sound sampler and two speakers mounted close to each forward road wheel. Although the simulator is fixed-base, feedback is given by steering torques and speeds at the steering wheel. Data is collected at 60Hz and includes information of the behaviour of the driver (i.e. driver controls), that of the car (position, speed, accelerations etc.) and other autonomous vehicles in the scene (e.g. identity, position and speed). The simulator is shown in Figure 34.


**Figure 34 – The Leeds driving simulator**

## 5.2. Scenarios and participants

Two groups of average drivers (25-50 years old) and two groups of elderly drivers (over 60 years old) were recruited for the Leeds simulator study. Each group drove the HASTE standard rural road, using the experimental design described above. A more detailed description of the participants used in the Leeds study is given in Table 25.

**Table 25 – Description of participants used in Leeds simulator study**

| Experiment | Driver Age (mean and SD) | Males (n) | Females (n) |
|---|---|---|---|
| Cognitive task and average drivers | 37.79 (8.21) | 12 | 12 |
| Visual task and average drivers | 31.7 (7.17) | 11 | 13 |
| Cognitive task and elderly drivers | 66.5 (5.32) | 13 | 11 |
| Visual task and elderly drivers | 71.5 (4.27) | 3 | 1 |

## 5.3. S-IVIS evaluated

Each group of participants drove the rural road whilst performing the visual task or the cognitive task. However, due to the majority of the elderly drivers becoming too motion sick to continue driving in the simulator, the study examining the interaction between the visual task and driving in elderly participants was abandoned.

## 5.4. Procedure

All participants were provided with brief written instructions for the experiment, and completed a consent form. Each participant was then briefed on the workings of the driving simulator and the S-IVIS task. Following a practice session with the S-IVIS, participants were trained on the driving simulator, and then practiced driving in combination with the S-IVIS task. Each subject was paid £15 at the end of the study.

## 5.5. Measures and analysis method

With respect to driving, measures of speed, lateral position and steering angle were measured. From these, several safety critical indicators were derived, such as lateral position variation, time to line crossing and reversal rate. Also a self reported measure of driving performance was collected. All measures were implemented according to the specifications in Appendix 2. The effects of the S-IVIS tasks and road complexity were analysed according to the specification in section 2.7, Indicators and Analysis. For the S-IVIS tasks, data were recorded and analysed according to the specification in section 2.7.3, S-IVIS measures and analysis.

## 5.6. Results

### 5.6.1. Effects of the cognitive task in Rural Road driving – Average drivers

#### *5.6.1.1. Self reported driving performance*

Analyses of variance showed an effect of the different road scenarios on self reported driving performance (subj_r), with drivers rating their performance worst for the curves and events. Drivers thought their performance worsened in the presence of the cognitive task, compared to baseline, although they did not believe their driving performance deteriorated significantly with an increase in the difficulty of this S-IVIS (see Table 26). Therefore, an increase in difficulty of driving scenario and the presence of the S-IVIS task was clearly seen by drivers as factors that increased their workload and reduced their driving performance.

**Table 26 – Analysis of self rated driving performance (subj_r), Cognitive task, Average drivers**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| self reported driving performance subj_r | 7.815 | 7.042 | 7.056 | 6.972 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

### *5.6.1.2. Longitudinal control*

When driving the straight and curved roads, the cognitive task was found to reduce the mean speed (mn_sp) and minimum speed (u_sp) of travel in the rural road, although this effect was only reliably different from baseline at the highest task difficulty level. (see Figure 35).

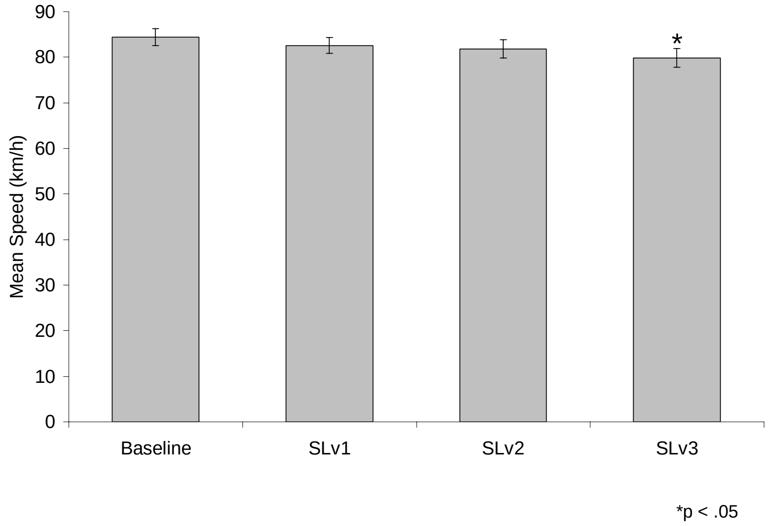



**Figure 35 – Mean speed (mn_sp), Cognitive task, Average drivers**

An effect of the cognitive task was also observed on a series of longitudinal measures during the event scenarios. As shown in Table 27, time to contact and distance headway with the lead vehicle were reduced in the presence of the cognitive task, suggesting that the cognitive demand required by the cognitive task may have prevented subjects from maintaining adequate longitudinal control of the car.

**Table 27 – Longitudinal measures in the events, Cognitive task, Average drivers**

| | Mean values | | | | Main effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| Mean time to collision [s] (mn_ttc) | 8.044 | 6.944 | 6.948 | 6.478 | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |
| Minimum distance headway [m] (mn_hwd) | 20.53 | 16.24 | 14.75 | 16 | ✓ | BL | × | ✓ | × |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |
| Mean of time headway local minima [s] (u_mn_hwd) | 2.279 | 1.893 | 1.953 | 1.979 | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |
| Standard deviation of time headway [s] (sd_hwd) | 1.373 | 0.997 | 0.862 | 0.972 | ✓ | BL | ✓ | ✓ | × |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |

### *5.6.1.3. Lateral control*

In terms of lateral control measures, the cognitive task was only found to have a reliable effect on the standard deviation of lateral position (sd_lp); with reliably less deviation in lateral position when driving was performed in conjunction with the secondary task (see Figure 36). Therefore, lateral control of the car was actually improved in the presence of the cognitive when compared to baseline. This result supports previous research, (e.g. Brookhuis, De Vries, & de Ward, 1991).

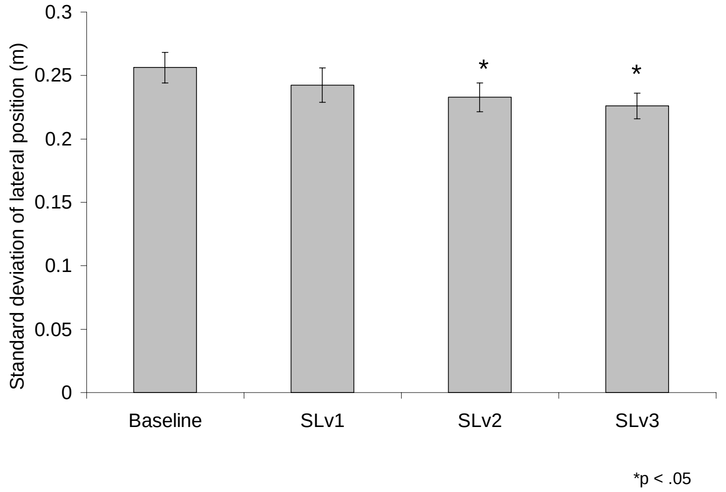



**Figure 36 – Standard deviation of lane position (sd_lp), Cognitive task, Average drivers**

### *5.6.1.4. S-IVIS performance*

Analysis of variance on the percentage of correct responses in the cognitive task revealed a main effect of driving, with pairwise comparisons showing that the percentage of correct responses (s_correct) produced in the event scenario was reliably lower than baseline, and all other driving scenarios (see Figure 37).

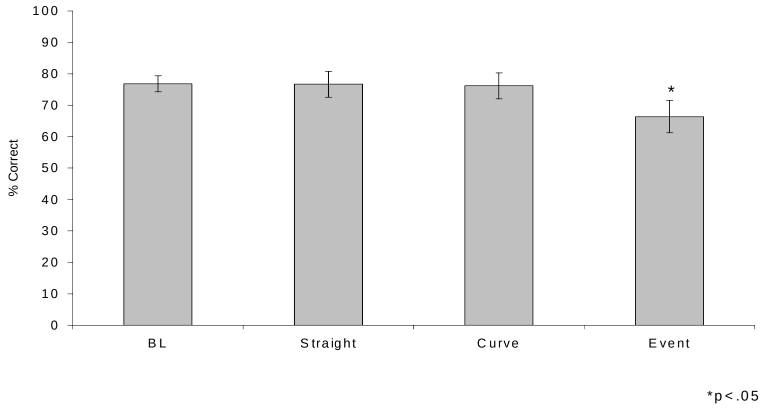



**Figure 37 – % correct responses (s_correct), Cognitive task, Average drivers**

An increase in the number of target sounds reduced the percentage of correct responses in a systematic manner, with the most significant deterioration in performance caused by the four target sound condition. The absence of an interaction between driving scenario and S-IVIS level suggests that this reduction in accuracy was true for all driving events (see Figure 38).

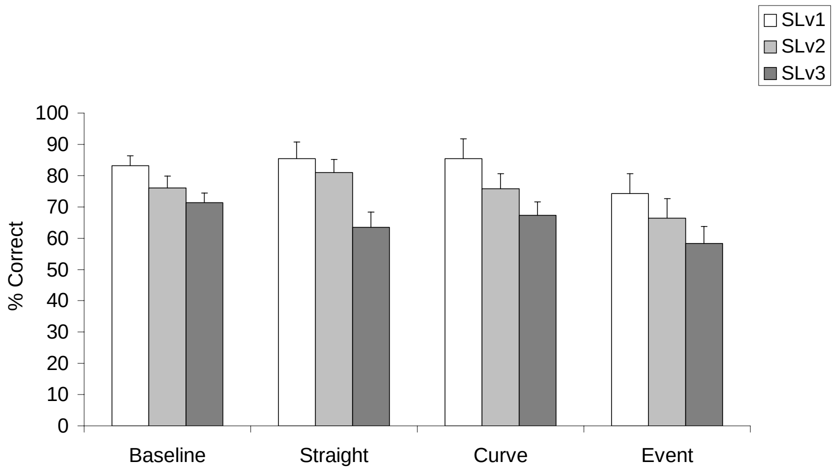



**Figure 38 – % correct responses for each driving event, Cognitive task, Average drivers**

The effect of driving on the percentage of incorrect (s_incorrect) and missed (s_missed) responses is shown in Figure 39 and Table 28. Both measures were found to increase with the number of target sounds, although an effect of driving was only found to be reliable on the percentage of missed responses, and then only when the cognitive task was performed during the event driving scenario. Therefore, the necessity to concentrate on negotiating with other traffic in the events meant that drivers prioritised the driving task, resulting in a higher rate of missed responses for the secondary S-IVIS task.

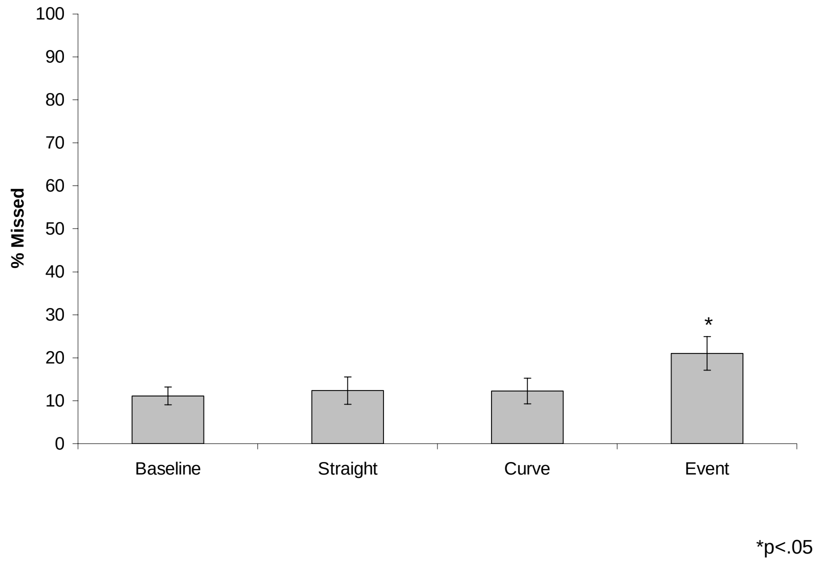



**Figure 39 – % missed responses, Cognitive task, Average drivers**

**Table 28 – Missed and incorrect responses by S-IVIS difficulty, Cognitive task, Average drivers**

| | Mean values | | | Significant Effects | | | Post Hoc test | | |
|---|---|---|---|---|---|---|---|---|---|
| Measure | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv2 | SLv3 |
| Percentage missed (s_missed) | 11.050 | 13.230 | 18.261 | ✓ | ✓ | × | SLv1 | × | ✓ |
| | | | | | | | SLv2 | | ✓ |
| Percentage incorrect (s_incorrect) | 7.349 | 12.338 | 16.692 | ✓ | × | × | SLv1 | ✓ | ✓ |
| | | | | | | | SLv2 | | ✓ |

Results of the ANOVA on percentage of false positive responses did not show any reliable effects, although there was a general fall in these responses with an increase in the number of target sounds. This was expected, due to the fall in the number of non-target sounds from difficulty level 1 to 3.

### 5.6.2. Effects of the cognitive task in Rural Road driving – Elderly drivers

#### *5.6.2.1. Self reported driving performance*

Elderly drivers provided different ratings for their performance (subj_r) in each driving scenario. The ANOVA revealed that on average, these drivers thought their performance was worst in the ‘event’ scenarios, compared to the straight and curved sections.

In terms of the effect of S-IVIS, drivers felt their performance was better in the baseline condition, than when they were required to perform the cognitive task. The self rated driving performance was also lower during the three target sound condition, compared to the two target sound condition, suggesting that drivers were conscious that an increase in S-IVIS workload may have reduced their driving performance. However, this reduction in rating was not seen in the four target sound condition. As shown below in section 5.6.3.4, an improved score in driving performance during the most difficult cognitive task level may have been due to an abandonment of the secondary task.

**Table 29 – Analysis of self rated driving performance (subj_r), Cognitive task, Elderly drivers**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| self reported driving performance (subj_r) | 7.63 | 6.63 | 6.203 | 6.551 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✓ | × |
| | | | | | | | | SLv2 | | | × |

#### *5.6.2.2. Longitudinal control*

As shown in Table 30, when driving the straight and curved sections, elderly drivers reduced their speed if they were required to complete the cognitive task. This reduction in speed compared to baseline was most when the task required memory for two and four target sounds. The secondary S-IVIS task was not found to have an effect on mean speed during the events, suggesting that drivers were already travelling at quite a low speed for these driving conditions.

**Table 30 – Mean speed (mn_sp) and minimum speed (u_sp), Cognitive task, Elderly drivers**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| Mean speed [km/h] (mn_sp) | 77.45 | 73.14 | 74.22 | 71.94 | ✓ | ✓ | ✓ | BL | ✓ | × | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |
| Minimum speed [km/h] (u_sp) | 71.8 | 67.49 | 68.26 | 66.88 | ✓ | ✓ | ✓ | BL | ✓ | × | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

In the event driving scenarios, concurrent performance on the cognitive task was found to cause a reduction in minimum time and distance headway (u_hwd, u_hwt), with the most deleterious effect observed during the four target sound condition (see Table 31). Therefore, despite travelling at around the same speed as the baseline condition, elderly drivers' distance to the lead car was greatly reduced in the presence of the most difficult the cognitive task condition, suggesting that the high cognitive load required by the secondary task caused a safety-critical risk to driving.

**Table 31 – Longitudinal measures in the events, Cognitive task, Elderly drivers**

| | Mean values | | | | Main effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| Minimum distance headway [m] (u_hwd) | 24.99 | 21.68 | 21.79 | 16.29 | ✓ | BL | × | × | ✓ |
| | | | | | | SLv1 | | × | ✓ |
| | | | | | | SLv2 | | | ✓ |
| Minimum time headway [s] (u_hwt) | 2.763 | 2.397 | 2.282 | 2.146 | ✓ | BL | × | × | ✓ |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |

### *5.6.2.3. Lateral control*

The effect of the cognitive task on lateral driving measures was quite weak in this group of drivers, and only approached significance for minimum time to line crossing (u_ttc), which was shown to increase in the presence of S-IVIS. Therefore, as with average aged drivers, lateral control improved in the presence of the S-IVIS task, when compared to baseline (see Table 32).

**Table 32 – Min time to line crossing (u_ttc), Cognitive task, Elderly drivers**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| Minimum time to line crossing [s] u_ttc | 1.422 | 1.721 | 1.516 | 1.587 | ✓ | ✓ | × | BL | ✓ | × | × |
| | | | | | | | | SLv1 | | ✓ | × |
| | | | | | | | | SLv2 | | | × |

### *5.6.2.4. S-IVIS performance*

The percentage of correct responses (s_correct) accomplished by elderly drivers was affected by driving, but only during the discrete events. As shown in Figure 40, there was also a fall in the percentage of correct responses as the number of target sounds increased from 2 to 4, confirming a gradual increase in difficulty of this task for elderly drivers.

This reduction in accuracy, caused by increasing target sounds, was found to be the same across all driving events, but more prominent in the discrete event condition (although a reliable interaction was not revealed by the ANOVA). Therefore, the necessity to negotiate with other traffic in the rural road was clearly the most distracting driving condition, taking attention away from the secondary task.

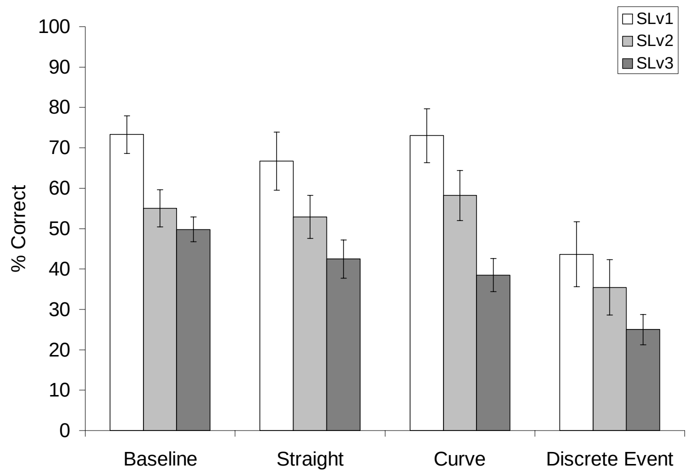



**Figure 40 – % correct responses (s_correct), Cognitive task, Elderly drivers**

The percentage of incorrect responses given by elderly drivers was similar when the cognitive task was performed alone and in conjunction with driving. However, concurrent driving produced many more missed responses, and the rate of missed responses increased with the number of target sounds. The interaction between driving and the number of target sounds, was found to be significant, with a higher number of missed responses (s_missed) observed during the discrete driving event (Figure 41). Therefore, as well as failing to produce as many correct responses in the events, elderly drivers seem to have abandoned their effort on the cognitive task during this driving scenario, in order to focus their effort on the primary driving task. Alternatively, the paced nature of the cognitive task meant that only responses produced in the correct time were used in the analysis. Therefore, the high proportion of missed responses for this group of drivers may have been due to longer response times, as a result of exceptionally high workload imposed by the primary and secondary tasks.

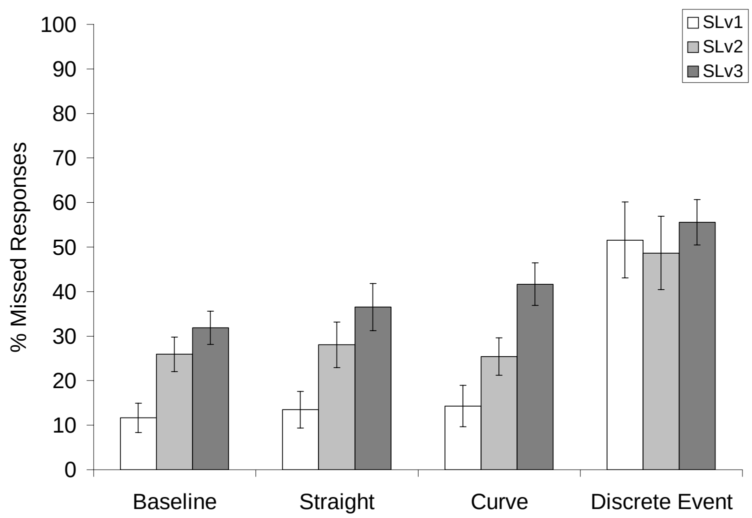



**Figure 41 – % missed responses (s_missed), Cognitive task, Elderly drivers**

### 5.6.3. Effects of the visual task in Rural Road driving – Average drivers

#### *5.6.3.1. Self reported driving performance*

Analysis of variance revealed that drivers thought their driving performance was worst during negotiation of the s-shaped curve, compared to the other driving scenarios. Also, the subjective rating in driving was found to decrease progressively with an increase in difficulty of the visual task, suggesting that drivers believed an increase in workload from the visual task S-IVIS had a direct effect on their driving performance (see Table 33).

**Table 33 – Analysis of self reported driving performance (subj_r), Visual task, Average drivers**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| Self reported driving performance (subj_r) | 7.773 | 6.472 | 5.806 | 5.5 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | × |

#### *5.6.3.2. Longitudinal control*

The ANOVA showed reliable effects of the visual task on mean speed (mn_sp) and a number of its derivatives, as well as on the mean and standard deviation of time and distance headway (mn_hwd/hwt, sd_hwd/hwt). The effect of the visual task on these values, averaged across the straight and curved driving scenarios, is summarised in Table 34.

**Table 34 –Longitudinal driving measures, Visual task, Average drivers**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| Mean speed [km/h] (mn_sp) | 83.07 | 76.78 | 74.75 | 73.07 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | ✓ |
| | | | | | | | | SLv2 | | | × |
| Standard deviation of speed [km/h] (sd_sp) | 2.668 | 4.14 | 4.349 | 5.31 | ✓ | × | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | ✓ |
| | | | | | | | | SLv2 | | | × |
| Minimum speed [km/h] (u_sp) | 78.34 | 70.45 | 68.32 | 64.98 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | ✓ |
| | | | | | | | | SLv2 | | | × |
| Mean distance headway [m] (mn_hwd) | 277.9 | 382.6 | 344.4 | 351.8 | × | ✓ | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |
| Standard deviation of distance headway [m] (sd_hwd) | 29.73 | 76.6 | 78.23 | 83.05 | ✓ | × | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |
| Mean time headway [s] (mn_hwt) | 12.09 | 18.65 | 17.85 | 18.89 | ✓ | × | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |
| Standard deviation of time headway [s] (sd_hwt) | 1.397 | 4.381 | 5.242 | 5.947 | ✓ | × | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

Analysis of longitudinal control in the critical event scenarios only showed a reliable effect of the visual task on the standard deviation of time headway (sd_hwt), with more deviation observed during performance of levels 2 and 3 of the task (see Figure 42).

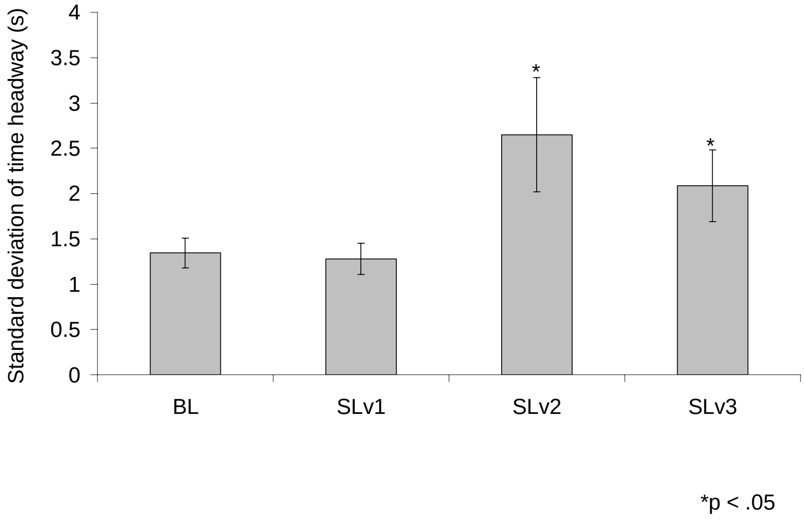



**Figure 42 – Standard deviation of time headway (sd_hwt) during events, Visual task, Average drivers**

### *5.6.3.3. Lateral control*

Standard deviation of lateral position (sd_lp) was found to vary reliably across the three road scenarios, and as expected, the highest deviation was observed in the curved roads. Deviation in lateral position was also found to increase reliably in the presence of the visual task, with more deviation caused by the two most difficult levels of the visual task – compared to baseline (see Figure 43).

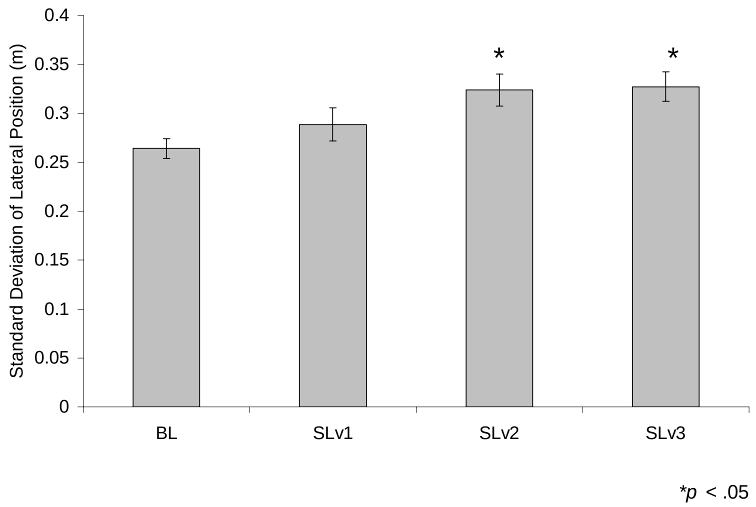



**Figure 43 – Lateral position variation (sd_lp) across all driving events, Visual task, Average drivers**

This reduction in lateral control, as a result of the visual task, was also shown by measures such as lane exceedence (lanex, see Figure 44 and the number of steering reversals (rr_st, see Figure 45).

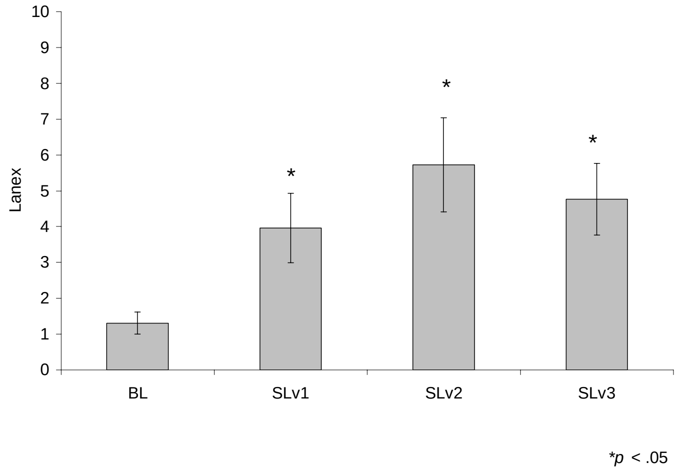



**Figure 44 – Lane exceedences (lanex), Visual task, Average drivers**

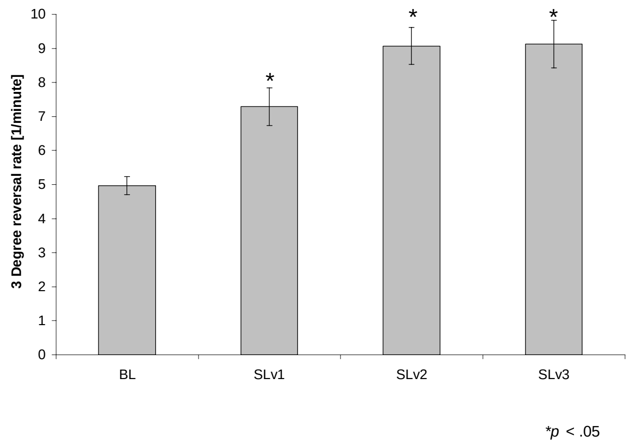



**Figure 45 – Number of 3 degrees reversal rate (rr_st3), Visual task, Average drivers**

Therefore, whilst drivers were aware that their performance on the visual task might affect their longitudinal control of the car, and reduced their speed accordingly, they were less aware of (or concerned with) a loss in lateral deviation control.

#### *5.6.3.4. S-IVIS performance*

Performance in the visual task was analysed as described in section *2.7.1 Common analysis method*. Compared to baseline, concurrent driving was found to increase reaction time in the visual task, and across the three driving scenarios, with the lowest reaction time observed in the straight road sections. In other words, having to negotiate the curves and dealing with other traffic in the road clearly demanded more visual attention towards activities in the road, reducing the speed at which drivers were able to respond to the visual task (see Figure 46).

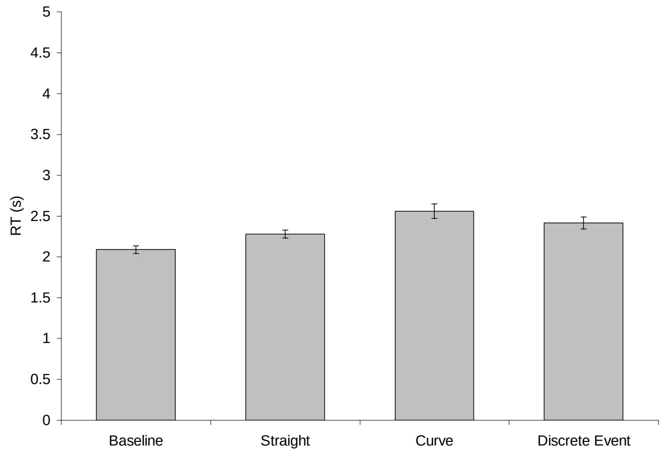



**Figure 46 – Reaction time (s_rt), Visual task, Average drivers**

Reaction time was shown to increase in a systematic manner from level 1 to 3 of the visual task, confirming an increase in the degree of visual attention required with task difficulty. This systematic increase was seen in both baseline performance of the task, and when the visual task was performed during simulated driving. However, the ANOVA showed a reliable interaction between driving and difficulty level of the visual task, with long reaction times to the most difficult version of the visual task during the curved sections (see Figure 47).

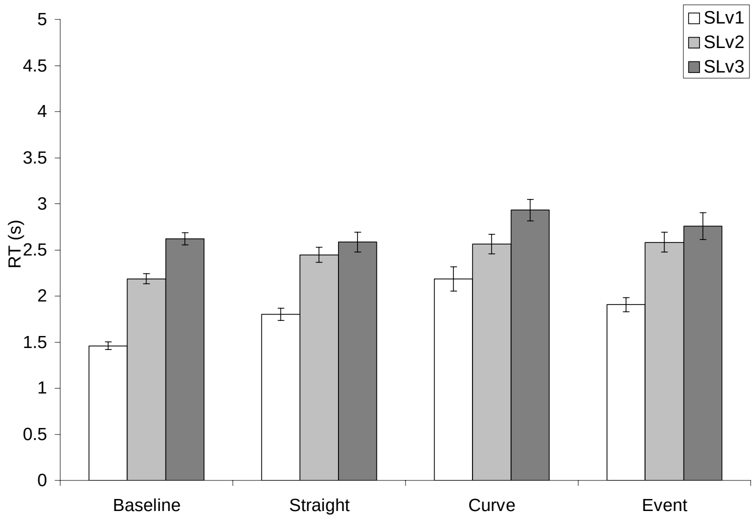



**Figure 47 – Reaction time (s_rt) by event type, Visual task, Average drivers**

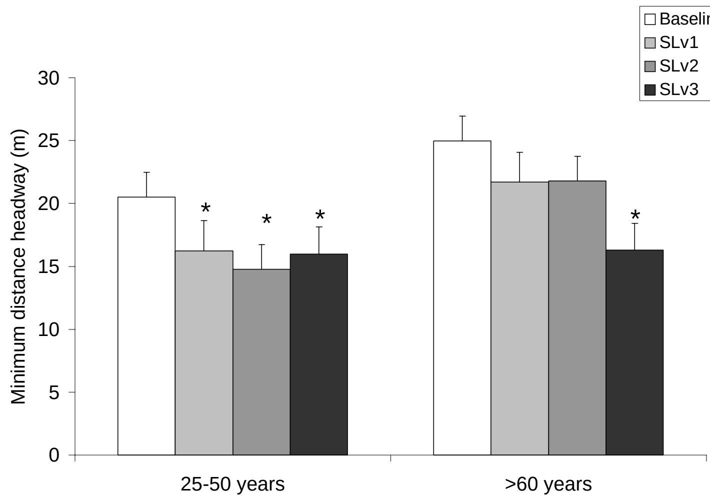
Simulated driving resulted in an increase in the percentage of incorrect (s_incorrect) and missed responses (s_missed) for the visual task. Also, these measures were found to be influenced by level of difficulty in the visual task. A reliable interaction was found between percentage of missed responses and driving scenario, with a large number of responses missed during the event driving scenarios. Therefore, as with the reaction time data, the requirement to deal with the more difficult driving scenarios was found to be detrimental to performance on the visual task, especially when a high workload was also required for the S-IVIS task

### 5.6.4. Comparison between Average and Elderly drivers

#### *5.6.4.1. Longitudinal control*

Mean speed (mn_sp) of the two groups was analysed using a repeated measures ANOVA with a between-subject factor of age. Elderly drivers' average speed during the straight and curved driving scenarios was found to be reliably lower than that of drivers aged between 25 and 50 years. However, mean driving speed of the two groups did not vary significantly in the presence of the S-IVIS or for the two driving scenarios. In other words, both groups were found to reduce their speed in the presence of S-IVIS (relative to baseline), and both groups drove slower in the curved sections of the road. However, a reliable interaction between driving scenario, age group and S-IVIS shows that when negotiating the s-shaped curves, elderly drivers reduced their speed more in the presence of S-IVIS than average drivers. Therefore, elderly drivers were clearly more aware of their limitations, and that the need to negotiate curves and respond to the cognitive task imposed a high workload, which necessitated a reduction in driving speed.

In terms of longitudinal control during the discrete events, a between-subjects ANOVA showed a difference in minimum distance headway (u_hwd) between young and elderly drivers. The analysis did not reveal an interaction, although as shown in Figure 48 in average drivers, introduction of S-IVIS cause an overall reduction in minimum distance headway (compared to baseline), whereas for elderly drivers, a substantial reduction in distance headway was only seen during the four target sound condition.




(*value reliably lower than baseline, p< .05)

**Figure 48 – Comparison of minimum distance headway (u_hwd) in average and elderly drivers**

As outlined above, elderly drivers either abandoned their effort on the cognitive task or did not respond in time during the discrete events, perhaps in order to manage the high workload of the driving task. To some extent, this attempt to focus on the primary task seems to have been beneficial in terms of longitudinal control during the easier versions of the task. However, the fact that the four target sound condition caused a possibly hazardous reduction in minimum distance headway suggests that elderly drivers may well have made on attempt on the cognitive task, and simply did not respond in time.

#### *5.6.4.2. S-IVIS performance*

As shown in Figure 49, the percentage of correct answers in elderly drivers was significantly less than that of average drivers, while elderly drivers also missed a significantly larger number of responses, compared to average drivers. As well as performing worse than average drivers overall, a reliable interaction between age and driving for both measures illustrates that concurrent driving was more deleterious to the performance of elderly drivers than that of average drivers. This may be partly due to the well-documented finding that the ability to direct attention to two complex (non-automated) tasks in a dual task paradigm is considerably reduced in elderly participants (e.g. McDowd,& Craik, 1988; Salthouse & Somberg, 1982).

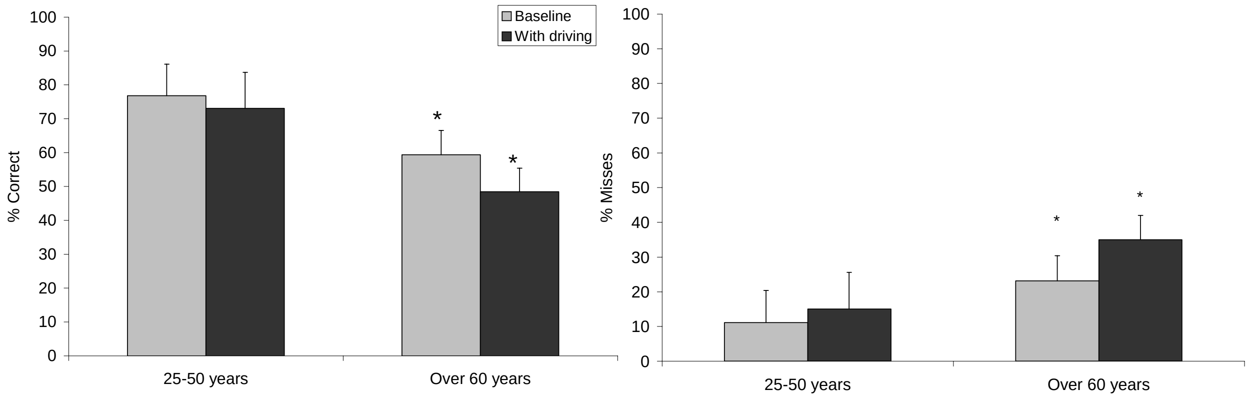



**Figure 49 – The performance of average and elderly drivers on the cognitive task**

### 5.6.5. Comparing the effects of the two S-IVIS on driving performance

#### *5.6.5.1. Longitudinal control*

As with all other analyses outlined above, driving performance during the two s-IVIS tasks was compared by analysing lateral and longitudinal data for the three road categories. Analysis of variance of the between-subject variable S-IVIS (the cognitive task, the visual task), revealed differences on longitudinal measures such as the mean (mn_sp), minimum (u_sp) and standard deviation of speed (sd_sp), as well as the mean (mn_hwd) and standard deviation (sd_hwd) of time headway. In each case, while the baseline levels for these variables were very similar across the two experiments, driving performance was affected very differently by the two S-IVIS tasks.

For instance, as shown in Figure 50, drivers reduced their speed, and increased their headway from the lead car when performing the visual task. On the other hand, they failed to reduce their speed adequately, and subsequently had quite short time headways with the lead car during performance of the cognitive task. Very similar results were also found for the above performance measures in the critical events. Therefore, drivers were clearly aware that their performance on the visual task may be detrimental to their driving unless they reduced their speed and kept a 'safe' distance from the lead car. However, they were somehow less aware of the detrimental effects of the cognitive task, and believed that this S-IVIS would not cause problems in the longitudinal control of the car.

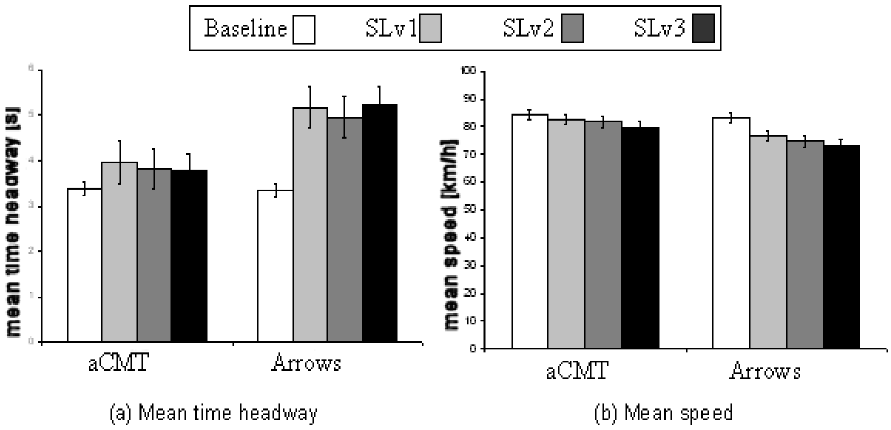



**Figure 50 – The effect of the two s-IVIS tasks on mean speed and time headway**

#### *5.6.5.2. Lateral control*

The two S-IVIS tasks were also shown to have very different effects on lateral driving control. For example, lane exceedence (lanex) with the visual task was substantially larger than with the cognitive. Indeed, as shown in Figure 51 baseline lane exceedence actually decreased with the addition of the cognitive task, but increased with concurrent the visual task. Therefore, as outlined above, performance of the visual S-IVIS was detrimental to lateral driving control, but it seems that the cognitive S-IVIS may actually be beneficial to lateral control (but see discussion below).

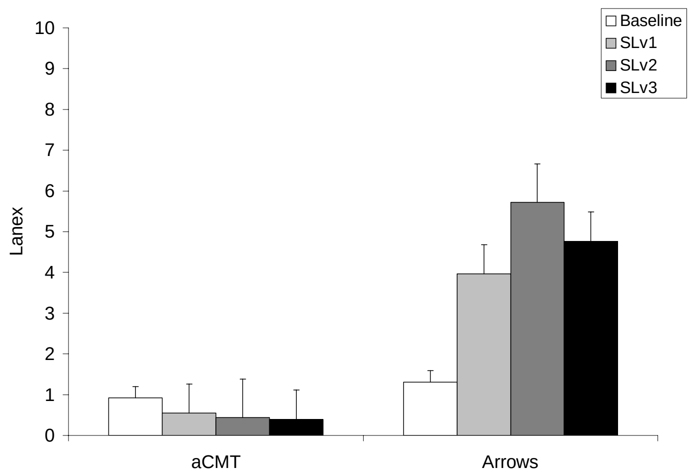



**Figure 51 – Effect of the two s-IVIS tasks on lane exceedence.**

This differential effect in lateral control imposed by the two tasks was also observed on other driving measures, as summarised in
Table 35.

**Table 35 – The effect of the two s-IVIS tasksnn on lateral control measures**

| | Mean values | |
|---|---|---|
| **Driving Measure** | **aCMT** | **Arrows** |
| Reversal rate of steering > $1^o$ (rr_st1) | 8.237* | 10.737 |
| Minimum time to line crossing [s] (u_tlc) | 1.670* | 1.326 |
| Standard Deviation of Lateral Position [m] (sd_lp) | 0.239* | 0.301 |

*Mean difference significant ($p < .05$).

## 5.7. Summary and conclusions

With respect to the effect of each S-IVIS task on driving performance, it is clear that while the visual task was most detrimental to lateral control measures, the high cognitive load imposed by the cognitive task resulted in a worsening of longitudinal control measures. The visual demand required for the visual task meant that steering was more erratic and there were more lateral deviations in the road, compared to baseline driving conditions. This was shown by measures such as the number of steering reversals, lane exceedence and standard deviation of lateral position.

The hazardous effects of the cognitive task were most prominent during the event scenarios, whereby headway measures were found to be markedly reduced by this task, compared to baseline. This shows the value of having the events scenarios. On the other hand, lateral control of the car was found to be improved by concurrent cognitive task performance, although as discussed in other sections of the report, future work should assess the effect of unexpected hazardous events on this improved lateral control.

As regards performance on the secondary task, this deteriorated in a systematic manner with an increase in difficulty level, and this was true for both baseline data and when S-IVIS was completed during concurrent driving. These results clearly demonstrate that the correct criteria were chosen in our attempt to create a systematic increase in S-IVIS workload. Apart from the cognitive task performance in average aged drivers, the different driving scenarios had differential effects on S-IVIS performance, with more detrimental effects from the curved sections and the event scenarios. Since both of these scenarios required a higher degree of attention towards the primary driving task, they caused reduced accuracy in the secondary S-IVIS tasks, especially for the more difficult (higher workload) versions of the task.

# 5.8. Measures summary tables

## 5.8.1. Rural road and the cognitive task (average drivers)

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 | |
| **Longitudinal control** | | | | | | | | | | | | |
| mn_sp [km/h] | 23.45 | 22.94 | 22.72 | 22.18 | ✓ | ✓ | | BL | × | × | ✓ | straight, curve |
| | | | | | | | | SLv1 | | × | ✓ | |
| | | | | | | | | SLv2 | | | × | |
| u_sp [km/h] | 22.08 | 21.67 | 21.46 | 20.81 | ✓ | ✓ | | BL | × | × | ✓ | straight, curve |
| | | | | | | | | SLv1 | | × | ✓ | |
| | | | | | | | | SLv2 | | | × | |
| mn_ttc [s] | 8.044 | 6.944 | 6.948 | 6.478 | ✓ | n/a | n/a | BL | ✓ | ✓ | ✓ | event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| pr_hwd [%] | 37.5 | 54.17 | 54.17 | 66.67 | ✓ | n/a | n/a | BL | × | × | ✓ | event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| u_hwd [m] | 20.53 | 16.24 | 14.75 | 16 | ✓ | n/a | n/a | BL | × | ✓ | × | event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| u_mn_hwt [s] | 2.279 | 1.893 | 1.953 | 1.979 | ✓ | n/a | n/a | BL | ✓ | ✓ | ✓ | event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| sd_hwt [s] | 1.373 | 0.997 | 0.862 | 0.972 | ✓ | n/a | n/a | BL | ✓ | ✓ | × | event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| rt_br [s] | 3.965 | 5.272 | 4.391 | 3.539 | ✓ | n/a | n/a | BL | ✓ | × | × | event |
| | | | | | | | | SLv1 | | × | ✓ | |
| | | | | | | | | SLv2 | | | × | |
| **Lateral control** | | | | | | | | | | | | |
| mn_lp [m] | 1.997 | 2.018 | 1.992 | 1.976 | ✓ | ✓ | × | BL | × | × | × | straight, curve event |
| | | | | | | | | SLv1 | | ✓ | ✓ | |
| | | | | | | | | SLv2 | | × | × | |
| st_lp [m] | 0.256 | 0.242 | 0.233 | 0.226 | ✓ | ✓ | ✓ | BL | × | ✓ | ✓ | straight, curve event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| rr_st3 [1/minute] | 5.569 | 6.667 | 7.333 | 6.75 | ✓ | n/a | n/a | BL | ✓ | ✓ | ✓ | event |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| **Workload** | | | | | | | | | | | | |
| subj_r | 7.773 | 6.472 | 5.806 | 5.5 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ | straight, curve event |
| | | | | | | | | SLv1 | | ✓ | ✓ | |
| | | | | | | | | SLv2 | | | × | |

| SIVIS | Mean values | | | Significant Effects | | | Post Hoc test | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv2 | SLv3 |
| s_correct [%] | 82.06 | 74.82 | 65.13 | ✓ | ✓ | × | SLv1 | ✓ | ✓ |
| | | | | | | | SLv2 | | ✓ |
| s_missed [%] | 11.05 | 13.23 | 18.26 | ✓ | ✓ | × | SLv1 | × | ✓ |
| | | | | | | | SLv2 | | ✓ |
| s_incorrect [%] | 7.35 | 12.34 | 16.69 | ✓ | × | × | SLv1 | ✓ | ✓ |
| | | | | | | | SLv2 | | ✓ |

### 5.8.2. Rural road and the cognitive task (elderly drivers)

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 | |
| **Longitudinal control** | | | | | | | | | | | | |
| mn sp | 77.45 | 73.14 | 74.22 | 71.94 | ✓ | ✓ | ✓ | BL | ✓ | ✗ | ✓ | straight, curve |
| | | | | | | | | SLv1 | | ✗ | ✗ | |
| | | | | | | | | SLv2 | | | ✗ | |
| u sp | 71.8 | 67.49 | 68.26 | 66.88 | ✓ | ✓ | ✓ | BL | ✓ | ✗ | ✓ | straight, curve |
| | | | | | | | | SLv1 | | ✗ | ✗ | |
| | | | | | | | | SLv2 | | | ✗ | |
| u ttc [s] | 1.422 | 1.721 | 1.516 | 1.587 | ✓ | ✓ | ✗ | BL | ✓ | ✗ | ✗ | straight, curve event |
| | | | | | | | | SLv1 | | ✓ | ✗ | |
| | | | | | | | | SLv2 | | | ✗ | |
| u hwd [m] | 24.99 | 21.68 | 21.79 | 16.29 | ✓ | n/a | n.a | BL | ✗ | ✗ | ✓ | event |
| | | | | | | | | SLv1 | | ✗ | ✓ | |
| | | | | | | | | SLv2 | | | ✓ | |
| u hwt [s] | 2.763 | 2.397 | 2.282 | 2.146 | ✓ | n/a | n.a | BL | ✗ | ✗ | ✓ | event |
| | | | | | | | | SLv1 | | ✗ | ✗ | |
| | | | | | | | | SLv2 | | | ✗ | |
| **Lateral control** | | | | | | | | | | | | |
| u tlc [s] | 1.422 | 1.721 | 1.516 | 1.587 | ✓ | ✓ | ✗ | BL | ✓ | ✗ | ✗ | straight, curve event |
| | | | | | | | | SLv1 | | ✓ | ✗ | |
| | | | | | | | | SLv2 | | | ✗ | |
| pr tlc [%] | 19.69 | 9.541 | 16.04 | 14.66 | ✓ | ✓ | ✗ | BL | ✓ | ✗ | ✗ | straight, curve event |
| | | | | | | | | SLv1 | | ✓ | ✗ | |
| | | | | | | | | SLv2 | | | ✗ | |
| **Workload** | | | | | | | | | | | | |
| subj r | 7.63 | 6.63 | 6.203 | 6.551 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✓ | straight, curve event |
| | | | | | | | | SLv1 | | ✓ | ✗ | |
| | | | | | | | | SLv2 | | | ✗ | |

| **S-IVIS** | **Mean values** | | | **Significant Effects** | | | **Post Hoc test** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv2 | SLv3 |
| s correct | 64.15 | 50.4 | 38.94 | ✓ | ✓ | ✗ | SLv1 | ✓ | ✓ |
| | | | | | | | SLv2 | | ✓ |
| s missed | 22.75 | 32.01 | 41.4 | ✓ | ✓ | ✓ | SLv1 | ✓ | ✓ |
| | | | | | | | SLv2 | | ✓ |
| s incorrect | 13.1 | 17.59 | 19.66 | ✓ | ✗ | ✗ | SLv1 | ✗ | ✓ |
| | | | | | | | SLv2 | | ✗ |

### 5.8.3. Rural road and the visual task

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 | |
| **Longitudinal control** | | | | | | | | | | | | |
| mn  sp [km/h] | 83.07 | 76.78 | 74.75 | 73.07 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✓ | straight, curve |
| | | | | | | | | SLv1 | | ✗ | ✓ | |
| | | | | | | | | SLv2 | | | ✗ | |
| st  sp [km/h] | 2.668 | 4.14 | 4.349 | 5.31 | ✓ | ✗ | ✗ | BL | ✓ | ✓ | ✓ | |
| | | | | | | | | SLv1 | | ✗ | ✓ | |
| | | | | | | | | SLv2 | | | ✗ | |
| u  sp [km/h] | 78.34 | 70.45 | 68.32 | 64.98 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✓ | straight, curve |
| | | | | | | | | SLv1 | | ✗ | ✓ | |
| | | | | | | | | SLv2 | | | ✗ | |
| mn  hwd [m] | 277.9 | 382.6 | 344.4 | 351.8 | ✗ | ✓ | ✗ | BL | ✓ | ✓ | ✓ | straight, curve |
| | | | | | | | | SLv1 | | ✗ | ✗ | |
| | | | | | | | | SLv2 | | | ✗ | |
| sd  hwd [m] | 29.73 | 76.6 | 78.23 | 83.05 | ✓ | ✗ | ✓ | BL | ✓ | ✓ | ✓ | straight, curve |
| | | | | | | | | SLv1 | | ✗ | ✗ | |
| | | | | | | | | SLv2 | | | ✗ | |
| mn  hwt [s] | 12.09 | 18.65 | 17.85 | 18.89 | ✓ | ✗ | ✗ | BL | ✓ | ✓ | ✓ | straight, curve |
| | | | | | | | | SLv1 | | ✗ | ✗ | |
| | | | | | | | | SLv2 | | | ✗ | |
| sd  hwt [s] | 1.397 | 4.381 | 5.242 | 5.947 | ✓ | ✗ | ✗ | BL | ✓ | ✓ | ✓ | straight, curve |
| | | | | | | | | SLv1 | | ✗ | ✗ | |
| | | | | | | | | SLv2 | | | ✗ | |
| **Lateral control** | | | | | | | | | | | | |
| st  lp [m] | 0.264 | 0.289 | 0.324 | 0.327 | | | | BL | ✗ | ✓ | ✓ | straight, curve event |
| | | | | | | | | SLv1 | | ✓ | ✓ | |
| | | | | | | | | SLv2 | | | ✗ | |
| lnx [%] | 1.308 | 3.965 | 5.725 | 4.763 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ | straight, curve event |
| | | | | | | | | SLv1 | | ✗ | ✗ | |
| | | | | | | | | SLv2 | | | ✗ | |
| rr  st1 [1/minute] | 7.847 | 10.69 | 12.68 | 11.76 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ | straight, curve event |
| | | | | | | | | SLv1 | | ✓ | ✗ | |
| | | | | | | | | SLv2 | | | ✗ | |
| rr  st3 [1/minute] | 4.972 | 7.292 | 9.069 | 9.125 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✓ | straight, curve event |
| | | | | | | | | SLv1 | | ✓ | ✓ | |
| | | | | | | | | SLv2 | | | ✗ | |
| rr  st5 [1/minute] | 3.528 | 5.389 | 6.597 | 7.042 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ | straight, curve event |
| | | | | | | | | SLv1 | | ✓ | ✓ | |
| | | | | | | | | SLv2 | | | ✗ | |
| rr  ste5 [1/minute] | 2.324 | 4.097 | 5.014 | 5.389 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ | straight, curve event |
| | | | | | | | | SLv1 | | ✓ | ✓ | |
| | | | | | | | | SLv2 | | | ✗ | |
| rswt  20 [1/minute] | 2 | 4.417 | 5.681 | 6.236 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ | straight, curve event |
| | | | | | | | | SLv1 | | ✓ | ✓ | |
| | | | | | | | | SLv2 | | | ✗ | |
| rswt  40 [1/minute] | 0.213 | 0.958 | 1.542 | 1.875 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✓ | straight, curve event |
| | | | | | | | | SLv1 | | ✗ | ✓ | |
| | | | | | | | | SLv2 | | | ✗ | |
| rswt  70 [1/minute] | 0.046 | 0.194 | 0.292 | 0.625 | ✓ | ✓ | ✓ | BL | ✗ | ✗ | ✓ | straight, curve event |
| | | | | | | | | SLv1 | | ✗ | ✓ | |
| | | | | | | | | SLv2 | | | ✗ | |
| **Workload** | | | | | | | | | | | | |
| subj  r | 7.773 | 6.472 | 5.806 | 5.5 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✓ | |
| | | | | | | | | SLv1 | | ✓ | ✓ | |
| | | | | | | | | SLv2 | | | ✗ | |

| SIVIS | Mean values | | | Significant Effects | | | Post Hoc test | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv2 | SLv3 |
| s  rt [s] | 1.838 | 2.445 | 2.724 | ✓ | ✓ | ✓ | SLv1 | ✓ | ✓ |
| | | | | | | | SLv2 | | ✓ |
| s  missed [%] | 0.146 | 0.333 | 1.229 | ✓ | ✓ | ✓ | SLv1 | ✓ | ✓ |
| | | | | | | | SLv2 | | ✓ |
| s  incorrect [%] | 1.389 | 7.292 | 10.88 | ✓ | ✓ | ✗ | SLv1 | ✓ | ✓ |
| | | | | | | | SLv2 | | ✓ |

# 6. The TNO Simulator Experiment

## 6.1. Test site

The TNO driving simulator consists of a BMW 318I, with normal controls, placed on a moving base platform with six degrees of freedom. Different subsystems are used to run the vehicle model, generate images, sounds, etc. Drivers have a horizontal forward view of 120°. The images were generated by three projectors.

## 6.2. Scenarios and participants

48 average drivers were participated in the experiment. Rural and urban road driving were included in the experiment. The rural road was designed according to the specification in section 2.6.1 - Rural Road. The urban road was developed by TNO. Its main characteristics are described in Table 36. The road incorporated pavement, houses, offices, churches, bus stops and a small park, see Figure 52.

**Table 36 – Main characteristics of the urban road.**

| | |
|---|---|
| Speed limit | 50 km/h |
| Length | Just over 6 km |
| Total road width | 5.2 m |
| Number of Lanes | 2 (1 per direction of travel) |
| Lane width | 2.60 m |
| Minimum radius of Curvature | 24 m |
| Junctions | 34 |

**Figure 52 – The urban road simulation**

Each road consisted of three repetitions of three driving scenarios, which were designed to vary in terms of workload and driving difficulty. These were:

1. Straight sections, requiring minimal workload compared to other scenarios.
2. Junctions, which required some negotiation by the driver.
3. Discrete events, requiring immediate attention by the driver.

There were six different discrete events matched in pairs; three for the experimental run (with S-IVIS) and three for the baseline run (without S-IVIS). It was assumed that paired events would result in similar driving behaviour. See Table 37 for the events.

**Table 37 – The events in the urban road**

| First set of events | Second set of events |
|---|---|
| Car leaving a bus stop just when the driver arrives | Car pulls out from the left side of the road |
| Lead car slows down for a pedestrian crossing the street | A car coming from the right, crossing a junction |
| Traffic light stays red until the driver almost comes to a complete stop | Traffic light stays red until the driver almost comes to a complete stop |

## 6.3. S-IVIS evaluated

Participants performed the visual task or the cognitive task. The S-IVIS tasks were used as specified in section 2.4 - Surrogate IVIS . Nine S-IVIS blocks were included per road type.

## 6.4. Experimental design

Two experiments were performed. One experiment with the visual task and one experiment with the cognitive task. In each experiment 24 participants were used. The experiment was designed according to the specification in *2.3- Experimental design*.

## 6.5. Procedure

Participants performed the experiment in pairs: One performed the cognitive task while driving and the other the visual task. Upon arrival, they received written instructions regarding the experiment and had the opportunity to ask questions. Then the experiment started for one participant while the other waited in a room nearby. Drivers were made familiar with the S-IVIS tasks and the driving simulator before the experiment started. An experimental session consisted of three parts: (1) drive while performing the S-IVIS, (2) drive without the S-IVIS, and (3) perform the S-IVIS static test (without driving). These three parts were balanced across participants. After each S-IVIS block and corresponding locations along the baseline run, the participants were asked to rate their driving performance on a scale from 1 (extremely poor) to ten (extremely good).

Each driver performed two experimental sessions, one session on a rural road and the other on an urban road. After an experimental session there was a break during which the other driver performed his or her's experimental session. A session on the urban road lasted approximately 30 minutes and on the rural road approximately 45 minutes.

## 6.6. Measures and analysis method

The analysis was conducted according to the description in section 2.7, Indicators and Analysis. The effects of road complexity (RLv) and S-IVIS difficulty (SLv) were investigated. A number of included measures could not be analysed either because of too many missing data or because the dependent variable was not normally distributed. These dependent variables were all related to headway and lane crossings. Also, the proportion of time-to-line crossing shorter than one second (the pr_tlc measure) could not always be analysed. Several measures related to speed, lateral position and steering wheel angle were however measured and analysed.

## 6.7. Results

### 6.7.1. Effects of the cognitive task in Rural Road driving

#### *6.7.1.1. Self reported driving performance*

Main effects of road complexity level and the cognitive task were found in the self reported driving performance (subj_r). The post-hoc analysis indicated that participants rated their driving performance in the baseline condition as better than in the cognitive task conditions. There was no interaction found between the two factors. The averages for the different levels of the cognitive task are presented in Table 38.

**Table 38 – Analysis of subjective rating of the driving performance (subj_r), Cognitive task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **subj_r** | 7.94 | 7.44 | 7.42 | 7.62 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

Post-hoc analysis further showed that they rated their driving performance lower during the events than during driving a curve or a straight road. The average values for each combination of S-IVIS level and road complexity level are presented in Figure 53.

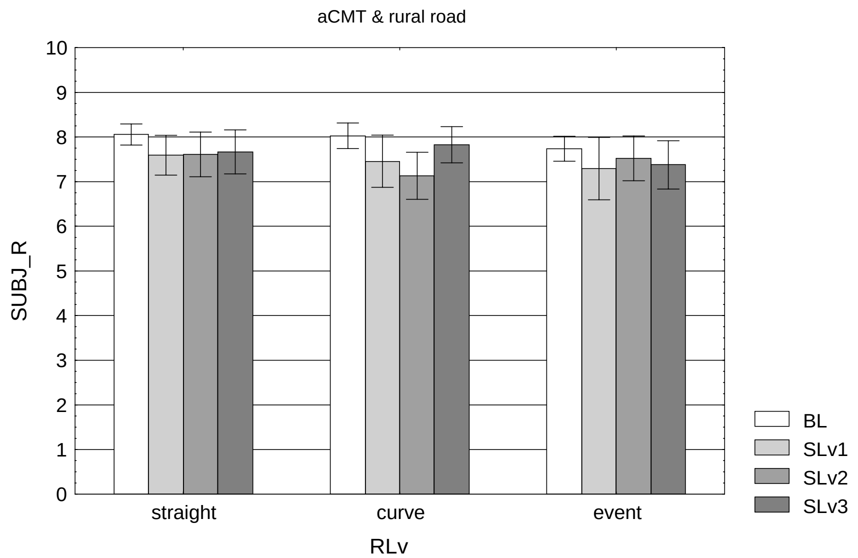



**Figure 53 – Average subjective ratings of driving performance (subj_r), Cognitive task, Rural road**

#### *6.7.1.2. Longitudinal control*

No effects of the cognitive task were found in any of the speed measures. The headway measures could not be analysed due to abnormally distributed data.

#### *6.7.1.3. Lateral control*

A main effect of SLv was found in lateral position (mn_ lp) and lateral position variation (st_lp); there was a small shift to the left and a slightly decreased lateral position variation as a result of the cognitive task. No significant differences were found between the averages of the cognitive task levels for lateral position and the lateral position variation.[3] See Table 39, Figure 54 and Figure 55. No effects were found in the TLC-measures.

In curves, the subjects drove significantly more to the left than in the straight road sections and during events. They swerved less on a straight road than in a curve or during event, and less in curves than during an event, and the average time-to-line crossing (mn_tlc) was the longest during a straight road segment. No interaction between SLv and RLv was found.

**Table 39 – Analysis of lateral position (mn_lp), lateral position variation (st_lp), Cognitive task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| mn_lp | 1.01 | 0.97 | 0.99 | 0.98 | ✓ | ✓ | × | BL | × | × | × |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |
| st_lp | 0.29 | 0.26 | 0.26 | 0.26 | ✓ | ✓ | × | BL | × | × | × |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

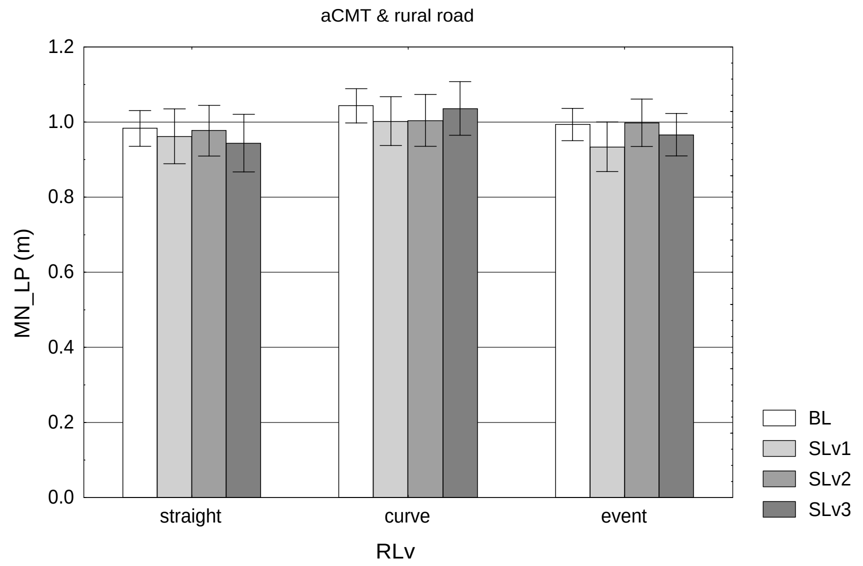



**Figure 54 – Mean lateral position (mn_lp), Cognitive task, Rural road**

[3] This outcome is possible since the post-hoc test used (Tukey HSD) is a rather conservative post-hoc test. In general post-hoc analyses take into account that several statistical comparisons are made at the same time and that therefore significant effects can be found by chance alone. As a consequence it can indicate that none of the levels of a factor differ significantly from each other while the ANOVA indicates a main effect for that factor.

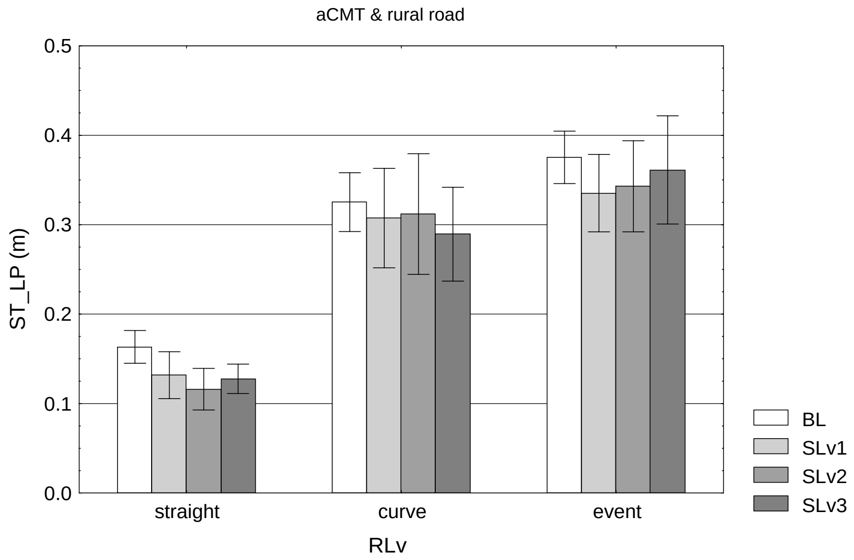



**Figure 55 – Lateral position variation (st_lp) Cognitive task, Rural road**

A main effect of the cognitive task level was found for all steering related variables, except for the seven degrees steering reversal rate (rr_st7). The largest effect was found in rr_st1. See Table 40 and Figure 56. The steering activity increased with the cognitive task difficulty. Post-hoc analyses showed that differences were mainly found between baseline and the experimental conditions, but not between the experimental conditions (SLv1-3). For the steering reversal rates 1 and 3 degrees there was also a significant difference between SLv1 and SLv3. An interaction between SLv and RLv was found for the steering reversal rates 1, 3 and 5, indicating that the effect of the cognitive task decreased as the road complexity level increased. With respect to the road complexity level, the post-hoc analyses generally indicated that driving along the straight road required the most effort.

**Table 40 – Analysis of steering reversal rates (rr_st1 – 5) and (hi_st), Cognitive task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | **BL** | **SLv1** | **SLv2** | **SLv3** | **SLv** | **RLv** | **SLv*RLv** | | **SLv1** | **SLv2** | **SLv3** |
| **rr_st1** | 0.64 | 0.81 | 0.84 | 0.87 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | ✓ |
| | | | | | | | | SLv2 | | | × |
| **rr_st3** | 0.50 | 0.57 | 0.59 | 0.62 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | ✓ |
| | | | | | | | | SLv2 | | | × |
| **rr_st5** | 0.41 | 0.45 | 0.47 | 0.48 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |
| **hi_st** | 0.36 | 0.40 | 0.40 | 0.41 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

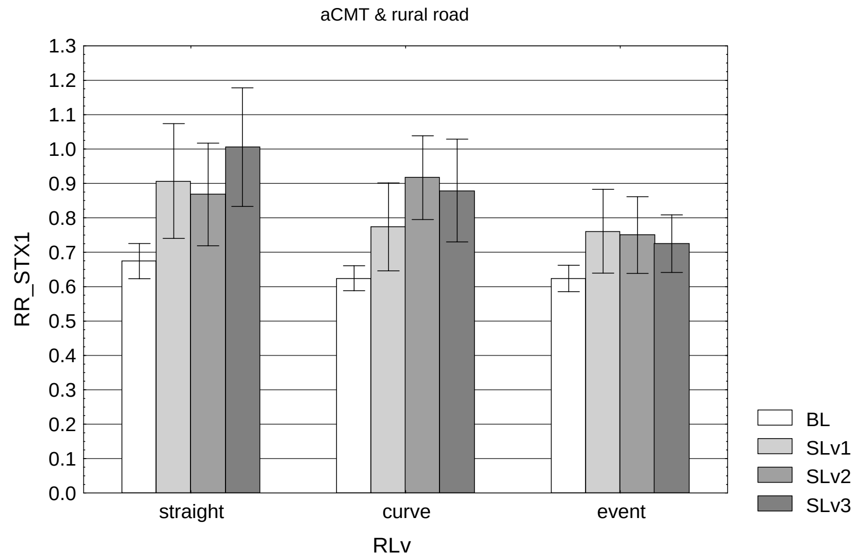



**Figure 56 – Average 1 degree steering reversal rate (rr_st1), Cognitive task, Rural road**

### *6.7.1.4. S-IVIS performance*

The results indicated a main effect of S-IVIS and road complexity level, but no interaction. The post-hoc analysis indicated that drievrs performed worse on the S-IVIS during an event. Furthermore, all S-IVIS levels differed from each other with best performance with SLv1 and the lowest with SLv3. The results are presented in Figure 57. The averages for the S-IVIS difficulty levels are presented in Table 41.

**Table 41 – Analysis of S-IVIS performance (s_cr), Cognitive task, Rural road**

| | Mean values | | | Significant Effects | | | Post Hoc test | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv2 | SLv3 |
| **s_cr** | 86.86 | 74.87 | 63.50 | ✓ | ✓ | ✗ | Slv1 | ✓ | ✓ |
| | | | | | | | SLv2 | | ✓ |

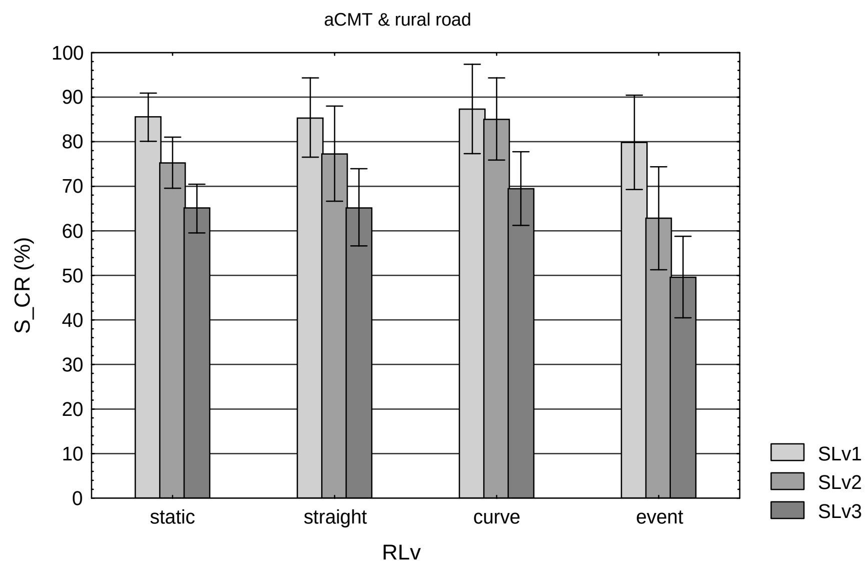



**Figure 57 – % correct responses (s_cr), Cognitive task, Rural road**

#### *6.7.1.5. Results summary*

Mean speed and speed variation were not influenced by performing the cognitive task in the rural road. The lateral performance data are less clear since a main effect was found while the post-hoc analyses did not show significant differences. However, looking at the results (see Figure 54 and Figure 55) one could presume that subjects tended to drive more to left while performing the cognitive task and swerved less. The adjustment in lateral performance is accompanied with an increase in steering effort when subjects performed the cognitive task. In general there was no difference between the different the cognitive task difficulty levels.

### 6.7.2. Effects of the visual task in Rural Road driving

#### *6.7.2.1. Self reported driving performance*

Main effects of road complexity level and the visual task difficulty level were found and also an interaction. Post-hoc analysis indicated that participants rated their driving performance in all the visual task conditions differently as well as in all road complexity levels. See Table 42 and Figure 58. These results follow a pattern; the more difficult the S-IVIS the lower the rating and the highest rating was for the baseline when they did not perform the visual task.

**Table 42 – Analysis of the subjective rating of the driving performance (subj_r), Visual task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **subj_r** | 8.11 | 7.35 | 6.86 | 6.51 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | ✓ |

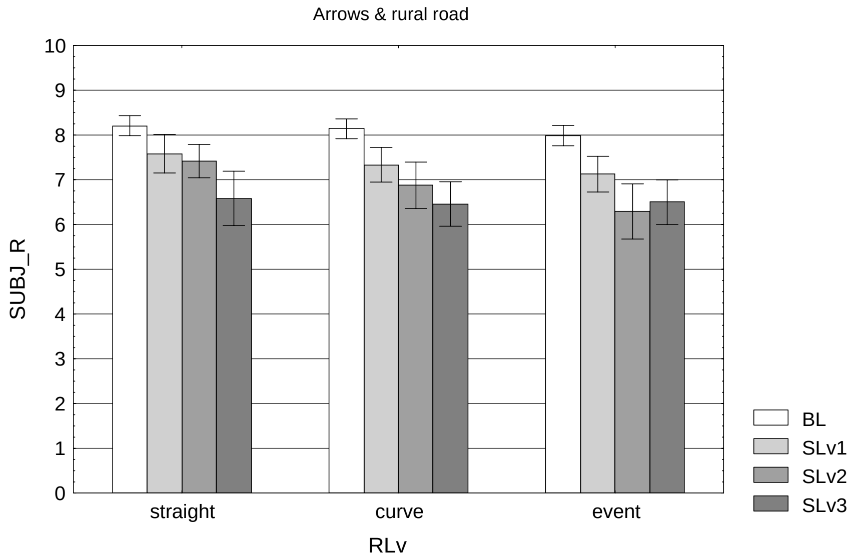



**Figure 58 – Self reported driving performance (subj_r), Visual task, Rural road**

#### *6.7.2.2. Longitudinal control*

The mean speed (mn_sp) was significantly reduced as an effect of the visual task difficulty. The post-hoc analysis, however, indicated no differences between the different experimental levels (SLv1-3). For the speed variation (st_sp) and the minimum speed (u_sp) no effect of the visual task was found. For all three dependent variables an effect of RLv was found. The post-hoc analysis showed that the speed-related measures differed between the events and driving scenarios, see Figure 59 and Table 43.

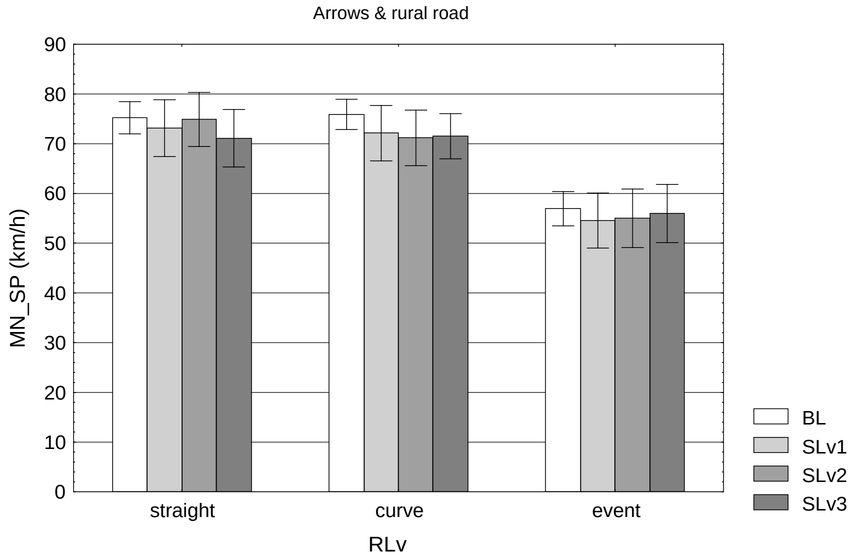



**Figure 59 – Mean driving speed (mn_sp), Visual task, Rural road**

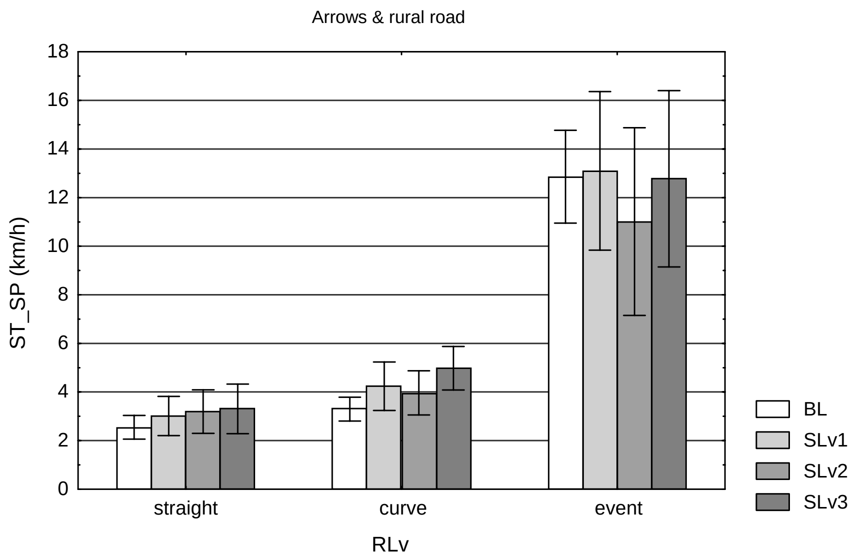



**Figure 60 – Speed variation (st_sp), Visual task, Rural road**

**Table 43 – Analysis of mean speed (mn_sp), Visual task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **mn_sp** | 69.35 | 66.61 | 67.02 | 66.19 | ✓ | ✓ | × | BL | × | × | × |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

### *6.7.2.3. Lateral control*

A main effect of the visual task difficulty level was found in lateral position (mn_lp), lateral position variation (st_lp), and the mean time-to-line crossing (mn_tlc). Post-hoc analyses showed that the mean lateral position in the baseline condition was more to the right than for SLv2 and SLv3. With respect to the lateral position variation the post-hoc analysis showed that in the baseline condition drivers swerved less than driving while performing the visual task. This was irrespective of the visual task difficulty level. Furthermore, they swerved less for SLv1 than SLv2. The mean time-to-line crossing was shorter (higher risk) in the baseline condition than with the S-IVIS levels SLv2 and SLv3. SLv1 differed significantly from SLv3.

For all three dependent variables a main effect was also found for road complexity level. Post-hoc analyses indicated that participants drove more to the left in curves than along a straight road or event, swerved more during events than in curves and on a straight road and also swerved more in a curve than along a straight road, and the time-to-line crossing was less on a straight road than in curves and during an event and also less while driving in a curve than during an event. There was no interaction found between road complexity level and S-IVIS level. See Figure 61, Figure 62 and Table 44.

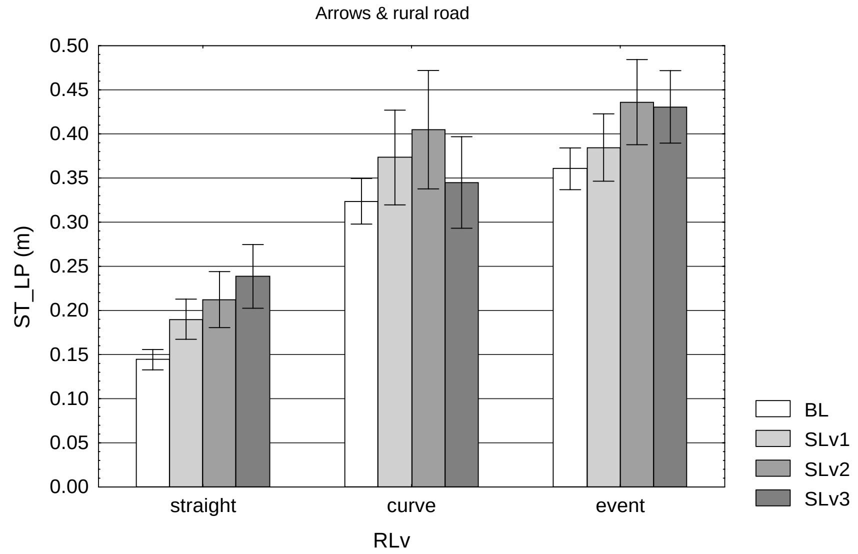



**Figure 61 – Lateral position variation (st_lp), Visual task, Rural road**

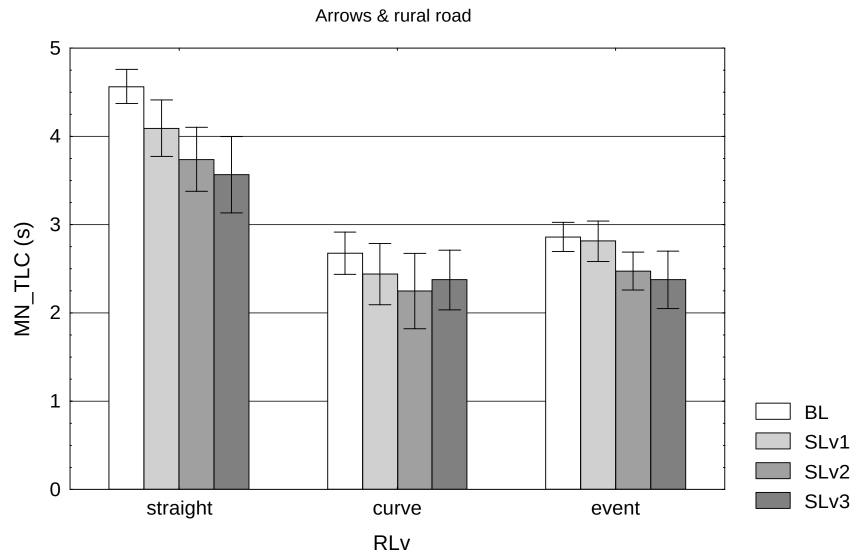



**Figure 62 – Average time-to-line crossing (mn_tlc), Visual task, Rural road**

**Table 44 – Analysis of lateral position measures (mn_lp), (st_lp) and (u_tlc), Visual task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **mn_lp** | 1.03 | 1.04 | 1.09 | 1.07 | ✓ | ✓ | × | BL | × | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |
| **st_lp** | 0.28 | 0.32 | 0.35 | 0.34 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✓ | × |
| | | | | | | | | SLv2 | | | × |
| **mn_tlc** | 3.34 | 3.11 | 2.81 | 2.77 | ✓ | ✓ | × | BL | × | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | ✓ |
| | | | | | | | | SLv2 | | | × |

All steering measures were significantly affected by the visual task, indicating an increased steering activity. There were, however, no significant differences between the difficulty levels of S-IVIS.

For steering reversal rate with a gap of one degree and for high proportion steering frequencies a main effect of road complexity level was found. The post-hoc analyses indicated that driving along the straight road required the most effort. With respect to the proportion of high steering frequency there was also a difference between the curves and the events.

There was only an interaction between the visual task difficulty level and road complexity level for the proportion of high steering frequency, Figure 63. The effect on steering reversal rates is presented by the steering reversal rate with a gap of one degree in Figure 64. One degree reversal rate and high frequency steering component mean values are presented in Table 45.

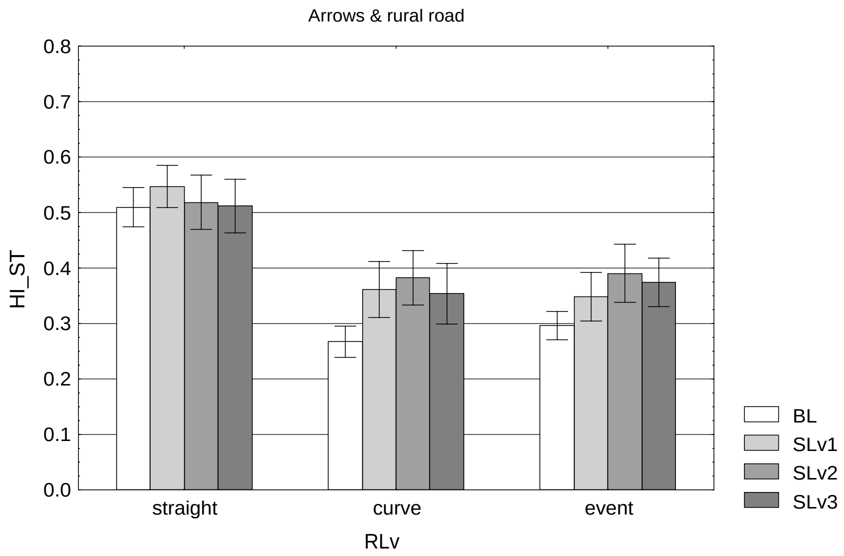



**Figure 63 – Average proportion of high frequency steering (hi_st), Visual task, Rural road**

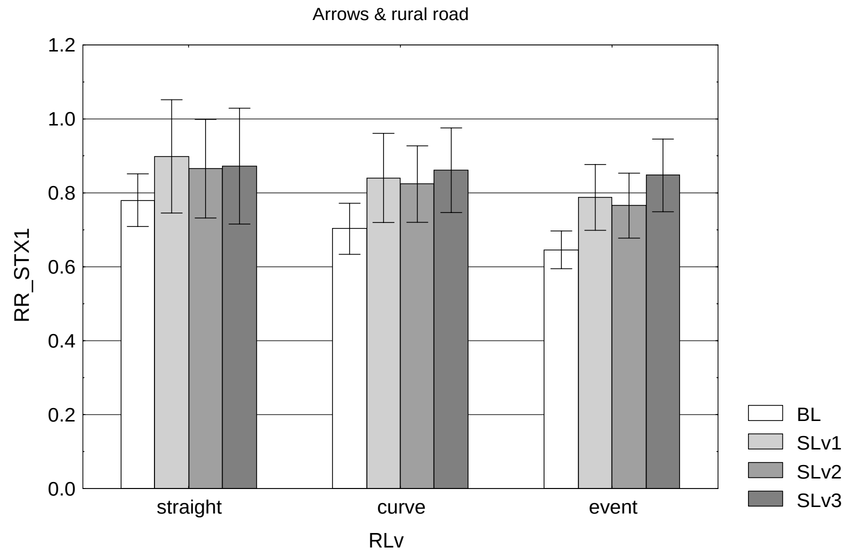



**Figure 64 – Average steering reversal rate with a gap of one degree (rr_st1), Visual task, Rural road**

**Table 45 – Analysis of steering measures (rr_st1 – 7) and (hi_st), Visual task, Rural road**

| | **Mean values** | | | | **Significant Effects** | | | **Post Hoc test** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **rr_st1** | 0.71 | 0.84 | 0.82 | 0.86 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **hi_st** | 0.36 | 0.42 | 0.43 | 0.41 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |

### *6.7.2.4. S-IVIS performance*

The results indicated a main effect of S-IVIS level and road complexity level; no interaction between these factors was found. The post-hoc analysis indicated that participants performed poorer during an event compared to the static and straight road condition. A significant difference was also found between the static and curve condition. Furthermore, all S-IVIS levels differed from each other with best performance with SLv1 and the worst with SLv3, Figure 65. The averages for the difficulty levels of S-IVIS are presented in Table 46.

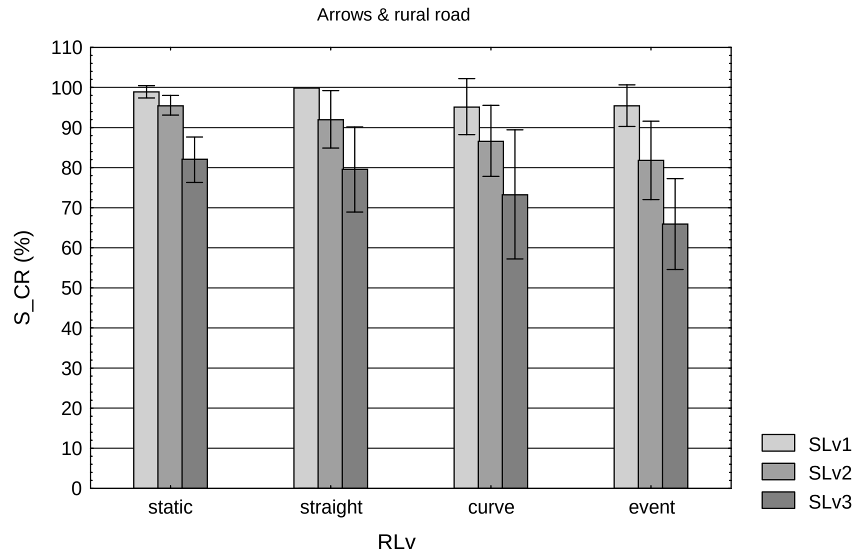



**Figure 65 – % correct responses (s_cr), Visual task, Rural road**

**Table 46 – Analysis of S-IVIS performance (s_cr), Visual task, Rural road**

| | **Mean values** | | | **Significant Effects** | | | **Post Hoc test** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv2 | SLv3 |
| **s_cr** | 98.04 | 91.32 | 77.50 | ✓ | ✓ | ✗ | Slv1 | ✓ | ✓ |
| | | | | | | | SLv2 | | ✓ |

### *6.7.2.5. Results summary*

Although the results suggest an adjustment in longitudinal performance for the different S-IVIS levels for the mean speed these results, however, are not clear. One reason is that the post-hoc analyses did not show any significant differences.

The lateral control performance showed an effect of S-IVIS level. Subjects swerved more when they had to perform the S-IVIS than in the baseline condition. Furthermore, they drove more to the right when they did not perform the S-IVIS than with the difficulty levels SLv2 and 3. The minimum time-to-line crossing was shorter with the higher difficulty levels (SLv2 and 3) than in the baseline condition (SLv1 also differed from SLv3). So drivers experienced more difficulty with lateral control when they had to perform the visual task.

With respect to steering effort, the results are clear and yet difficult to interpret for reasons mentioned above. The results indicated an increased steering effort when drivers had to perform the S-IVIS. This was irrespective of the difficulty level of the S-IVIS. However, main effects were also found for the different events (with exception of the proportion of high steering frequencies).

## 6.7.3. Effects of the cognitive task in Urban Road driving

### *6.7.3.1. Self reported driving performance*

Effects of the cognitive task and road complexity levels were found in subj_r (see Figure 66). The post-hoc analyses showed that driving in the baseline condition was rated higher than driving while performing the cognitive task. There was no difference between the difficulty levels of the cognitive task. Furthermore, no significant differences were found between the different road complexity levels. The average values for S-IVIS are presented in Table 47.

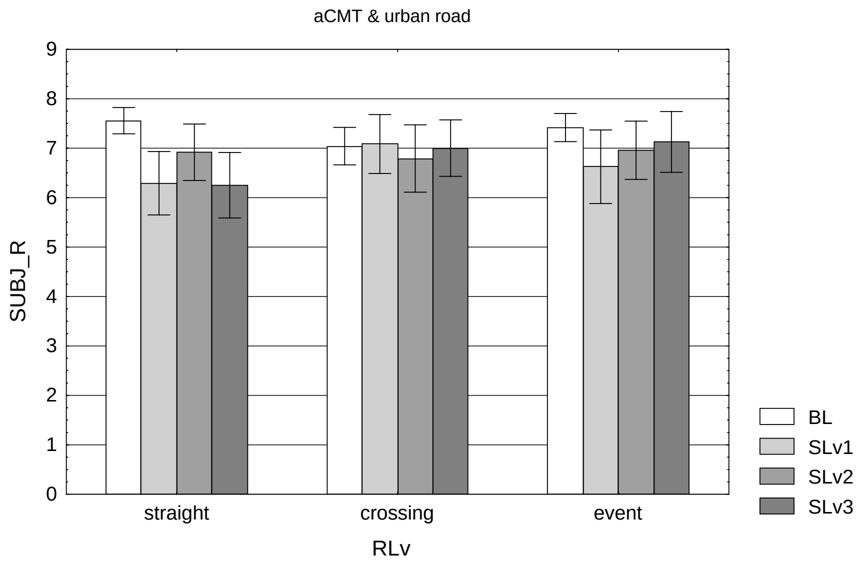



**Figure 66 – Self reported driving performance (subj_r), Cognitive task, Urban road**

**Table 47 – Analysis of the subjective rating of driving performance (subj_r), Cognitive task, Urban road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **subj_r** | 7.34 | 6.67 | 6.89 | 6.79 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

### *6.7.3.2. Longitudinal control*

A main effect of S-IVIS level was found in the mean speed (mn_sp), see Figure 67. SLv2 resulted in significantly lower speed than SLv1 and BL. The differences were however small – only 1-2 km/h. For the mean speed, speed variation and the minimum speed a main effect of road complexity level was found. The post-hoc analyses showed that during the event the average and minimum speed was the lowest and the speed variation was the highest. The minimum speed (u_sp) on straight road segments was higher than on a crossing and the speed variation (st_sp) was lower on a straight road. An interaction between S-IVIS level and road complexity level was found for the mean speed. See Figure 67 Figure 68 and Figure 69 and Table 48.

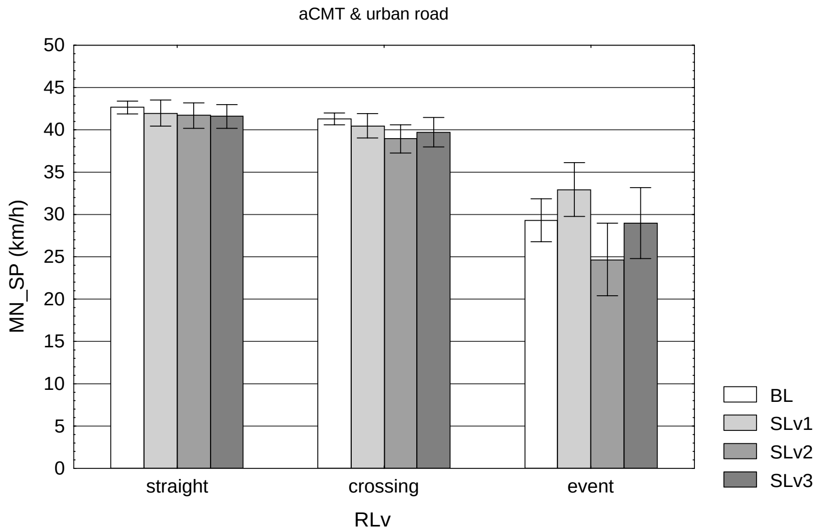



**Figure 67 – Mean speed (mn_sp), Cognitive task, Urban road**

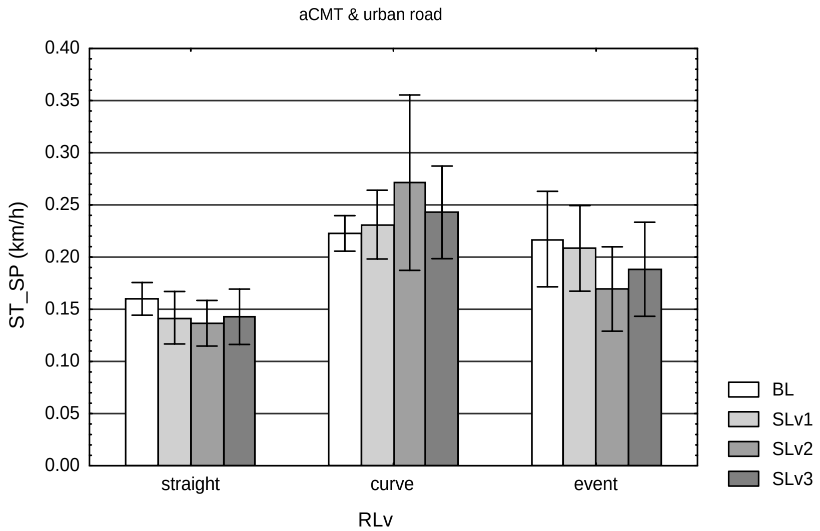



**Figure 68 – Speed variation (st_sp), Cognitive task, Urban road**

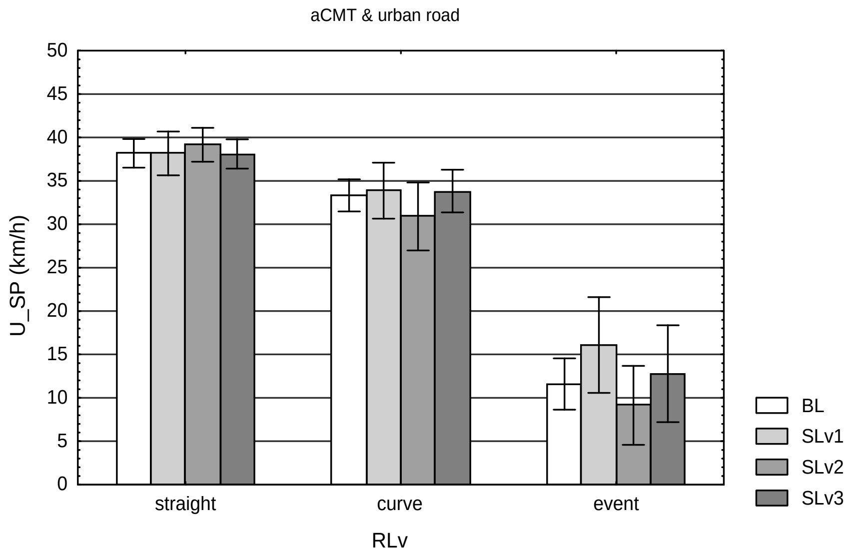



**Figure 69 – Minimum speed (u_sp), Cognitive task, Urban road**

**Table 48 – Analysis of mean speed (mn_sp), Cognitive task, Urban road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **mn_sp** | 37.75 | 38.47 | 35.10 | 36.76 | ✓ | ✓ | ✓ | BL | × | ✓ | × |
| | | | | | | | | SLv1 | | ✓ | × |
| | | | | | | | | SLv2 | | | × |

### *6.7.3.3. Lateral control*

No effects of the cognitive task were found in the lateral position related measures. Effects were however found in the majority of the steering reversal rate measures (1, 3 and 5 degrees, but not for 7 degrees). See Figure 70 and Table 49. The reversal rate increased as the cognitive task was active. No differences were found between the experimental levels though.

Effects of road complexity level were found in most lateral control measures, indicating a more stable lateral control in the straight segments.

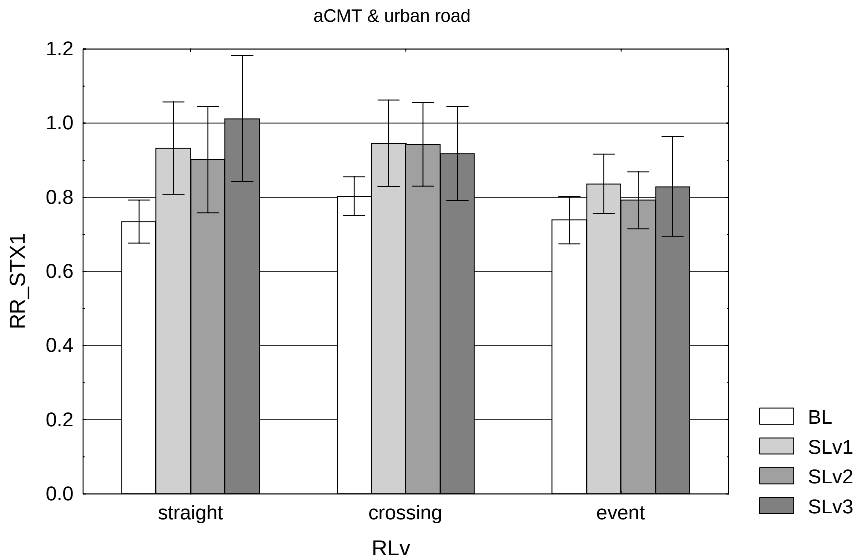



**Figure 70 – 1 degree reversal rate (rr_st1), Cognitive task, Urban road**

**Table 49 – Analysis of 1, 3 and 5 degrees reversal rate (rr_st1, 2, 5), Cognitive task, Urban road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **rr_st1** | 0.76 | 0.90 | 0.88 | 0.92 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |
| **rr_st3** | 0.59 | 0.68 | 0.65 | 0.68 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |
| **rr_st5** | 0.50 | 0.58 | 0.52 | 0.57 | ✓ | ✓ | × | BL | ✓ | × | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

### *6.7.3.4. S-IVIS performance*

The results indicated a main effect of the visual task difficulty level and road complexity level, no interaction was found. The post-hoc analysis indicated that subjects had a lower percentage of correct responses during an event compared to the other road complexity levels. Also the performance in the static condition was higher than on a crossing. Furthermore, all S-IVIS difficulty levels differed from each other with the highest performance for Slv1 and the lowest for SLv3. The results for the different combinations of the visual task difficulty level and road complexity level are presented in Figure 71. Table 50 presents the average values for the S-IVIS difficulty levels.

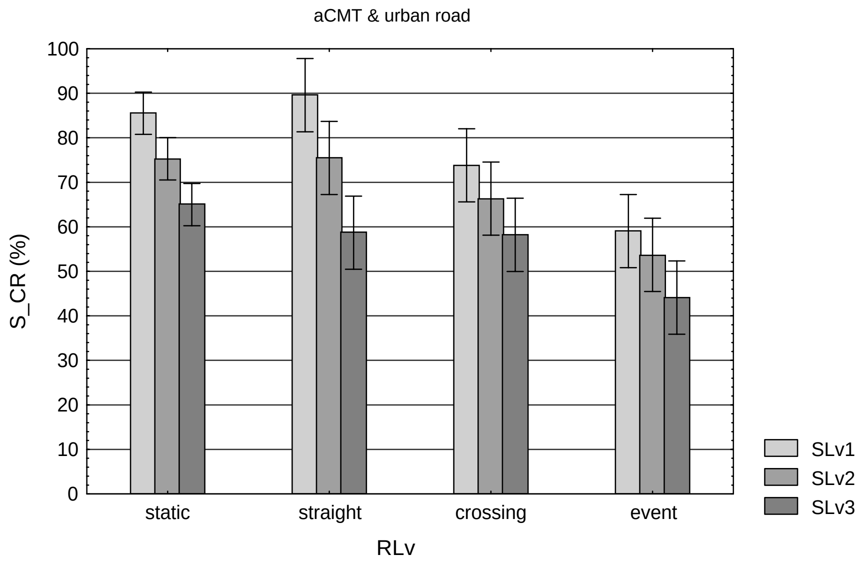



**Figure 71 – % correct responses (s_cr), Cognitive task, Urban road**

**Table 50 – Analysis of S-IVIS performance (s_cr), Cognitive task, Urban road**

| | Mean values | | | Significant Effects | | | Post Hoc test | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv2 | SLv3 |
| **s_cr** | 76.98 | 67.70 | 56.50 | ✓ | ✓ | × | Slv1 | ✓ | ✓ |
| | | | | | | | SLv2 | | ✓ |

### *6.7.3.5. Results summary*

Effects were only found on mean speed and reversal rate for the visual task difficulty level. The speed results however are not very clear because only SLv2 differed from SLv1 and driving without the S-IVIS. So there is no clear difference between the different levels of the S-IVIS. Furthermore, a main effect of mean speed was also found for the different events. Drivers did not seem to adjust their lateral driving behaviour while performing the cognitive task. The absence of adjustment of the lateral driver behaviour was however accompanied with an increase in steering effort when performing the S-IVIS. Three of the five steering effort measures indicated a difference between driving in the baseline condition and driving with the S-IVIS.

## 6.7.4. Effects of the visual task in Urban Road driving

### *6.7.4.1. Self reported driving performance*

The visual task resulted in significantly increased self reported driving performance (subj_r). No differences were found between the experimental levels though. The road complexity resulted in increased subj_r. No interaction was found. See Figure 72 and Table 51.

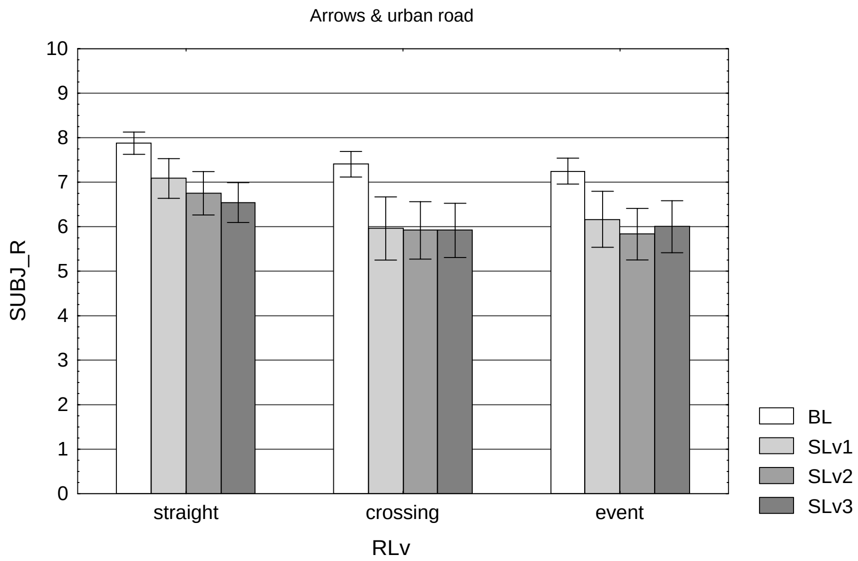



**Figure 72 – Average subjective ratings of driving performance (subj_r), Visual task, Urban road**

**Table 51 – Analysis of the subjective rating of the driving performance (subj_r), Visual task, Urban road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **subj_r** | 7.51 | 6.40 | 6.17 | 6.15 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

### *6.7.4.2. Longitudinal control*

A main effect of the visual task difficulty level was found for mean speed (mn_sp) and minimum speed (u_sp). Post-hoc analyses showed that for the mean speed there was only a significant difference between the baseline condition and SLv2. With respect to the minimum speed there was significant difference between SLv2 and both SLv1 and the baseline condition. So, there was no clear difference between driving while performing the S-IVIS and the baseline condition.

A main effect was also found for road complexity level for mean speed, speed variation and minimum speed. Post-hoc analyses indicated that during the event the average and minimum speed was the lowest and the speed variation was the highest. The highest average and minimum speed was found while driving on the straight segment. On this segment the speed variation was the lowest. For all three speed related measures interactions were found between S-IVIS and road complexity level.

The average, standard deviation and minimum speed for the different values of the visual task difficulty level and road complexity level is presented in Figure 73 - Figure 75. The average values for speed, speed variation and minimum speed for the different visual task difficulty levels are presented in Table 52.

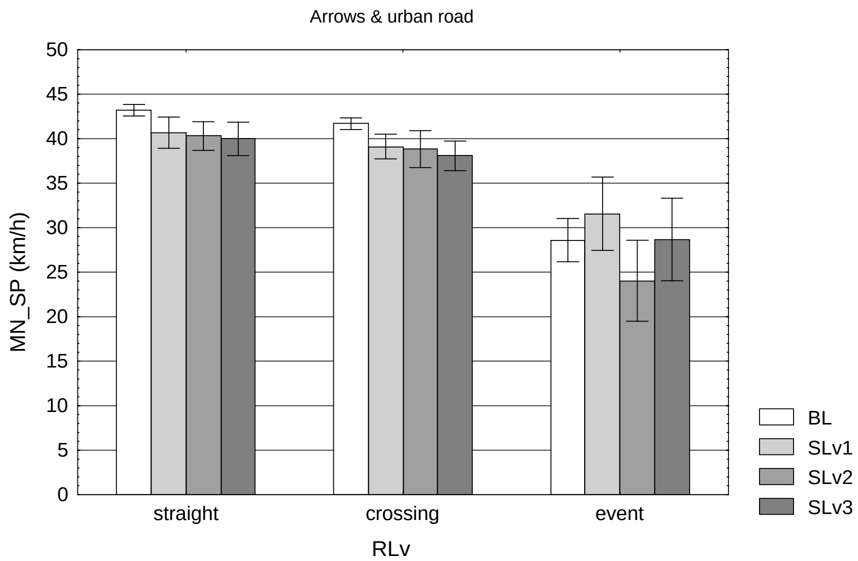



**Figure 73 – Mean speed (mn_sp), Visual task, Urban road**

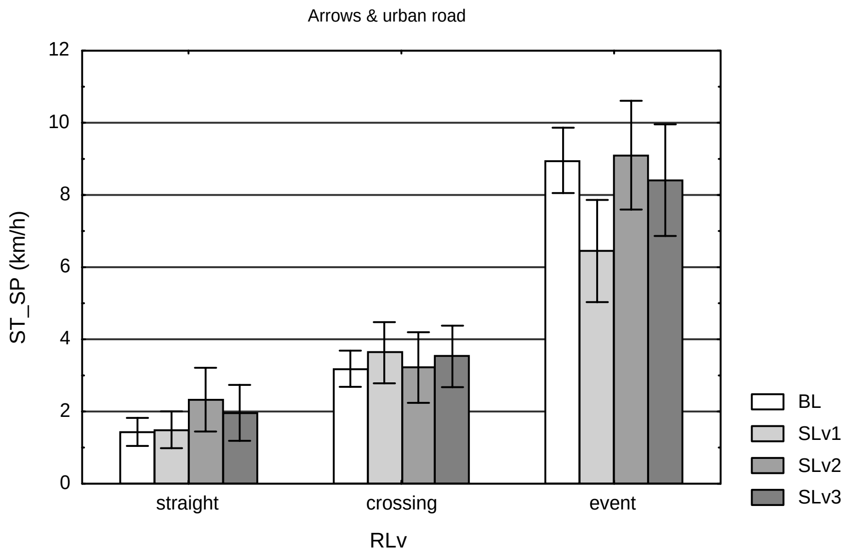



**Figure 74 – Speed variation (st_sp), Visual task, Urban road**

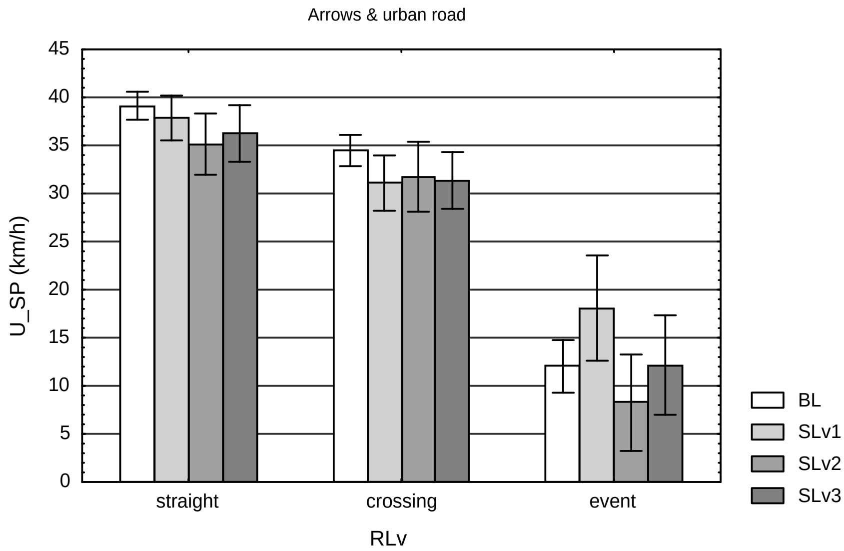



**Figure 75 – Minimum speed (u_sp), Visual task, Urban road**

**Table 52 – Analysis of mean speed (mn_sp) and minimum speed (u_sp), Visual task, Urban road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **mn_sp** | 37.83 | 37.12 | 34.39 | 35.57 | ✓ | ✓ | ✓ | BL | × | ✓ | × |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |
| **U_sp** | 28.54 | 29.01 | 25.04 | 26.59 | ✓ | ✓ | ✓ | BL | × | ✓ | × |
| | | | | | | | | SLv1 | | ✓ | × |
| | | | | | | | | SLv2 | | | × |

### *6.7.4.3. Lateral control*

The visual task affected all lateral control measures significantly, indicating a deteriorated lateral control performance and a few centimetres lateral position shift to the left. The post-hoc analysis identified significant effects between experimental levels and the baseline level, but not in between the experimental levels. See Figure 76, Figure 77 and Table 53.

A main effect of road complexity level was found for mean lateral position (mn_lp), lateral position variation (st_lp), mean TLC (mn_tlc) and proportion of TLC minima less than one second (pr_tlc). The post-hoc analyses indicated that subjects drove more to the right and swerved less on a straight road than on a crossing and during an event. The mean time-to-line crossing was the highest on the straight road and the proportion time-to-line crossing less than one second was the lowest on the straight road. Subjects also swerved more on a crossing than during an event and the proportion TLC shorter than one second was higher on a crossing than during an event.

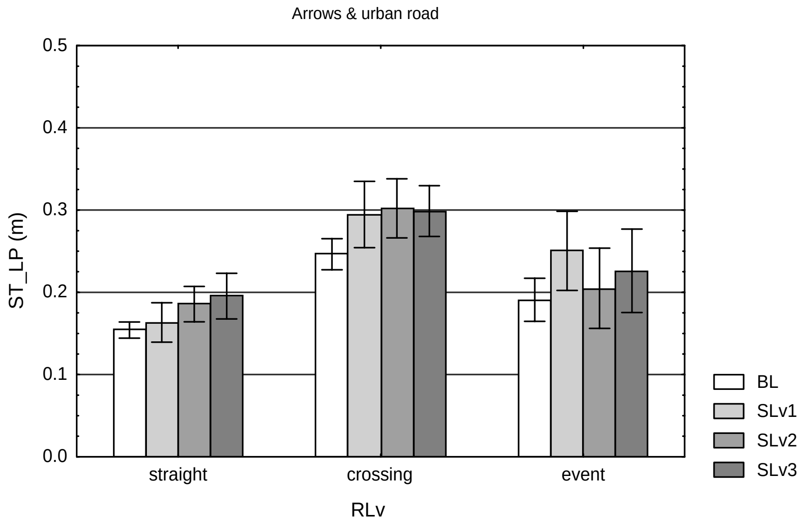



**Figure 76 – Lateral position variation (st_lp), Visual task, Urban road**

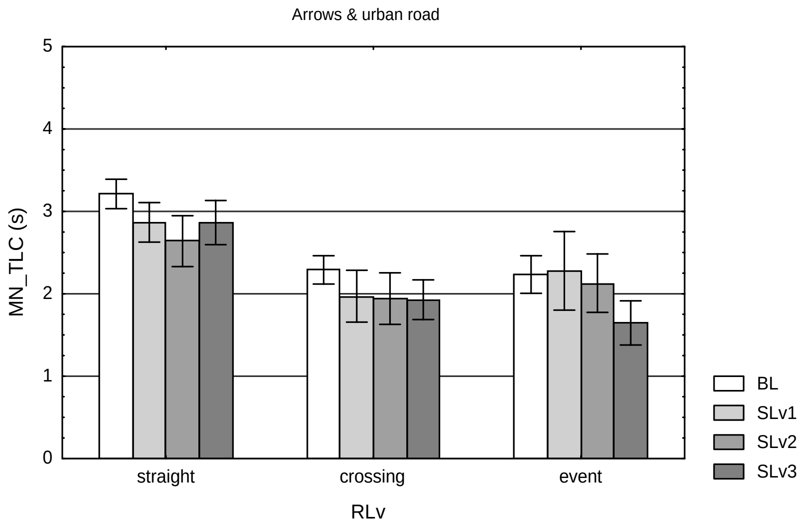



**Figure 77 – Mean time-to-line crossing (mn_tlc), Visual task, Urban road**

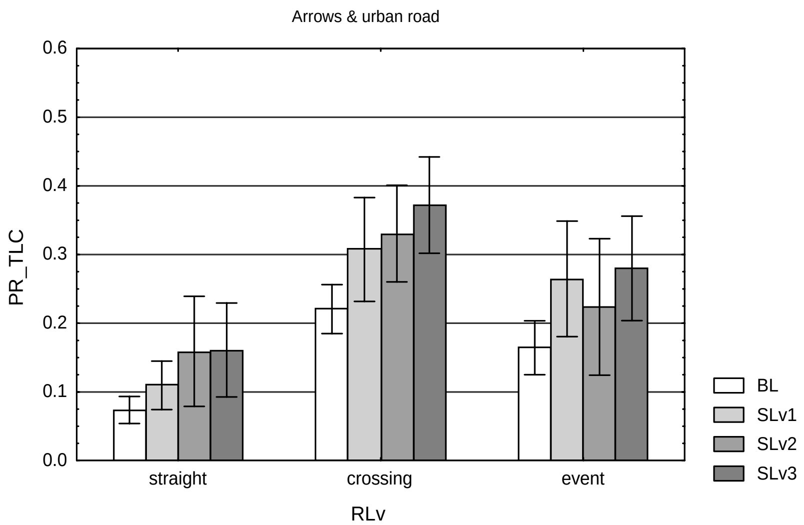



**Figure 78 – Average proportion of time-to-line crossings less than one second (pr_tlc), Visual task**

**Table 53 – Analysis of lateral position measures, (st_lp), (mn_tlc) and Pr_tlc, Visual task, Urban road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| st_lp | 0.20 | 0.24 | 0.23 | 0.24 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |
| Mn_tlc | 2.58 | 2.37 | 2.24 | 2.15 | ✓ | ✓ | × | BL | × | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |
| Pr_tlc | 0.15 | 0.23 | 0.24 | 0.27 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

For all steering effort measures a main effect for the visual task difficulty level was found. The post-hoc analyses of the steering reversal measures showed that when subjects had to perform the visual task the steering effort was higher than in the baseline condition, but that no differences were found between the experimental levels. For the proportion of high steering frequencies the results indicated that only SLv1 and 2 differed from the baseline condition, thus being less sensitive than the reversal rate measures. It was also found that more steering effort was required in the event situations than in the straight roads. No interactions were found. As an example of the outcome the average values of the steering reversal rate with gap of one degree is presented in Figure 79. The average values of examples of the different steering effort related measures for the different the visual task difficulty levels are presented in Table 54.

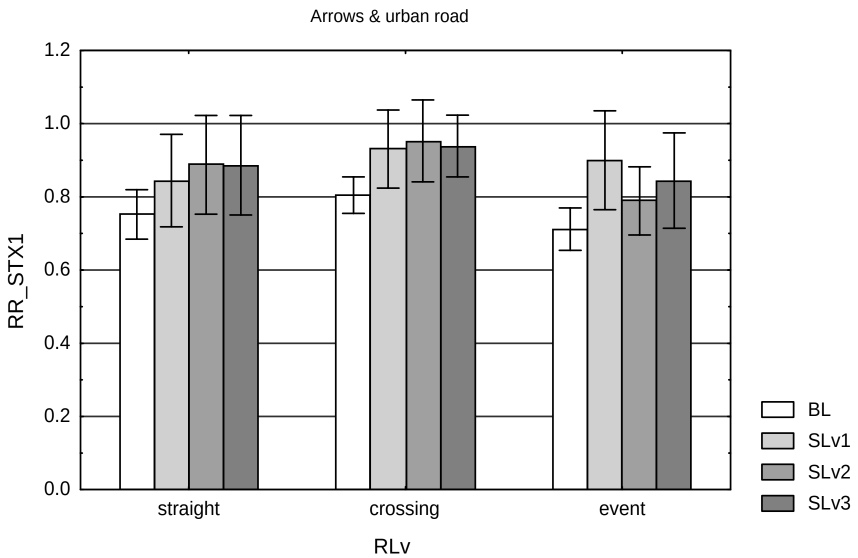



**Figure 79 – One degree steering reversal rate (rr_st1), Visual task, Urban road**

**Table 54 – Analysis of steering measures (rr_st1) and (hi_st), Visual task, Urban road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **rr_st1** | 0.76 | 0.89 | 0.88 | 0.89 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |
| **hi_st** | 0.33 | 0.38 | 0.38 | 0.36 | ✓ | ✓ | × | BL | ✓ | ✓ | × |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

### *6.7.4.4. S-IVIS performance*

The results indicated a main effect of the visual task difficulty level and road complexity level; no interaction between these factors was found. The post-hoc analysis indicated that subjects had a higher percentage of correct responses during the static condition than during driving (straight, crossing or event). The percentage of correct responses was also higher in the straight condition than during an event. Furthermore, all S-IVIS difficulty levels differed from each other with highest performance with Slv1 and the lowest with SLv3. The results are presented in Figure 80. The averages for the S-IVIS difficulty levels are presented in Table 55.

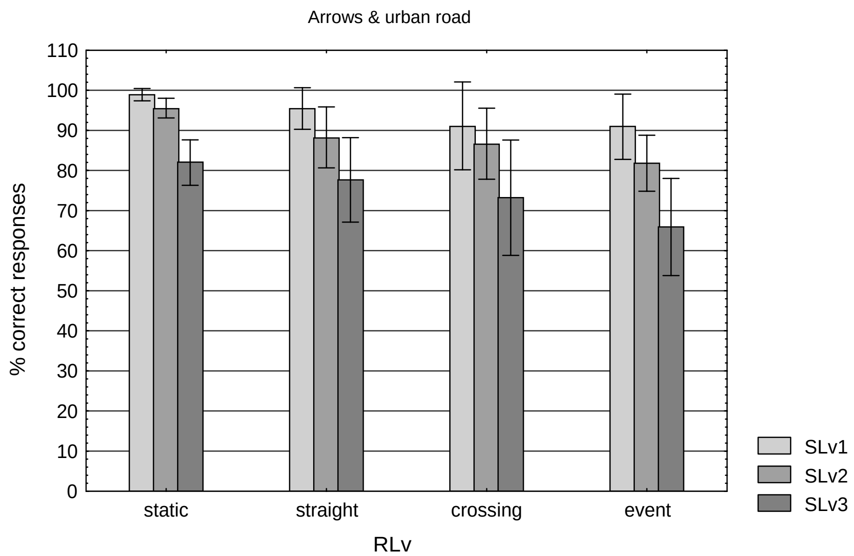



**Figure 80 – % correct responses (s_cr), Visual task, Urban road**

**Table 55 – Analysis of S-IVIS performance (s_cr), Visual task, Urban road**

| | Mean values | | | Significant Effects | | | Post Hoc test | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv2 | SLv3 |
| s_cr | 95.83 | 90.63 | 77.17 | ✓ | ✓ | × | Slv1 | ✓ | ✓ |
| | | | | | | | SLv2 | | ✓ |

### *6.7.4.5. Result summary*

The results showed no clear effect of adjustments of longitudinal driving behaviour when subjects had to perform the visual task on the urban road. The lateral driving behaviour was however influenced, especially for SLv2 and SLv3. This resulted in more swerving and shorter time-to-line crossing values. This was despite the fact that the steering effort also increased when subjects performed the visual task. In general there were no real differences between the difficulty levels of S-IVIS. However, one has to bear in mind that for most dependent variables a main effect was found for the different events.

### 6.7.5. Comparison between S-IVIS tasks

In general the results indicated that drivers adjusted their driving behaviour when they drove while performing the S-IVIS. This effect was clearer when subjects performed the visual task than when they performed the cognitive task. Although not statistically tested, the analyses of the performance with the S-IVIS tasks suggested that the visual task was performed better than the cognitive task. On the rural road there were 87.9% correct responses on the visual task and 71.9% on the cognitive task, and on the urban road there were 83.5% correct responses on the visual task and 67.37% on the cognitive task.

## 6.8. Summary and conclusions

Of the dependent variables the steering effort related measures (steering reversal rate and proportion high steering frequencies) were most often affected by the experimental conditions (S-IVIS condition and road condition). With respect to driving behaviour the lateral performance was most often influenced. The results generally showed that driving while performing an S-IVIS worsened the lateral control (e.g., more swerving) compared to driving in the baseline condition. Although the steering effort increased while performing the S-IVIS, the lateral control performance nevertheless decreased.

Many of the results did not indicate differences in driving performance between the different difficulty levels of the S-IVIS tasks (SLv1, SLv2, and Slv3). One explanation is that the subjects decreased their performance on the secondary task in order to keep their driving performance at a constant level. There are certainly indications of this in the findings on secondary task performance, where the percentage of correct responses decreased with increases in driving difficulty. On the other hand, there were some important safety-related indicators where performance did get worse as secondary task difficulty increased. Examples of this are lane position variation and time to line crossing, particularly on the rural road.

To some extent, the results suggest that for assessing effects of IVIS on driving performance there are no real differences between the urban road and the rural road. However, there are some suggestions that the rural road provides clearer findings.

## 6.9. Measures summary tables

As stated a number of mandatory measures could not be analysed either because of too many missing data or because the dependent variable was not normally distributed. These dependent variables were all related to headway (time or distance) and lane crossings. For the same reasons the proportion of TLC shorter than one second could only be analysed for the urban road.

### 6.9.1. Rural road and the cognitive task

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **subj_r** | 7.94 | 7.44 | 7.42 | 7.62 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **mn_sp** | 62.69 | 62.92 | 62.62 | 62.22 | ✗ | ✓ | ✗ | BL | ✗ | ✗ | ✗ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **st_sp** | 6.16 | 7.13 | 6.34 | 6.33 | ✗ | ✓ | ✗ | BL | ✗ | ✗ | ✗ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **u_sp** | 51.19 | 49.27 | 50.35 | 50.85 | ✗ | ✓ | ✗ | BL | ✗ | ✗ | ✗ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **mn_lp** | 1.01 | 0.97 | 0.99 | 0.98 | ✓ | ✓ | ✗ | BL | ✗ | ✗ | ✗ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **st_lp** | 0.29 | 0.26 | 0.26 | 0.26 | ✓ | ✓ | ✗ | BL | ✗ | ✗ | ✗ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **mn_tlc** | 3.4 | 3.45 | 3.44 | 3.56 | ✗ | ✓ | ✗ | BL | ✗ | ✗ | ✗ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **pr_tlc** | not analysed | | | | | | | | | | |
| **rr_st1** | 0.64 | 0.81 | 0.84 | 0.87 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✓ |
| | | | | | | | | SLv2 | | | ✗ |
| **rr_st3** | 0.5 | 0.57 | 0.59 | 0.62 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✓ |
| | | | | | | | | SLv2 | | | ✗ |
| **rr_st5** | 0.41 | 0.45 | 0.47 | 0.48 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **rr_st7** | 0.31 | 0.34 | 0.35 | 0.37 | ✗ | ✗ | ✗ | BL | ✗ | ✗ | ✗ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **hi_st** | 0.36 | 0.4 | 0.4 | 0.41 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |

### 6.9.2. Rural road and the visual task

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **subj_r** | 8.11 | 7.35 | 6.86 | 6.51 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | ✓ |
| **mn_sp** | 69.35 | 66.61 | 67.02 | 66.19 | ✓ | ✓ | ✗ | BL | ✗ | ✗ | ✗ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **st_sp** | 6.24 | 6.78 | 6.06 | 7.02 | ✗ | ✓ | ✗ | BL | ✗ | ✗ | ✗ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **u_sp** | 55.94 | 53.06 | 55.03 | 51.63 | ✗ | ✓ | ✗ | BL | ✗ | ✗ | ✗ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **mn_lp** | 1.03 | 1.04 | 1.09 | 1.07 | ✓ | ✓ | ✗ | BL | ✗ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **st_lp** | 0.28 | 0.32 | 0.35 | 0.34 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✓ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **mn_tlc** | 3.34 | 3.11 | 2.81 | 2.77 | ✓ | ✓ | ✗ | BL | ✗ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✓ |
| | | | | | | | | SLv2 | | | ✗ |
| **pr_tlc** | not analysed | | | | | | | | | | |
| **rr_st1** | 0.71 | 0.84 | 0.82 | 0.86 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **rr_st3** | 0.52 | 0.61 | 0.62 | 0.64 | ✓ | ✗ | ✗ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **rr_st5** | 0.43 | 0.51 | 0.53 | 0.54 | ✓ | ✗ | ✗ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **rr_st7** | 0.34 | 0.45 | 0.47 | 0.46 | ✓ | ✗ | ✗ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **hi_st** | 0.36 | 0.42 | 0.43 | 0.41 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |

## 6.9.3. Urban road and the cognitive task

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| subj_r | 7.34 | 6.67 | 6.89 | 6.79 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| mn_sp | 37.75 | 38.47 | 35.1 | 36.76 | ✓ | ✓ | ✓ | BL | ✗ | ✓ | ✗ |
| | | | | | | | | SLv1 | | ✓ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| st_sp | 4.6 | 3.72 | 4.66 | 4.19 | ✗ | ✓ | ✗ | BL | ✗ | ✗ | ✗ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| u_sp | 27.69 | 29.37 | 26.4 | 28.24 | ✗ | ✓ | ✗ | BL | ✗ | ✗ | ✗ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| mn_lp | 0.49 | 0.5 | 0.48 | 0.5 | ✗ | ✓ | ✗ | BL | ✗ | ✗ | ✗ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| st_lp | 0.2 | 0.19 | 0.19 | 0.19 | ✗ | ✓ | ✗ | BL | ✗ | ✗ | ✗ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| mn_tlc | 2.49 | 2.49 | 2.49 | 2.57 | ✗ | ✓ | ✗ | BL | ✗ | ✗ | ✗ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| pr_tlc | 0.17 | 0.16 | 0.14 | 0.15 | ✗ | ✓ | ✗ | BL | ✗ | ✗ | ✗ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| rr_st1 | 0.76 | 0.9 | 0.88 | 0.92 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| rr_st3 | 0.59 | 0.68 | 0.65 | 0.68 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| rr_st5 | 0.5 | 0.58 | 0.52 | 0.57 | ✓ | ✓ | ✗ | BL | ✓ | ✗ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| rr_st7 | 0.42 | 0.48 | 0.43 | 0.47 | ✗ | ✓ | ✗ | BL | ✗ | ✗ | ✗ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| hi_st | 0.33 | 0.34 | 0.33 | 0.34 | ✗ | ✓ | ✗ | BL | ✗ | ✗ | ✗ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |

### 6.9.4. Urban road and the visual task

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **subj_r** | 7.51 | 6.4 | 6.17 | 6.15 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **mn_sp** | 37.83 | 37.12 | 34.39 | 35.57 | ✓ | ✓ | ✓ | BL | ✗ | ✓ | ✗ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **st_sp** | 4.53 | 3.86 | 4.88 | 4.63 | ✗ | ✓ | ✓ | BL | ✗ | ✗ | ✗ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **u_sp** | 28.54 | 29.01 | 25.04 | 26.59 | ✓ | ✓ | ✓ | BL | ✗ | ✓ | ✗ |
| | | | | | | | | SLv1 | | ✓ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **mn_lp** | 0.5 | 0.52 | 0.54 | 0.57 | ✓ | ✓ | ✗ | BL | ✗ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✓ |
| | | | | | | | | SLv2 | | | ✗ |
| **st_lp** | 0.2 | 0.24 | 0.23 | 0.24 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **mn_tlc** | 2.58 | 2.37 | 2.24 | 2.15 | ✓ | ✓ | ✗ | BL | ✗ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **pr_tlc** | 0.15 | 0.23 | 0.24 | 0.27 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **rr_st1** | 0.76 | 0.89 | 0.88 | 0.89 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **rr_st3** | 0.59 | 0.7 | 0.68 | 0.68 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **rr_st5** | 0.5 | 0.6 | 0.58 | 0.58 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **rr_st7** | 0.42 | 0.53 | 0.52 | 0.5 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **hi_st** | 0.33 | 0.38 | 0.38 | 0.36 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✗ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |

# 7. The Transport Canada Simulator Experiment

## 7.1. Test site

Transport Canada carried out this research using the University of Calgary Driving Simulator (UCDS), which was integrated by DriveSafety Corporation, and further customized by the Cognitive Ergonomics Research Laboratory (CERL). Three projectors display a simulated visual environment that encompasses 150˚ of the driver's forward view. Road and vehicle noise are simulated, as well as the noise of passing vehicles. The driver sits in a Saturn SL1 that is situated in front of the screens as depicted in Figure 81 below. The brake, accelerator, steering, speedometer, interior lights and fan are all fully operational.

**Figure 81 – The University of Calgary Driving Simulator**

Within the vehicle cabin, video and audio systems are used for participant monitoring, communication and to record participant and experimenter activities. An eye movement detection system recorded the driver gaze angle. In Figure 82, the recorded simulator views are depicted.


Upper left, real time eye movement cross hairs;

Upper right, S-IVIS touchscreen;

Lower left, participant face with ASL eye movement system infrared display on left eye;

Lower right, high resolution forward screen view

**Figure 82 – Recorded simulator views**

## 7.2. Scenarios and participants

### 7.2.1. Participants

Data were collected for forty-seven participants (23 females and 24 males) between the ages 20 to 35 years. For the visual S-IVIS task there were 8 males and 8 female participants in each of the age ranges 20 to 25 years, 26 to 30 years, and 31 to 35 years. Data were not collected in the cognitive S-IVIS task for one female participant in the 26 to 30 year category due to numerous cancellations. Participants were recruited primarily from the University of Calgary, but also throughout the City of Calgary through newspaper advertisements and posters. Each volunteer participated in two 90-minute sessions.

### 7.2.2. Rural road

The rural roadway resembled a paved secondary highway in North America. See Figure 83. The roadway contained two lanes, one for each direction, and no parked cars were encountered. There were no signalised intersections and participants simply had to follow the straight and curved portions of the roadway. The background scenery was largely composed of grassy meadows with sparse trees and occasional farms or houses off to the side. There were no pedestrians or cyclists and the ambient traffic was low, averaging 14 vehicles per minute. The posted speed limit was 100 km/ hr. The rural road was constructed to be as similar as possible to the rural road specifications.

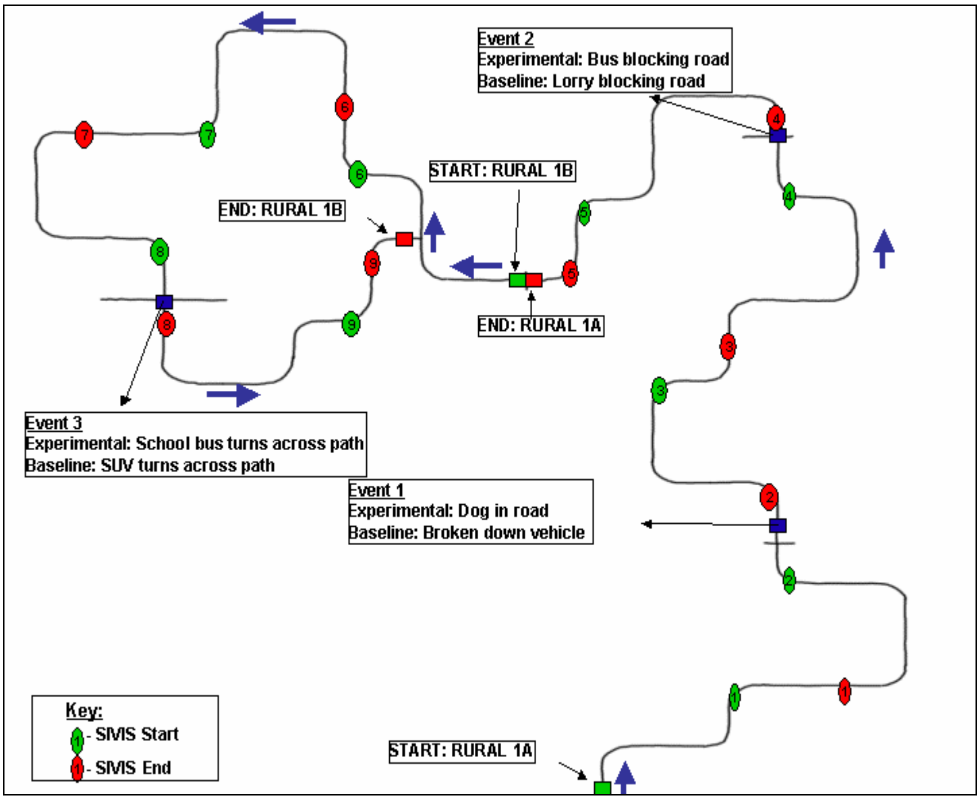
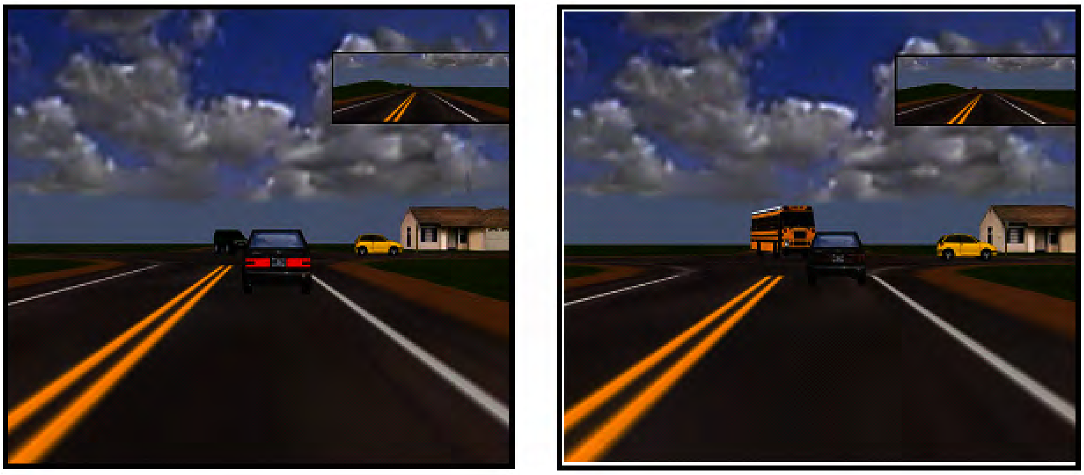



**Figure 83 – Schematic of rural route**

The baseline and experimental routes were identical except for the nature of the three events embedded within each route. There were three baseline events and three experimental events. The baseline events were as follows: (a) a parked vehicle on side of the road that is obstructing traffic; (b) a truck blocking the roadway in front of the driver; and (c) a SUV turns left in front of the lead vehicle (see Figure 85, left). For the experimental drive, a truck, and a bus (see Figure 85, right) replaced the event objects in a, b, and c respectively. The events of the baseline and experimental runs were thus not counterbalanced, as they should have been according the experimental design specification.



*Baseline* *Experimental*

**Figure 84 – Rural events for a vehicle that turns in front of the lead vehicle**

### 7.2.3. Urban road

The urban roadway was modelled on routes typically found in major North American cities. Generally, the roadway had two lanes, one in each direction, and oftentimes, there were parked cars on the side of the roads. Several major intersections were encountered throughout the drive and at specified locations participants were required to turn at four of those intersections. Pedestrians and cyclists travelled along the sidewalks and the ambient traffic was established at 19 vehicles per minute. The posted speed limit was 50 km/h. The participants also encountered industrial areas within this scenario. These segments were included to eliminate boredom and give the drivers a break from the intensity of the route. The industrial segments consisted of one lane in each direction with no parked cars or pedestrians encountered in the industrial areas. There were no intersections in the industrial areas; the participants had to follow the curved roadways with some straight sections. The posted speed limit for the industrial areas was 70 km/h. See Figure 85 for a schematic of the urban road.

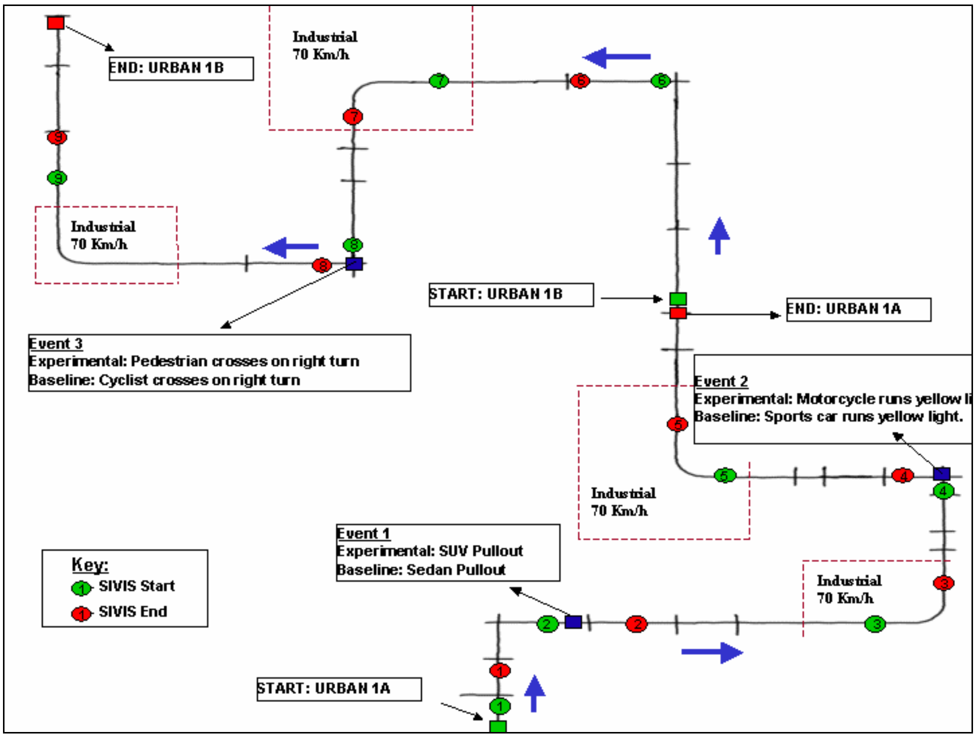



**Figure 85 – Schematic of urban route**

Drivers in the urban scenario were presented with on-screen instructions to let them know when they would be required to turn at upcoming intersections. As for the rural road, there were a total of six events. The three baseline events were as follows: (a) a parked car pulls out in front of the driver on the right (see Figure 86, left), (b) an oncoming car crosses an intersection while the driver is making a left turn, (c) a cyclist crosses the road at an intersection while the driver makes a right turn. For the experimental run, the events were identical except that an SUV (see Figure 86, right), a motorcycle, and a pedestrian replaced the event objects in a, b, and c respectively. The order of events between baseline and experimental drive were not counterbalanced.

*Baseline* *Experimental*

**Figure 86 – Urban events for a parked vehicle that pulls out in front of the participant.**

## 7.3. S-IVIS evaluated

Both the visual task S-IVIS task and cognitive S-IVIS task was used in this experiment. The three difficulty levels of the S-IVIS tasks were included. 9 S-IVIS blocks were included in each experimental run.

## 7.4. Procedure

Each participant completed two 90-minute experimental sessions, one for each route that they drove. On the first day, participants underwent vision testing, S-IVIS and simulator practice, and an experimental session (i.e. baseline and S-IVIS experimental drives of either the rural or urban drive depending on counterbalancing). The second day was structured into practice on the opposite drive (i.e., rural if urban was driven in the first session, etc.), baseline and S-IVIS experimental drives. After the completion of each session, participants were debriefed and compensated.

Participants were fitted and calibrated with the ASL eye tracking system (Applied Sciences Laboratory, 2000) for the collection of eye movement data. The participants were instructed to drive as they do normally. Participants also provided subjective rating (by verbal report) of their workload at the end of each S-IVIS task presentation.

After completing both sessions, participants were debriefed as to the purpose of the study and paid. Any questions raised by the participant were answered during the debriefing process. The static S-IVIS test was not included in this study.

## 7.5. Measures and analysis method

All measures were implemented according to the specifications. The self reported driving performance (subj_r) was not collected. Instead, a measure of self reported workload (subj_wl) was included. This measure provided a general impression from participants of the cognitive and physical work that they have performed for a given period of time. This measure was collected by only Transport Canada. After each presentation of the S-IVIS task, participants were asked "how hard were you working mentally and physically over the last minute in order to accomplish the task you were supposed to perform? Please rate your workload on a scale from 1-10 where 1 is "no effort" and 10 is "extreme effort". Thus lower values on the scale represent less workload.

Two main independent factors were investigated in the present study: S-IVIS Level (SLv) (BL, 1, 2, 3) and Road Complexity Level (RLv). Not all dependent measures were applicable in all combinations of independent factor levels; consequently the analyses differed somewhat between measures. In general, the statistical analysis approach followed the specifications outlined in 2.7 -Indicators and Analysis.

## 7.6. Results

The dependent variables collected for driving performance are presented in the following sections. A summary of all measures and their effects, including those for the Urban Route is provided in the measures summary table.

The presentation of the results and discussion will focus on the results from the Rural Road as these are the most complete. Results from the Urban Road are discussed after the results for the Rural Road. In general, the results for the Urban Road are compatible with those for the Rural Road. Analyses of the data for the Urban Road are not as robust as those for the Rural Road due to design differences and counterbalancing irregularities. Analyses were performed for the Driving measures collected from the simulator, the Workload Ratings and the S-IVIS performance measures. Eyetracking measures were not analysed as part of Urban Road work.

### 7.6.1. Effects of the cognitive task in Rural Road driving

#### *7.6.1.1. Longitudinal control*

The results for Mean Speed (mn_sp) are presented in Figure 87 and Table 56. Drivers drove more quickly on the straight segments of the road (98.27 km/h) compared with the curved segments of the road (97.05 km/h). Interestingly, the drivers showed a tendency to increase their speed relative to baseline (96.77 km/h) when performing the cognitive S-IVIS task at the easy (98.67 km/h) and medium (98.44 km/h) levels, but not for the difficult level (96.75 km/h).

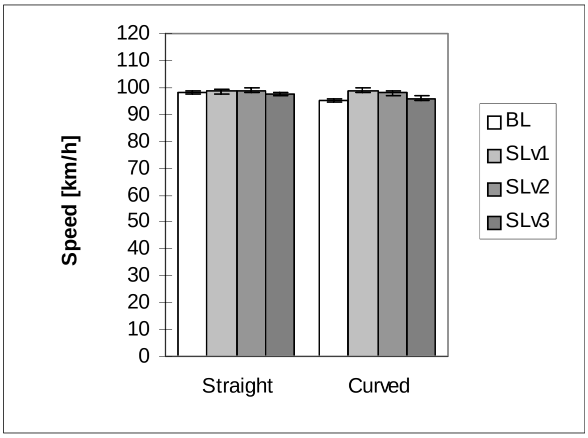



**Figure 87 – Mean Speed (mn_sp), Cognitive task, Rural road**

**Table 56 – Analysis of mean speed (mn_sp), Cognitive task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| mn_sp [km/h] | 96.77 | 98.67 | 98.44 | 96.75 | ✓ | ✓ | × | BL | ✓ | ✓ | × |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

The data for Speed Variation (st_sp) are presented in Figure 88 and Table 57. The significant effects in this analysis are due primarily to the extreme value observed for the baseline drive on the curved segments.  For the straight segments of the road, there were no significant differences observed. Although there was a tendency for the variation in speed to be greater when driving on the curved road and performing the difficult level of the cognitive S-IVIS, this difference is not significantly different in any of the comparisons.

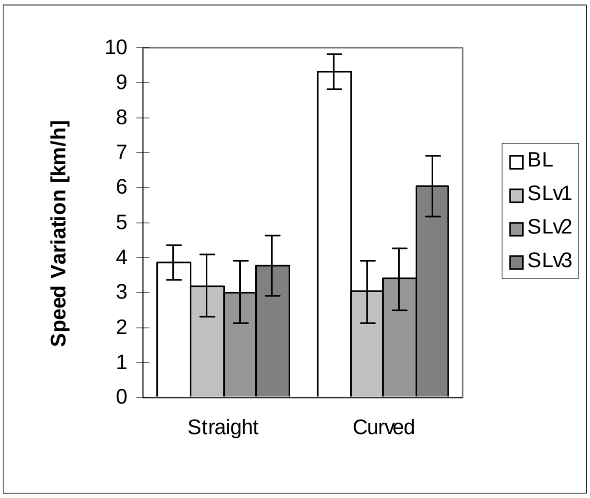



**Figure 88 – Speed variation (st_sp), Cognitive task, Rural road**

**Table 57 – Analysis of speed variation (st_sp), Cognitive task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test: Curved Only | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| st sp [km/h] | 6.59 | 3.11 | 3.21 | 4.91 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | × |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

Figure 89 and Table 58 present the data for Speed Change (d_sp). Greater speed changes were found for the curved road segments compared with the segments of straight road. An examination of the interaction revealed that there were no significant differences among the S-IVIS levels for the straight road conditions where means ranged from 10.21 to 13.55 km/h. In the case of the curved road, however, a number of differences were significant but those relying on comparisons to the baseline must be viewed with caution. There are significant differences, however, within the levels of the S-IVIS task itself which indicate that an increase in cognitive S-IVIS difficulty is associated with increase in speed change.

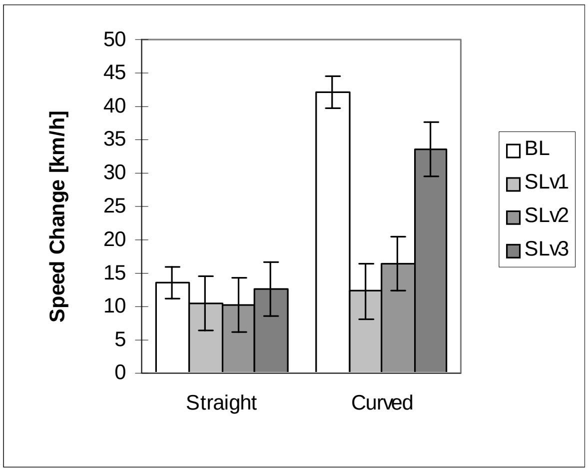



**Figure 89 – Speed change (d_sp), Cognitive task, Rural road**

**Table 58 – Analysis of speed change (d_sp), Cognitive task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **d sp [km/h]** | 27.86 | 11.36 | 13.31 | 23.14 | ✓ | ·✓ | ✓ | BL | ✓ | ✓ | × |
| | | | | | | | | SLv1 | | × | ✓ |
| | | | | | | | | SLv2 | | | × |

**The Minimum Speed data (u_sp) are presented in Figure 90 and**

Table 59. Exploration of the interaction revealed that there were no differences among the conditions for the straight segments of road (means range from 90.73 to 93.61 km/h). In the case of the curved road, however, a number of differences were significant but those relying on comparisons to the baseline must be viewed with caution. There were significant differences, however, within the levels of the S-IVIS task itself suggesting that lower minimum speed is associated with an increase in cognitive S-IVIS task difficulty.

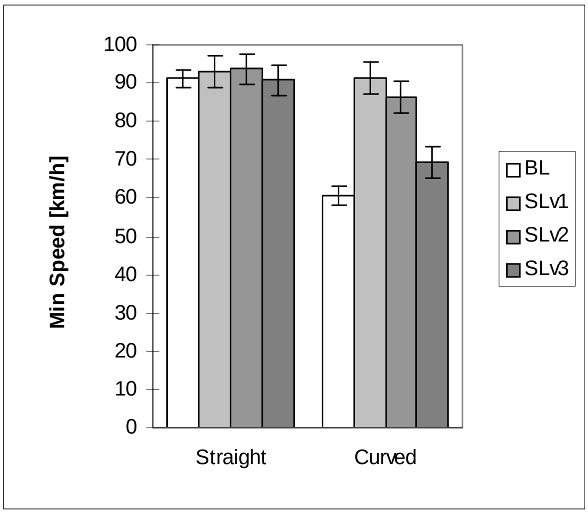



**Figure 90 – Minimum speed (u_sp), Cognitive task, Rural road**

**Table 59 – Analysis of minimum speed (u_sp), Cognitive task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **u sp [km/h]** | 75.90 | 92.12 | 89.94 | 80.04 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | × |
| | | | | | | | | SLv1 | | × | ✓ |
| | | | | | | | | SLv2 | | | × |

For a number of the other analyses for dependent measures, there was insufficient data for the analyses or the analyses were not significant. Data insufficiency was a result of technical problems. Only headway related data was affected by this insufficiency. The analysis for Minimum TTC (u_ttc) was not significant. A number of the headway-related measures could not be calculated due to missing data: Mean Distance Headway (mn_hwd), Distance Headway Variation (sd_hwd), Minimum Distance Headway (u_hwd), Mean Headway Time (mn_hwt), Time Headway Variation (sd_hwt), and Minimum Time Headway (u_hwt). The analysis for Brake Reaction time for the Event 1, where there was sufficient data for analysis, was not significant.

### *7.6.1.2. Lateral control*

The results for Lateral Position (mn_lp) were not significant. The results for Lateral Position Variation (st_lp) are presented in Figure 91 and Table 60. Drivers exhibited more variability within their lanes when they drove on the curved segments of the road (.40m) compared with when the drove on the straight segments of the road (.31m) as indicated by the main effect for road complexity level. Interestingly, drivers showed less variability within their lane when they were engaged in the most demanding cognitive S-IVIS task (.33m). This difference was significant only when compared with the baseline condition (.37m).

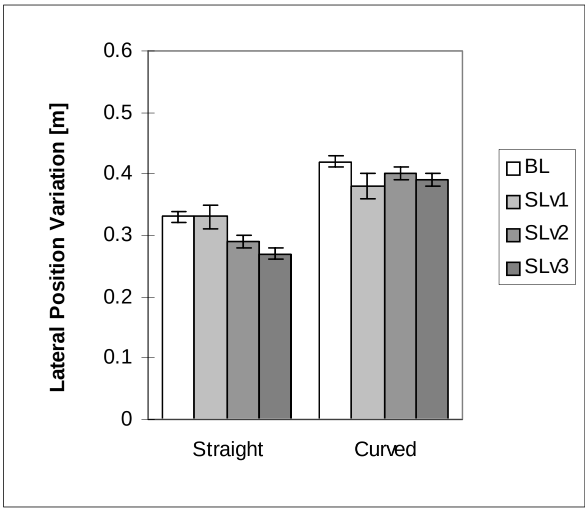



**Figure 91 – Lateral position variation (st_lp), Cognitive task, Rural road**

**Table 60 – Analysis of lateral position variation (st_lp), Cognitive task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **st lp [m]** | .37 | .35 | .34 | .33 | ✓ | ✓ | × | BL | × | × | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

#### *7.6.1.3. Workload*

With respect to the eye tracking measures, only the measure of Percent Road Centre (%_rc) representing the percentage of time that drivers spent looking at the area of road centre was relevant to the cognitive task. This measure, however, did not yield significant results as a function of task difficulty as has been found in previous work (e.g., Harbluk, Noy & Eizenman, 2000; Recarte & Nunes, 2000).

The data for the Self reported workload measure (self_wl) are presented in Figure 92 and Table 61. Workload ratings made by the participants proved to be sensitive to the manipulations of S-IVIS difficulty for the cognitive task. These ratings also reflected differences in road difficulty (straight vs curved roadways).

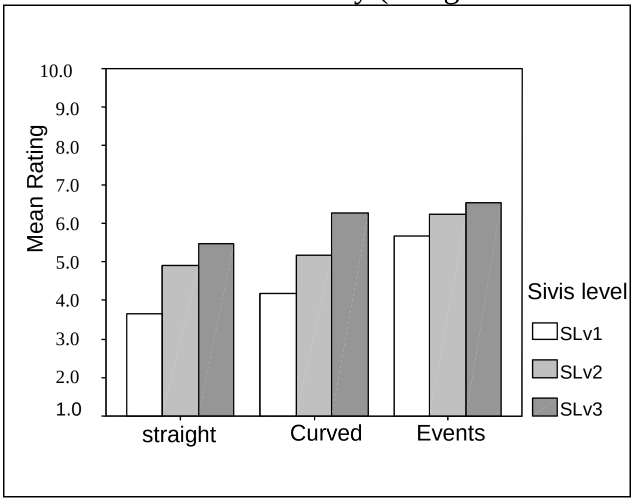



**Figure 92 – Self reported driving performance (subj_wl), Cognitive task, Rural road**

**Table 61 – Analysis of self reported workload (subj_wl), Cognitive task, Rural road**

| | **Mean values** | | | | **Significant Effects** | | | **Post Hoc test** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | | SLv2 | SLv3 |
| **subj_wl** | | 4.49 | 5.44 | 6.09 | ✓ | ✓ | × | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | × |

#### *7.6.1.4. S-IVIS performance*

The results for Percent Correct Responses for the cognitive task are presented in Figure 93 and Table 62. There was a clear effect of S-IVIS difficulty on the percentage of correct answers that the drivers made. Drivers made fewer correct responses as task difficulty increased. This was observed across the driving environments.

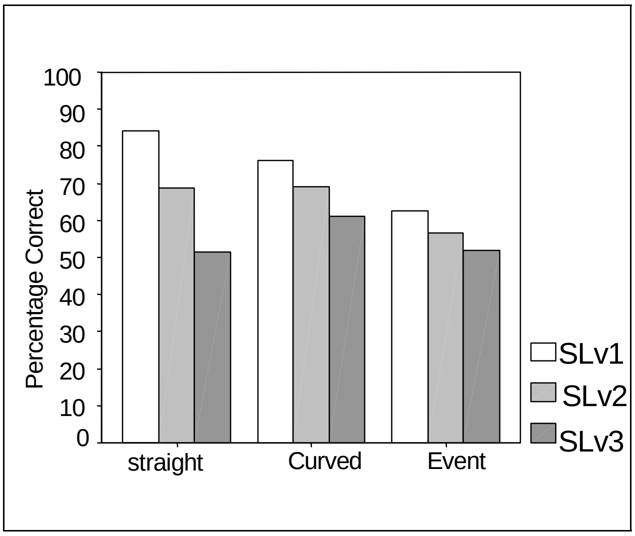



**Figure 93 – % correct responses (s_correct), Cognitive task, Rural road**

**Table 62 – Analysis of percent correct responses (s_correct [%]), Cognitive task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | | SLv2 | SLv3 |
| s_correct [%] | | 74.16 | 64.73 | 54.71 | ✓ | ✓ | × | SLv1 | | × | ✓ |
| | | | | | | | | SLv2 | | | × |

There were no significant differences in the data for the cognitive task Missed Responses (s_missed). The results for the Percent Incorrect Responses (s_ incorrect) are presented in Figure 94 and Table 63. The analyses indicated that the percentage of incorrect responses was greater in the difficult S-IVIS condition compared with the easy S-IVIS condition.

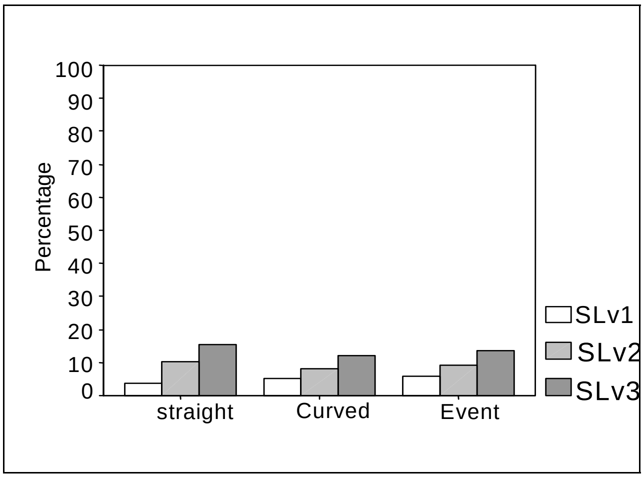



**Figure 94 – % incorrect responses (s_incorrect), Cognitive task, Rural road**

**Table 63 – Analysis of % incorrect responses (s_incorrect [%]), Cognitive task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | | SLv2 | SLv3 |
| s_incorrect [%] | N/a | 4.83 | 9.18 | 13.77 | ✓ | × | × | SLv1 | | × | ✓ |
| | | | | | | | | SLv2 | | | × |

## 7.6.2. Effects of the visual task in Rural Road driving

### *7.6.2.1. Longitudinal control*

Figure 95 and Table 64 present the Mean Speed (mn_sp) data for drivers in the visual task S-IVIS condition. Performing the visual task S-IVIS task resulted in a reduction in driving speed. There was no effect of S-IVIS difficulty, however. Driving speed was lower than baseline for all the S-IVIS conditions but no differences were observed among the S-IVIS conditions

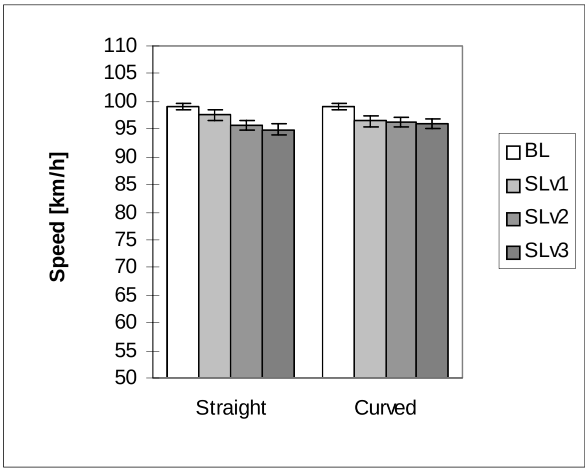



**Figure 95 – Mean speed (mn_sp), Visual task, Rural Road**

**Table 64 –Analysis of mean speed (mn_sp), Visual task, Rural Road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **mn_sp [km/h]** | 99.09 | 96.99 | 95.95 | 95.39 | ✓ | × | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

Neither the analysis for Speed variation (st_sp) nor the analysis for Speed Change (d_sp) produced significant results. The results for Minimum Speed (u_sp) are presented in Figure 96 and Table 65. Lower minimum speeds were observed when drivers were engaged in the visual task S-IVIS task while driving but only the difference between the baseline (93.20 km/h) and the difficult level (89.89 km/h) was significant.

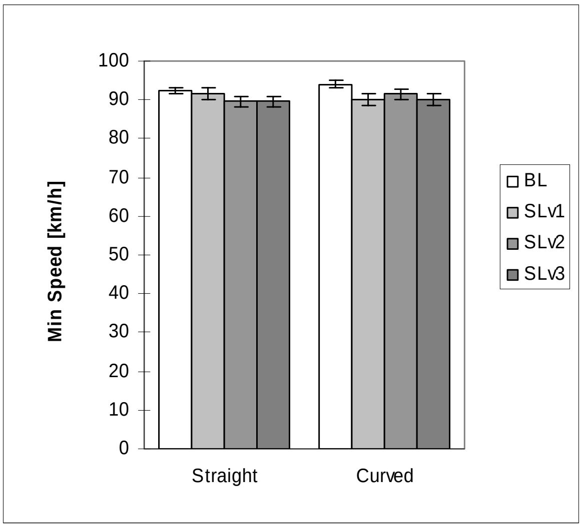



**Figure 96 – Min speed (u_sp), Visual task, Rural Road**

**Table 65 – Analysis of minimum speed (u_sp), Visual task, Rural Road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **u sp [km/h]** | 93.20 | 90.77 | 90.52 | 89.86 | ✓ | × | × | BL | × | × | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

As with the headway-related measures for the cognitive task, there was insufficient data for many of the analyses and the results for others were not significant. The analyses for Minimum TTC (u_ttc) and Mean Time Headway (mn_hwd) were not carried out due to insufficient data. The analyses for Mean Distance Headway (mn_hwd), Distance Headway Variation (sd_hwd), Minimum Distance Headway (u_hwd), and Time Headway Variation (sd_hwt) were not significant. In the analysis for Minimum Time Headway (u_hwt) there was an effect of road but not of S-IVIS.

The data for Brake Reaction Time during the visual task is presented in Figure 97 and Table 66. These data represent the drivers' time to react to the Event situations. Brake Reaction Time was measured manually from the appearance of the hazardous event until the onset of braking by the driver. This method to measure reaction time differed from the other test sites, where reaction time was measured from brake onset of the lead vehicle. Data were available for Events 1 and 3 in the Rural Road the visual task but there was not sufficient data from Event 2 to include it in the analysis. There was a tendency for drivers to react more slowly to the event when engaged with the visual task S-IVIS while driving as well as an indication that increased level of S-IVIS difficulty led to an increase in reaction time. These differences are shown primarily in the comparison of SLv2 with SLv2 and BL.

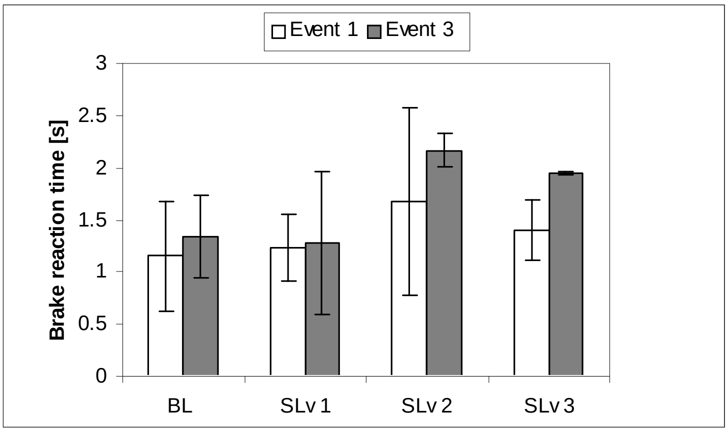



**Figure 97 – Brake reaction time (rt_br), Visual task, Rural Road**

**Table 66 – Analysis of brake reaction time (rt_br [s]), Visual task, Rural Road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **rt br [s]** Event 1&3 | 1.22 | 1.26 | 1.97 | 1.58 | ✓ | × | × | BL | × | ✓ | × |
| | | | | | | | | SLv1 | | ✓ | × |
| | | | | | | | | SLv2 | | | × |

### *7.6.2.2. Lateral control*

The analyses for Lateral Position (mn_lp) did not reveal any effects of the visual task S-IVIS. There was an effect of road complexity level in that drivers in the curved segments of the road tended to drive to the right of the lane (.33 m) but on the straight segments they drove at the centre of the lane (-.01 m).

The results for Lateral Position Variation (st_lp) are presented in Figure 98 and Table 67. Overall, drivers exhibited more variability within their lanes when they drove on the curved segments of the road (.45 m) compared with when the drove on the straight segments of the road (.38 m). The only significant impact of the visual task S-IVIS on lateral position variation was observed between SLv1 (.39 m) and SLv2 (.45 m); drivers exhibited greater variability within the lane when using the medium level of S-IVIS (SLv2) than they did when using the easy level of S-IVIS (SLv1).

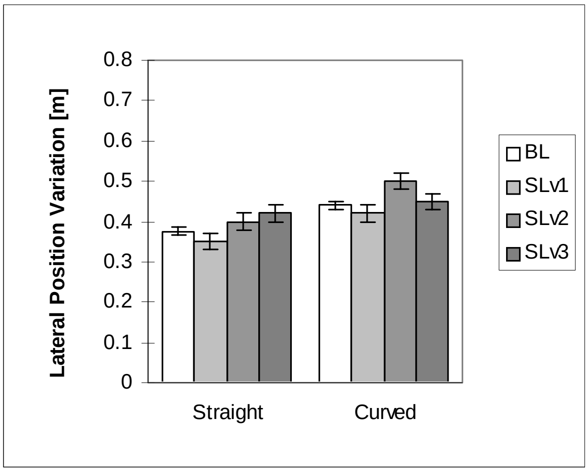



**Figure 98 – Lateral position variation (st_lp), Visual task, Rural Road**

**Table 67 – Analysis of lateral position variation (st_lp [m]), Visual task, Rural Road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **st lp [m]** | .41 | .39 | .45 | .44 | ✓ | ✓ | × | BL | × | × | × |
| | | | | | | | | SLv1 | | × | ✓ |
| | | | | | | | | SLv2 | | | × |

### *7.6.2.3. Workload*

The glance frequency (n_gl) that drivers made to the screen to complete the visual task S-IVIS tasks was recorded. These data are provided in Figure 99 and Table 68. The glance frequency to the S-IVIS was significantly higher for the High level of S-IVIS difficulty compared to the Low Level of S-IVIS difficulty. This finding helps to explain how drivers dealt with the increasing complexity of the visual task – they simply looked at the S-IVIS more often although they kept their glances about the same duration as is shown in the next analysis.

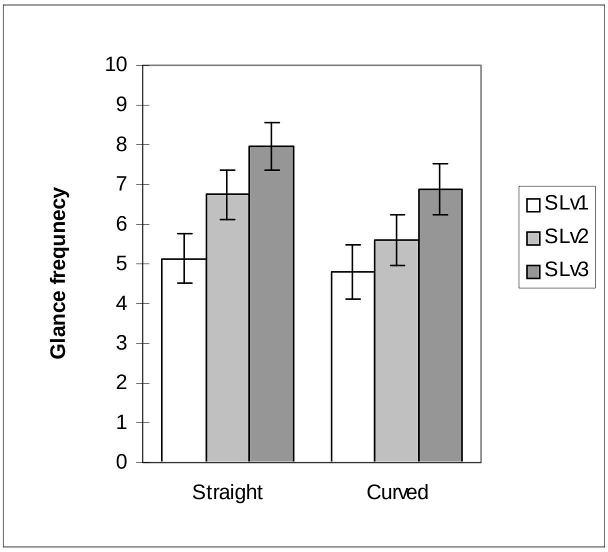



**Figure 99 – Glance frequency (n_gl) to the S-IVIS, Visual task, Rural Road**

**Table 68 – Analysis of glance frequency (n_gl), Visual task, Rural Road**

| | **Mean values** | | | | **Significant Effects** | | | **Post Hoc test** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | | SLv2 | SLv3 |
| **n_gl** | | 4.97 | 6.17 | 7.42 | ✓ | × | × | SLv1 | | × | ✓ |
| | | | | | | | | SLv2 | | | × |

The Durations of the Glances made by drivers was examined. There were no significant differences observed for Mean Glance duration (d_gl) as a function of S-IVIS task difficulty or road complexity. All means were in the range of .59 to .64 seconds. This was an unexpected finding as many previous studies have found that glance duration to an in-vehicle device increases as the task difficulty increases (e.g., Green, 1998). One possible reason for the lack of that effect in the present work might lie in the nature of the task itself. That is, the visual task S-IVIS task is completely machine paced, not driver paced. The data from the previous analysis examining Glance Frequency indicate that drivers looked more often at the S-IVIS as the task difficulty increased, even though their individual glances did not increase in duration.

Figure 100 and Table 69 present the data for Total Glance Duration (tot_gl), the sum of the duration of the individual glances made while completing a task. The results indicate that as the S-IVIS task difficulty increased, drivers spent greater amounts of the total task time looking at the S-IVIS screen. This difference was significant in the case of the Low Difficulty level compared with the high difficulty level and marginally greater for the comparison between the low and medium levels of difficulty. This finding confirms the expectation that drivers spend greater amounts of time looking away from the road when they are trying to do more demanding in-vehicle tasks.

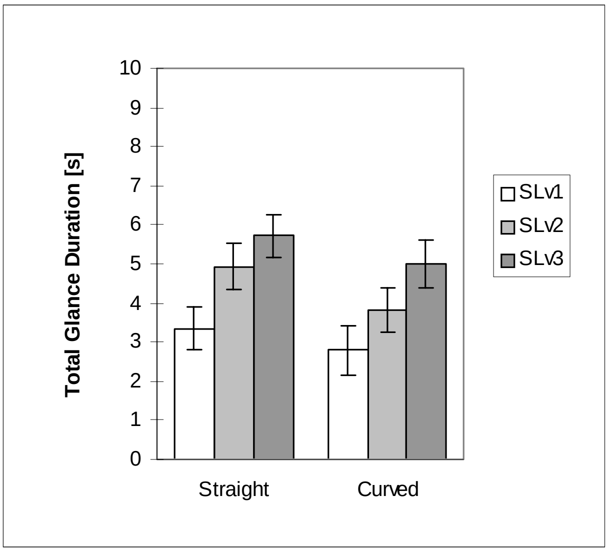



**Figure 100 – Total glance duration (tot_gl) to S-IVIS, Visual task, Rural Road**

**Table 69 – Analysis of total glance duration (tot_gl [s]), Visual task, Rural Road**

| | | Mean values | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | | SLv2 | SLv3 |
| **tot_gl*** | | 3.07 | 4.38 | 5.36 | ✓ | × | × | SLv1 | | × | ✓ |
| | | | | | | | | SLv2 | | | × |

The measure of “Percentage of Road Centre” (%_rc) is an interesting measure in that it is used in different ways depending on whether one is examining data from a visual type task or a cognitive type of task. A reduction in time spent looking in this area would be expected when a driver’s attention is drawn to the interior of the vehicle to perform a task. The opposite prediction is made for distraction arising from a cognitive or auditory source where drivers were not required to look away from the road. In these cases, drivers would be expected to spend increasing amounts of time looking at the forward view centre of the road as their cognitive distraction increased and they spent less time surveying their driving environment.

As can be seen in Figure 101 and Table 70, the percentage of time that drivers spent looking at the area of “road centre” decreased as the level of the visual task S-IVIS task difficulty increased. This is consistent with drivers spending more time looking away from the road to the S-IVIS the visual task display for the more difficult tasks. All pairwise tests comparing levels of S-IVIS were significant. Although there is a significant interaction for road by S-IVIS level, the effects are similar but more pronounced for the curved road.

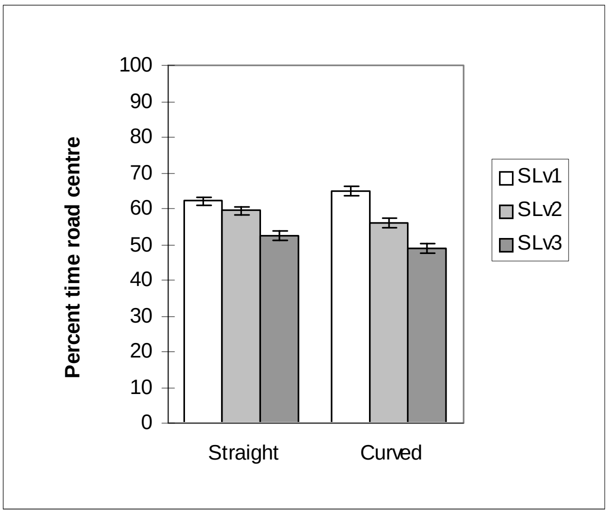



**Figure 101 – Percent time road Centre (%_rc), Visual task, Rural Road**

**Table 70 – Analysis of percent road centre (%_rc), Visual task, Rural Road**

| | | Mean values | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | | SLv2 | SLv3 |
| **%_rc** | | 63.93 | 57.68 | 50.66 | ✓ | × | ✓ | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | ✓ |

Figure 102 and Table 71 present the data for the Workload Ratings (subj_wl) made by the drivers in the visual task S-IVIS Task. These Workload Ratings proved to be sensitive to the manipulations of S-IVIS difficulty for the visual task as well as the cognitive task. These ratings also reflected differences in road difficulty (straight vs curved roadways).

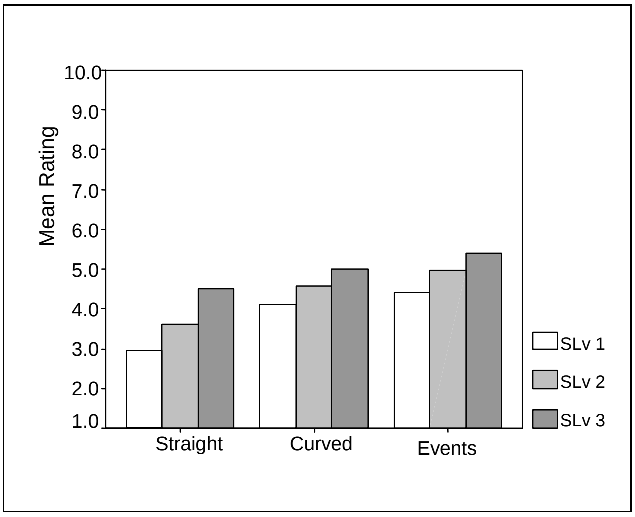



**Figure 102 – Self reported driving performance (subj_wl), Visual task, Rural Road**

**Table 71 – Analysis of self reported workload ratings (subj_wl), Visual task, Rural Road**

| | | Mean values | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | | SLv2 | SLv3 |
| **subj_wl** | | 3.83 | 4.39 | 4.97 | ✓ | ✓ | × | SLv1 | | × | ✓ |
| | | | | | | | | SLv2 | | | × |

#### *7.6.2.4. S-IVIS Performance*

The Percentage of Correct Responses (s_correct) made by drivers in the various the visual task S-IVIS conditions are presented in Figure 103 and Table 72. There was a clear effect of S-IVIS difficulty on the percentage of correct answers that the drivers made. Drivers made fewer correct responses as task difficulty increased. This was observed in all the driving environments.

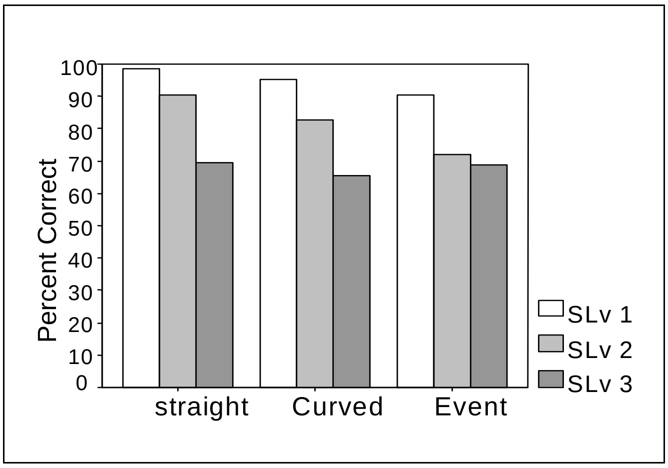



**Figure 103 – % correct responses, Visual task, Rural Road**

**Table 72 – Analysis of % correct responses (s_correct[%]), Visual task, Rural Road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | | SLv2 | SLv3 |
| **s_correct[%]** | | 94.68 | 81.71 | 67.82 | ✓ | ✓ | × | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | ✓ |

Drivers' reaction times for the visual task S-IVIS (s_rt) task are presented in Figure 104 and Table 73. Reaction time to the secondary S-IVIS task was measured for driving on straight and curved segments as well as during the events. Across all these environments, drivers took longer to respond to the more difficult tasks.

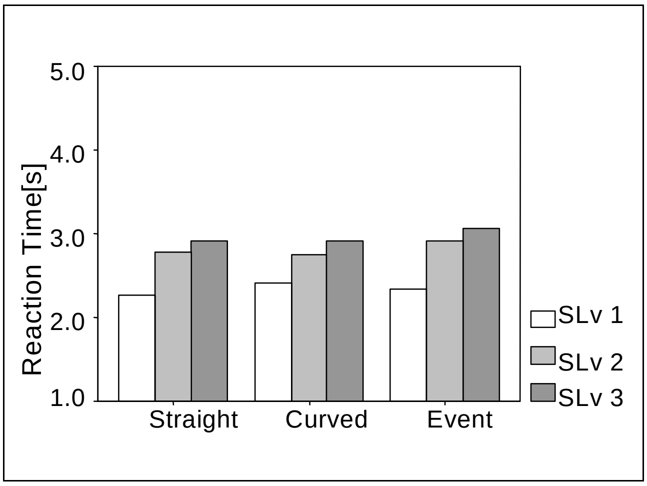



**Figure 104 – Reaction time (s_rt), Visual task, Rural Road**

**Table 73 – Analysis of reaction time (s_rt) [s], Visual task, Rural Road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | | SLv2 | SLv3 |
| **s_rt [s]** | | 2.34 | 2.81 | 2.96 | ✓ | × | × | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | × |

The Percentage of Missed Responses (s_missed) for drivers in the visual task S-IVIS task are presented in Figure 105 and Table 74. The results indicated that drivers missed more responses as task difficulty increased.

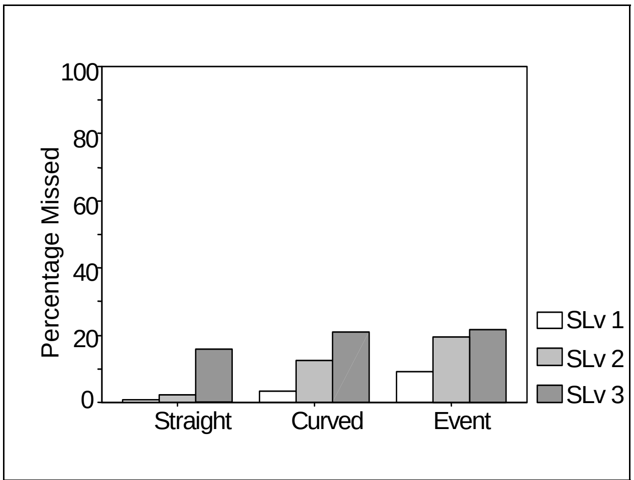



**Figure 105 – % missed responses, Visual task, Rural Road**

**Table 74 – Analysis of % missed responses (s_missed [%]), Visual task, Rural Road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | | SLv2 | SLv3 |
| **s_missed [%]** | | 4.40 | 11.34 | 19.44 | ✓ | ✓ | × | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | ✓ |

## 7.6.3. Effects of the cognitive task in Urban Road driving

### *7.6.3.1. Longitudinal Control*

In the straight segments of the Urban Road, significant effects for the cognitive task were found for measures of Mean speed [mn_sp], Speed Variability [st_sp], Speed Change [d_sp], Minimum Speed [u_sp] much the same as were found in the Rural Road. None of the analyses were significant in the Curved Urban Road analyses. Two of the headway measures, Minimum Headway Distance [u_hwd] and Minimum Headway Time [u_hwt] showed an effect of the cognitive task in the analyses for Straight Urban Road but not in the analyses for the Curved Urban segments.

### *7.6.3.2. Lateral Control*

The only significant measure for lateral control found was lateral position variation for the Curved Urban road segments.

#### 7.6.3.3. Workload

The ratings (subj_wl) reflected the increase in task difficulty for the cognitive task in the Urban environment for the straight and curved parts of the route.

#### 7.6.3.4. S-IVIS Performance

The cognitive task S-IVIS performance data was similar to that found for the Rural Road with the exception that the difference among conditions for Percent Correct in the Straight sections was not significant although the means were in the expected direction.

### 7.6.4. Effects of the visual task in Urban Road driving

#### 7.6.4.1. Longitudinal Control

In the straight segments of the Urban Road, significant effects for the cognitive task were found for measures of Headway Distance Variability [sd_hwd] and Headway Time Variability [sd_hwt], although neither of these effects was observed in either the Rural Road the visual task analyses or the Urban Road Curved analyses.

Of greater interest was the significant effect found for the Brake Reaction Time measure for Event 1 in the Urban analysis. Drivers reacted more slowly to the unexpected event when they were engaged with the in-vehicle the visual task. In addition, there was an effect of task difficulty on reaction times. This finding replicated that found in the Rural the visual task analysis.

Two findings were significant for the analysis for the Curved segments for the Urban analysis: Mean Speed [mn_sp] and Minimum Speed [u_sp].

#### 7.6.4.2. Lateral Control

Measures of Mean Lateral position [mn_lp] and Lateral position Variability [st_lp] were significant but only in the analysis for the straight sections of the Urban Road.

#### 7.6.4.3. Workload

The ratings reflected the increase in the task difficulty for the visual task in the Urban environment for the straight and curved parts of the route.

#### 7.6.4.4. S-IVIS Performance

The visual task S-IVIS performance data was similar to that found for the Rural Road; i.e. a clear reduction of correct responses as an effect of S-IVIS difficulty.

## 7.7. Results Summary & Conclusions

The goal of this research was to provide answers to the following questions:

- Which measures are sensitive to S-IVIS performance while driving?
- Which measures are sensitive to increases in S-IVIS difficulty?
- Also of interest was any difference in the sensitivity of the measures to the two types of S-IVIS tasks.

The summary and discussion which follow centre primarily on the results from the Rural Road Analyses since these provide the most robust and coherent set of findings. Two factors contributed to problems with the urban route. A counterbalancing error in the presentation of the S-IVIS tasks which resulted in an unbalanced ANOVA design. The route also included some variation in posted speed as the curved were posted at 70kph and the straights at 50kph. Results from the Urban Road are interspersed when appropriate. Overall, the Urban Road was not as successful a testing environment as the Rural Road, perhaps because of greater variability in the driving environment leading to smaller experimental power.

### 7.7.1. Summary of Effects for Longitudinal Control Measures:

#### *7.7.1.1. Longitudinal control*

Several of the speed-related measures were sensitive to the manipulations of task versus no task and also the effects of the levels of S-IVIS. For example, mean speed (mn_sp) showed different effects for the type of S-IVIS. Drivers performing the visual task reduced their speed relative to the baseline when performing the tasks. Drivers performing the cognitive S-IVIS tasks showed the opposite effect; that is, they showed a tendency to increase their speed (for the easy and medium task levels) when carrying out the cognitive S-IVIS task while driving. During the Cognitive, drivers also drove faster on the straight compared to the curved sections of the road. Mean speed is a useful measure that would be very easy and cost effective to collect.

Minimum speed (u_sp) analyses for the visual task indicated that drivers had a slower minimum speed for the visual task SLv3 compared to without the visual task. For the cognitive task, a significantly lower minimum speed was observed for the difficult level of the S-IVIS when compared to each of the easy and medium levels. The comparisons with the baseline level for the cognitive S-IVIS task for the Minimum Speed and Speed Change (d_sp) dependent variables was problematic due to the large amount of variation observed in the baseline level. Speed variation (st_sp) showed no significant effects.

In the case of the Urban Road, the effects for the speed-related variables were inconsistent. Effects were observed for some of these variables in the Urban Road the cognitive task Straight and Urban Road the visual task Curved, but not for the Urban Road the cognitive task curved or Urban Road the visual task Straight analyses.

There is not much to add from the analyses of Headway Measures. In the case of the visual task S-IVIS, Minimum Distance Headway (u_hwd) and Minimum Time Headway (u_hwt) showed an effect of road complexity level such that drivers tended to have shorter Headway Time & Distance when on curves. In the case of the cognitive S-IVIS, the only effect that was found was an effect of S-IVIS versus no task for Minimum Distance Headway and this was only a marginal effect.

There are several possible reasons why the headway measures were not successful. There was a considerable amount of missing data for these analyses; many participants simply did not try to closely follow the lead vehicle and the simulator did not collect data on the lead vehicle if farther away than 100 metres. Participants were instructed never to pass the lead vehicle, but they were not asked to closely follow the lead vehicle. Numerous styles of lead vehicle following are possible (e.g., Fancher, et al., 1998). One might expect very short headways for distracted drivers, but we also know that as the demand increases on drivers to perform in-vehicle tasks, they often slow down and increase their headway. These two factors work in opposition and with individual differences in willingness and/or ability to follow a lead vehicle result in a set of driving measures with abundant missing data and a lot of variability.

In the case of the Urban Road analyses, a few of the headway-related measures were significant, but the results do not present an orderly picture. For the cognitive task, two of the headway measures, Minimum Headway Distance (u_hwd) and Minimum Headway Time (u_hwt) showed an effect of the cognitive task in the analyses for Straight but not Curved sections of the Urban Road. In the straight segments of the Urban Road with the visual task, significant effects were found for measures of Distance Headway Variability (sd_hwd) and Time Headway Variability (sd_hwt).

In summary, the headway measures, at least as they were implemented in this study, do not add much to the understanding of the influence of visual and cognitive distraction on driving behaviour.

#### *7.7.1.2. Events*

Drivers' reaction times to unexpected events (Brake Reaction Time rt_br) in the driving environment were examined as one of the measures in this project. Drivers displayed a tendency to react more slowly to the event when they were engaged with the visual task S-IVIS task. In the Rural Road scenario, they also showed an effect of S-IVIS difficulty level in that reaction time to difficulty Level 2 were significantly longer than those to Level 1 or to the baseline. It should be noted that a considerable amount of data were missing from this analysis and that the available data from Event 1 & 3 were pooled for the analysis. Similar effects were observed in the Urban Road scenario for the visual task.

The analyses of other dependent measures for the Events did not provide much that assists in the discrimination of S-IVIS impact on driving performance. These analyses suffered from a small number of observations and also a small window for measurement (30s). Those other findings that were significant (some of the speed measures and headway measures) provided similar information to that provided in the general simulator driving measures.

The findings indicate that Brake Reaction Time measures may be a useful way to examine distraction from in-vehicle devices. One advantage of using such measures is that they provide strong parallels to real world driving and the safety-relevant incidents that occur. There are, however, concerns that should be raised. The first of these relates to this specific experiment. These analyses are based on a small amount of data due to the combination of the design of the study as well as data loss resulting from simulator considerations or subjects not "driving as expected". There is also considerable variability in the data. In this particular study, Events were not counterbalanced across baseline and experimental conditions. As a result, the specific events were not experimentally controlled although they were equivalent in design.

Clearly not all events are equally effective. The most effective format for events are "surprise" events such as vehicle incursions, pullouts or lead vehicles braking rapidly and unexpectedly. In these situations one is more likely to obtain a clear go/no-go response. Other situations lend themselves to more ambiguity and less clear driver responses. For example, a driver may have sufficient time to monitor the approach of a vehicle that will turn across its path and as a result no sudden response is required. In many of the events they are already braking prior to the event, and therefore there is no way to distinguish the braking for the event from regular braking.

#### *7.7.1.3. Lateral control*

Mean lateral position (mn_lp) was not very sensitive to the S-IVIS tasks or the manipulations of difficulty within the S-IVIS tasks. The only significant effects were for the road manipulation within the visual task Rural Road and for the Urban the visual task Straight Road analysis which showed and an effect for S-IVIS. Consequently it was not a very useful measure.

Lateral Position Variability (st_lp) showed more promise. For both types of S-IVIS in Rural Road, there was an effect of road complexity level. Of greater interest, however, Lateral Position Variability (st_lp) was sensitive to the S-IVIS tasks. In the case of the visual task, greater lateral position variability was observed in the medium compared with the easy task levels. In the case of the cognitive S-IVIS, the opposite type of effect was observed where a reduced level of lateral position variability was observed with the difficult level of the cognitive S-IVIS compared to the baseline driving. For the Urban Road, Lateral position Variability was sensitive to task/no-task for Urban the visual task Straight segments and to levels of the S-IVIS in the Urban the cognitive task curved segments.

These results should be viewed with some caution, however, since effects are not observed consistently across the various conditions. Further comparison with results from other experiments within the HASTE project should aid in interpreting the robustness of these effects.

#### *7.7.1.4. Workload*

In summary, self reported workload (subj_wl) proved to be sensitive to the manipulations of S-IVIS difficulty for both the visual task and the Cognitive. These ratings also reflected differences in road difficulty (straight vs curved roadways).

The eye tracking measures provided useful data relevant to the difficulty level of the visual task S-IVIS task. Although glance durations (d_gl) did not increase with task difficulty, the number of glances (n_gl) to the S-IVIS to complete the task did. This was reflected in a greater amount of time spent looking away from the road as shown in the total glance duration data (tot_gl) and the reduction in time spent not looking at the road.

The results were not so clear for the cognitive S-IVIS task where it was expected that higher levels of cognitive distraction from the more demanding levels of the task would result in more time spent looking at the area designated “road centre”. Although the general pattern of the data was consistent with this idea, significant differences in performance were not found. Further analyses examining the data by different methods may prove useful. Eyetracking measures provide a useful analysis of task performance and provide hard data on the time drivers look away from the road for example. However, the use of these systems and their follow up analyses may be cost prohibitive.

Measures summary tables

### 7.7.2. Rural road and the cognitive task

| | Mean values | | | | Effects | | | Post Hoc test | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 | |
| **Longitudinal control** | | | | | | | | | | | | |
| mn_sp [km/h] | 96.77 | 98.67 | 98.44 | 96.75 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✗ | |
| | | | | | | | | SLv1 | | ✗ | ✗ | |
| | | | | | | | | SLv2 | | | ✗ | |
| st sp [km/h] | 6.59 | 3.11 | 3.21 | 4.91 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✗ | post hoc for curved only |
| | | | | | | | | SLv1 | | ✗ | ✗ | |
| | | | | | | | | SLv2 | | | ✗ | |
| d sp [km/h] | 27.86 | 11.36 | 13.31 | 23.14 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✗ | |
| | | | | | | | | SLv1 | | ✗ | ✓ | |
| | | | | | | | | SLv2 | | | ✗ | |
| u sp [km/h] | 75.90 | 92.12 | 89.94 | 80.04 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✗ | |
| | | | | | | | | SLv1 | | ✗ | ✓ | |
| | | | | | | | | SLv2 | | | ✗ | |
| u ttc [s] | 7.31 | 11.75 | 8.24 | 8.33 | ns | | | | | | | |
| mn hwd [m] | | | | | | | | | | | | not analysed |
| sd hwd [m] | | | | | | | | | | | | not analysed |
| u hwd [m[ | | | | | | | | | | | | not analysed |
| mnhwt [s] | | | | | | | | | | | | not analysed |
| sd hwt [s] | | | | | | | | | | | | not analysed |
| u hwt [s] | | | | | | | | | | | | not analysed |
| rt br [s] | 1.27 | 1.14 | 1.32 | 1.16 | ns | | | | | | | |
| **Lateral control** | | | | | | | | | | | | |
| mn lp [m] | .60 | .60 | 0.59 | .60 | ns | | | | | | | |
| st lp [m] | .37 | .35 | 0.34 | 0.33 | ✓ | ✓ | ✗ | BL | ✗ | ✗ | ✓ | |
| | | | | | | | | SLv1 | | ✗ | ✗ | |
| | | | | | | | | SLv2 | | | ✗ | |
| **Workload** | | | | | | | | | | | | |
| %_rc** | 80.21 | 82.12 | 79.21 | 83.40 | ns | ✓ | ✗ | | | | | |
| subj_wl | N/a | 4.49 | 5.44 | 6.09 | ✓ | ✓ | ✗ | SLv1 | | ✓ | ✓ | |
| | | | | | | | | SLv2 | | | ✗ | |
| **aCMT results** | | | | | | | | | | | | |
| s_correct [%] | N/a | 74.16 | 64.73 | 54.71 | ✓ | ✓ | ✗ | SLv1 | | ✗ | ✓ | |
| | | | | | | | | SLv2 | | | ✗ | |
| s_missed [%] | N/a | 18.12 | 22.22 | 26.69 | ns | | | SLv1 | | | | |
| s_incorrect [%] | N/a | 4.83 | 9.18 | 13.77 | ✓ | ✗ | ✗ | SLv1 | | ✗ | ✓ | |
| | | | | | | | | SLv2 | | | ✗ | |

**%_rc = % of time spent looking at road centre

### 7.7.3. Rural road and the visual task

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 | |
| **Longitudinal control** | | | | | | | | | | | | |
| mn_sp [km/h] | 99.09 | 96.99 | 95.95 | 95.39 | ✓ | ✗ | ✗ | BL | ✓ | ✓ | ✓ | |
| | | | | | | | | SLv1 | | ✗ | ✗ | |
| | | | | | | | | SLv2 | | | ✗ | |
| st sp [km/h] | 3.4 | 3.82 | 3.57 | 3.49 | ns | | | | | | | |
| d sp [km/h] | 11.36 | 12.25 | 11.94 | 11.51 | ns | | | | | | | |
| u sp [km/h] | 93.2 | 90.77 | 90.52 | 89.86 | ✓ | ✗ | ✗ | BL | ✗ | ✗ | ✓ | |
| | | | | | | | | SLv1 | | ✗ | ✗ | |
| | | | | | | | | SLv2 | | | ✗ | |
| min ttc [s] | | | | | | | | | | | | not analysed |
| mn hwd [m] | 67.76 | 62.28 | 66.64 | 69.82 | ns | | | | | | | |
| sd hwd [m] | 7.25 | 7.54 | 9.96 | 9.8 | ns | | | | | | | |
| u hwd [m] | 54.92 | 48.06 | 50.77 | 50.47 | ns | | | | | | | |
| mn hwt [s] | | | | | | | | | | | | not analysed |
| sd hwt [s] | 0.27 | 0.32 | 0.4 | .42 | ns | | | | | | | |
| u hwt [s] | 1.92 | 1.55 | 1.71 | 1.54 | ns | ✓ | ✗ | | | | | |
| rt br [s] Event 1&3 | 1.22 | 1.26 | 1.97 | 1.58 | ✓ | ✗ | ✗ | BL | ✗ | ✓ | ✗ | |
| | | | | | | | | SLv1 | | ✓ | ✗ | |
| | | | | | | | | SLv2 | | | ✗ | |
| **Lateral control** | | | | | | | | | | | | |
| mn lp [m] | 0.2 | 0.19 | 0.15 | 0.12 | ns | ✓ | ✗ | | | | | |
| st lp [m] | 0.41 | 0.39 | 0.45 | 0.44 | ✓ | ✓ | ✗ | BL | ✗ | ✗ | ✗ | |
| | | | | | | | | SLv1 | | ✗ | ✓ | |
| | | | | | | | | SLv2 | | | ✗ | |
| **Workload** | | | | | | | | | | | | |
| n_gl | N/a | 4.97 | 6.17 | 7.42 | ✓ | ✗ | ✗ | SLv1 | | ✗ | ✓ | |
| | | | | | | | | SLv2 | | | ✗ | |
| mn_gd | N/a | 0.59 | 0.64 | 0.64 | ns | | | SLv1 | | | | |
| tot_gl* | N/a | 3.07 | 4.38 | 5.36 | ✓ | ✗ | ✗ | SLv1 | | ✗ | ✓ | |
| | | | | | | | | SLv2 | | | ✗ | |
| %_rc** | N/a | 63.93 | 57.68 | 50.66 | ✓ | ✗ | ✓ | SLv1 | | ✓ | ✓ | |
| | | | | | | | | SLv2 | | | ✓ | |
| subj_wl | N/a | 3.83 | 4.39 | 4.97 | ✓ | ✓ | ✗ | SLv1 | | ✗ | ✓ | |
| | | | | | | | | SLv2 | | | ✗ | |
| **Arrows results** | | | | | | | | | | | | |
| s_correct[%] | N/a | 94.68 | 81.71 | 67.82 | ✓ | ✓ | ✗ | SLv1 | | ✓ | ✓ | |
| | | | | | | | | SLv2 | | | ✓ | |
| s_rt [s] | N/a | 2.34 | 2.81 | 2.96 | ✓ | ✗ | ✗ | SLv1 | | ✓ | ✓ | |
| | | | | | | | | SLv2 | | | ✗ | |
| s_missed [%] | N/a | 4.4 | 11.34 | 19.44 | ✓ | ✓ | ✗ | SLv1 | | ✓ | ✓ | |
| | | | | | | | | SLv2 | | | ✓ | |
| s_incorrect [%] | N/a | 0.93 | 6.94 | 12.5 | ✓ | ✗ | ✗ | SLv1 | | ✓ | ✓ | |
| | | | | | | | | SLv2 | | | ✓ | |

*tot_gl = total of glance times to S-IVIS

**%_rc = % of time spent looking at road centre

### 7.7.4. Urban road and the cognitive task: straight segments

| | Mean values | | | | Effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| **Longitudinal control** | | | | | | | | | |
| mn_sp [km/h] | 51.24 | 47.61 | 48.28 | 48.16 | ✓ | BL | ✓ | ✗ | ✗ |
| | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | SLv2 | | | ✗ |
| st sp [km/h] | 2.98 | 4.12 | 4.06 | 4.44 | ✓ | BL | ✗ | ✗ | ✓ |
| | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | SLv2 | | | ✗ |
| d sp [km/h] | 12.88 | 15.64 | 16.86 | 18.01 | ✓ | BL | ✗ | ✗ | ✓ |
| | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | SLv2 | | | ✗ |
| u sp [km/h] | 43.99 | 38.09 | 37.85 | 37.27 | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | SLv2 | | | ✗ |
| u ttc [s] | 7.45 | 7.39 | 6.75 | 8.62 | ns | | | | |
| mn hwd [m] | 38.91 | 41.52 | 37.17 | 45.81 | ns | | | | |
| sd hwd [m] | 5.64 | 6.99 | 6.45 | 6.92 | ns | | | | |
| u hwd [m] | 27.54 | 16.48 | 12.66 | 20.98 | ✓ | BL | ✗ | ✓ | ✗ |
| | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | SLv2 | | | ✗ |
| mn hwt [s] | 2.84 | 3.37 | 2.57 | 3.45 | ns | | | | |
| sd hwt [s] | 0.45 | .58 | 0.51 | .47 | ns | | | | |
| u hwt [s] | 2.05 | 1.24 | 0.95 | 1.61 | ✓ | BL | ✗ | ✓ | ✗ |
| | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | SLv2 | | ✗ | ✗ |
| rt br [s] Event | 0.77 | .68 | 0.69 | 0.82 | ns | | | | |
| **Lateral control** | | | | | | | | | |
| mn lp [m] | .25 | 0.23 | 0.23 | 0.23 | ns | | | | |
| st lp [m] | .14 | 0.17 | 0.15 | .17 | ns | | | | |
| **Workload** | | | | | | | | | |
| subj_wl | N/a | 3.69 | 4.37 | 5.17 | ✓ | SLv1 | | ✓ | ✓ |
| | | | | | | SLv2 | | | ✓ |
| **aCMT results** | | | | | | | | | |
| s_correct[%] | N/a | 75.56 | 60.32 | 62.8 | ns | SLv1 | | | |
| s_missed [%] | N/a | 19.44 | 30.95 | 16.37 | ns | SLv1 | | | |
| s_incorrect [%] | N/a | 4.44 | 7.14 | 16.07 | ns | SLv1 | | | |

### 7.7.5. Urban road and the cognitive task: curved segments

| | Mean values | | | | Effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| **Longitudinal control** | | | | | | | | | |
| mn_sp [km/h] | 72.42 | 69.49 | 69.4 | 67.08 | ✓ | BL | ✗ | ✗ | ✓ |
| | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | SLv2 | | | ✗ |
| st sp [km/h] | 2.95 | 3.66 | 3.49 | 3.83 | ns | | | | |
| d sp [km/h] | 32.31 | 31.51 | 27.59 | 26.97 | ns | | | | |
| u sp [km/h] | 66.74 | 63.54 | 62.63 | 60.77 | ✓ | BL | ✗ | ✗ | ✓ |
| | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | SLv2 | | | ✗ |
| u ttc [s] | 10.62 | 9.72 | 8.45 | 12.47 | ns | | | | |
| mn hwd [m] | 51.38 | 51.56 | 50.94 | 48.74 | ns | | | | |
| sd hwd [m] | 7.62 | 6.02 | 10.55 | 7.68 | ns | | | | |
| u hwd [m] | 38.34 | 41.24 | 33.5 | 33.97 | ns | | | | |
| mn hwt [s] | 2.65 | 2.65 | 2.64 | 2.58 | ns | | | | |
| sd hwt [s] | .45 | .35 | 0.58 | .40 | ns | | | | |
| u hwt [s] | 1.93 | 2.08 | 1.69 | 1.75 | ns | | | | |
| **Lateral Control** | | | | | | | | | |
| mn lp [m] | 0.49 | 0.51 | 0.6 | 0.54 | ns | | | | |
| st lp [m] | 0.35 | 0.35 | 0.35 | 0.4 | ns | | | | |
| **Workload** | | | | | | | | | |
| subj_wl | N/a | 4.38 | 3.91 | 5.28 | ✓ | SLv1 | | ✗ | ✓ |
| | | | | | | SLv2 | | | ✓ |
| **Arrows results** | | | | | | | | | |
| s_correct[%] | N/a | 98.96 | 87.5 | 76.56 | ✓ | SLv1 | | ✗ | ✓ |
| | | | | | | SLv2 | | | ✗ |
| s_rt [s] | N/a | 2.22 | 2.68 | 2.77 | ✓ | SLv1 | | ✓ | ✓ |
| | | | | | | SLv2 | | | ✗ |
| s_missed [%] | N/a | 0 | 8.33 | 14.06 | ✓ | SLv1 | | ✗ | ✓ |
| | | | | | | SLv2 | | | ✗ |
| s_incorrect [%] | N/a | 1.04 | 4.17 | 9.38 | ✓ | SLv1 | | ✗ | ✓ |
| | | | | | | SLv2 | | | ✗ |

### 7.7.6. Urban and the visual task: straight segments

| | Mean values | | | | Effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| **Longitudinal control** | | | | | | | | | |
| mn_sp [km/h] | 48.72 | 46.97 | 46.73 | 46.75 | ns | | | | |
| st sp [km/h] | 3.33 | 2.82 | 3.29 | 3.52 | ns | | | | |
| d sp [km/h] | 26.73 | 25.09 | 23.35 | 22.76 | ns | | | | |
| u sp [km/h] | 42.08 | 41.20 | 40.63 | 40.30 | ns | | | | |
| u ttc [s] | 8.47 | 12.52 | 7.97 | 9.93 | ns | | | | |
| mn hwd [m] | 43.61 | 48.70 | 53 | 52.99 | ns | | | | |
| sd hwd [m] | 5.19 | 6.74 | 8.3 | 7.95 | ✓ | BL | × | ✓ | ✓ |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |
| u hwd [m] | 33.44 | 37.48 | 38.89 | 39.41 | ns | | | | |
| mn hwt [s] | 3.15 | 3.69 | 4.04 | 4.02 | ns | | | | |
| sd hwt [s] | .43 | .60 | 0.71 | .67 | ✓ | BL | × | ✓ | ✓ |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |
| u hwt [s] | 2.29 | 2.61 | 2.85 | 2.92 | ns | | | | |
| rt br [s] | 0.77 | 0.7 | 0.82 | 1.23 | ✓ | BL | × | × | ✓ |
| | | | | | | SLv1 | | × | ✓ |
| | | | | | | SLv2 | | | × |
| **Lateral Control** | | | | | | | | | |
| mn lp [m] | 0.24 | 0.23 | 0.15 | 0.17 | ✓ | BL | × | ✓ | ✓ |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |
| st lp [m] | 0.12 | 0.11 | 0.15 | 0.16 | ✓ | BL | × | × | ✓ |
| | | | | | | SLv1 | | × | ✓ |
| | | | | | | SLv2 | | | × |
| **Workload** | | | | | | | | | |
| Subj_wl | N/a | 2.75 | 3.81 | 3.91 | ✓ | SLv1 | | × | ✓ |
| | | | | | | SLv2 | | | ✓ |
| **Arrows results** | | | | | | | | | |
| s_correct [%] | N/a | 98.96 | 93.23 | 77.6 | ✓ | SLv1 | | × | ✓ |
| | | | | | | SLv2 | | | ✓ |
| s_rt [s] | N/a | 2.14 | 2.62 | 2.72 | ✓ | SLv1 | | × | ✓ |
| | | | | | | SLv2 | | | ✓ |
| s_missed [%] | N/a | 1.04 | 2.08 | 15.63 | ✓ | SLv1 | | × | ✓ |
| | | | | | | SLv2 | | | ✓ |
| s_incorrect [%] | N/a | N/a | 4.69 | 6.77 | × | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |

### 7.7.7. Urban and the visual task: curved segments

| | Mean values | | | | Effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| **Longitudinal control** | | | | | | | | | |
| mn_sp [km/h] | 72.42 | 69.49 | 69.4 | 67.08 | ✓ | BL | × | × | ✓ |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |
| st sp [km/h] | 2.95 | 3.66 | 3.49 | 3.83 | ns | | | | |
| d sp [km/h] | 32.31 | 31.51 | 27.59 | 26.97 | ns | | | | |
| u sp [km/h] | 66.74 | 63.54 | 62.63 | 60.77 | ✓ | BL | × | × | ✓ |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |
| u ttc [s] | 10.62 | 9.72 | 8.45 | 12.47 | ns | | | | |
| mn hwd [m] | 51.38 | 51.56 | 50.94 | 48.74 | ns | | | | |
| sd hwd [m] | 7.62 | 6.02 | 10.55 | 7.68 | ns | | | | |
| u hwd [m] | 38.34 | 41.24 | 33.5 | 33.97 | ns | | | | |
| mn hwt [s] | 2.65 | 2.65 | 2.64 | 2.58 | ns | | | | |
| sd hwt [s] | .45 | .35 | 0.58 | .40 | ns | | | | |
| u hwt [s] | 1.93 | 2.08 | 1.69 | 1.75 | ns | | | | |
| **Lateral Control** | | | | | | | | | |
| mn lp [m] | 0.49 | 0.51 | 0.6 | 0.54 | ns | | | | |
| st lp [m] | 0.35 | 0.35 | 0.35 | 0.4 | ns | | | | |
| **Workload** | | | | | | | | | |
| subj_wl | N/a | 4.38 | 3.91 | 5.28 | ✓ | SLv1 | | × | ✓ |
| | | | | | | SLv2 | | | ✓ |
| **Arrows results** | | | | | | | | | |
| s_correct[%] | N/a | 98.96 | 87.5 | 76.56 | ✓ | SLv1 | | × | ✓ |
| | | | | | | SLv2 | | | × |
| s_rt [s] | N/a | 2.22 | 2.68 | 2.77 | ✓ | SLv1 | | ✓ | ✓ |
| | | | | | | SLv2 | | | × |
| s_missed [%] | N/a | 0 | 8.33 | 14.06 | ✓ | SLv1 | | × | ✓ |
| | | | | | | SLv2 | | | × |
| s_incorrect [%] | N/a | 1.04 | 4.17 | 9.38 | ✓ | SLv1 | | × | ✓ |
| | | | | | | SLv2 | | | × |

# 8. The VTEC Simulator Experiment

## 8.1. Test site

The Volvo Technology AB simulator was used in the experiment. The participants sat in a Volvo S80 with automatic gearbox, placed in front of a display with a horizontal field of view of approximately 135 degrees. See Figure 106. No back projection was incorporated, thus the mirrors provided no information of relevance to the driver. The cabin was equipped with two colour cameras, one directed at the driver's face and the other on the S-IVIS screen, which presented the arrow task, positioned above the centre control within the vehicle. The image of the front view was also recorded. Sound in the mock-up was recorded to enable coding of subjects' responses to the cognitive task S-IVIS task.

The Seeing Machines' 'faceLAB 3.0 system' was used for collecting eye movement data. A detailed description of the system as well as the in-house developed VDM (Visual Demand Measurement) Tool used for analysis can be found in Larsson (2003).

**Figure 106– The VTEC driving simulator. Left, the outside; right, the interior**

## 8.2. Scenarios and participants

The experimental routes consisted of a motorway and a rural road, previously described in *2.6-Road and Traffic Environments*.

Forty-eight subjects participated in the experiment. 37 (77%) were male, 11 (23%) female. Their average age was 40.6 years (range: 25-62) and on average they had held a license for 20 years (range: 5-43). On average they had driven 23,102 km the past 12 months, and had an average total mileage of 375,056 km. None of the subjects were professional drivers

## 8.3. S-IVIS evaluated

Both the visual task as well as the cognitive task were used in the experiment. Both tasks included the three original levels of difficulty. For task descriptions see *2.4-Surrogate IVIS* .

## 8.4. Experimental design and procedure

The two independent factors investigated were S-IVIS level (SLv) and Road complexity levels (RLv). The study consisted of four sub-studies, where the two S-IVIS tasks were performed on both the motorway the rural road, where subjects were split with respect to S-IVIS task. No quantitative comparisons were made between the sub-studies.

The forty-eight subjects were divided into two groups. The first group drove with the cognitive task and the second group with the visual task. All subjects drove twice on the rural road (experimental run and baseline run; balanced) and then twice on the motorway (experimental run and baseline run; balanced) with short breaks in between the four runs to avoid simulator sickness. The static S-IVIS test was included either before or after the rural road driving.

During each of the two experimental runs the S-IVIS was presented on nine occasions. The order of difficulty level (SLv) in the S-IVIS task was balanced over participants. Each SLv of S-IVIS was presented three times. After each S-IVIS segment and at the corresponding locations during the baseline drives, the subjects were asked by a recorded voice to give a subjective rating of own driving performance on a 10-point scale (the subj_r measure).

## 8.5. Measures and analysis method

In the present study, 38 measures were computed: 5 lane-position and TLC related measures, 5 steering wheel related measures, 4 speed measures, 15 headway-related measures, 8 eye-movement-related measures and one measure of subjective rating. Detailed definitions are given in Appendix 2.

The main independent factors investigated were S-IVIS task complexity (SLv) and road complexity (RLv). The analysis was performed according to the common method described in section *2.7-Indicators and Analysis*.

## 8.6. Results

The detailed experimental design differed somewhat between measures - for some measures, only two road levels (“RLv1 Straight” and “RLV2 Curve”) were investigated, while for others, the third road level (“Event”) was included as well. The number of factors investigated for each measure is indicated in the graphs.

### 8.6.1. Effects of the cognitive task in Rural Road driving

#### *8.6.1.1. Self reported driving performance*

In general, the results for the subjective ratings in the rural cognitive task condition indicate strong effects of the S-IVIS, but no differences between S-IVIS levels, as shown in Figure 107 and Table 75. There was also an effect of road level, although this effect only occurred for RLv3 (Event).

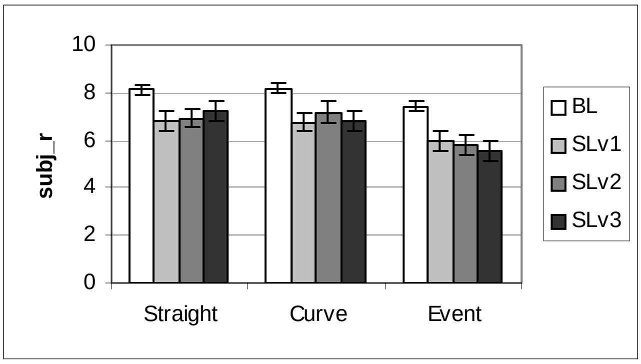



**Figure 107 – Self reported driving performance (subj_r), Cognitive task, Rural road**

**Table 75 – ANOVA results for subjective ratings, Cognitive task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| subj_r | 7.9 | 6.5 | 6.6 | 6.5 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

The main conclusion from these results is that drivers report that their driving performance degrades as a result of performing the cognitive task. However, they did not perceive any difference between the cognitive task complexity levels.

### *8.6.1.2. Longitudinal control*

There were no effects of the cognitive task on longitudinal control performance.

### *8.6.1.3. Lateral control*

The analysis revealed three principal effects of the cognitive task on control measures in the rural cognitive task condition. First, there was a small but significant shift in mean lateral position to the right in the lane, Figure 108 and Table 76.

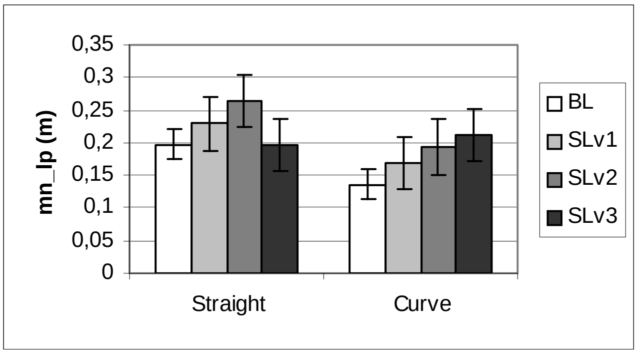



**Figure 108 – Mean lateral position, Cognitive task, Rural road**

**Table 76 – ANOVA results for mean lateral position, Cognitive task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **mn_lp [m]** | 0.15 | 0.20 | 0.23 | 0.20 | ✓ | ✓ | × | BL | × | ✓ | × |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

This effect, (also found for the visual task on the rural road - but not in any of the motorway scenarios), could be interpreted as a more or less conscious desire to increase the safety margins to oncoming traffic when the driving performance is judged to be impaired.

The second main effect found for the cognitive task was a reduction in lateral position variation. This result was also found in the motorway scenario. It was also observed that the road level has a strong impact on this measure. The *st_lp* analysis is presented in Figure 109 and Table 77.

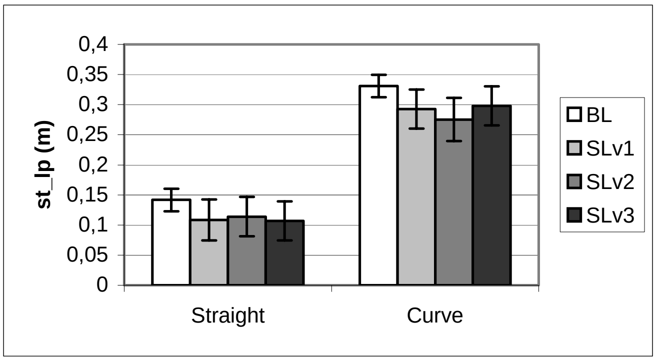



**Figure 109 – Standard deviation of lateral position (st_lp), Cognitive task, Rural road**

**Table 77 – ANOVA results for standard deviation of lateral position, Cognitive task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **st_lp [m]** | 0.24 | 0.2 | 0.19 | 0.2 | ✓ | ✓ | × | BL | × | ✓ | × |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

The third main effect found for the cognitive task was an increased amount of micro steering corrections. This is evidenced by a significantly increased number of steering reversals larger than 1 degree (*rr_st1*). However, when the reversal threshold was increased to 3 degrees (or more), the effect disappeared. The analysis results for *rr_st1* are given in Figure 110 and Table 78.

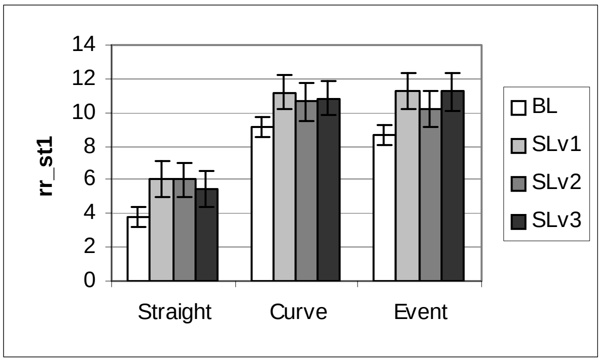



**Figure 110 – Steering wheel reversal rate (threshold 1q deg.), Cognitive task, Rural road**

**Table 78 – ANOVA results for steering wheel reversal rate (threshold 1 deg.), Cognitive task, Rural road**

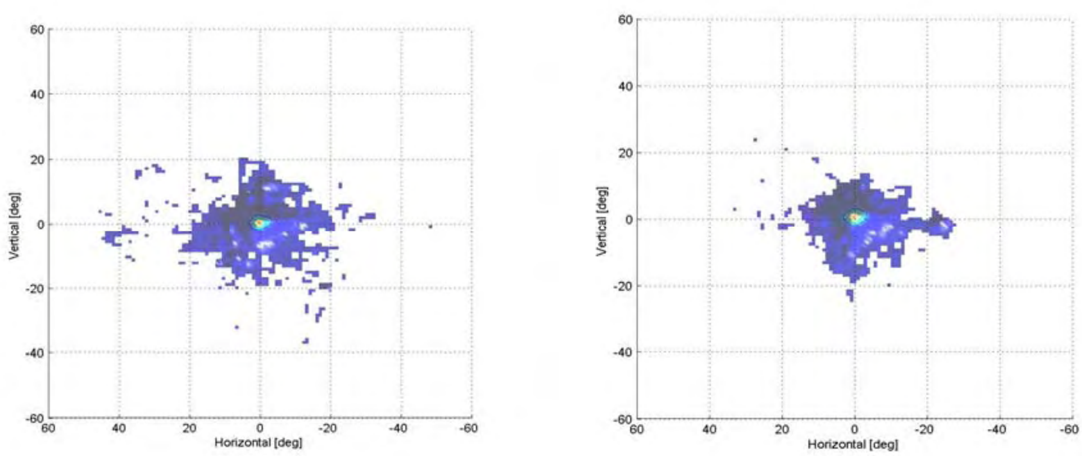
| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **rr_st1** | 7.2 | 9.5 | 9.0 | 9.2 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

The increased amount of steering activity was also indicated by significant effects in the high frequency steering (*hi_st*), and rapid steering wheel turns (*rswt*) measures.

Taken together, the reduced lateral variation and the increased amount of steering micro corrections seem to indicate that more *effort* is put into the lateral control task during the cognitive task performance, which leads to more precise lane keeping performance. This hypothesis is further supported by the results from the eye-movement analysis in the following section.

### *8.6.1.4. Eye movements*

In the eye-movement analysis, some eye tracking data (18%) had to be removed due to poor quality. The principal variable analysed in the cognitive task analysis was variation in gaze angle. Figure 111 shows spatial density plots for the gaze directions, comparing baseline and the cognitive task level 3 data. As the figure indicates, the cognitive task performance leads to a strong concentration of gaze angles towards the road centre. The density was normalised by the size of the data set in order to yield comparable values on the z-axis.




*Baseline*

*Experimental*
*SLv1-3 levels aggregated*

**Figure 111 – Gaze data during driving, Cognitive task, Rural road**

The statistical analysis for the standard deviation of gaze angle (*st_ga*) is given in Figure 112 and Table 79.

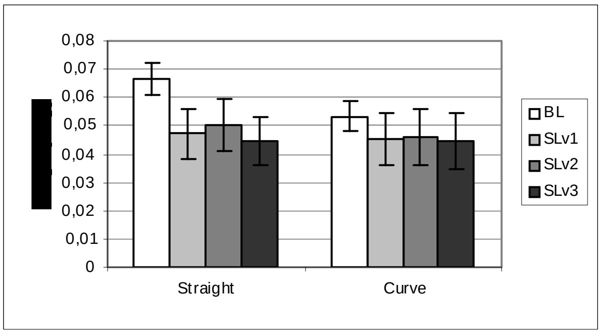



**Figure 112 – Gaze angle standard deviation (st_ga), Cognitive task, Rural road**

**Table 79 – ANOVA results for gaze angle standard deviation (st_ga), Cognitive task, Rural road**

| | **Mean values** | | | | **Significant Effects** | | | **Post Hoc test** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **st_ga (deg)** | 0.060 | 0.046 | 0.048 | 0.045 | ✓ | × | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

These results support existing studies demonstrating gaze concentration as a result of cognitive load effect (e.g. Recarte and Nunes, 2003). The present study also provides novel results on how this gaze concentration is related to effects on driving performance (reduced lateral variation and increased number of steering micro corrections).

Although the mechanisms behind the phenomenon are still rather unclear, a general interpretation could be that the observed effects occur as the result of an increased effort (optimisation of cognitive resources) in order to maintain lateral control performance at an acceptable level when the cognitive load increases.

Importantly for the HASTE objectives, the present results do not indicate any direct safety-critical effects of the cognitive task on driving performance, but rather the opposite (increased lateral control). However, this apparent improvement in driving performance has been accompanied by a change in glance patterns so that glances are concentrated on the road ahead at the expense of the periphery. Other studies have demonstrated that cognitive load significantly impairs event detection ability (e.g. Recarte and Nunes, 2003). Thus, suitable event detection measures may need to be incorporated in the future HASTE test regime.

### *8.6.1.5. S-IVIS performance*

Performance on the cognitive task was analysed in terms of percentage of correct, incorrect and missed responses. Performance while driving was compared with performance while static. For comparison between Static and Driving see RLv in Table 80 below.

As shown in Table 91, correct and incorrect responses show main effects on difficulty level. Correct responses also show an effect on RLv. No interaction effect was shown.

**Table 80 – Performance on Cognitive task, Rural road**

| Cognitive task, Rural | Mean values | | | | Significant Effects | | | Post Hoc test | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv2 | SLv3 |
| s_correct [%] | Rural | 75,7 | 65,2 | 64,5 | ✓ | ✓ | × | SLv1 | ✓ | ✓ |
| | Static | 84,0 | 77,3 | 69,9 | | | | SLv2 | | × |
| s_missed [%] | Rural | 15,4 | 18,4 | 19,0 | × | × | × | SLv1 | | |
| | Static | 9,0 | 7,9 | 11,0 | | | | SLv2 | | |
| s_incorrect[%] | Rural | 8,9 | 16,3 | 16,5 | ✓ | × | × | SLv1 | ✓ | ✓ |
| | Static | 7,0 | 14,8 | 19,1 | | | | SLv2 | | × |

*RLv equals Static and Rural*

According to the post-hoc test (Figure 113 and Figure 114) the correct and incorrect responses differ significantly between SLv1 and SLv2 as well as between SLv1 and SLv3. No difference is shown between SLv2 and SLv3.

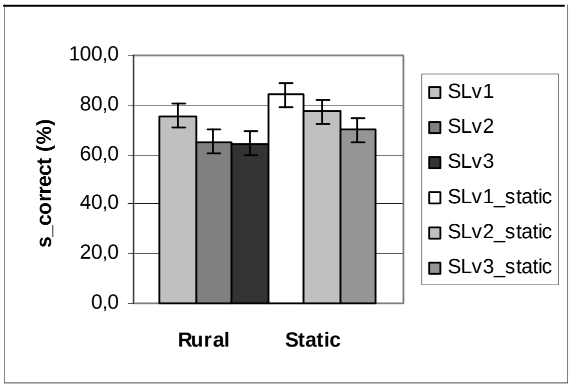



**Figure 113 – % correct responses, Cognitive task, Rural road**

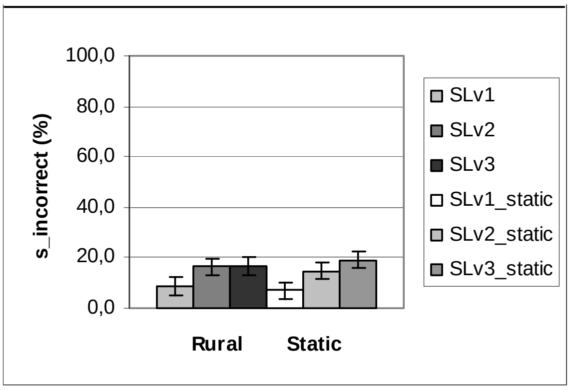



**Figure 114 – % incorrect responses, Cognitive task, Rural road**

It can be concluded that the patterns for dynamic performance differ from those obtained for static performance. In particular, while static testing indicated a linear relation between the cognitive task performance and S-IVIS level (SLv), this is not the case while driving. Thus, it is clear that dynamic the cognitive task performance cannot be reliably predicted from static performance.

## 8.6.2. Effects of the visual task in Rural Road driving

### *8.6.2.1. Self reported driving performance*

The results for the self-reported assessments of own driving performance (subj_r) for the rural-visual task condition are presented in Figure 115 and Table 81. As can be seen, the self-reported performance decreased monotonically for all road levels. There were significant differences between all S-IVIS levels except between 2 and 3 (however, the pairwise comparison between SLv 2 and 3 revealed a tendency that SLv3 yields lower ratings (p=0.052). There was also a significant effect of road level.

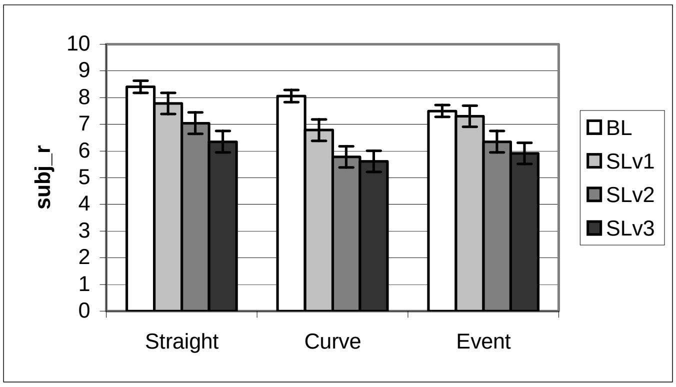



**Figure 115 – Self reported driving performance (subj_r), Visual task, Rural road**

**Table 81 – ANOVA results for the self rated driving performance (subj_r), Visual task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| subj_r | 8 | 7.3 | 6.4 | 6 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | × |

### *8.6.2.2. Longitudinal control*

Two general effects of the visual task on longitudinal control were found: (1) reduced speed and (2) increased headway to the lead vehicle. Figure 116 shows the results for the mean speed (mn_sp). The results show a significant reduction of mean speed in the S-IVIS conditions. All differences between baseline and S-IVIS levels were significant, as shown inTable 82. There were no effects of road level complexity. There were however no differences between the experimental levels (SLv1, 2 and 3).

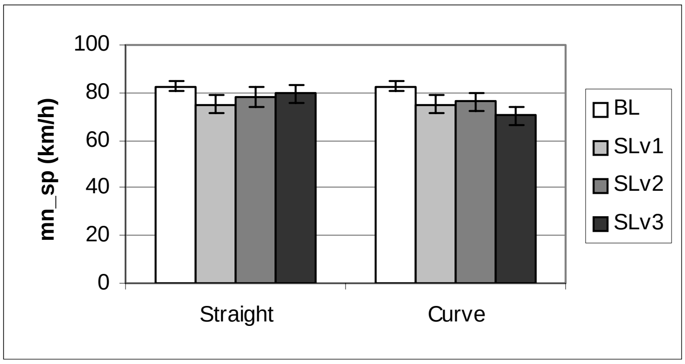



**Figure 116 – Mean speed (mn_sp), Visual task, Rural road**

**Table 82 – ANOVA results for the analysis of mean speed (mn_sp), Visual task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| mn_sp (km/h) | 82.5 | 75 | 77.3 | 75.2 | ✓ | × | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

The other speed magnitude measures investigated, minimum speed (*u_sp*) and speed difference between beginning and end of the segment (*d_sp*) yielded similar results. There was also a significant increase in the speed variation, as indicated by the standard deviation of speed measure (*st_sp*). However, this was probably largely an effect of a monotonic speed reduction rather than oscillatory control behaviour.

The results for the mean time headway measure (*mn_hwt*) in the straight and curved road sections are shown in Figure 117. As the ANOVA analysis in Table 83 shows, there was a significant effect of the visual task on mean time headway. Similar results were found for distance time headway (*mn_hwd*). The time and distance headway variation (*st_hwt* and *st_hwd*) also increased significantly as a result of the visual task. No effects were found on headway or speed in the Event (RLv3) condition.

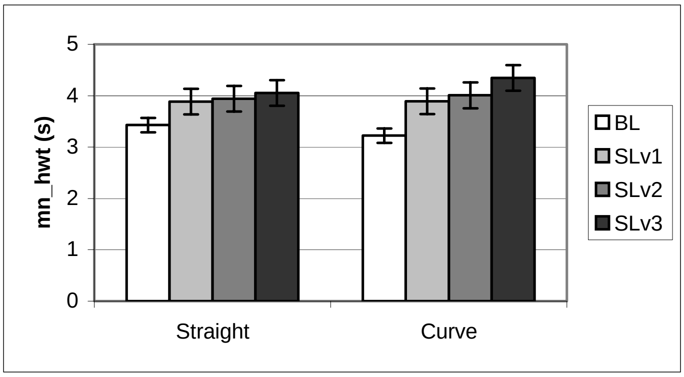



**Figure 117 – Mean time headway (mn_hwt), Visual task, Rural road**

**Table 83 – ANOVA results for mean time headway (mn_hwt), Visual task, Rural road**

| | **Mean values** | | | | **Significant Effects** | | | **Post Hoc test** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **mn_hwt (s)** | 3.3 | 3.9 | 4.0 | 4.2 | ✓ | × | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

The likely explanation for these results is that drivers reduce speed and increase headway in order to increase safety margins when visually distracted. However, it is unclear whether the speed reduction occurred in order to increase headway, or whether it occurred independently of the lead car. The fact that that speed reduction also occurred in the motorway scenario (where no lead car was present) gives some supports to the latter hypothesis (although the two factors may of course combine).

### *8.6.2.3. Lateral control*

Three principal effects were found for the visual task on lateral control: (1) a shift towards the right in the lane, (2) strongly increased lateral position variation (weaving) and (3) large, sluggish steering wheel movements. The results for the mean lateral position (mn_lp) are given in Figure 118 and Table 84. As the results show, the lateral position shift increased with S-IVIS level up to a certain point (SLV3). However, only the differences between baseline and the three S-IVIS levels were significant. There was also a significant effect of road level (a larger shift in straight sections).

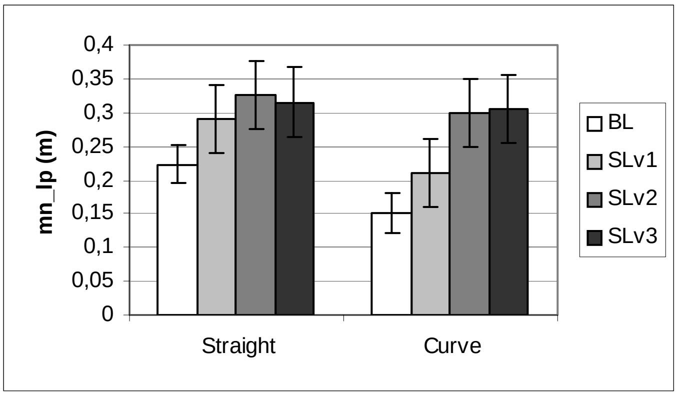



**Figure 118 – Mean lateral position (mn_lp), Visual task, Rural road**

**Table 84 – ANOVA results for mean lateral position (mn_lp), Visual task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **mn_lp (m)** | 0.19 | 0.25 | 0.31 | 0.31 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

As for the cognitive task on the rural road, this effect could be interpreted as a desire of the driver to increase safety margins towards potential oncoming traffic on the rural road during visual distraction. The fact that this effect was not found in the motorway scenario (which had divided double lanes) lends some support for this hypothesis.

The results for lateral position variation (st_lp) are given in Figure 119 and Table 85. As can be seen in the Figure, the lateral position variation increased almost linearly with S-IVIS level in the Straight condition, while an upper level of accepted variation seems to be present in the Curve condition. This leads to a significant interaction between SLv and RLv. The ANOVA analysis also indicates that all SLv levels differed except for SLv2 vs. SLv3. There is also a very strong effect of road level.

Similar results were found for the mean Time to Line Crossing (mn_tlc), indicating that it measures roughly the same effect as *st_lp*.

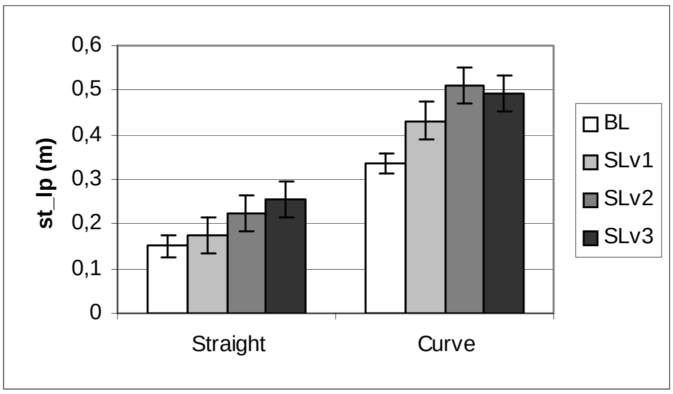



**Figure 119 – Standard deviation of lateral position (st_lp), Visual task, Rural road**

**Table 85 – ANOVA results for standard deviation of lateral position (mn_lp), Visual task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **st_lp [m]** | 0.24 | 0.30 | 0.37 | 0.38 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | × |

An alternative way to quantify reduced lane keeping performance is to compute the proportion of time/events where a critical threshold is exceeded. In the present study, two such measures were included: (1) the proportion of time spent outside the lane boundaries (*lanex*) and the proportion of TLC minima less than 1 second (*pr_tlc*). These measures yielded essentially the same results and thus only the *pr_tlc* results are reported here. The results are given in Figure 120 and Table 86.

As the results show, during straight road driving, the number of TLC minima less than one second is close to zero, while the S_IVIS performance causes several close encounters (or complete lane crosses), indicating strong lane weaving for several drivers. Moreover, the measure is clearly strongly sensitive to road level (the effects are much stronger).

It should be pointed out that, like *lanex*, the floor effect (pr_tlc = 0 for many subjects) leads to a distribution that is strongly skewed and the variances differ widely between SLv (and RLv-) level, which strongly violates the ANOVA assumptions and makes these types of measures problematic for statistical testing.

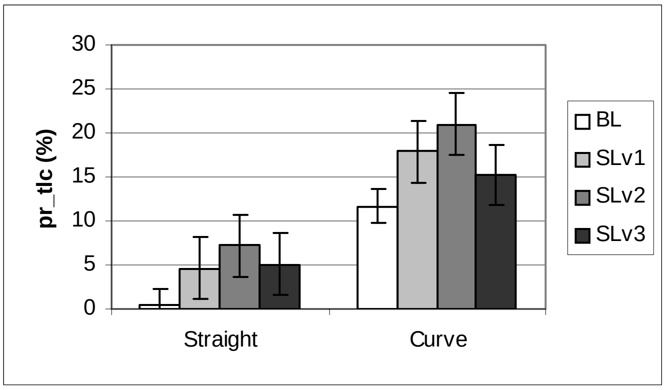



**Figure 120 – Proportion of TLC minima less than 1 second (pr_tlc), Visual task, Rural road**

**Table 86 – ANOVA results for proportion TLC minima less than 1 second (pr_tlc), Visual task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **pr_tlc (%)** | 6.0 | 11.3 | 14.0 | 10.1 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

The third main effect found, i.e. The presence of large sluggish steering wheel movements, is here illustrated by the analysis of the steering wheel reversal rate measure in Figure 121 and

Table 87. In the results presented, a 1-degree threshold was used (similar to the cognitive task analysis above). However, in contrast to the cognitive task analysis, significant effects were also found for larger thresholds (3, 5 and 7 degrees), indicating a rather different effect of the visual task compared to the cognitive task (large, sluggish, steering wheel movements as opposed to micro corrections). Strong significant effects were also found for other steering wheel measures investigated, e.g. standard deviation of steering angle (*st_st*), steering entropy (*en_st*), high frequency steering (*hi_st*) and rapid steering wheel turns (*rswt*, both for 5 and 10 deg/s velocity thresholds). It was also found that, although the *st_st* measure yielded significant results, it was found to be rather crude compared to the other measures and strongly sensitive to variance induced by the driving situation.

As for several of the other lateral control measures (e.g. *st_lp*), it can be observed from Figure 121 that the steering wheel reversal rate increased monotonically with SLv in the Straight condition, while it followed an asymptotical pattern in the Curve condition (with no increase between SLV2 and 3). This indicates the presence of a "minimum accepted limit of lateral control degradation" – or, in other words, a minimum degree of control required to stay on the road (or keep within accepted safety margins).

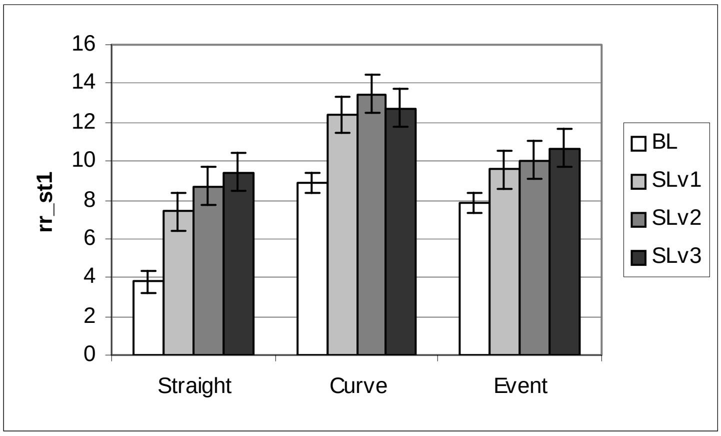



**Figure 121 – Steering wheel reversal rate, 1 second threshold (rr_st1), Visual task, Rural road**

**Table 87 – ANOVA results for steering wheel reversal rate (rr_st1), Visual task, Rural road**

| | **Mean values** | | | | **Significant Effects** | | | **Post Hoc test** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **rr_st1** | 6.8 | 9.7 | 10.7 | 10.9 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | ✓ |
| | | | | | | | | SLv2 | | | × |

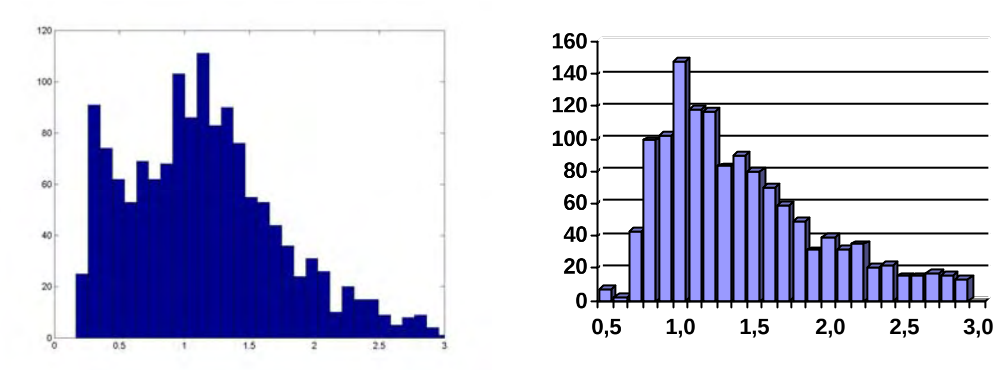
### *8.6.2.4. Eye movements*

For the glance-based measures for the visual task, comparison to a baseline is not meaningful (as there is no reason to expect glances to the S-IVIS display in a no-task condition). Thus, for the visual task, only differences between S-IVIS levels were analysed.

Three principal measures are reported here: (1) Single glance duration (mn_gd), (2) the number of glances towards the S-IVIS display (n_gl), and (3) percentage road centre (prc), i.e. The proportion of glance time spent towards the road centre.

Due to poor quality of the eye-tracking data for some subjects, 30% of the data had to be excluded from the analysis.

The distribution of single glance durations to the S-IVIS display is illustrated in Figure 122, and compared to existing data collected manually by Rockwell (1988). As can be observed, there is a peak at about 0.3 s in the present data. A plausible explanation is that this is an effect of the forced-paced nature of the visual task. By contrast to the self-paced radio task used by Rockwell, the subjects in the present study were prompted at regular intervals to respond to the S-IVIS task. This may have led to short, anticipatory "check" glances to the display to detect the onset of a new task. This type of strategy was indeed reported by some subjects. Check glances were found in all S-IVIS levels.




*Current study* *Rockwell (1988)*

**Figure 122 – Distribution of single glance durations, Visual task, Rural road**

The comparison of mean single glance durations for the three S-IVIS levels is presented in Figure 123 and

Table 88. As can be observed, the *mn_gd* increased almost linearly as a function of S-IVIS level. The differences between SLv1-SLv3 and SLv2-SLv3 were significant. There was also a significant effect of road level, where the Curve condition led to significantly shorter glances. This can be interpreted as a result of the higher visual demand imposed in curves condition to straight sections, leaving less visual resources for the S-IVIS task.

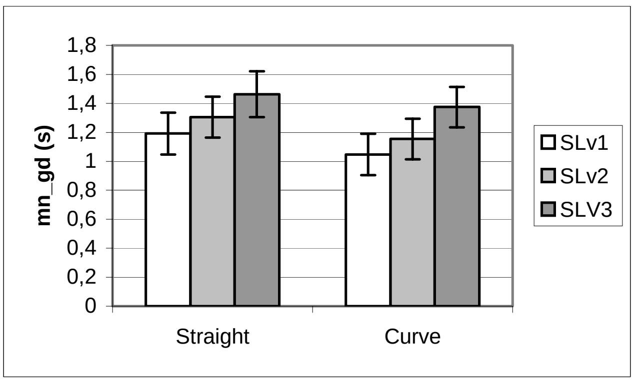



**Figure 123 – Mean single glance durations (mn_gd), Visual task, Rural road**

**Table 88 – ANOVA results for mean single glance durations (mn_gd), Visual task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| mn_gd (s) | n/a | 1.12 | 1.23 | 1.42 | ✓ | ✓ | × | SLv1 | | × | ✓ |
| | | | | | | | | SLv2 | | | ✓ |

Figure 124 and Table 89 presents the results for the effect of S-IVIS difficulty on the number of glances directed towards the IVIS display (glance frequency) on the rural road. The pattern differs somewhat from that of the glance duration data. While the number of glances on the straight road (RLv1) seems to increase rather linearly with S-IVIS difficulty (like the glance durations), this is not the case in curves (where SLv 3 generates slightly fewer glances). Moreover, the glance frequency did not differ significantly between road complexity levels.

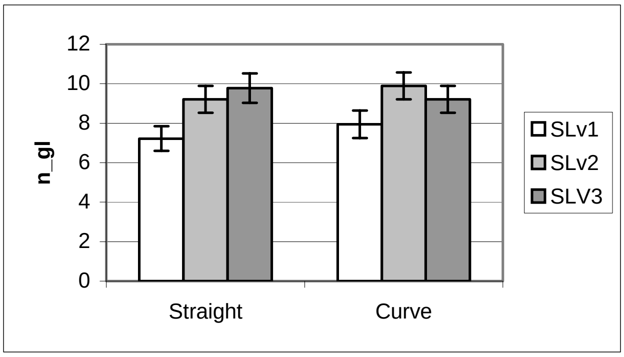



**Figure 124 – Glance frequency (n_gl), Visual task, Rural road**

**Table 89 – ANOVA results for glance frequency (n_gl), Visual task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| n_gl | n/a | 7.6 | 9.6 | 9.5 | ✓ | × | × | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | × |

Glance duration and glance frequency could be combined in order to yield a single measure of visual demand. One such measure is the proportion of IVIS glance time of the total task time (or total glance time, *pr_glt*). An alternative way is to compute the proportion of glance time directed towards the road centre. This leads to the percentage road centre (*prc*) measure (Victor and Johansson, in preparation). *prc* has the further advantage that it can be computed from raw eye-movement data (i.e. it does not require segmentation into glances). *pr_glt* and *prc* yielded similar results and, thus, only the latter is reported here.

The results from the *prc* analysis are presented in Figure 125 and Table 90. By contrast to the other measures, significant differences were found between all S-IVIS levels, indicating that *prc* is more sensitive to S-IVIS effects than any of glance duration and glance frequency alone. However, a drawback is that it is not diagnostic of the glance strategy employed (frequent short glances are generally safer than infrequent very long glances, although their may yield the same *prc* value).

Other measures investigated were the glance duration variation (*sd_gd*), the number of glances longer than 2 seconds (*n_gl2*). The results were generally in line with the results for the measures reported here.

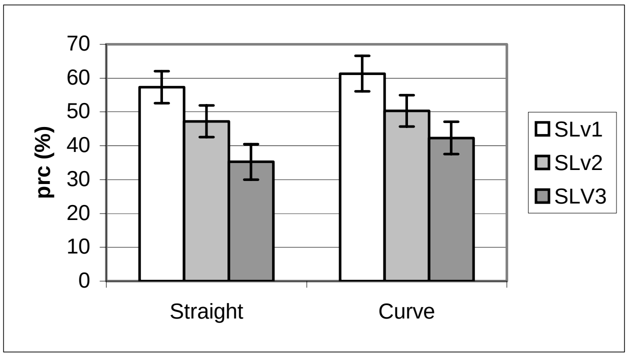



**Figure 125 – ANOVA results for % road centre (prc), Visual task, Rural road**

**Table 90 – ANOVA results for % road centre (prc), Visual task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| prc (%) | n/a | 59.3 | 48.8 | 38.8 | ✓ | ✓ | × | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | ✓ |

### *8.6.2.5. S-IVIS performance*

Performance on the visual task was analysed in terms of reaction time to each of the three levels of difficulty as well as percentage correct, incorrect and missed responses. Performance while driving was compared with performance while static. For comparison between Static and Driving see RLv in Table 91 below.

As shown in Table 91, all four measures show main effects of difficulty level. Correct, Missed and Reaction times also show main effects on RLv as well as interaction effects.

**Table 91 – Mean values and significance testing of Visual task, Rural road**

| **Arrow_Rural** | | Mean values | | | Significant Effects | | | Post Hoc test | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv2 | SLv3 |
| s_correct[%] | Rural | 98,6 | 85,1 | 81,1 | ✓ | ✓ | ✓ | SLv1 | ✓ | ✓ |
| | Static | 99,5 | 94,7 | 84,1 | | | | SLv2 | | ✓ |
| s_rt[s] | Rural | 2,0 | 2,6 | 2,8 | ✓ | ✓ | ✓ | SLv1 | ✓ | ✓ |
| | Static | 2,1 | 2,1 | 2,2 | | | | SLv2 | | × |
| s_missed[%] | Rural | 0,7 | 4,6 | 8,3 | ✓ | ✓ | ✓ | SLv1 | ✓ | ✓ |
| | Static | 0,0 | 2,1 | 7,5 | | | | SLv2 | | ✓ |
| s_incorrect[%] | Rural | 0,7 | 10,3 | 10,6 | ✓ | × | × | SLv1 | ✓ | ✓ |
| | Static | 0,5 | 3,2 | 8,3 | | | | SLv2 | | ✓ |

The post-hoc tests showed a decrease in correct responses along with an increase in S-IVIS complexity (Figure 126). The opposite was true for missed responses (see Figure 128) and incorrect responses (see Figure 127) which increased along with increasing S-IVIS complexity. Reaction times were significantly higher for SLv 2 and 3 compared to SLv1 (see Figure 129). However, there was no significant difference between SLv 2 and 3.

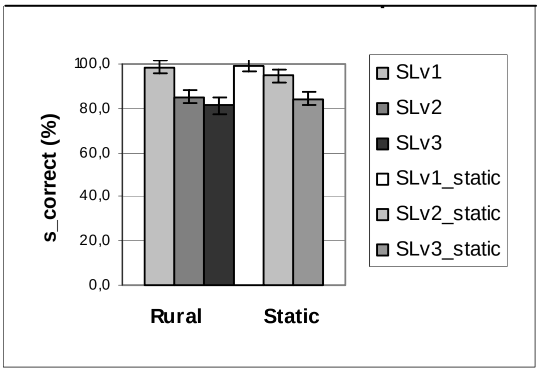



**Figure 126 – % correct responses, Visual task, Rural road**

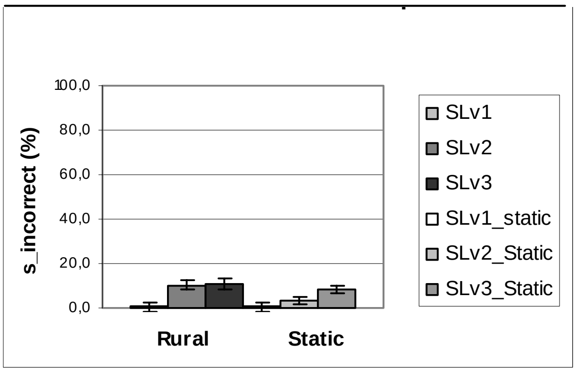



**Figure 127 – % incorrect responses, Visual task, Rural road**

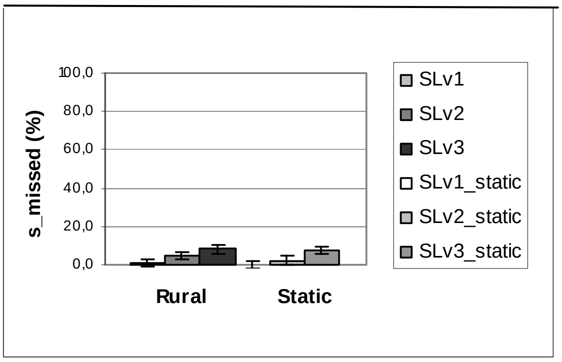



**Figure 128 – % missed responses, Visual task, Rural road**

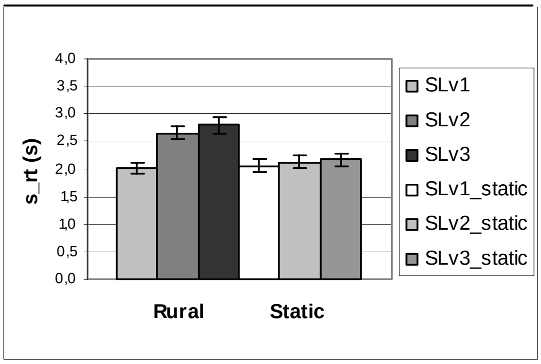



**Figure 129 – Reaction times, Visual task, Rural road**

## 8.6.3. Effects of the cognitive task in motorway driving

This section presents the results for the motorway-cognitive task condition. Detailed discussions of the results are only given if the results depart significantly from the rural condition discussed above.

### *8.6.3.1. Self reported driving performance*

Figure 130 and Table 92 present the results for the cognitive task-motorway condition. The results indicate a significant effect of the cognitive task S-IVIS task, but no differences between S-IVIS levels.

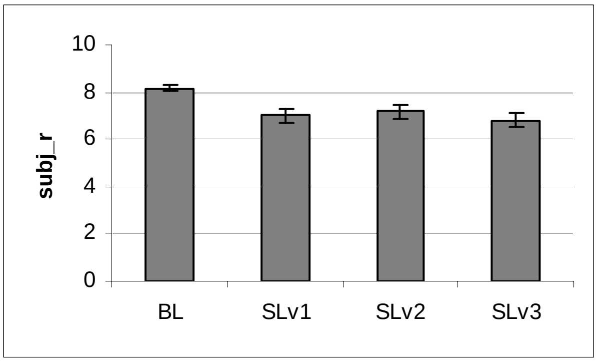



**Figure 130 – Self reported driving performance (subj_r), Cognitive task, Motorway**

**Table 92 – ANOVA results for self rated driving performance (subj_r), Cognitive task, Motorway**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| subj_r | 8.2 | 7.0 | 7.2 | 6.8 | ✓ | n/a | n/a | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

### *8.6.3.2. Longitudinal control*

As described above, the motorway scenario included a braking event, where the idea was to measure the effect of the cognitive task on brake reaction time. However, due to large variances induced by the driving scenarios, a proper analysis of these data was not possible. In general, no effect of the cognitive task on longitudinal control (speed and headway) was found in the motorway-cognitive task condition.

### *8.6.3.3. Lateral control*

In the motorway scenario, ambient traffic resulted in overtaking situations. In order to reduce the variance induced by overtaking behaviours, data from 2 seconds before and 2 after the overtaking were removed. Moreover, when the vehicle had entered the left lane, the reference point was shifted to the centre of the new lane. This operation was performed before calculating on the *mn_lp* and *st_lp* measures.

In contrast to the results from the rural road, the cognitive task performance did not result in any significant shift to the right in lateral position. Figure 131 and Table 93 presents the effect of the cognitive task on lateral position variation in the motorway condition. The results are essentially similar to those obtained for the rural road, i.e. The lateral position variation was significantly *reduced* as a result of the cognitive task performance.

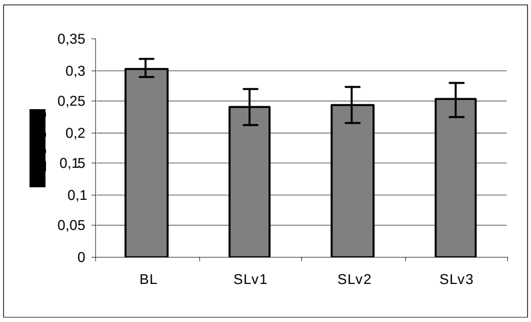



**Figure 131 – Standard deviation of lateral position (st_lp), Cognitive task, Motorway**

**Table 93 – ANOVA results for standard deviation of lateral position (st_lp), Cognitive task, Motorway**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| st_lp (m) | 0.30 | 0.24 | 0.24 | 0.25 | ✓ | n/a | n/a | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

No significant effects were obtained for the other lateral position measures, i.e. lane exceedences (*lanex*), mean TLC minima (*mn_TLC*) and percentage TLC minima less than 1 s. (*pr_tlc*). Moreover, no significant results were found for steering wheel movement measures.

### *8.6.3.4. Eye movements*

As in the rural road condition, the only eye-movement parameter analysed in the cognitive task was the variation in gaze direction. In the present study, this was measured in two ways: (1) standard deviation of gaze angle (*st_ga*) and (2) the percentage road centre. (*prc*). Both gave essentially the same results (while only *st_ga* indicated a significant difference in the rural condition). Thus, only the results for *st_ga* are reported here.

The results for the standard deviation of gaze angle (*st_ga*) are presented in Figure 132 and Table 94. The effect is essentially similar to the rural road results, i.e. performing the cognitive task results in reduced gaze variance (i.e. higher gaze concentration towards the road centre).

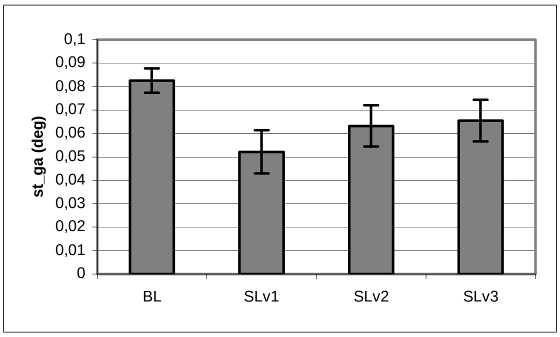



**Figure 132 – Standard deviation of gaze angle (st_ga), Cognitive task, Motorway**

**Table 94 – ANOVA results for standard deviation of gaze angle (st_ga), Cognitive task, Motorway**

| | **Mean values** | | | | **Significant Effects** | | | **Post Hoc test** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| st_gd (deg) | 0.083 | 0.052 | 0.063 | 0.065 | ✓ | n/a | n/a | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

### *8.6.3.5. S-IVIS performance*

Performance on the cognitive task, while driving on Motorway, was analysed in the same way as for Rural road (see section above). As shown in Table 95, Correct and Incorrect responses showed main effects on difficulty level. An effect of RLv in Correct responses was also found. No interaction effect was found.

**Table 95 – Mean values by S-IVIS difficulty level, Cognitive task, Motorway**

| the cognitive task_Mw | | Mean values | | | Significant Effects | | | Post Hoc test | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv2 | SLv3 |
| s_correct [%] | Mw | 74,8 | 63,4 | 63,0 | ✓ | ✓ | ✗ | SLv1 | ✓ | ✓ |
| | Static | 83,3 | 77,3 | 69,7 | | | | SLv2 | | ✗ |
| s_missed [%] | Mw | 16,2 | 20,8 | 19,2 | ✗ | ✗ | ✗ | SLv1 | | |
| | Static | 9,3 | 7,9 | 12,0 | | | | SLv2 | | |
| s_incorrect [%] | Mw | 9,0 | 15,7 | 17,8 | ✓ | ✗ | ✗ | SLv1 | ✓ | ✓ |
| | Static | 7,4 | 14,8 | 18,3 | | | | SLv2 | | ✗ |

As also can be seen in Figure 133 and Figure 134 there are differences between SLv1 and 2 as well as between 1 and 3. No significant difference is shown between SLv2 and 3.

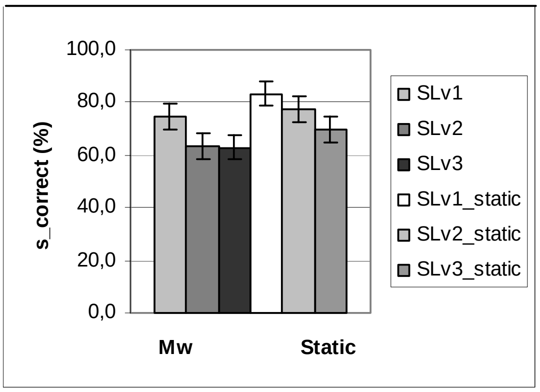



**Figure 133 – % correct responses, Cognitive task, Motorway**

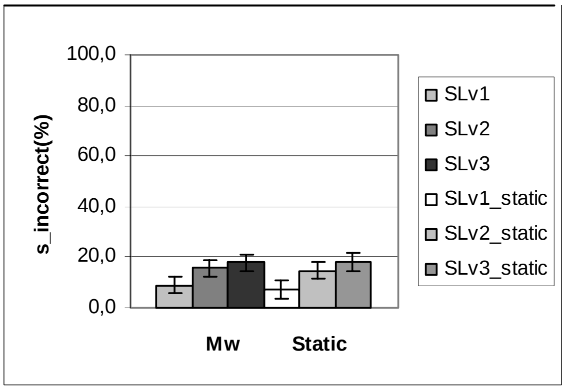



**Figure 134 – % incorrect responses, Cognitive task, Motorway**

As in the cognitive task-rural condition, different patterns were obtained in the static and dynamic conditions.

### 8.6.4. Effects of the visual task in Motorway driving

This section presents the results for the motorway-visual task condition. Detailed discussions of results are only given if the results depart significantly from the results from the rural-visual task condition (presented and discussed above).

#### *8.6.4.1. Self reported driving performance*

The results for subjective ratings in the visual task-motorway condition are presented in Figure 135 and Table 96. There were significant differences between all S-IVIS levels except between SLv 2 and 3.

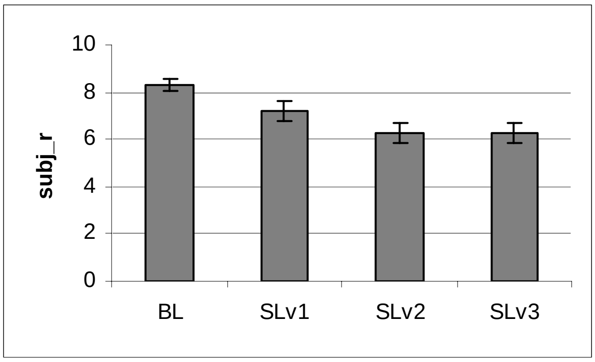



**Figure 135 – Self reported driving performance, Visual task, Motorway**

**Table 96 – ANOVA results for self rated driving performance, Visual task, Motorway**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| subj_r | 8.3 | 7.2 | 6.3 | 6.3 | ✓ | n/a | n/a | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | × |

### *8.6.4.2. Longitudinal control*

As described above, the motorway scenario included a braking event, where the idea was to measure the effect of the visual task on brake reaction time. However, due to large variances induced by the driving scenarios, a proper analysis of these data was not possible. As in the rural condition, there was a small but significant reduction in speed as a result of the visual task. The results are presented in Figure 136 and Table 97. Only the difference between baseline and SLv 3 was significant. Of the other speed measures, minimum speed (*u_sp)* indicated a significant difference while speed difference (*d_sp*) did not. There was also an increase in the speed variation (st_sp), although this could mainly be attributed largely to a monotonous speed reduction.

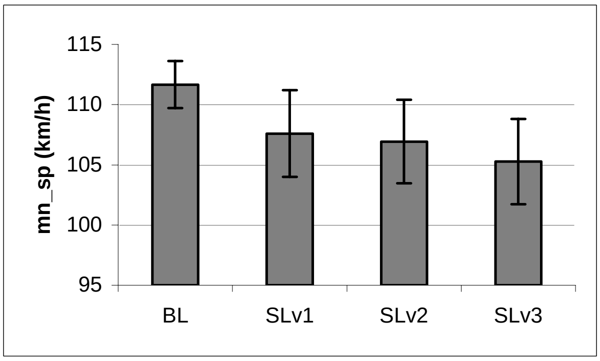



**Figure 136 – Mean speed (mn_sp), Visual task, Motorway**

**Table 97 – ANOVA results for mean speed (mn_sp), Visual task, Motorway**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| mn_sp (km/h) | 111 | 108 | 107 | 105 | ✓ | n/a | n/a | BL | × | × | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

#### *8.6.4.3. Lateral control*

No significant effects were found for the mean lateral position (mn_lp) measure as has been discussed above in the presentation of rural- visual task results. A possible explanation for this is the lack of oncoming traffic in this environment.

For the continuous lateral position measures, significant effects were found for both standard deviation of lateral position (*st_lp*) and the mean of TLC minima (*mn_tlc*). The results for *st_lp* are presented in Figure 137 and Table 98.

For the lateral position swerving measures (indicating line crossing or near encounters), a significant effect was found for *pr_tlc* (the proportion TLC minima less than 1 second), but not for *lanex* (the proportion of lane exceedences). The main reason for the different results for *lanex* in the two road types (effect on rural, no effect on motorway) was probably the difference in lane width, resulting in less lane exceedence events on the motorway.

The results for *pr_tlc* are presented in Figure 138 and Table 99. As the results show, effects were only found between baseline and SLv 2- 3.

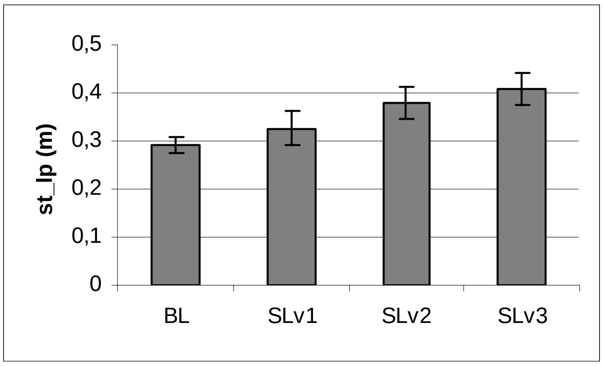



**Figure 137 – Lateral position standard deviation (st_lp), Visual task, Motorway**

**Table 98 – ANOVA results for lateral position standard deviation (st_lp), Visual task, Motorway**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| st_lp (m) | 0.29 | 0.33 | 0.38 | 0.40 | ✓ | n/a | n/a | BL | × | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | ✓ |
| | | | | | | | | SLv2 | | | × |

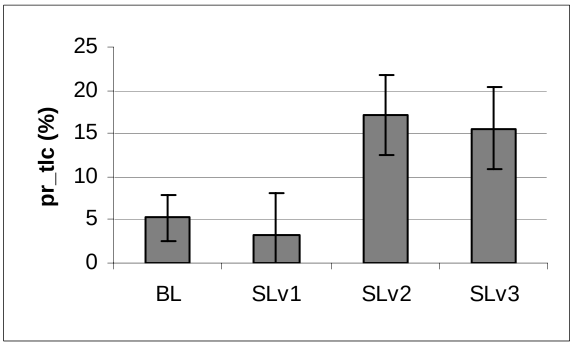



**Figure 138 – Proportion of TLC minima < 1 s. (pr_tlc), Visual task, Motorway**

**Table 99 – ANOVA results for the proportion of TLC minima < 1 s. (pr_tlc), Visual task, Motorway**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| pr_tlc (%) | 5.2 | 3.3 | 17.2 | 15.6 | ✓ | n/a | n/a | BL | × | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | × |

The results of the visual task on steering wheel movements followed the same general pattern as for the rural road, although the effects were slightly weaker. Significant effects were found for standard deviation of steering angle (*st_st*), steering wheel reversal rate with all thresholds (rr_st1-7), steering entropy (*en_st*), high frequency steering (*hi_st*) and rapid steering wheel turns (*rswt*, both for 5 and 10 deg/s velocity thresholds). The results for *rr_st1* are presented in Figure 139 and Table 100.

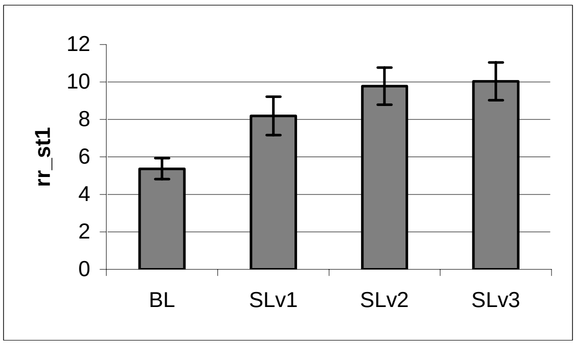



**Figure 139 – Steering wheel reversal rate (1 degree threshold, rr_st1), Visual task, Motorway**

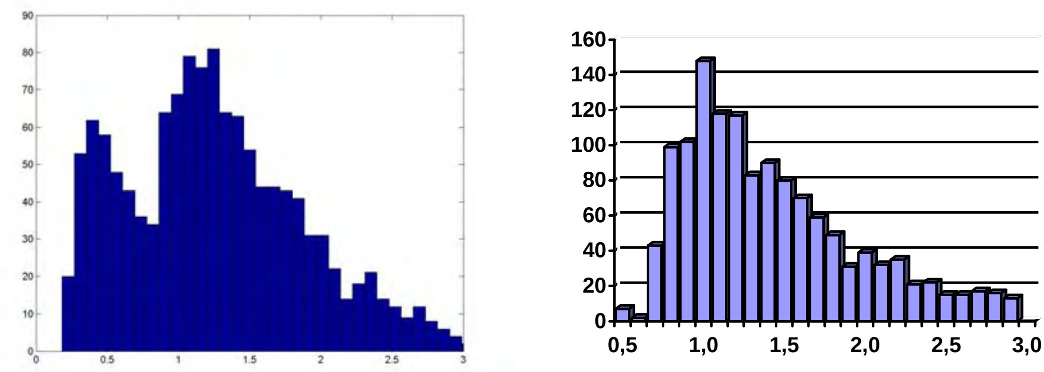
**Table 100 – ANOVA results for steering reversal rate (1 degree threshold, rr_st1), Visual task, Motorway**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| rr_st1 | 5.4 | 8,2 | 9.7 | 10.0 | ✓ | n/a | n/a | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

### *8.6.4.4. Eye movements*

As in the rural road and the visual task, only differences between S-IVIS difficulty levels were investigated.

The distribution of single glance durations to the S-IVIS display is illustrated inFigure 122, and compared to existing data collected manually by Rockwell (1988). As can be observed, the general distributions are similar, with the exception of an additional peak at about 0.4 s in the present data (compared to 0.3 seconds in the rural-visual task condition). For further discussion of this, see the corresponding section in the rural-visual task analysis above. The results for mean single glance duration are presented in Figure 141 and Table 101.




*Current study* *Rockwell (1988)*

**Figure 140 – Distribution of single glance durations, Visual task, Motorway**

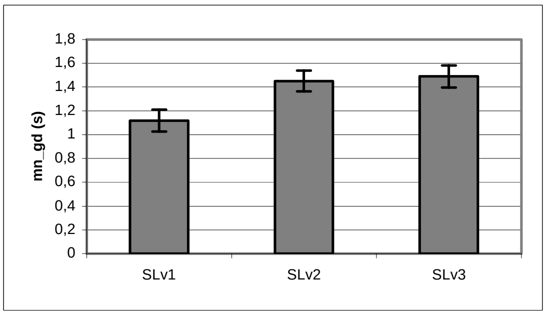



**Figure 141 – Mean single glance duration (mn_gd), Visual task, Motorway**

**Table 101 – ANOVA results for mean single glance duration (mn_gd), Visual task, Motorway**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| mn_gd (s) | n/a | 1.12 | 1.45 | 1.49 | ✓ | n/a | n/a | BL | n/a | n/a | n/a |
| | | | | | | | | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | × |

The results from the glance frequency (*n_gl*) analysis are given in Figure 142 and Table 102. Like the mean glance duration, SLv2-3 differs significantly from SLv1.

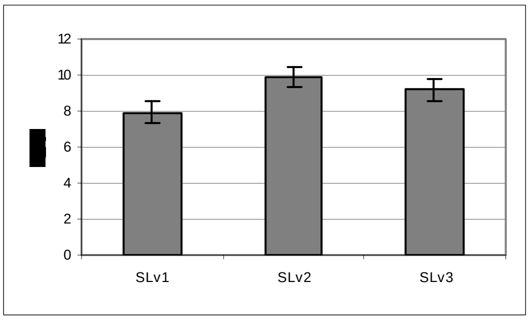



**Figure 142 – Glance frequency (n_gl), Visual task, Motorway**

**Table 102 – ANOVA results for glance frequency (n_gl), Visual task, Motorway**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| n_gl | n/a | 8.0 | 9.9 | 9.2 | ✓ | n/a | n/a | BL | n/a | n/a | n/a |
| | | | | | | | | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | × |

Significant effects were found for both measures combining glance duration and frequency, i.e. proportion of glance time of total task time (*pr_glt*) and percent road centre (*prc*). An important difference from the rural-visual task results was that there was no difference between SLv2 and 3 in the motorway scenario (while, in the rural scenario, significant differences were found between all S-IVIS levels). The results for *prc* are presented in Figure 143 and Table 103.

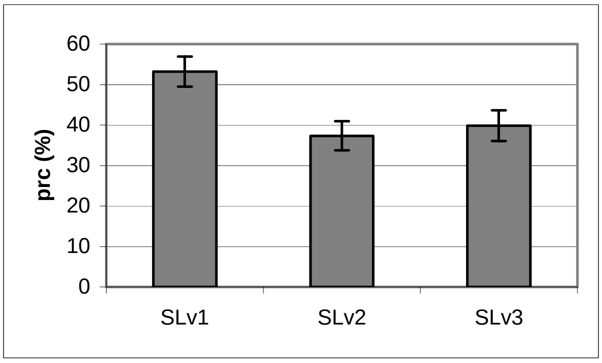



**Figure 143 – Percent road centre (prc), Visual task, Motorway**

**Table 103 – ANOVA results for percent road centre (prc), Visual task, Motorway**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **prc (%)** | n/a | 53.2 | 37.3 | 38.9 | ✓ | n/a | n/a | BL | n/a | n/a | n/a |
| | | | | | | | | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | × |

Other measures investigated were the glance duration variation (*sd_gd*), the number of glances longer than 2 seconds (*n_gl2*). The results were generally in line with the results for the measures reported here.

### *8.6.4.5. S-IVIS performance*

Performance on the visual task, while driving on Motorway, was analysed in the same way as for Rural road (see section above).

As shown in Table 91, all four measures show main effects of difficulty level and RLv as well as interaction effects.

**Table 104 – Mean values and significant effects, Visual task, Motorway**

| Arrow_Mw | | Mean values | | | Significant Effects | | | Post Hoc test | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv2 | SLv3 |
| s_correct [%] | Mw | 98,1 | 74,9 | 77,0 | ✓ | ✓ | ✓ | SLv1 | ✓ | ✓ |
| | Static | 99,5 | 94,7 | 84,1 | | | | SLv2 | | ✓ |
| s_rt [s] | Mw | 1,9 | 2,9 | 2,9 | ✓ | ✓ | ✓ | SLv1 | ✓ | ✓ |
| | Static | 2,1 | 2,1 | 2,2 | | | | SLv2 | | × |
| s_missed [%] | Mw | 1,9 | 10,2 | 11,1 | ✓ | ✓ | ✓ | SLv1 | ✓ | ✓ |
| | Static | 0,0 | 2,1 | 7,5 | | | | SLv2 | | ✓ |
| s_incorrect [%] | Mw | 0,0 | 14,9 | 11,9 | ✓ | ✓ | ✓ | SLv1 | ✓ | ✓ |
| | Static | 0,5 | 3,2 | 8,3 | | | | SLv2 | | × |

The post-hoc analyses show effects of S-IVIS difficulty between all three complexity levels for correct (see Figure 144) and missed responses (see Figure 146). For reaction times and incorrect responses there are significant differences between SLv1 and 2 and between 1 and 3 but not between 2 and 3 (see Figure 146 and Figure 147).

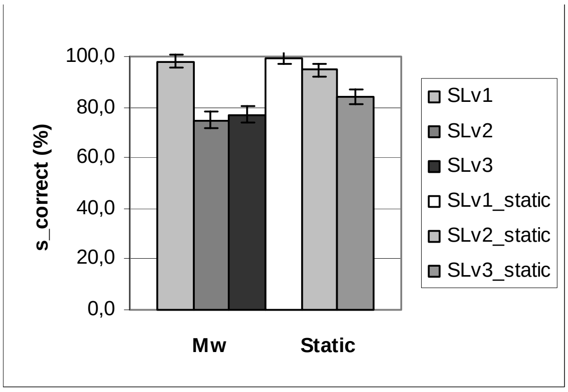



**Figure 144 – % correct responses, Visual task, Motorway**

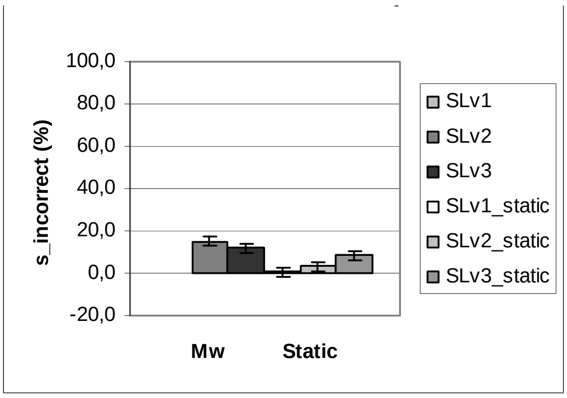



**Figure 145 – % incorrect responses, Visual task, Motorway**

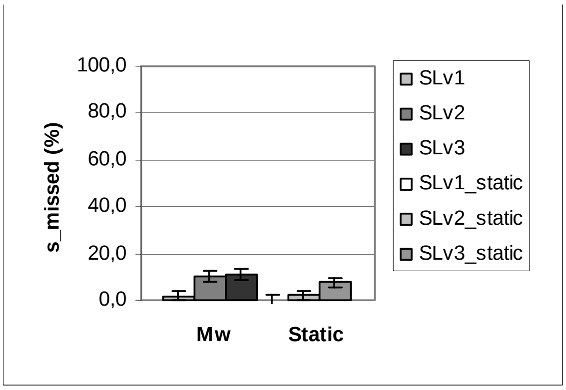



**Figure 146 – % missed responses, Visual task, Motorway**

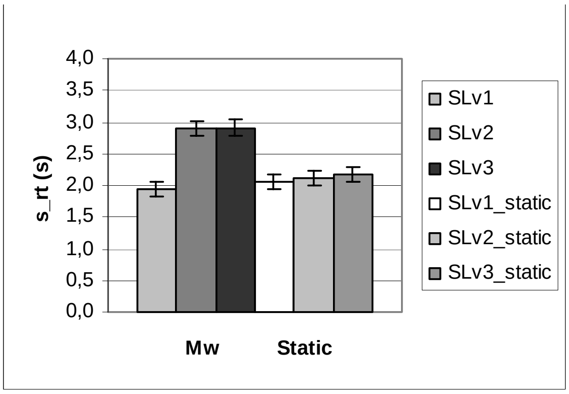



**Figure 147 – Reaction times, Visual task, Motorway**

## 8.7. Summary and conclusions

### 8.7.1. General overview

An important negative result from the present study was that no effects were found for the brake reaction time and headway measures in the critical events (RLv2 on motorway and RLv3 on the rural road). This could most likely be attributed to problems with the scenarios used in the present study, which induced large variance that overshadowed any effects of S-IVIS. Thus, an important conclusion of the present study is that scenarios involving surrounding traffic are very difficult to set up in a way appropriate for IVIS evaluation, even in simulators.

In general, the results for the rural road and motorway were similar, although there was a tendency for slightly stronger effects on the motorway. However, the two S-IVIS tasks (visual and the cognitive task) had very different effects. An overview of the effects found for the two tasks is given in Table 105.

**Table 105 – Overview of the effects of the cognitive and visual tasks**

| Measure type | Effects of the cognitive task | Dependent measures indicating the effect | Effects of the visual task | Dependent measures indicating the effect |
|---|---|---|---|---|
| **Lateral control** | Shift towards the right (only on rural road) | *mn_lp* | Shift towards the right (only on rural road) | *mn_lp* |
| | Reduced lateral position variance | *st_lp* | Increased lateral position variance and number of lane exceedences | *st_lp, lanex, pr_tlc, mn_tlc* |
| | Increased amount of micro-corrections <= 1 deg. (only on rural road) | *rr_st_1, hi_st, en_st, rswt_5-10* | Larger, more frequent, less ordered and faster steering wheel movements | *st_st, rr_st_1-7, hi_st, en_st, rswt_5-10* |
| **Longitudinal control** | No effects found | - | Speed reduction<br>Increased speed variation | *mn_sp, u_sp, sp_diff*<br>*st_sp* |
| | | | Increased distance and time headway | *mn_hwd, mn_hwt* |
| | | | Increased distance and time headway variation | *sd_hwd, sd_hwt* |
| **Eye movements** | Increased gaze concentration towards the road centre | *st_ga, prc* | Increased duration of single glances to IVIS (for increased SLv). | *mn_gd, n_gl2, pr_gl2* |
| | | | Increased single glance duration variation (for increased SLv). | *sd_gd* |
| | | | Increased number of glances to IVIS (for increased SLv) | *n_gl* |
| | | | Reduced proportion of fixations on to the road centre | *prc, mn_glt* |
| **Subjective ratings** | Reduced ratings of own driving performance | *subj_r* | Reduced ratings of own driving performance | *subj_r* |

The general effects of the two S-IVIS task types are summarised below:

### 8.7.2. S-IVIS performance

The results from the analysis of the S-IVIS performance clearly demonstrate that dynamic performance (performance while driving) can in general not be reliably predicted from static performance.

Moreover, at least for the cognitive task, the effect of the S-IVIS task on the dependent measures is not linearly related with either static or dynamic task performance. While performance differences were found between SLv in both static and dynamic conditions, there were no such differences in any of the dependent measures (similar effects for all SLv). A likely explanation for this is that the effects of the S-IVIS task on driving is not simply a linear function of difficulty, but are also strongly affected by the driver's strategies for allocation of mental and visual resources.

### 8.7.3. Effects of the visual task

In general, the visual task had strong effects on most of the dependent measures. A common pattern was that the effects increased monotonically with IVIS load (although not linearly, as further discussed below). Three main types of effects of the visual task could be observed:

#### *8.7.3.1. Reduced lateral control performance*

Strong effects were found on both lane-related and steering wheel movement measures. Lane exceedences and excessive lane weaving was common as well as large sluggish steering wheel movements. Effects were generally stronger in curves than in straight sections.

An interesting finding for both the lane and steering wheel measures is that there are some indications of a ceiling effect in that they do not generally increase linearly as a function of S-IVIS difficulty (SLv), but rather asymptotically toward a limiting value of control degradation. In this study, this pattern is more pronounced when road level complexity (RLv) increases. This indicates the presence of a minimum target level of degraded control. When this level is reached, either the increased demand has to be compensated for (e.g. by reducing speed) or the effort has to be increased. This effect could mean that it is difficult to differentiate between effects of different IVIS in demanding driving scenarios.

There was no evidence for any reduction in longitudinal control performance. The effects of speed and headway could rather be interpreted as a desire to compensate to the increased visual load (see below).

#### *8.7.3.2. Increased visual demand*

In the analysis of glance-based measures, comparisons were only made between S-IVIS levels (no baseline comparison). The results show that glances become longer and more frequent and less fixations are directed towards the road centre when S-IVIS complexity level increases. The results also show that, as may be expected, visual demand measures are strongly related to vehicle control. When the proportion of gaze time directed towards the road centre decreased, control performance was reduced.

An interesting result was that the single glance duration towards S-IVIS was significantly reduced in curves (thus increasing the percentage road centre, *prc*) as compared to straight sections. This could be interpreted as a re-allocation of resources from the S-IVIS task to the vehicle control task in order to cope with the increased road level complexity.

#### *8.7.3.3. Compensatory effects*

In addition to examine the effects on vehicle control and visual demand, several *compensatory* behaviours were observed. First, there was a shift towards the right in the lane (on the rural road), which could be interpreted as an increase in safety margins to potential oncoming traffic. Second, there was a speed reduction and an increase in headway to the lead vehicle. It is not clear whether this speed reduction was mainly due to a desire to increase headway specifically or whether it occurred in order to increase time-based safety margins in general (i.e. slowing down independently of the lead vehicle). In any case, this could be interpreted as adaptation in order to keep safety margins (or perceived risk) within satisfactory boundaries.

#### *8.7.3.4. Conclusions – effects of the visual S-IVIS task*

A general conclusion from the present results is that the effect of visual S-IVIS on driving behaviour is the result of a complex interaction between factors related to (1) the S-IVIS task (type, difficulty etc.), (2) the driving scenario (type, complexity etc.) and (3) the driver (ability, allocation strategy etc.). Further analysis is needed to identify the precise nature of this interaction. An important consequence for present purposes is that it is absolutely necessary to keep the scenario complexity (road type, road width, speed etc.) under strict control when evaluating IVIS.

### 8.7.4. Effects of the cognitive task

In general, the effects of the cognitive task were weaker than the effects of the visual S-IVIS. Moreover, the effects were very different in nature. The cognitive task resulted in reduced lateral position variance, an increased concentration of gaze fixations towards the road centre and an increased amount of steering micro corrections. This strongly indicates increased vehicle control compared to baseline. However, the subjects still rated their own driving performance as severely reduced compared to baseline.

Moreover, there were no differences between the effects of the three S-IVIS levels. A simple explanation for this would be that the S-IVIS levels actually did not differ in difficulty. However, the results from the S-IVIS performance analysis clearly demonstrate different effects of the three SLv. The difference between S-IVIS performance and actual effect on driving is probably related to the drivers' effort allocation strategies (as discussed above).

Importantly, except for the subjective performance ratings, *the present results provide no evidence for reduced safety as a result of the cognitive task*. Rather, the results seem to indicate the opposite, i.e. improved vehicle control performance. However, since most cognitive resources are allocated towards the S-IVIS task and the driving control task, there are little resources left for detection of unexpected hazards. Thus, degraded hazard detection performance would be expected as a result of the cognitive task performance. This hypothesis could not be confirmed by the present study (for reasons outlined above), but has been clearly demonstrated elsewhere (e.g. Recarte and Nunes, 2003). This reduced ability is probably recognised by the drivers (more or less consciously), which would explain the reduced subjective performance ratings obtained in the present study.

The general conclusion is that the current driving measures are not capable of assessing the accident risk of cognitive IVIS tasks in a test regime. It could perhaps be argued that measures of gaze concentration could be used as a surrogate measure for hazard detection performance. However, it may be difficult to distinguish these effects from positive behavioural effects e.g. an increased attention to the road ahead when the road complexity increases. It would probably also be difficult to convince the public/equipment manufactures of an assessment criterion of this kind. Thus, it seems clear that proper assessment of cognitive IVIS tasks requires some type of event detection metric.

## 8.8. Measures summary tables

This section provides a summary of the ANOVA results presented above. These represent only a sub-set of the significant results obtained in the study. See the text above for indications of other measures for which significant results were obtained.

### 8.8.1. Rural road and the cognitive task

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **subj_r** | 7.9 | 6.5 | 6.6 | 6.5 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **mn_lp [m]** | 0.15 | 0.2 | 0.23 | 0.2 | ✓ | ✓ | ✗ | BL | ✗ | ✓ | ✗ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **st_lp [m]** | 0.24 | 0.2 | 0.19 | 0.2 | ✓ | ✓ | ✗ | BL | ✗ | ✓ | ✗ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **rr_st1** | 7.2 | 9.5 | 9 | 9.2 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **st_ga (deg)** | 0.06 | 0.046 | 0.048 | 0.045 | ✓ | ✗ | ✗ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **pr_tlc (%)** | 6 | 11.3 | 14 | 10.1 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |

### 8.8.2. Rural road and the visual task

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **subj_r** | 8 | 7.3 | 6.4 | 6 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | ✗ |
| **mn_sp (km/h)** | 82.5 | 75 | 77.3 | 75.2 | ✓ | ✗ | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **mn_hwt (s)** | 3.3 | 3.9 | 4 | 4.2 | ✓ | ✗ | ✗ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **mn_lp (m)** | 0.19 | 0.25 | 0.31 | 0.31 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **st_lp [m]** | 0.24 | 0.3 | 0.37 | 0.38 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | ✗ |
| **pr_tlc (%)** | 6 | 11.3 | 14 | 10.1 | ✓ | ✓ | ✗ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **rr_st1** | 6.8 | 9.7 | 10.7 | 10.9 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✓ |
| | | | | | | | | SLv2 | | | ✗ |
| **mn_gd (s)** | n/a | 1.12 | 1.23 | 1.42 | ✓ | ✓ | ✗ | BL | | | |
| | | | | | | | | SLv1 | | ✗ | ✓ |
| | | | | | | | | SLv2 | | | ✓ |
| **n_gl** | n/a | 7.6 | 9.6 | 9.5 | ✓ | ✗ | ✗ | BL | | | |
| | | | | | | | | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | ✗ |
| **prc (%)** | | 59.3 | 48.8 | 38.8 | ✓ | ✓ | ✗ | BL | | | |
| | | | | | | | | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | ✓ |

### 8.8.3. Motorway and the cognitive task

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **subj_r** | 8.2 | 7 | 7.2 | 6.8 | ✓ | n/a | n/a | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **st_lp (m)** | 0.3 | 0.24 | 0.24 | 0.25 | ✓ | n/a | n/a | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |
| **st_gd (deg)** | 0.83 | 0.52 | 0.63 | 0.65 | ✓ | n/a | n/a | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | | | SLv2 | | | ✗ |

### 8.8.4. Motorway and the visual task

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **subj_r** | 8.3 | 7.2 | 6.3 | 6.3 | ✓ | n/a | n/a | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | × |
| **mn_sp (km/h)** | 111 | 108 | 107 | 105 | ✓ | n/a | n/a | BL | × | × | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |
| **st_lp (m)** | 0.29 | 0.33 | 0.38 | 0.4 | ✓ | n/a | n/a | BL | × | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | ✓ |
| | | | | | | | | SLv2 | | | × |
| **pr_tlc (%)** | 5.2 | 3.3 | 17.2 | 15.6 | ✓ | n/a | n/a | BL | × | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | × |
| **rr_st1** | 5.4 | 8,2 | 9.7 | 10 | ✓ | n/a | n/a | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |
| **mn_gd (s)** | n/a | 1.12 | 1.45 | 1.49 | ✓ | n/a | n/a | BL | | | |
| | | | | | | | | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | × |
| **n_gl** | n/a | 8 | 9.9 | 9.2 | ✓ | n/a | n/a | BL | | | |
| | | | | | | | | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | × |
| **prc (%)** | n/a | 53.2 | 37.3 | 38.9 | ✓ | n/a | n/a | BL | | | |
| | | | | | | | | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | × |

# 9. The VTI Driving Simulator Experiment

## 9.1. Test site

The VTI driving simulator was used in this study (Nilsson, 1989; Nordmark, 1994). The simulator is a high fidelity, moving base dynamic driving simulator, repeatedly validated (Haakamies-Blomqvist, Östlund, Henriksson, & Heikkinen, 2000; Harms, 1996). See Figure 148. In the simulator, driving behaviour can be measured with high accuracy. An ambulatory digital recorder (Vitaport 2, Temec BV) was used for measuring cardiac and nervous activities. A touch display and standard computer speakers were installed in the simulator for managing the S-IVIS tasks.

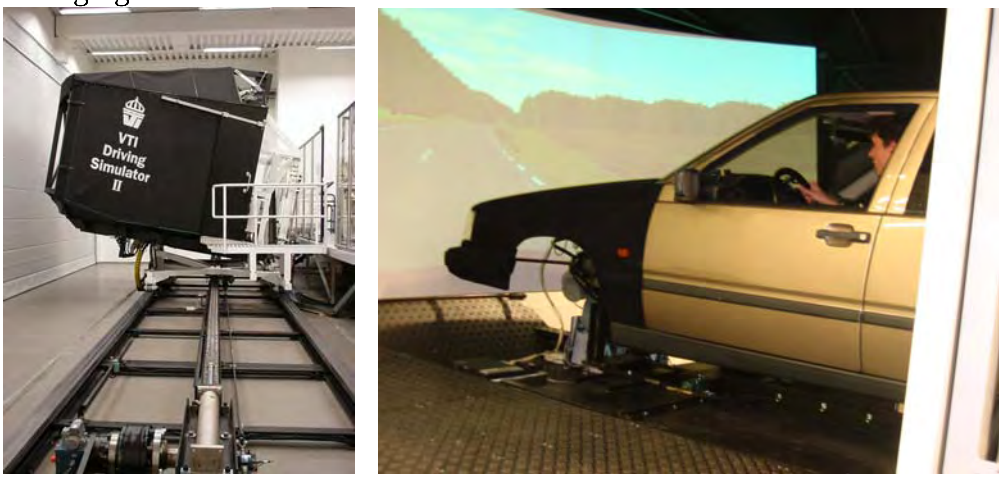



Figure 148 – The VTI driving simulator. Left, exterior; right, the vehicle cabin.

## 9.2. Scenarios and participants

### 9.2.1. Participants

Forty eight average drivers were included in the study, 30 (62.5%) were male and 18 (37.5%) female. Their average age was 38 years (range 25-53) and the average time they had held their license was 18 years (range 4-35). On average they had driven 16,900 km (range 750-60,000) in the past 12 months and had an average total mileage of 265,000 km (range 40,000-1,000,000).

### 9.2.2. Rural road

The rural road was implemented according to the rural road description in *2.6.1-Rural Road*. The length of the route was 29 km and included three road complexity levels; *straight*, *curved* road and *events*. The events in the VTI simulator study were not sheep or fallen trees, as in the rural road definition. Instead vehicles or road works blocked the road. The signed speed limit was 90 km/h, which corresponded to most rural roads in Sweden.

### 9.2.3. Motorway

The motorway was implemented according to the description in *2.6.2-Motorway*. The motorway was 46 km long and included two road complexity levels; *normal* road conditions and *events*.

## 9.3. S-IVIS evaluated

Both the visual task and the cognitive task were included. The original three complexity levels described in *2.4-Surrogate IVIS* were used.

## 9.4. Experimental design

S-IVIS complexity and road complexity were within-subject-factors. The experimental design also included two road types and two S-IVIS tasks. These are however not treated as factors since no between S-IVIS or road type statistical comparisons were made. Each participant used only one of the two S-IVIS. Each road was run twice; with the S-IVIS and without the S-IVIS. The runs are referred to as the *experimental* and *baseline* runs. The S-IVIS was activated nine times per experimental run.

The experimental design described in *2.3-Experimental design* was used for the rural road. For the motorway, the same design was used, although the road complexity levels RLv1 and RLv2 were collapsed into *normal* driving conditions. RLv3 corresponded to *Event*.

All participants conducted the static S-IVIS test as specified in the standard experimental design. This test was conducted either before or after driving the rural road. The order was counterbalanced.

## 9.5. Procedure

The participants received written and spoken instructions. Electrodes for the physiological measuring were attached. The participants practised driving on the rural road for 10 minutes to familiarise themselves with the simulator. Then, the participants drove the experimental and baseline runs; first in the rural road, and then in the motorway. During the runs, the participants were asked to rate his/her driving performance. The road environment and the participant's face were recorded on video. After driving, the participants signed a document approving/not approving VTI to use the video recordings for scientific purposes.

## 9.6. Measures and analysis method

Speed, lateral position and steering angle were measured. From these, several safety critical indicators were derived, such as lateral position variation, time to line crossing and reversal rate. All measures were implemented according to the specifications in Appendix 2. The effects of the S-IVIS tasks and road complexity were analysed according to the common specification. For the S-IVIS tasks, the proportion of correct responses, misses and reaction time was recorded according to the specification in *2.7.3-S-IVIS measures and analysis*. These results were however only compared qualitatively.

## 9.7. Results

Below, the results are reported for rural road and motorway separately. Also, the results are reported for the cognitive task and the visual task separately. There are result summary tables for all measures in *9.9 Measures summary tables*. In these, mean values, main effects and post hoc tests are included.

## 9.7.1. Effects of the cognitive task in Rural Road driving

### *9.7.1.1. Self reported driving performance*

There were significant differences between each the cognitive task difficulty level (SLv) and baseline (BL) in the self reported driving performance (subj_r). subj_r did however not discriminate between the experimental levels (SLv1 - SLv3). The rated driving performance was 7.7 without the cognitive task and 7.0 with the cognitive task. See Figure 149 and Table 106. The 95% confidence interval is indicated by error bars.

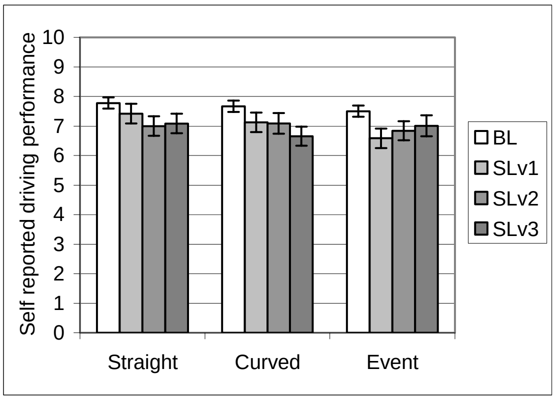



**Figure 149 – Self reported driving performance (subj_r), Cognitive task, Rural road**

**Table 106 – Analysis of self reported driving performance (subj_r), Cognitive task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| SubjR | 7,65 | 7,04 | 6,98 | 6,92 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

### *9.7.1.2. Longitudinal control*

The longitudinal control measures were analysed separately for straight/curved road and events due to the lead vehicle’s brake profile in the events.

The expected reaction to the S-IVIS distraction was a compensatory reduction in speed. Instead, for the cognitive task there was a pattern in mean speed (mn_sp) and speed change (d_sp) that indicated that speed increased with S-IVIS difficulty. See Figure 150. Although not significant, this effect could be explained by the drivers being distracted in monitoring the own speed, which indicates more risky driving behaviour. This hypothesis is further strengthened by the significant increase in speed variation as an effect of the cognitive task difficulty; 1.9 km/h for BL to 2.3 for SLv3. See Figure 151 and Table 107. The speed measures were not analysed for the event since the speed was primarily controlled by the lead vehicle.

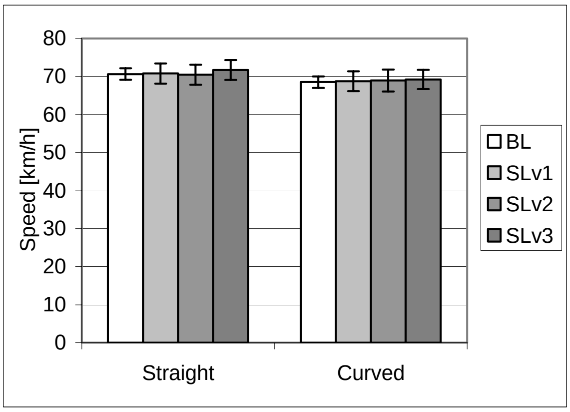



**Figure 150 – Mean speed (mn_sp), Cognitive task, Rural road**

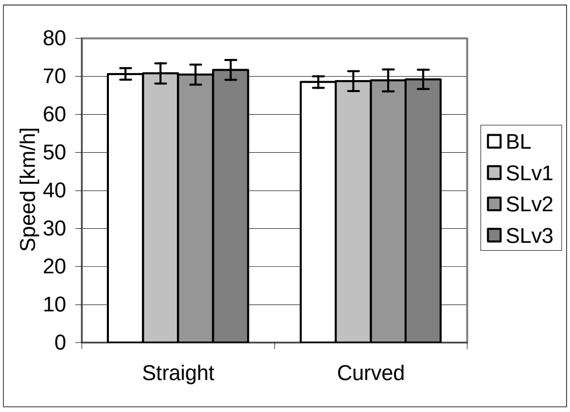



**Figure 151 – Speed variation (sd_st), Cognitive task, Rural road**

**Table 107 – Analysis of speed variation (sd_st), Cognitive task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| st_sp [km/h] | 1,87 | 2,11 | 2,17 | 2,31 | ✓ | × | × | BL | × | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

In the interaction with the lead vehicle in the straight and curved road sections no effects were found except that the time and distance headway variation (sd_hwt and sd_hwd) increased with S-IVIS difficulty. These effects were however so small (+ 1 to 2 metres) that they cannot be considered being of any safety impact. The trends in the different headway safety measures, such as mean headway and min headway, indicated that the mean distance and time headways (e.g. mn_hwd) were increased as the S-IVIS task became more difficult. This would indicate a compensatory behaviour trying to increase the safety margin to the lead vehicle. See Figure 152. These effects were however not significant.

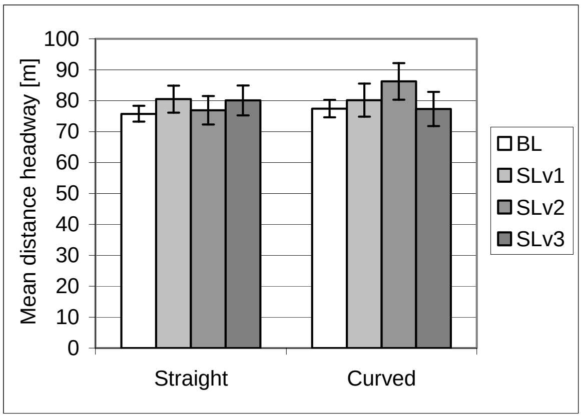



**Figure 152 – Mean distance headway (mn_hwd), Cognitive task, Rural road**

In the events, the min distance headway (u_hwd) was significantly reduced by 5 metres for SLv1 and SLv2 compared to baseline, but not for SLv3. As the S-IVIS difficulty increased from 1 to 2 to 3, however, the headway tended to increase again, but not reaching the BL value. See Figure 153 and

Table 108. (Note that the effect of the cognitive task did not appear as significant in the ANOVA analysis. The differences found were identified in the post hoc test.) The same pattern was found in mean headway (mn_hwd and mn_hwt), again not significantly. The increase in headway from SLv1 to SLv3 could be explained by the drivers mobilising more efforts to compensate for the increased cognitive demands as the cognitive task became more difficult. However, with the S-IVIS active (SLv1, 2 and 3), the drivers were already distracted to the degree of not being able to sufficiently assess their own travel speed or behaviour of the lead vehicle. This resulted in the drivers not being able to cohere with the slowing down of the lead vehicle. This would explain why the same pattern in headway was not found for the straight and curved road segments; in the non event situations (straight and curved) the lead vehicle maintained a constant speed to which the drivers had adapted even before the S-IVIS was activated. It may be hypothesised that cognitive distraction leads to less ability to assess the dynamic behaviour of one's own vehicle and other road users.

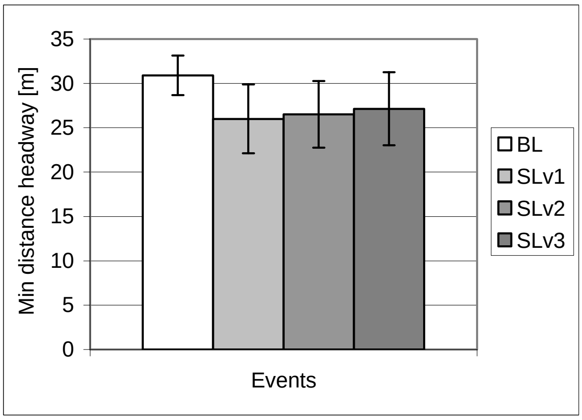



**Figure 153 – Min distance headway (u_hwd), Cognitive task, Rural road**

**Table 108 – Analysis of min distance headway (u_hwd), Cognitive task, Rural road**

| | Mean values | | | | Effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| u_hwd [m] | 30,9 | 25,99 | 26,51 | 27,14 | × | BL | ✓ | ✓ | × |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |

The brake reaction time was measured in the events. Although the mean values increased with S-IVIS difficulty (Figure 154), this effect was not significant. The large average reaction time values (4-5 seconds) indicate that the events were not as critical as was intended. Reaction time was thus not a very feasible safety indicator to include in this specific scenario.

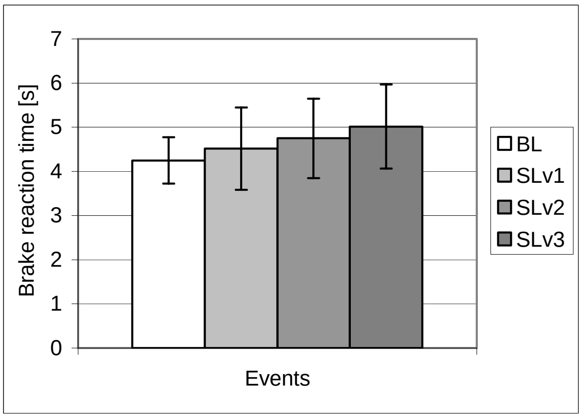



**Figure 154 – Reaction time (br_rt) to the events, Cognitive task, Rural road**

### *9.7.1.3. Lateral control*

The lateral position (mn_lp) was significantly shifted closer to the centre line as an effect of S-IVIS task complexity. The maximum shift was 3 cm. The safety impact of shift in lateral position is however not well understood. It may be a compensatory effect to increase the distance to objects that are considered hazardous to the driver.

The one degree reversal rate (rr_st1) increased significantly with S-IVIS difficulty; from 31 rev/minute (without S-IVIS) to 34 rev/minute (with S-IVIS). See Figure 155 and Table 109. For reversals of larger amplitude (> 3 degrees), no effect was found. The steering entropy followed the same pattern as rr_st1 and increased significantly, indicating a less predictable steering behaviour. It is remarkable that the entropy indicated less predictability for the straight road than for the curved road and event situations. For all other measures, the opposite was found, which is easy to understand since the steering activity increases with road curvature. No effect of the cognitive task was found in the high frequency component of the steering activity. The effect of S-IVIS on the steering measures was most pronounced in the straight road sections. The increased steering activity did however not result in any change in lateral position variation (st_lp) or any of the time to line crossing measures (e.g. mn_tlc).

It seems as if the cognitive load of the cognitive task resulted in a more active or nervous steering behaviour, possibly to due to a general mobilisation of resources to compensate for the increased cognitive demands. Based on the lateral control measures, it cannot be argued that the cognitive load resulted in any decrease in lateral control performance, rather the opposite.

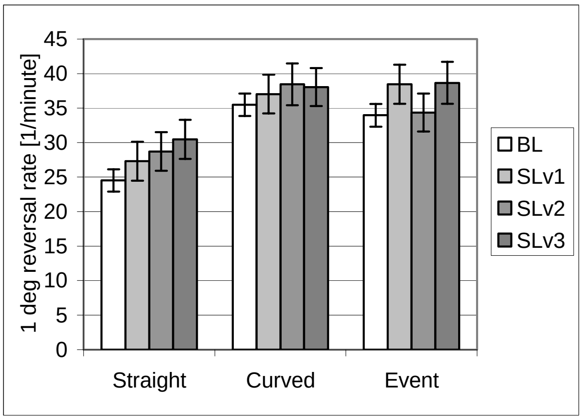



**Figure 155 – 1 degree reversal rate (rr_st1), Cognitive task, Rural road**

**Table 109 – Analysis of 1 degree reversal rate (rr_st1), Cognitive task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| rr_st1 [1/minute] | 31,32 | 34,26 | 33,83 | 35,71 | ✓ | ✓ | × | BL | ✓ | × | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

### *9.7.1.4. Workload*

There was no effect of the cognitive task in the inter-beat-intervals (ibi). There was however an effect of the cognitive task on mean skin conductance (dc_eda) and variation (ac_eda). See Figure 156 and Table 110. The effect on ac_eda and dc_eda were very similar.

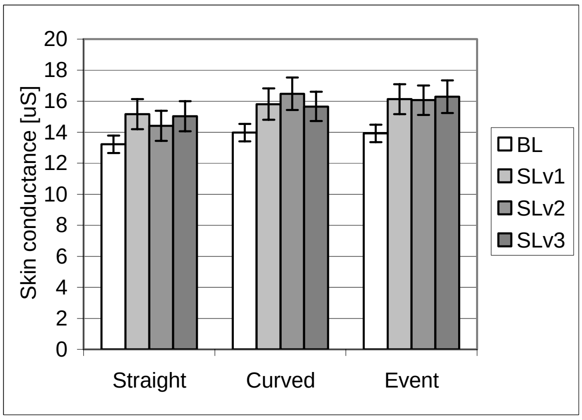



**Figure 156 – Mean skin conductance (dc_eda), Cognitive task, Rural road**

**Table 110 – Analysis of mean skin conductance (dc_eda), Cognitive task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| dc_eda [uS] | 13,70 | 15,70 | 15,65 | 15,66 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

### *9.7.1.5. S-IVIS performance*

The cognitive task results indicate that the performance was approximately the same for the static and driving condition. For the events, however, the performance was reduced. It can be concluded that the cognitive task was prioritised and not abandoned during driving, as was intended. See Figure 157, Figure 158, for the cognitive task % correct responses and missed responses.

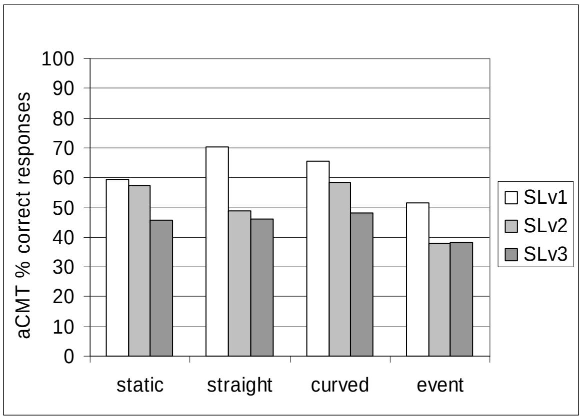



**Figure 157 – % correct responses, Cognitive task, Rural road**

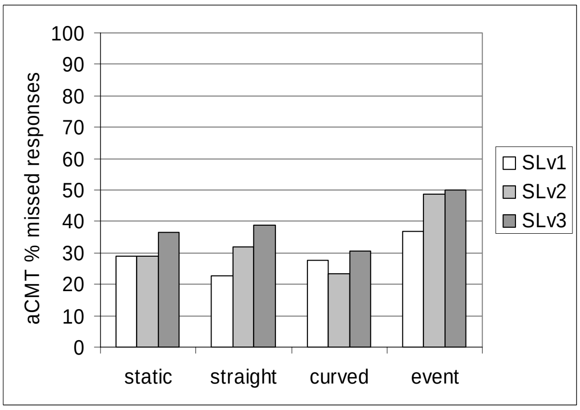



**Figure 158 – % missed responses, Cognitive task, Rural road**

## 9.7.2. Effects of the visual task in Rural Road driving

### *9.7.2.1. Self reported driving performance*

The rated driving performance (subj_r) decreased significantly with the visual task difficulty; from 8.0 for the baseline condition to 6.0 for the event condition. See Figure 159 and Table 111. There was an interaction effect between SLv and RLv, indicating that the visual task affected the driving performance more on curvy than straight roads ($p<0.001$). This was not surprising since the visual tracking of the road curvature requires more attention if the road is curved compared to straight. (The corresponding effects were not found for the cognitive task, which supports this explanation).

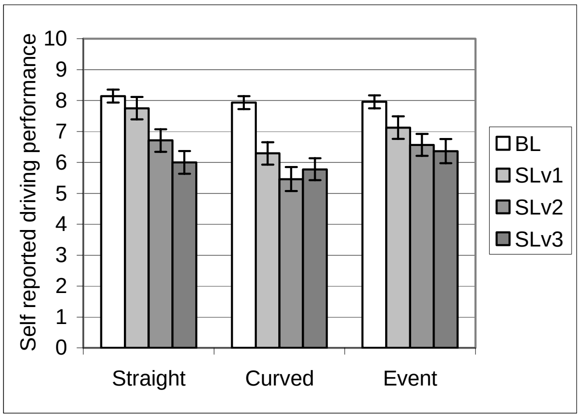



**Figure 159 – Self reported driving performance (subj_r), Visual task, Rural road**

**Table 111 – Analysis of self reported driving performance (subj_r), Visual task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| subj_r | 8,01 | 7,06 | 6,24 | 6,05 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | × |

### *9.7.2.2. Longitudinal control*

For straight and curved roads, the speed was reduced as an effect of the visual task difficulty. In speed change (d_sp) this effect was significant: 3 km/h reduction with the visual task. For mean speed (mn_sp), the effect was strongly indicative (p=0.058). For neither of the speed measures, was it possible to discriminate between the S-IVIS difficulty levels when the visual task was active. As for the cognitive task, an indication was found that SLv3 resulted in an increased speed comparing to SLv2. See Figure 160. There was also an effect in speed variation, probably resulting from the reduction in speed.

In the headway measures, there was a significant effect of the visual task on mean time headway (mn_hwt) indicating that the headway was increased with the visual task difficulty. See Figure 161 and Table 112. This is considered a compensatory behaviour, although very small; less than one second and no differences between the experimental conditions (SLv1 - SLv3). There was no headway decrease corresponding to the indicated speed increase for SLv3. The safety margin to the lead vehicle was thus maintained. There was an effect of the visual task on headway variation (st_hwd, sd_hwt), but not of any magnitude relevant to safety.

The decrease in speed and increase in headway were most likely related to compensatory behaviour to increase the margin to the lead vehicle. The indicated increase in speed for SLv3 however indicates a performance decrease in the monitoring of one's own and lead vehicle speeds.

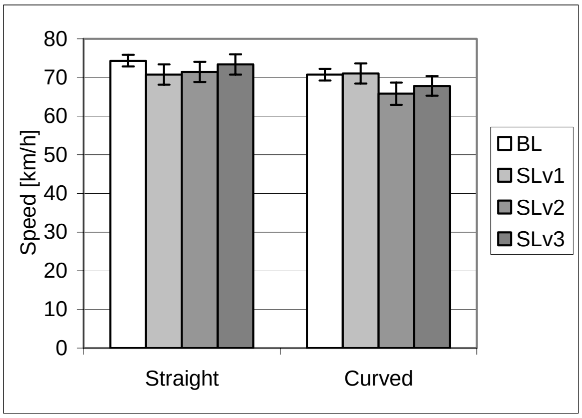



**Figure 160 – Mean speed (mn_sp), Visual task, Rural road**

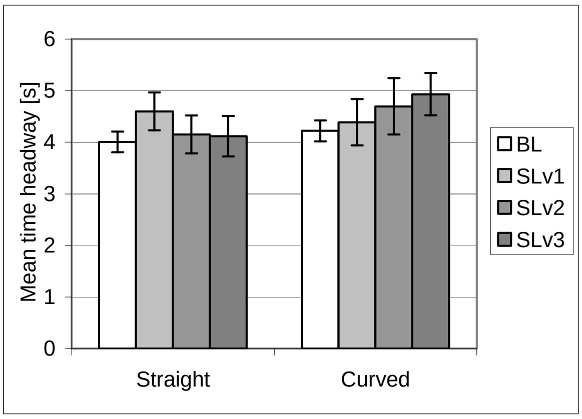



**Figure 161 – Mean time headway (mn_hwt), Visual task, Rural road**

**Table 112 – Analysis of mean time headway (mn_hwt), Visual task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| mn_hwt [s] | 4,12 | 4,50 | 4,42 | 4,52 | ✓ | ✓ | × | BL | ✓ | × | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

In the critical events no effects of the visual task were found, which suggests that the visual task did not result in any observable deterioration or compensation in the speed control as the lead car braked. As found for the cognitive task, the brake reaction time increased with the visual task difficulty, but not significantly. See Figure 162. The absence of an effect was probably due to learning effects and the relatively low risk of a collision in the event situations.

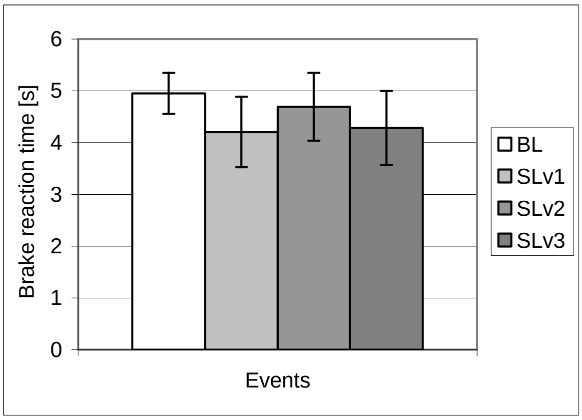



**Figure 162 – Brake reaction time (br_rt), Visual task, Rural road**

### *9.7.2.3. Lateral control*

As for the cognitive task, a significant shift towards the centre line was found as an effect of task difficulty. No conclusions can however be made on the impact on risk of accidents.

In all seven steering measures, it was found that an increase in the visual task difficulty resulted in a more active, nervous and unpredictable steering behaviour. See Figure 163 nd Table 113 for an example of steering activity. Also, the lateral position variation (st_lp) increased 5 cm for the experimental condition, and the mean time to line crossing (mn_tlc) decreased by 1 second. See Figure 164, Figure 165, Table 114 and Table 115. The most plausible explanation for these results is that the visual distraction led to reduced visual tracking of the lateral position of the vehicle, which the drivers tried to compensate by increased steering activity. This was however not successful, since the lateral position variation increased and TLC decreased.  Steering entropy and 3 degrees steering reversal rate were the most sensitive measures and could discriminate between all SLvs except for between SLv2 and SLv3.

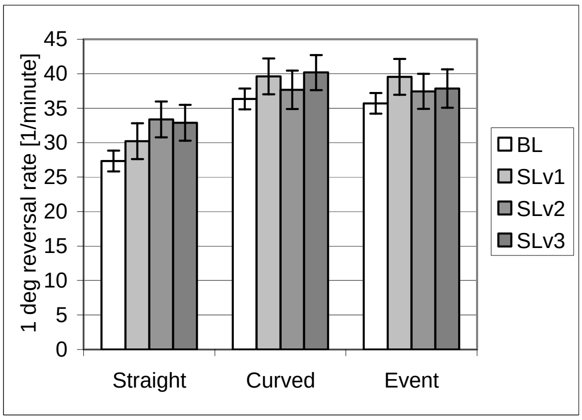



**Figure 163 – One degree reversal rate (rr_st1), Visual task, Rural road**

**Table 113 – Analysis of one degree reversal rate (rr_st1), Visual task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| rr_st1 [1/minute] | 33,12 | 36,45 | 36,16 | 36,96 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

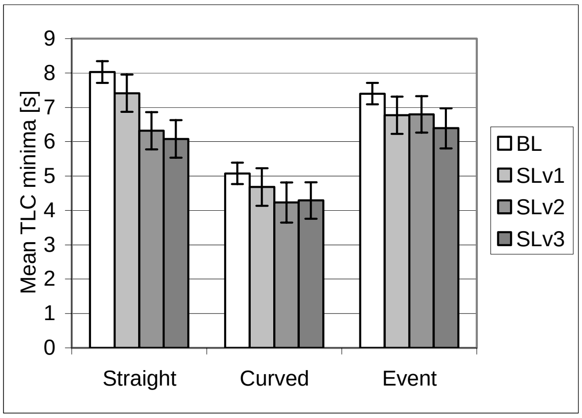



**Figure 164 – Mean time to line crossing (mn_tlc), Visual task, Rural road**

**Table 114 – Analysis of mean time to line crossing (mn_tlc), Visual task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| mn_tlc [s] | 6,84 | 6,29 | 5,78 | 5,59 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | ✓ | ✓ |
| | | | | | | | | SLv2 | | | × |

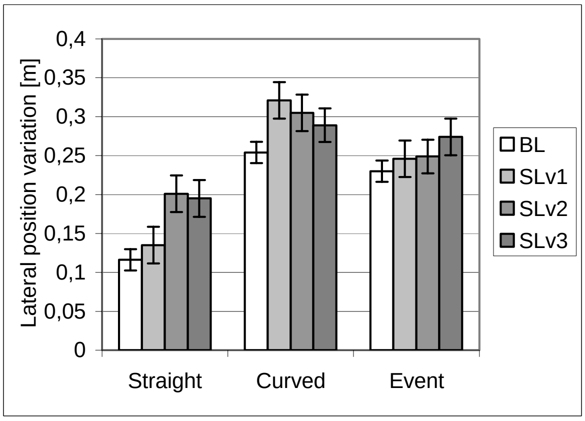



**Figure 165 – Lateral position variation (st_lp), Visual task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| st_lp [m] | 0,20 | 0,23 | 0,25 | 0,25 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

**Table 115 – Analysis of lateral position variation (st_lp), Visual task, Rural road**

### *9.7.2.4. Workload*

The mean skin conductance and variation increased with the visual task difficulty indicating an increased level of stress and workload. See Figure 166 and Table 116. There was no effect on inter-beat-intervals.

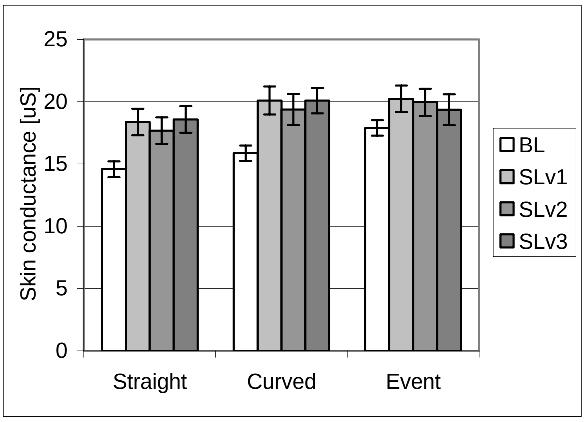



**Figure 166 – Mean skin conductance (dc_eda), Visual task, Rural road**

**Table 116 – Analysis of mean skin conductance (dc_eda), Visual task, Rural road**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| eda_dc [uS] | 16,11 | 19,56 | 19,00 | 19,33 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

### *9.7.2.5. S-IVIS performance*

The visual task results were slightly contradictory. The percentage of correct responses indicate that performance was somewhat worse for the driving conditions compared to the static condition. The reaction time, however indicate the opposite; a decreased reaction time for the driving condition. The decreased reaction time for the driving condition could be an effect of the driver trying to complete and thus dispense of the task quicker during driving than during a static test. This hypothesis is supported by the decrease in correct responses for the driving condition. The reaction time results also indicate that the curved condition resulted in the least reaction time, but still had approximately the same hit rate as for the straight and event conditions. Possibly this is also a result of the driver trying to finish the task quicker if the driving task is more difficult, although not affecting the hit rate. See Figure 167, Figure 168, for percent correct responses and reaction time. There was no tendency to give up the task.

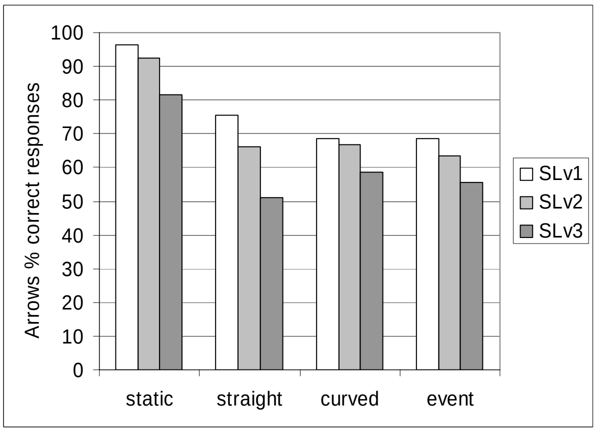



**Figure 167 – % correct responses, Visual task, Rural road**

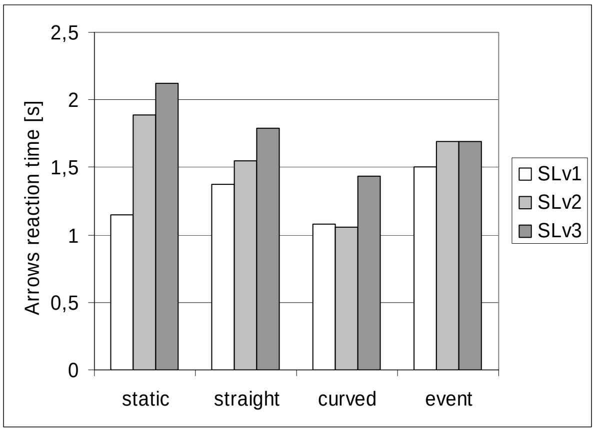



**Figure 168 – Reaction time, Visual task, Rural road**

## 9.7.3. Effects of the cognitive task in Motorway driving

### *9.7.3.1. Self reported driving performance*

The cognitive task resulted in a significant decrease of the self reported driving performance (subj_r). The mean ratings decreased from 8.0 to 7.2. See Figure 169 and Table 117. As for the visual task, subj_r discriminated between all S-IVIS difficulty levels except between SLv2 and SLv3, and was thus a very sensitive measure in this study.

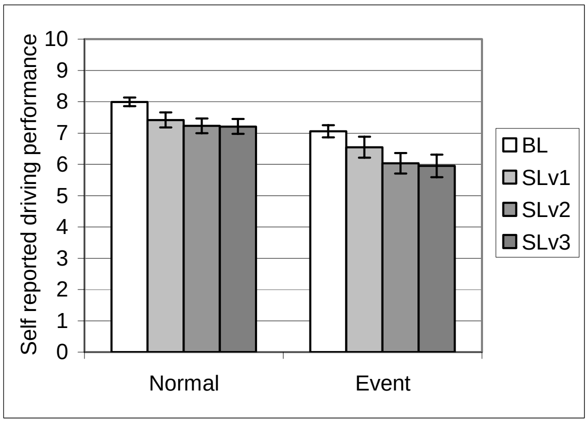



**Figure 169 – Self reported driving performance (subj_r), Cognitive task, Motorway**

**Table 117 – Analysis of self reported driving performance (subj_r), Cognitive task, Motorway**

| | Mean values | | | | Effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| subj_r | 7,52 | 6,98 | 6,63 | 6,58 | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | SLv1 | | ✓ | ✓ |
| | | | | | | SLv2 | | | × |

### *9.7.3.2. Longitudinal control*

No effects in any speed measures were found for the cognitive task. There was however a pattern in mean speed that indicated that the speed rose for higher SLvs, but not significantly. See Figure 170. As in the rural road, this could indicate a decreased performance in monitoring thei own travel speed which is a dangerous behaviour. However, there is less support for this hypothesis in the motorway driving than in the rural road driving.

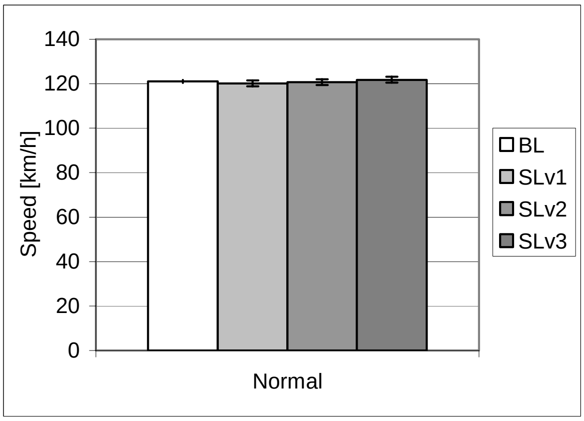



**Figure 170 – Mean speed (mn_sp), Cognitive task, Motorway**

In the events situations, reaction time, headway measures and time to collision measures were analysed. No effects were found.

### *9.7.3.3. Lateral control*

Several steering measures were included, but not all were possible to analyse. The rapid steering wheel turnings, collected in e.g. rswt_40, only occurred a few times. Also measures based on lane deviations or near deviations (e.g. lane exceedences and TLC values less than one second) were not possible to analyse. It can be concluded that the lateral control did not reach a safety critical level in the motorway driving. TLC did however appear as sensitive in the rural road, where the driving lane was narrower.

No steering measures were affected by the cognitive task. But the lateral position variation *decreased* with task complexity. The difference between with and without the cognitive task was 2 cm. See Figure 171 and Table 118. Also there were indications that mean TLC was increased with the visual task difficulty (p=0.051); 9.4 seconds as the visual task was active compared to 8.5 when not active. Based on the lateral control measures, it cannot be argued that the cognitive load resulted in any decrease in lateral control, rather the opposite; an improved lateral control. As discussed in the rural road results for the cognitive task, this could be an effect of the driver mobilising resources to cope with the task - resources spilling over to the driving task.

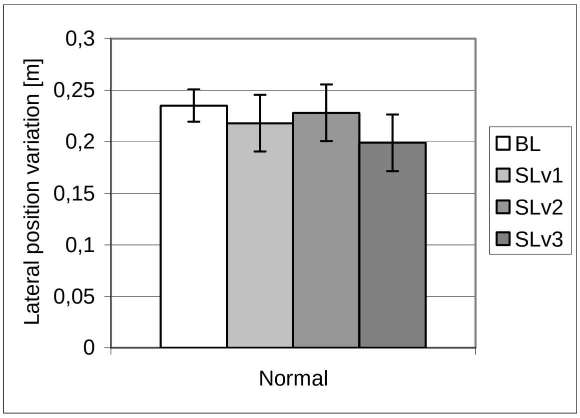



**Figure 171 – Lateral position variation (st_lp), Cognitive task, Motorway**

**Table 118 – Analysis of lateral position variation (st_lp), Cognitive task, Motorway**

| | Mean values | | | | Effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| st_lp [m] | 0,24 | 0,22 | 0,23 | 0,2 | ✓ | BL | × | × | ✓ |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |

### *9.7.3.4. Workload*

Although there were indications that the inter-beat-intervals and skin conductance measures indicated an increased level of stress and workload as the cognitive task difficulty increased, these effects were not significant. The imposed level of stress of the cognitive task was thus rather small. As reported above, effects of the cognitive task on workload were found in the rural road.

### *9.7.3.5. S-IVIS performance*

The cognitive task % correct responses in the normal conditions of the motorway was slightly better compared to the static test. This is not so strange since the static test was only counterbalanced with respect to the rural road driving. The static test was always conducted before the motorway. Therefore, the effect in correct responses is most likely a learning effect. In the rural road, the performance in static and straight/curved road was approximately equal.

In the motorway event condition, the cognitive task performance was less than in normal driving conditions. This is explained by the driver almost exclusively abandoning the S-IVIS task when the interfering vehicle cut in and/or braked. See Figure 172, Figure 173.

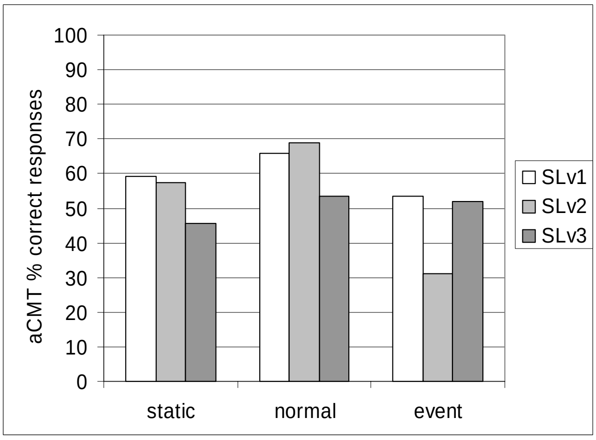



**Figure 172 – % correct responses, Cognitive task, Motorway**

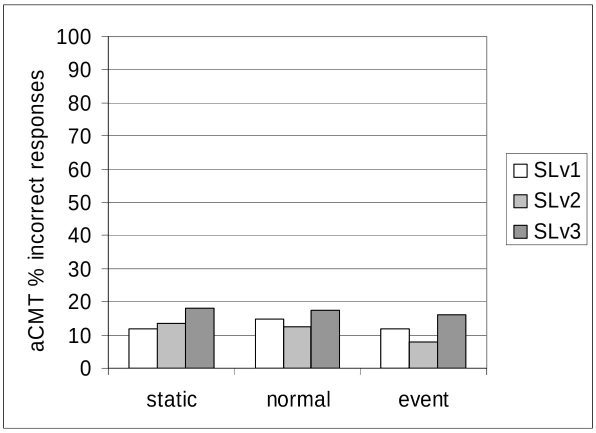



**Figure 173 – % missed responses, Cognitive task, Motorway**

## 9.7.4. Effects of the visual task in Motorway driving

### *9.7.4.1. Self reported driving performance*

The visual task resulted in significant decrease of the self reported driving performance. The mean ratings decreased from 8.1 to 6.6. subj_r could discriminate between all SLvs except between SLv1 and SLv3. See Figure 174 and Table 119.

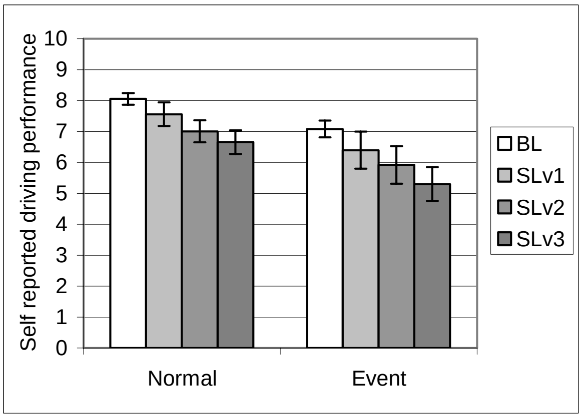



**Figure 174 – Self reported driving performance (subj_r), Visual task, Motorway**

**Table 119 – Analysis of self reported driving performance (subj_r), Visual task, Motorway**

| | Mean values | | | | Effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| subj_r | 8,25 | 6,98 | 7,13 | 6,17 | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | SLv1 | | × | ✓ |
| | | | | | | SLv2 | | | ✓ |

### *9.7.4.2. Longitudinal control*

For the visual task, the speed (mn_sp) was reduced with task difficulty. The average speed difference with/without the visual task was 3 km/h. See Figure 175 and Table 120. An effect was also found in speed change (d_sp). There was an average increase in speed of 2.6 km/h for the baseline condition, which at first glance seems strange. However, during some of the baseline blocks there were cars to be overtaken, resulting in increased speed. No effects were found in speed variation.

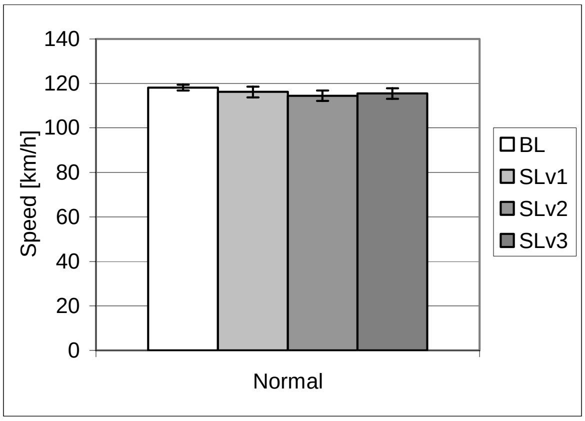



**Figure 175 – Mean speed (mn_sp), Visual task, Motorway**

**Table 120 – Analysis of mean speed (mn_sp), Visual task, Motorway**

| | Mean values | | | | Effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| mn_sp [km/h] | 109,75 | 106,54 | 107,26 | 108,25 | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | SLv1 | | × | ✓ |
| | | | | | | SLv2 | | | × |

In the events, the brake reaction time increased by 0.3 seconds from the baseline condition (without the visual task) to SLv3, although not significantly. Indications were also found in the headway measures. See Figure 176.

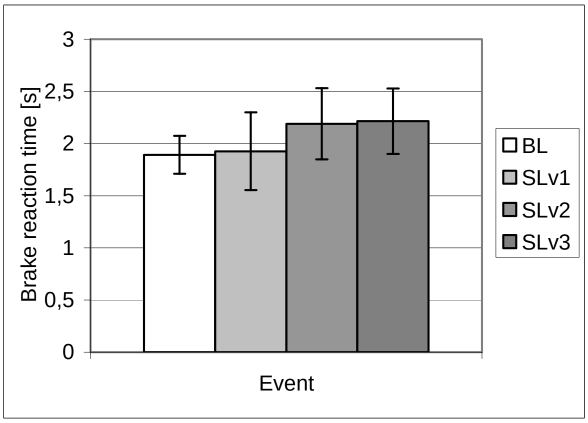



**Figure 176 – Brake reaction time (rt_br), Visual task, Motorway**

### *9.7.4.3. Lateral control*

The cognitive task data in the motorway showed that it was not possible to analyse some lateral control measures since the lateral control did not reach a safety critical level. These measures were rapid steering wheel turnings and lane crossing or near lane crossing measures

The lateral position variation (st_lp) was 4 cm larger with the visual task compared to without. The effect of the visual task was however not significant (p=0.055), but still strongly indicative. See Figure 177. Main effects were found in all analysed steering measures, and the most sensitive measure was steering entropy (en_st), see Figure 178 and Table 121. No effects were found in the TLC-measures. These results indicate that the visual task resulted in a more unpredictable, nervous or active steering behaviour, although not safety critical. No effects were found in mean lateral position (mn_lp), although the results indicated that it was shifted towards the centre line as an effect of the cognitive task.

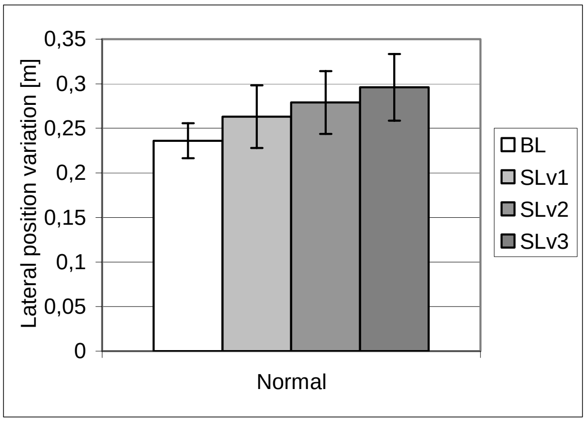



**Figure 177 – Lateral position variation (st_lp), Visual task, Motorway**

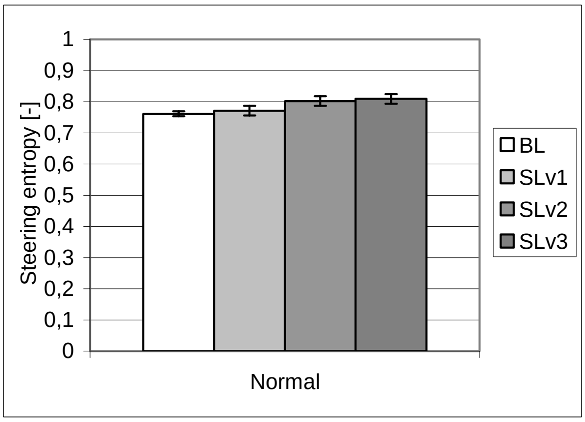



**Figure 178 – Steering entropy (en_st), Visual task, Motorway**

**Table 121 – Analysis of steering entropy (en_st), Visual task, Motorway**

| | Mean values | | | | Effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| en_st [-] | 0,76 | 0,77 | 0,8 | 0,81 | ✓ | BL | × | ✓ | ✓ |
| | | | | | | SLv1 | | ✓ | ✓ |
| | | | | | | SLv2 | | | × |

### *9.7.4.4. Workload*

There was an effect of the visual task on mean skin conductance (dc_eda) and variation (ac_eda). ac_eda and dc_eda varied very similarly with the visual task difficulty. See Figure 179 for and Table 122 for dc_eda. No effect was however found in inter-beat-intervals. Heart rate variability was analysed, but no effect was found.

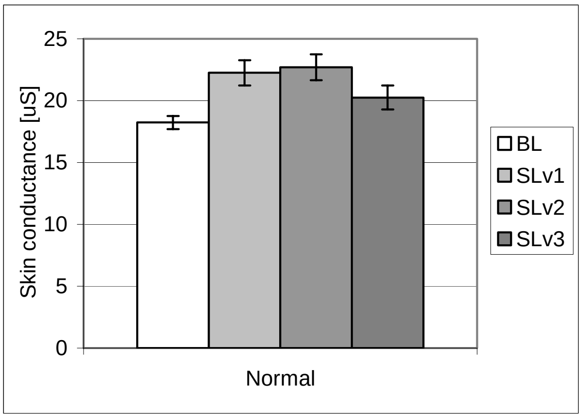



**Figure 179 – Mean skin conductance (dc_eda), Visual task, Motorway**

**Table 122 – Analysis of mean skin conductance (dc_eda), Visual task, Motorway**

| | Mean values | | | | Effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| dc_eda [uS] | 18,23 | 22,25 | 22,69 | 20,26 | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | SLv1 | | × | ✓ |
| | | | | | | SLv2 | | | ✓ |

### *9.7.4.5. S-IVIS performance*

The visual task results indicated the same as the cognitive task; the visual task was indeed highly prioritised, as was intended. See Figure 180, Figure 181.

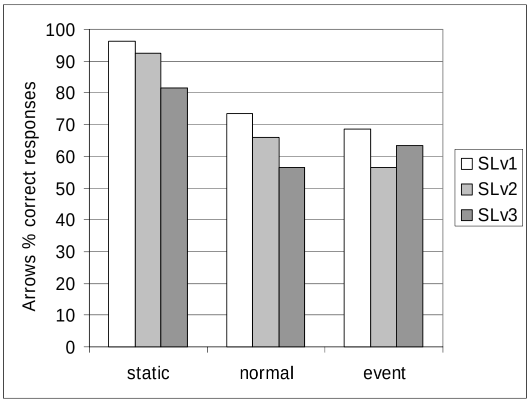



**Figure 180 – % correct responses, Visual task, Motorway**

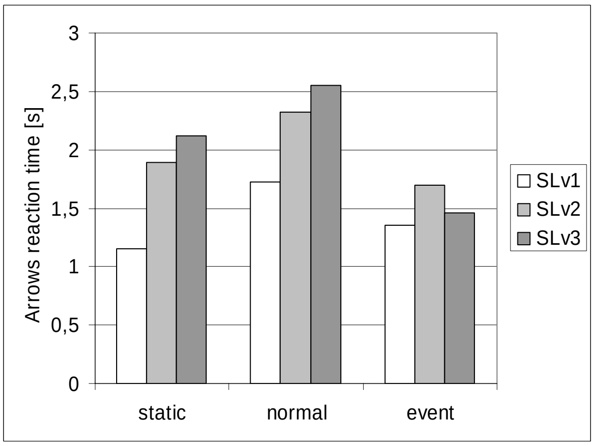



**Figure 181 – Reaction time, Visual task, Motorway**

## 9.8. Summary and conclusions

In general, the visual task affected the driving performance and workload indicators more than the cognitive task. The visual task caused increased steering activity and decreased lateral stability. The cognitive task resulted in somewhat increased stability. Both tasks resulted in decreased car following performance and speed control. In the rural road, more measures were affected by the S-IVIS tasks than in the motorway. In particular, lateral control was more affected in the rural road.

The rural road scenario included more car following than the motorway. Results were also found in the car interaction measures in the rural road. This is an advantage of the rural road. The car following situations were however considered annoying by several participants; they thought that the lead vehicle drove too close ahead of them. This resulted in great between participants variation in all car interaction measures.

### 9.8.1. Self reported driving performance

The self reported driving performance (subj_r) was the most sensitive measure in this experiment and discriminated between most combinations of S-IVIS difficulty levels. Most significant differences were found for the visual task in the motorway and least for the cognitive task in rural road. It can however be argued that in the included scenarios, the participants were very aware of the distraction of the S-IVIS tasks, which most likely influenced the self reported driving performance. For a real IVIS, it is possible that the driver is not aware of the distraction to the same extent as in this experiment. Therefore, the validation of this measure in WP3 is most crucial.

### 9.8.2. Longitudinal control

The visual task resulted in a reduction in speed, and to some extent also to a less stable speed keeping. The speed reduction, found in mean speed (mn_sp) and in speed change (d_sp), was most likely a result of compensating for the increased visual demands. It was however found that the speed tended (not significant effect) to increase for the most difficult S-IVIS level in both road types for both S-IVIS tasks. The explanation for this behaviour could be that the distracting S-IVIS tasks decreased the capability to monitor their own travel speed. If so, in vehicle information systems may result in highly dangerous driving behaviour; increased speed and a distracted driver. More results support this hypothesis: For the cognitive task in the rural road events, it was found that the min headway (u_hwd) was significantly less as the cognitive task was active. It was also found that the headway variation (sd_hwt/sd_hwd) increased with the cognitive task and the visual task difficulty in the rural road.

It is reasonable to assume that the distraction of the S-IVIS tasks would decrease the event detection performance. No significant results were found in brake reaction time (rt_br), but there were indications that the reaction time increased as an effect of S-IVIS difficulty.

The most promising longitudinal control performance measures were speed change (d_sp), headway variation (sd_hwt/sd_hwd) and mean speed.

### 9.8.3. Lateral control

The visual task resulted in the deterioration of lateral control. This was reflected in most steering measures, and to some extent in lateral position variation and time to line crossing. The results were more pronounced in the rural road than in the motorway, most likely due to the more varied road curvature. It was also found that the visual distraction affected the lateral control more as the road curvature in the rural road increased; there was an interaction between S-IVIS difficulty and road complexity in most lateral control results.

The cognitive task did however not reduce the lane keeping performance. On the contrary, there were indications that it lead to stabilised lane keeping; the lateral position variation decreased in the motorway. The steering activity did however increase as an effect of the cognitive task, indicating a more nervous and unpredictable steering behaviour.

The most promising lateral control performance measures were mean time to line crossing (mn_tlc), steering entropy (en_st), reversal rate (rr_st), high frequency steering (hi_st) and lateral position variation (st_lp), in that order.

### 9.8.4. Workload

The inter-beat-intervals (ibi) and skin conductance (dc_eda, ac_eda) indicated a higher stress level as the S-IVIS was active. The effect on IBI (inversed heart rate) was however very small; only about one beat per minute between baseline and driving condition. For the cognitive task in motorway, one of the measures - mean EDA - was decreased as the cognitive task was active, indicating the opposite - decreased stress level.

# 9.9. Measures summary tables

## 9.9.1. Rural road and the cognitive task

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 | |
| **Self reported driving performance** | | | | | | | | | | | | |
| subj_r | 7.65 | 7.04 | 6.98 | 6.92 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ | all RLvs |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| **Longitudinal control** | | | | | | | | | | | | |
| mn_sp [km/h] | 69.59 | 69.78 | 69.72 | 70.45 | ns | | | | | | | straight/curved |
| st_sp [km/h] | 1.87 | 2.11 | 2.17 | 2.31 | ✓ | × | × | BL | × | ✓ | ✓ | straight/curved |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| d_sp [km/h] | 0.63 | -0.58 | 0.71 | 0.76 | ns | | | | | | | straight/curved |
| u_ttc [s] | | | | | | | | | | | | not analysed |
| mn_ttc [s] | 11.05 | 10.15 | 11.31 | 10.9 | ns | n/a | n/a | | | | | event |
| pr_ttc [%] | | | | | | | | | | | | not analysed |
| tet [%] | | | | | | | | | | | | not analysed |
| Hwt0 | 4.03 | 3.98 | 4.17 | 3.95 | ns | | | | | | | straight/curved |
| Hwt0 | 4.3 | 4.18 | 4.21 | 4.44 | ns | n/a | n/a | | | | | event |
| mn_hwd [m] | 0.96 | 1.76 | 1.89 | 1.83 | ns | | | | | | | straight/curved |
| mn_hwd [m] | 53.64 | 48.84 | 50.08 | 52.42 | ns | n/a | n/a | | | | | event |
| u_mn_hwd [m] | 31.61 | 29.9 | 32.6 | 31.41 | ns | n/a | n/a | | | | | event |
| pr_hwd [%] | | | | | | | | | | | | not analysed |
| sd_hwd [m] | 0.36 | 0.46 | 0.4 | 0.43 | ✓ | ✓ | × | BL | ✓ | × | ✓ | straight/curved |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| sd_hwd [m] | 1.4 | 1.2 | 1.25 | 1.33 | ns | n/a | n/a | | | | | event |
| u_hwd [m] | 68.1 | 69.68 | 72.14 | 69.02 | ns | | | | | | | straight/curved |
| u_hwd [m] | 30.9 | 25.99 | 26.51 | 27.14 | ns | n/a | n/a | | | | | event |
| mn_hwt [s] | 4.21 | 4.37 | 4.49 | 4.25 | ns | | | | | | | straight/curved |
| mn_hwt [s] | 5.21 | 4.69 | 4.84 | 5.01 | ns | n/a | n/a | | | | | event |
| u_mn_hwt [s] | 2.43 | 2.49 | 2.59 | 2.51 | ns | n/a | n/a | | | | | event |
| pr_hwt [%] | | | | | | | | | | | | not analysed |
| sd_hwt [s] | 6 | 8.02 | 7.23 | 7.41 | ✓ | ✓ | × | BL | ✓ | × | ✓ | straight/curved |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| sd_hwt [s] | 16.51 | 17.49 | 17.41 | 18.22 | ns | n/a | n/a | | | | | event |
| u_hwt [s] | 3.67 | 3.7 | 3.89 | 3.65 | ns | | | | | | | straight/curved |
| u_hwt [s] | 3.36 | 3.12 | 3.34 | 3.34 | ns | n/a | n/a | | | | | event |
| rt_br [s] | 4.25 | 4.52 | 4.75 | 5.02 | ns | n/a | n/a | | | | | event |
| **Lateral control** | | | | | | | | | | | | |
| mn_lp [m] | 1.88 | 1.85 | 1.85 | 1.86 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ | all RLvs |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| st_lp [m] | 0.22 | 0.2 | 0.22 | 0.22 | ns | | | | | | | all RLvs |
| mn_tlc [s] | 6.99 | 7.13 | 7.15 | 7.04 | ns | | | | | | | all RLvs |
| pr_tlc [%] | | | | | | | | | | | | not analysed |
| lnx [%] | | | | | | | | | | | | not analysed |
| rr_st1 [1/minute] | 31.32 | 34.26 | 33.83 | 35.71 | ✓ | ✓ | × | BL | ✓ | × | ✓ | all RLvs |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| rr_st3 [1/minute] | 17.53 | 18.28 | 18.43 | 19.31 | ns | | | | | | | all RLvs |
| hi_st [deg] | 0.72 | 0.74 | 0.76 | 0.76 | ns | | | | | | | all RLvs |
| en_st [-] | 0.76 | 0.78 | 0.79 | 0.79 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ | all RLvs |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| **Workload** | | | | | | | | | | | | |
| ibi [ms] | 806.14 | 796.75 | 789.96 | 788.66 | ns | | | | | | | all RLvs |
| hrv [ms] | | | | | | | | | | | | not analysed |
| dc_eda [uS] | 13.7 | 15.7 | 15.65 | 15.66 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ | all RLvs |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| ac_eda [uS] | 0.43 | 0.51 | 0.49 | 0.52 | ✓ | ✓ | × | BL | ✓ | × | ✓ | all RLvs |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |

### 9.9.2. Rural road and the visual task

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 | |
| **Self reported driving performance** | | | | | | | | | | | | |
| subj_r | 8.01 | 7.06 | 6.24 | 6.05 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ | all RLvs |
| | | | | | | | | SLv1 | | ✓ | ✓ | |
| | | | | | | | | SLv2 | | | × | |
| **Longitudinal control** | | | | | | | | | | | | |
| mn_sp [km/h] | 72.54 | 70.88 | 68.62 | 70.58 | ns | | | | | | | straight/curved |
| st_sp [km/h] | 2.0 | 2.42 | 2.97 | 2.65 | ns | | | | | | | straight/curved |
| d_sp [km/h] | 0.68 | -2.85 | -5.58 | -3.54 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ | straight/curved |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| mn_ttc [s] | 10.21 | 11.35 | 10.46 | 10.39 | ns | n/a | n/a | | | | | event |
| pr_ttc [%] | | | | | | | | | | | | not analysed |
| tet [%] | | | | | | | | | | | | not analysed |
| Hwt0 | 3.82 | 3.82 | 3.72 | 3.73 | ns | | | | | | | straight/curved |
| Hwt0 | 4.52 | 4.18 | 4.34 | 4.17 | ns | n/a | n/a | | | | | event |
| mn_hwd [m] | 78.55 | 81.13 | 82.47 | 83.55 | ns | | | | | | | straight/curved |
| mn_hwd [m] | 53.24 | 54.58 | 54.6 | 52.8 | ns | n/a | n/a | | | | | event |
| u_mn_hwd [m] | 31.46 | 29.35 | 29.34 | 31.68 | ns | n/a | n/a | | | | | event |
| pr_hwd [%] | | | | | | | | | | | | not analysed |
| sd_hwd [m] | 0.35 | 0.61 | 0.71 | 0.75 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ | straight/curved |
| | | | | | | | | SLv1 | | × | ✓ | |
| | | | | | | | | SLv2 | | | × | |
| sd_hwd [m] | 1.34 | 1.3 | 1.57 | 1.45 | ns | n/a | n/a | | | | | event |
| u_hwd [m] | 69.5 | 69.5 | 69.72 | 71.37 | ns | | | | | | | straight/curved |
| u_hwd [m] | 28.97 | 30.75 | 29.29 | 29.45 | ns | n/a | n/a | | | | | event |
| mn_hwt [s] | 4.12 | 4.5 | 4.42 | 4.52 | ✓ | ✓ | × | BL | ✓ | × | ✓ | straight/curved |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| mn_hwt [s] | 5.22 | 5.22 | 5.3 | 5.03 | ns | n/a | n/a | | | | | event |
| u_mn_hwt [s] | 2.3 | 2.06 | 2.38 | 2.35 | ns | n/a | n/a | | | | | event |
| pr_hwt [%] | | | | | | | | | | | | not analysed |
| sd_hwt [s] | 6.21 | 10.82 | 12.48 | 12.68 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ | straight/curved |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| sd_hwt [s] | 17.87 | 16.61 | 18.06 | 16.61 | ns | n/a | n/a | | | | | event |
| u_hwt [s] | 3.55 | 3.69 | 3.63 | 3.71 | ns | | | | | | | straight/curved |
| u_hwt [s] | 3.41 | 3.45 | 3.3 | 3.23 | ns | n/a | n/a | | | | | event |
| rt_br [s] | 4.95 | 4.21 | 4.69 | 4.28 | ns | n/a | n/a | | | | | event |
| **Lateral control** | | | | | | | | | | | | |
| mn_lp [m] | 1.83 | 1.82 | 1.78 | 1.78 | ✓ | ✓ | ✓ | BL | × | ✓ | ✓ | all RLvs |
| | | | | | | | | SLv1 | | ✓ | ✓ | |
| | | | | | | | | SLv2 | | | × | |
| st_lp [m] | 0.2 | 0.23 | 0.25 | 0.25 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ | all RLvs |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| mn_tlc [s] | 6.84 | 6.29 | 5.78 | 5.59 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ | all RLvs |
| | | | | | | | | SLv1 | | ✓ | ✓ | |
| | | | | | | | | SLv2 | | | × | |
| pr_tlc [%] | | | | | | | | SLv1 | | | | not analysed |
| lnx [%] | | | | | | | | SLv1 | | | | not analysed |
| rr_st1 [1/minute] | 33.12 | 36.45 | 36.16 | 36.96 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ | all RLvs |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| rr_st3 [1/minute] | 18.77 | 23.8 | 25.81 | 25.98 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ | all RLvs |
| | | | | | | | | SLv1 | | ✓ | ✓ | |
| | | | | | | | | SLv2 | | | × | |
| hi_st [deg] | 0.75 | 1.08 | 1.17 | 1.2 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ | all RLvs |
| | | | | | | | | SLv1 | | × | ✓ | |
| | | | | | | | | SLv2 | | | × | |
| en_st [-] | 0.76 | 0.82 | 0.84 | 0.84 | ✓ | × | ✓ | BL | ✓ | ✓ | ✓ | all RLvs |
| | | | | | | | | SLv1 | | ✓ | ✓ | |
| | | | | | | | | SLv2 | | | × | |
| rswt_40 [1/minute] | | | | | | | | | | | | not analysed |
| rswt_70 [1/minute] | | | | | | | | | | | | not analysed |
| **Workload** | | | | | | | | | | | | |
| ibi [ms] | 758.75 | 751.77 | 755.64 | 763.04 | ns | | | | | | | all RLvs |
| hrv [ms] | | | | | | | | | | | | not analysed |
| eda_dc [uS] | 16.11 | 19.56 | 19.00 | 19.33 | ✓ | ✓ | × | BL | ✓ | ✓ | ✓ | all RLvs |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |
| eda_ac [uS] | 0.58 | 0.89 | 0.88 | 0.91 | ✓ | ✓ | ✓ | BL | ✓ | ✓ | ✓ | all RLvs |
| | | | | | | | | SLv1 | | × | × | |
| | | | | | | | | SLv2 | | | × | |

### 9.9.3. Motorway and the cognitive task

| | Mean values | | | | Main effect | Post Hoc test | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 | |
| **Self reported driving performance** | | | | | | | | | | |
| subj_r | 7.52 | 6.98 | 6.63 | 6.58 | ✓ | BL | ✓ | ✓ | ✓ | normal. events RLv sign |
| | | | | | | SLv1 | | ✓ | ✓ | |
| | | | | | | SLv2 | | | × | |
| **Longidutinal control** | | | | | | | | | | |
| mn_sp [km/h] | 121.01 | 120.14 | 120.69 | 121.77 | ns | | | | | normal |
| st_sp [km/h] | 2.89 | 3.25 | 2.96 | 3.17 | ns | | | | | normal |
| d_sp [km/h] | 2.37 | 1.09 | 1.79 | 3.81 | ns | | | | | normal |
| mn_ttc [s] | 3.51 | 3.9 | 3.39 | 3.75 | ns | | | | | event |
| pr_ttc [%] | | | | | | | | | | not analysed |
| tet [%] | | | | | | | | | | not analysed |
| u_mn_hwd [m] | 17.17 | 20.14 | 16.59 | 17.02 | ns | | | | | event |
| pr_hwd [%] | | | | | | | | | | not analysed |
| u_mn_hwt [s] | 0.94 | 1.06 | 0.91 | 0.86 | ns | | | | | event |
| pr_hwt [%] | | | | | | | | | | not analysed |
| rt_br [s] | 1.77 | 1.68 | 1.78 | 1.6 | ns | | | | | event |
| **Lateral control** | | | | | | | | | | |
| mn_lp [m] | 1.02 | 0.98 | 0.99 | 0.95 | ns | | | | | normal |
| st_lp [m] | 0.24 | 0.22 | 0.23 | 0.2 | ✓ | BL | × | × | ✓ | normal |
| | | | | | | SLv1 | | × | × | |
| | | | | | | SLv2 | | | × | |
| mn_tlc [s] | 8.52 | 9.02 | 9.4 | 8.95 | ns | | | | | normal |
| pr_tlc [%] | | | | | | | | | | not analysed |
| lnx [%] | | | | | | | | | | not analysed |
| rr_st1 [1/minute] | 25.39 | 24.98 | 25.26 | 27.82 | ns | | | | | normal |
| hi_st [deg] | 0.44 | 0.42 | 0.44 | 0.42 | ns | | | | | normal |
| en_st [-] | 0.76 | 0.76 | 0.78 | 0.79 | ns | | | | | normal |
| rswt_40 [1/minute] | | | | | | | | | | not analysed |
| rswt_70 [1/minute] | | | | | | | | | | not analysed |
| **Workload** | | | | | | | | | | |
| ibi [ms] | 841.13 | 835.04 | 835.94 | 829.17 | ns | | | | | normal |
| hrv [ms] | 5436.7 | 3552.83 | 5117.09 | 3967.11 | ✓ | BL | ✓ | × | × | normal |
| | | | | | | SLv1 | | × | × | |
| | | | | | | SLv2 | | | × | |
| dc_eda [uS] | 16.23 | 15.87 | 16.94 | 16.43 | ns | | | | | normal |
| ac_eda [uS] | 0.49 | 0.36 | 0.42 | 0.39 | ns | | | | | normal |

## 9.9.4. Motorway and the visual task

| | Mean values | | | | Main effect | Post Hoc test | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 | |
| **Self reported driving performance** | | | | | | | | | | |
| subj_r | 7.57 | 6.98 | 6.47 | 5.98 | ✓ | BL | ✓ | ✓ | ✓ | normal, event effect of RLv too |
| | | | | | | SLv1 | | ✓ | ✓ | |
| | | | | | | SLv2 | | | ✓ | |
| **Longitudinal control** | | | | | | | | | | |
| mn_sp [km/h] | 118.08 | 116.16 | 114.47 | 115.50 | ✓ | BL | × | ✓ | × | normal |
| | | | | | | SLv1 | | × | × | |
| | | | | | | SLv2 | | | × | |
| st_sp [km/h] | 2.71 | 2.82 | 3.42 | 2.69 | ns | | | | | normal |
| d_sp [km/h] | 2.59 | -1.6 | -3.12 | -1.73 | ✓ | BL | ✓ | ✓ | ✓ | normal |
| | | | | | | SLv1 | | × | × | |
| | | | | | | SLv2 | | | × | |
| mn_ttc [s] | 3.54 | 3.5 | 2.89 | 3.4 | ns | | | | | event |
| pr_ttc [%] | | | | | | | | | | not analysed |
| tet [%] | | | | | | | | | | not analysed |
| u_mn_hwd [m] | 15.07 | 16.4 | 14.75 | 13.81 | ns | | | | | event |
| pr_hwd [%] | | | | | | | | | | not analysed |
| u_mn_hwt [s] | 0.84 | 0.85 | 0.61 | 0.82 | ns | | | | | event |
| pr_hwt [%] | | | | | | | | | | not analysed |
| rt_br [s] | 1.89 | 1.93 | 2.19 | 2.21 | ns | | | | | event |
| **Lateral control** | | | | | | | | | | |
| mn_lp [m] | 0.93 | 0.97 | 0.92 | 0.92 | ns | | | | | normal |
| st_lp [m] | 0.24 | 0.26 | 0.28 | 0.3 | ns | | | | | normal |
| mn_tlc [s] | 8.12 | 7.67 | 7.24 | 7.7 | ns | | | | | normal |
| pr_tlc [%] | | | | | | | | | | not analysed |
| lnx [%] | | | | | | | | | | not analysed |
| rr_st1 [1/minute] | 26.35 | 29.87 | 29.99 | 30.31 | ✓ | BL | ✓ | ✓ | ✓ | normal |
| | | | | | | SLv1 | | × | × | |
| | | | | | | SLv2 | | | × | |
| hi_st [deg] | 0.42 | 0.46 | 0.54 | 0.56 | ✓ | BL | × | ✓ | ✓ | normal |
| | | | | | | SLv1 | | × | × | |
| | | | | | | SLv2 | | | × | |
| en_st [-] | 0.76 | 0.77 | 0.8 | 0.81 | ✓ | BL | × | ✓ | ✓ | normal |
| | | | | | | SLv1 | | ✓ | ✓ | |
| | | | | | | SLv2 | | | × | |
| rswt_40 [1/minute] | | | | | | | | | | not analysed |
| rswt_70 [1/minute] | | | | | | | | | | not analysed |
| **Workload** | | | | | | | | | | |
| ibi [ms] | 790.85 | 788.65 | 784.18 | 777.09 | ns | | | | | normal |
| hrv [ms] | 2654.59 | 1677.57 | 2112.50 | 2221.90 | ns | | | | | normal |
| dc_eda [uS] | 18.23 | 22.25 | 22.69 | 20.26 | ✓ | BL | ✓ | ✓ | ✓ | normal |
| | | | | | | SLv1 | | × | ✓ | |
| | | | | | | SLv2 | | | ✓ | |
| ac_eda [uS] | 0.45 | 0.96 | 0.9 | 0.79 | ✓ | BL | ✓ | ✓ | ✓ | normal |
| | | | | | | SLv1 | | × | ✓ | |
| | | | | | | SLv2 | | | × | |

## 9.10. S-IVIS results summary tables

Cognitive task, Rural road

| Measure | SLv1 | SLv2 | SLv3 |
|---|---|---|---|
| correct [%] | 62.4 | 48.4 | 44.1 |
| missed [%] | 29.0 | 34.6 | 39.8 |
| incorrect [%] | 8.5 | 17.0 | 16.0 |

Cognitive task, Motorway

| | Mean values | | |
|---|---|---|---|
| Measure | SLv1 | SLv2 | SLv3 |
| correct [%] | 59.7 | 50.0 | 52.7 |
| missed [%] | 26.9 | 39.8 | 30.6 |
| incorrect [%] | 13.4 | 10.2 | 16.7 |

Cognitive task, Static

| | Mean values | | |
|---|---|---|---|
| Measure | SLv1 | SLv2 | SLv3 |
| correct [%] | 59.2 | 57.4 | 45.7 |
| missed [%] | 28.9 | 29.0 | 36.4 |
| incorrect [%] | 11.9 | 13.6 | 18.0 |

Visual task, Rural road

| | Mean values | | |
|---|---|---|---|
| Measure | SLv1 | SLv2 | SLv3 |
| correct [%] | 71.0 | 65.5 | 55.0 |
| rt [s] | 1.32 | 1.43 | 1.64 |
| missed [%] | 21.8 | 24.1 | 32.1 |
| incorrect [%] | 7.3 | 10.4 | 12.9 |

Visual task, Motorway

| | Mean values | | |
|---|---|---|---|
| Measure | SLv1 | SLv2 | SLv3 |
| correct [%] | 71.1 | 61.1 | 59.9 |
| rt [s] | 1.54 | 2.01 | 2.00 |
| missed [%] | 22.6 | 30.0 | 30.9 |
| incorrect [%] | 6.4 | 8.8 | 9.2 |

Visual task, Static

| | Mean values | | |
|---|---|---|---|
| Measure | SLv1 | SLv2 | SLv3 |
| correct [%] | 96.3 | 92.5 | 81.7 |
| rt [s] | 1.15 | 1.89 | 2.12 |
| missed [%] | 2.0 | 0.8 | 0.8 |
| incorrect [%] | 1.7 | 6.7 | 10.1 |

# 10. The TRAIL Field Experiment

## 10.1. Test site

Test rides were performed in the North of the Netherlands in and around the village of Haren (south of Groningen). The route included the following sections where measurements were completed: 12 km motorway, 8 km rural (80 km/h speed limit) road, and 5 km urban driving. These measurement segments were connected by rural and urban roads that were not analysed. Completion of one test ride took around 30 minutes.

The instrumented vehicle of the Department of Psychology at the University of Groningen was used for the experiment. This car, a Renault 19, was equipped with dual controls for the test leader to take over control in case of emergency and a computer operated by the experimenter that sampled driving speed and steering wheel position at 10 Hz. The car was also equipped with four video cameras, one directed at the driver's face, one registering the front view and one the rear view, and one camera pointed at the right hand (edge) line (see Figure 182).

**Figure 182 – Camera pointed at edge line**

Electrodes were attached to the driver's chest and the R-peaks of the ECG were registered as events time stamped to 1 ms accuracy in a file on the car's computer.

## 10.2. Scenarios and participants

Experienced drivers, i.e. holding a licence for at least 5 years and having driven over 10,000 km, were invited for the experiment. Twenty-four volunteers participated, 19 (79%) were male, 5 (21%) female. Their average age was 40 years (range : 22-62) and on average they had held a licence for 19 years (sd: 13*)*. On average they had driven 17,500 km (sd: 16,500) the past 12 months, and had an average total mileage of 275,000 km.

The experimental route included motorway, two lanes plus emergency shoulder, with a speed limit of 120 km/h. In the middle of the motorway segment driven there was a weaving section (a combined entrance/exit). Also included was a rural road, speed limit 80 km/h, mainly straight, fringed with trees. The urban section included a main urban priority road as well as a minor residential area road. The latter road was not a priority road, was curved and cluttered, with a number of side-roads. The speed limit for both roads was 50 km/h, although the residential road could not be safely driven at that maximum speed.

## 10.3. S-IVIS evaluated

Only the visual S-IVIS was included in this experiment. Three levels of difficulty were included, ½, 1, and 2 (described in section 2.4 - Surrogate IVIS ), here referred to as SLv1, 2 and 3. Six stimuli per S-IVIS difficulty level were presented. Each stimulus was presented for 5 seconds, taking in total 30 seconds. Trials were repeated once, summing up to a total of 12 stimuli per difficulty level. Order of S-IVIS difficulty was balanced over subjects, half completed the test in order 1-2-3, the other half completed the test in order 3-2-1.

## 10.4. Experimental design

All participants completed two test rides, one with the visual S-IVIS ("experimental"), one without the additional task ("baseline"), and the order of these two rides was balanced over participants. The order in which road types were passed ('direction') was also balanced. Difficulty levels were repeated once ("Trial"). Finally, the static S-IVIS test was conducted, where the visual task was used as a single task. The static test was either completed before or after completion of all test rides. After that an ECG resting measurement completed the test.

## 10.5. Analysis method and measures

Speed and steering wheel position were sampled at 10 Hz. From these the following parameters were calculated: average speed (mn_sp), speed variation (st_sp), and steering wheel position variation (st_st). A repeated measures Anova was performed to statistically evaluate effects.

After each S-IVIS burst and at the same points during the baseline rides the subjective rating of driving performance (subj_r) was verbally given, triggered by the experimental leader who asked for this rating. Driving performance in terms of lateral control (line crossing) and longitudinal control (speed) was also assessed by the test leader who sat next to the driver. Average heart rate (actually, inter-beat-interval IBI [ms]) as well as power spectral analyses in the 0.10 Hz band (HRV) were calculated again per burst and at identical sections during the baseline ride. These parameters were also calculated for the static S-IVIS test and the resting period.

## 10.6. Results

The following main effects are reported:

| | | |
|---|---|---|
| S-IVIS | = | Experimental (IVIS) condition vs. Baseline (no IVIS) |
| Roadtype | = | Motorway / Rural / Urban |
| Level | = | S-IVIS level 1, 2, 3 |
| Trial | = | $1^{st}$ vs. $2^{nd}$ |

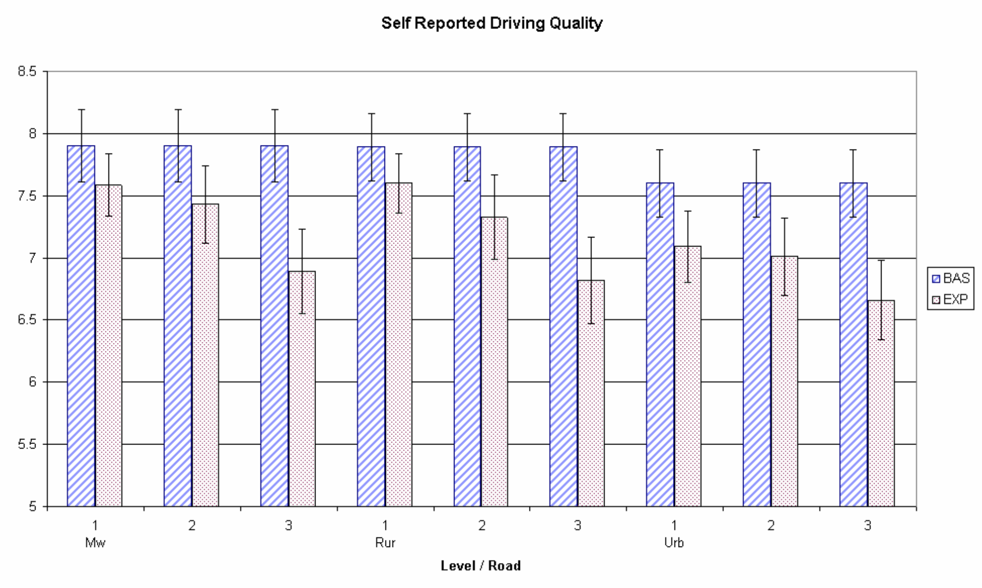
Significant interactions between these effects are also reported. In the case of observer data not all effects are statistically tested, in particular not if differences are very large and obvious.

### 10.6.1. Self reported driving performance

Self-reported ratings of driving performance (subj_r) on a scale from 1, "I drove extremely poorly", to 10, "I drove extremely well" were made during the test rides and were verbalised after driving over segments of interest. Effects were found of adding the S-IVIS (driving performance rated as poorer), of road type; lowest ratings for driving in the built-up area, and of IVIS-level (S-IVIS x level); the more difficult the S-IVIS task the lower the rating of driving performance. See Figure 183 and Table 123.

**Table 123 – Self reported driving performance (subj_r), Visual task, All road types**

| | Mean values | | | | Effect | | Post Hoc test | | | Road type |
|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 | |
| **Self reported driving performance** | | | | | | | | | | |
| subj_r | 7.60 | 7.09 | 7.01 | 6.66 | ✓ | BL | × | ✓ | ✓ | Urban |
| | | | | | | SLv1 | | ✓ | × | |
| | | | | | | SLv2 | | | ✓ | |
| subj_r | 7.89 | 7.60 | 7.33 | 6.82 | ✓ | BL | ✓ | ✓ | ✓ | Rural |
| | | | | | | SLv1 | | ✓ | ✓ | |
| | | | | | | SLv2 | | | ✓ | |
| subj_r | 7.90 | 7.59 | 7.43 | 6.89 | ✓ | BL | × | ✓ | × | Motorway |
| | | | | | | SLv1 | | ✓ | ✓ | |
| | | | | | | SLv2 | | | ✓ | |




*(BAS= baseline, without S-IVIS, Exp= experimental, Visual task)*

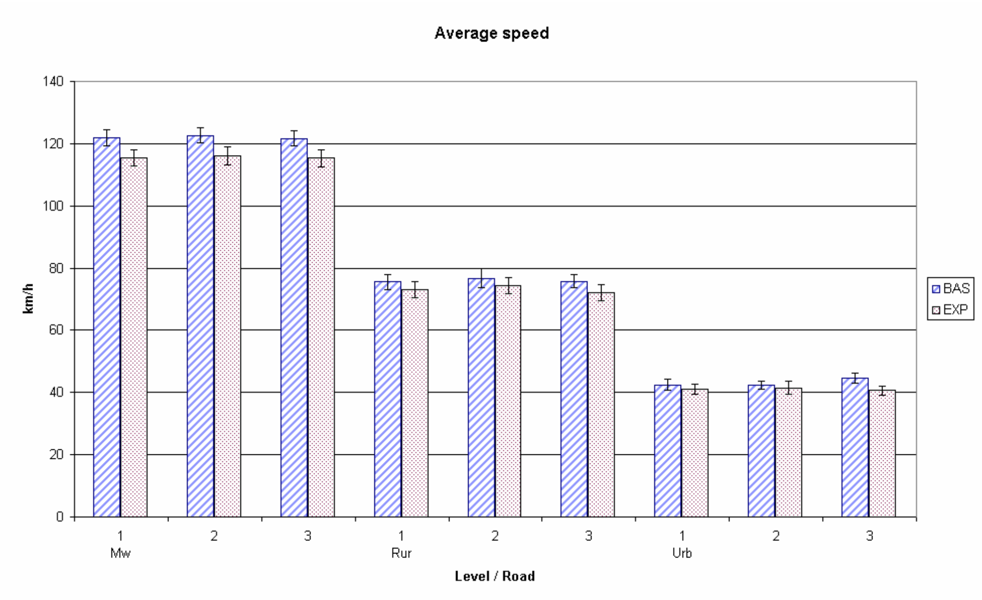
**Figure 183 – Self-reported driving performance (subj_r) per road type, S-IVIS level and condition**

### 10.6.2. Longitudinal control

The speed (mn_sp) was significantly reduced with the visual task compared to without (-3.6 km/h). The effect was most pronounced in the motorway (-6.4 km/h from BL to SLv3). See also Figure 184 and Table 124. No interaction effects were found in speed.

**Table 124 – Mean speed (mn_sp), Visual task, All road types**

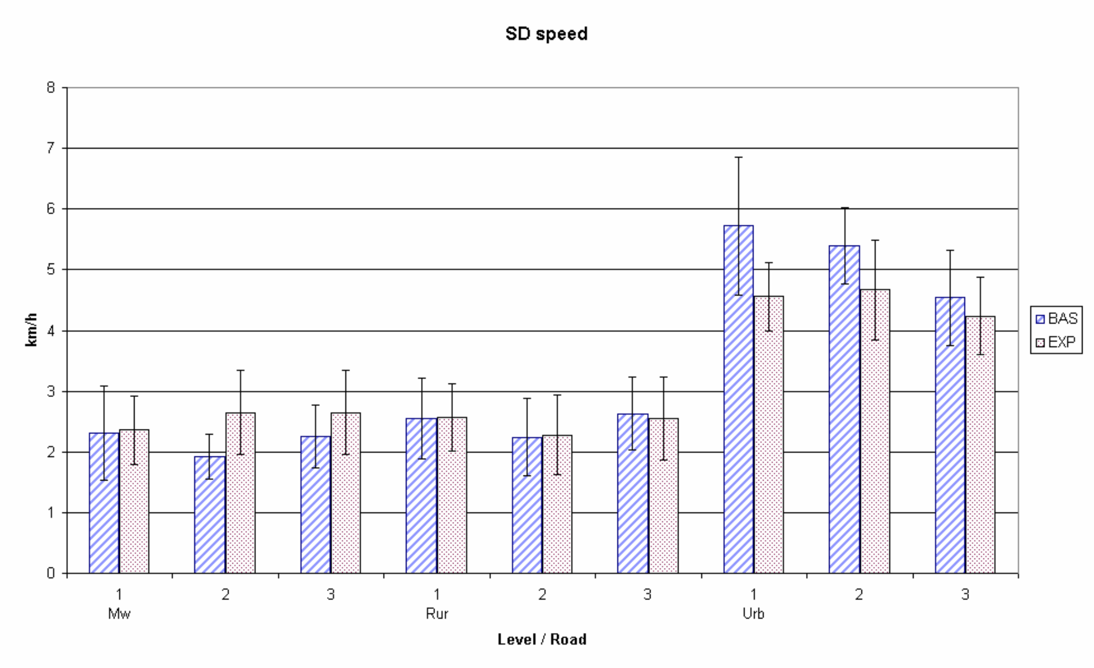
| | Mean values | | | | Effect | | Post Hoc test | | | Road type |
|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 | |
| **Self reported driving performance** | | | | | | | | | | |
| mn_sp [km/h] | 43.2 | 41.3 | 41.5 | 40.6 | ✓ | BL | × | × | ✓ | Urban |
| | | | | | | SLv1 | | × | × | |
| | | | | | | SLv2 | | | × | |
| mn_sp [km/h] | 76 | 73.1 | 74.3 | 72.1 | ✓ | BL | × | × | ✓ | Rural |
| | | | | | | SLv1 | | × | × | |
| | | | | | | SLv2 | | | ✓ | |
| mn_sp [km/h] | 122.1 | 115.5 | 116.1 | 115.4 | ✓ | BL | ✓ | ✓ | ✓ | Motorway |
| | | | | | | SLv1 | | × | × | |
| | | | | | | SLv2 | | | × | |




*(BAS= baseline, without S-IVIS, Exp= experimental, Visual task)*

**Figure 184 – Mean speed (mn_sp) [km/h] on the different roads**

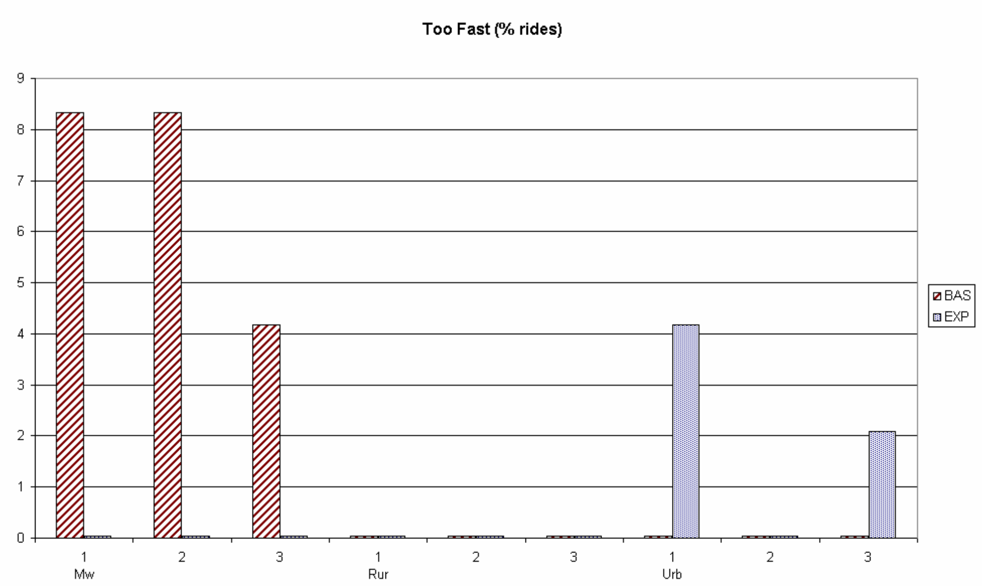
Only in the urban road, a minor decrease in speed variation as an effect of the visual task was found (- 1km/h from BL to SLv3), indicating a slightly more stable speed control. More variation in speed (st_sp) was found on urban roads. With the S-IVIS system 'on', variation in speed was + 0.4 km/h higher on the motorway, but 0.7 km/h lower in the urban area. See Figure 185.




*(BAS= baseline, without S-IVIS, Exp= experimental, Visual task)*

**Figure 185 – Speed variation [km/h] (st_sp) on the different roads**

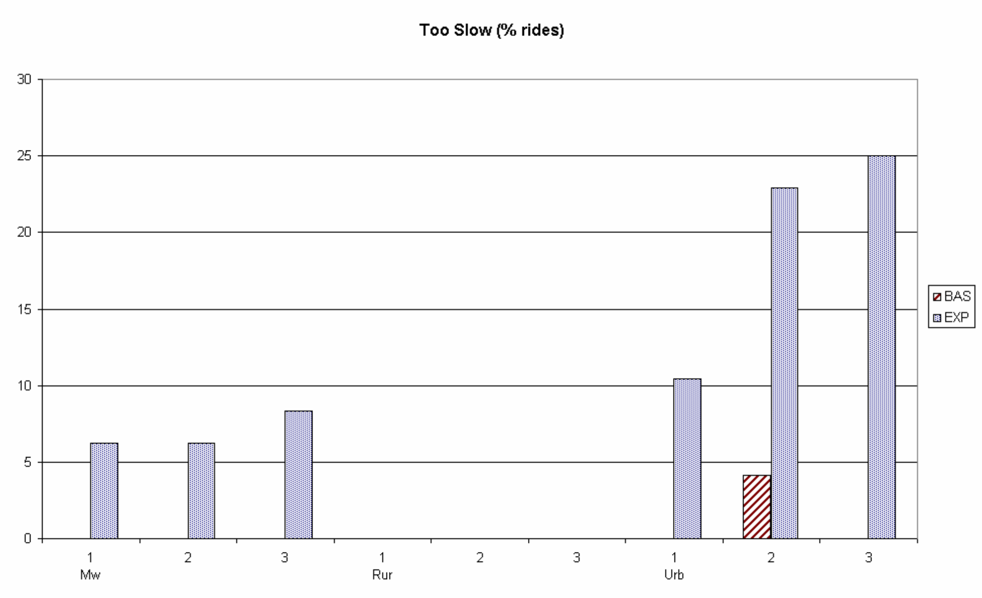
In addition to registration of driving speed in terms of km/h driven, driving speed was also judged by the observer relative to the local conditions. If speed deviated from normal or acceptable it was coded as "Too fast", "Too slow", or in conditions of high variation in speed as "Irregular". See Figure 186 and Figure 187 and Figure 188.




*(BAS= baseline, without S-IVIS, Exp= experimental, Visual task)*

**Figure 186 – % of test rides where the observer judged speed to be too *fast* for the local conditions**

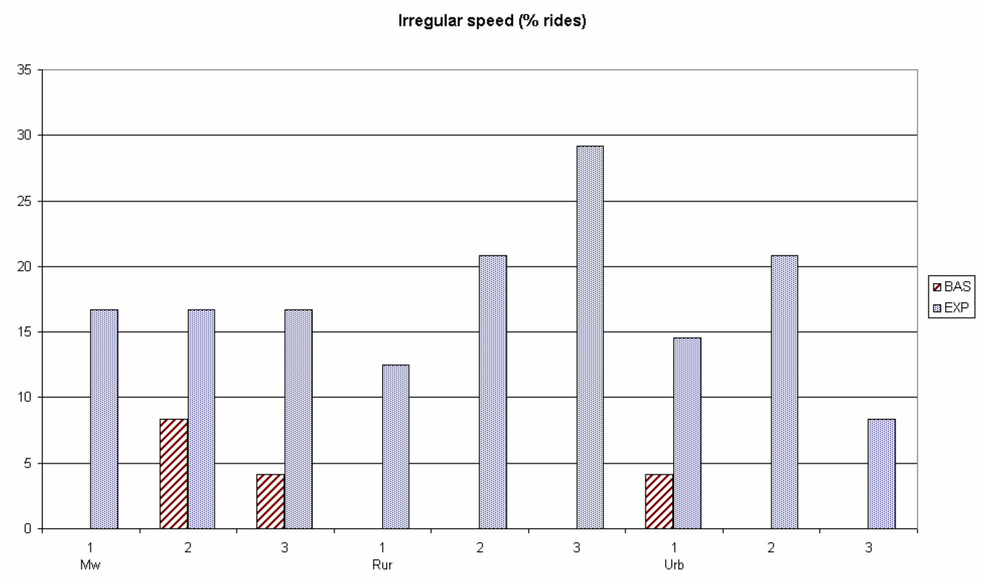
In the baseline conditions around 7 % of the rides driving speed was too fast, but *only* on the motorway. In the built up area speed was too fast in 2 % of the *experimental* conditions.




*(BAS= baseline, without S-IVIS, Exp= experimental, Visual task)*

**Figure 187 – % of test rides where the observer judged speed to be too *slow* for the local conditions**

Driving too slow for the local conditions mainly happened while being occupied with the secondary task, in particular while driving in the built-up area. Speed on the rural road was never judged to be too fast or too slow, neither in experimental nor in the baseline conditions.




*(BAS= baseline, without S-IVIS, Exp= experimental, Visual task)*

**Figure 188 – % of test rides where the observer judged speed control to be irregular.**

Irregular speed was most frequently observed, again mainly in the dual-task (experimental) condition. On 17% of the rides, on all road types, irregular speed was noted, compared with 2% of the baseline rides.

### 10.6.3. Lateral control

Swerving behaviour was scored by the observer and ranked into three categories of seriousness; 0 normal swerving, 1 increased swerving, and 2 large increase in swerving exceeding the lane. All baseline rides were rated as normal swerving. In the experimental conditions swerving increased the most in *S-IVIS level 3* conditions. See Figure 189.

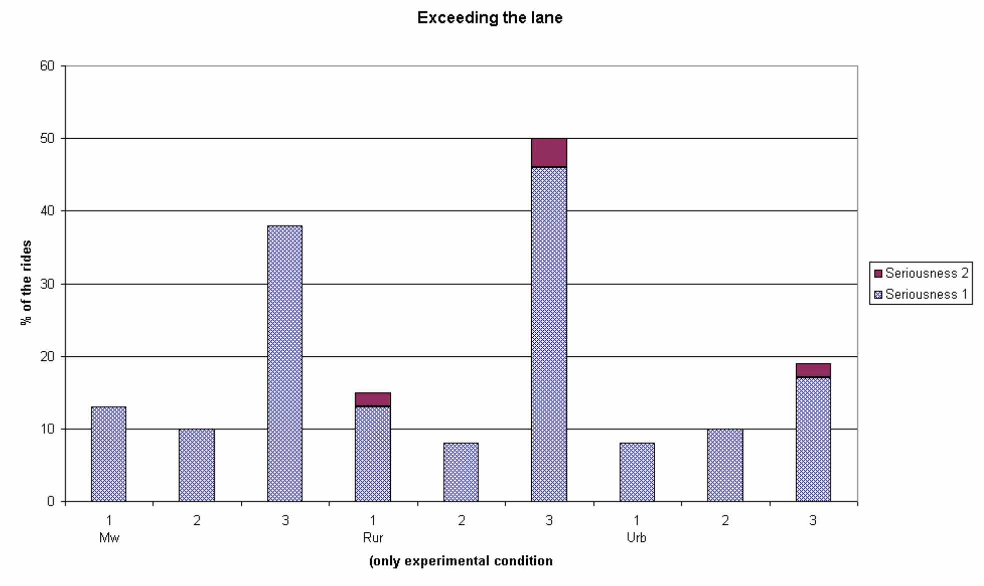
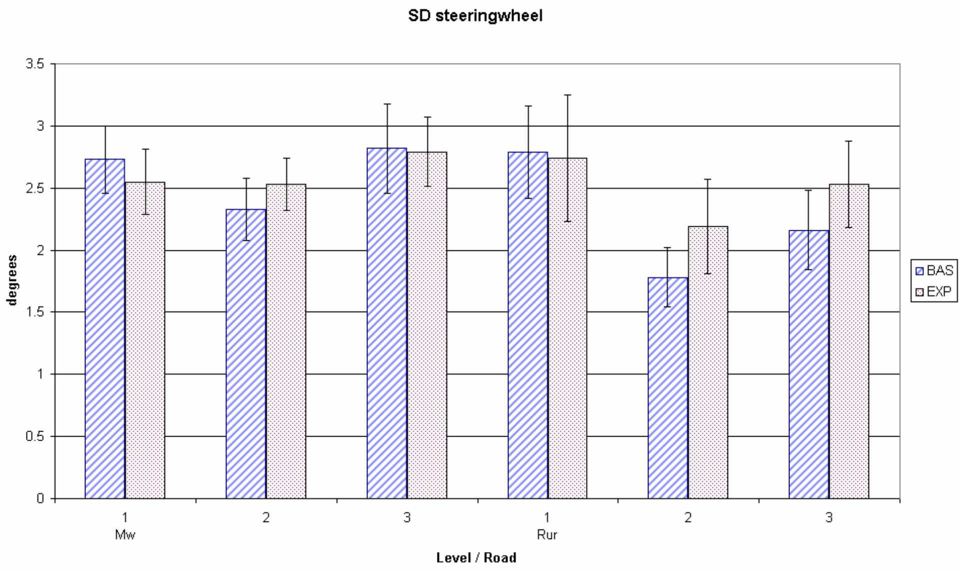



**Figure 189 – % of rides with increased swerving.**

Seriousness was scored with two levels 1 (increased swerving) and 2 (exceeding the lane). As in the baseline condition this happened in none of the cases this condition is not displayed (all seriousness rated "0")

Steering wheel angle variation (st_st) was not assessed on the urban roads as these roads contained several curves. On the other roads there seemed to be a square relationship with difficulty level, thus the lowest steering wheel angle variation for SLv2. No effects of the visual task were thus found in st_st, Figure 190




(BAS= baseline, without S-IVIS, Exp= experimental, Visual task)

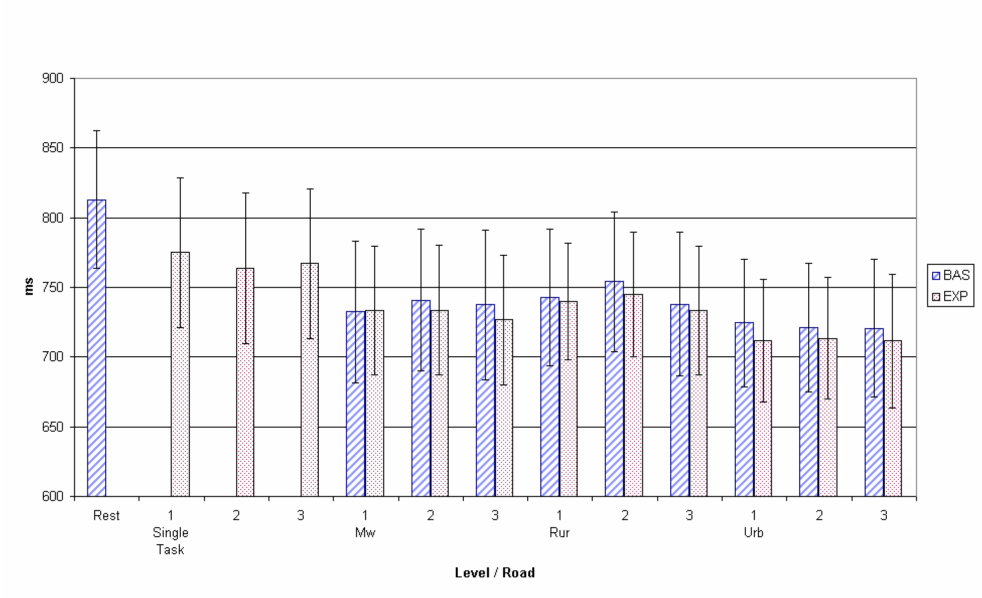
**Figure 190 – Steering wheel angle variation (st_st) on the different roads**

### 10.6.4. Workload

Participants' ECG was registered during the whole experiment, i.e. during the experimental conditions with dual task performance, during single-task driving performance (baseline) and single-task S-IVIS performance while the car was standing still, and during a rest measurement when the participant sat quietly in the parked car. Inter-Beat-Interval (IBI) was recorded as the time between successive R-peaks. IBI can be converted to heart rate by this relation: heart beat (in beats/minute) = 60 000 / IBI (in milliseconds).

In addition to the tests to assess effects of S-IVIS on IBI, a repeated measures Anova was performed to assess effects of *driving* (Rest and Single task S-IVIS versus Baseline and dual task driving), of *S-IVIS* (Rest and baseline versus baseline and experimental driving) and interactions.

Compared with the rest measurement, single S-IVIS task performance increased heart rate by 4 beats per minute. Driving on the motorway increased heart rate with on average an additional 4 beats per minute, irrespective if drivers were performing the secondary task (thus no effect of S-IVIS in either of the road types). There was a main effect of road type, in the built-up area heart rate was higher than on the rural road and motorway. See Figure 191.




*(BAS= baseline, without S-IVIS, Exp= experimental, Visual task)*

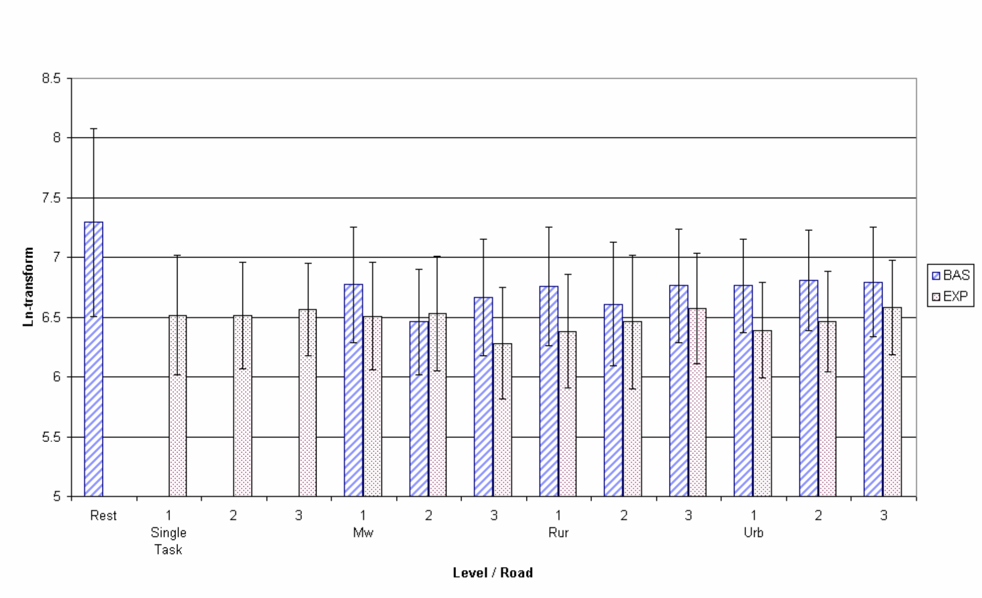
**Figure 191 – Average IBI [ms] on the different roads**

The 0.10 Hz component of heart rate variability (HRV) reflects mental effort (e.g., Mulder & Mulder, 1981). Due to the idiosyncratic nature of heart rate, the measure is best normalised by a natural logarithmic transformation (Van Roon, 1998). With *increased* effort HRV is *reduced*.

The visual task resulted in reduced heart rate variability (hrv). In motorway, the effects were most pronounced. See Table 125. A clear effect of driving was found, in particular compared with rest measurements. Dual task performance, although more visually than central demanding, also reduced heart rate variability. The different S-IVIS difficulty levels did not have an effect on heart rate variability. See Figure 192**.**

**Table 125 – Heart rate variability (hrv), Visual task, All road types**

| | Mean values | | | | Effect | | Post Hoc test | | | Road type |
|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 | |
| **Self reported driving performance** | | | | | | | | | | |
| hrv [ln-transform] | 6.79 | 6.39 | 6.47 | 6.58 | ✓ | BL | ✓ | × | × | Urban |
| | | | | | | SLv1 | | × | × | |
| | | | | | | SLv2 | | | × | |
| hrv [ln-transform] | 6.71 | 6.38 | 6.46 | 6.57 | ✓ | BL | ✓ | × | × | Rural |
| | | | | | | SLv1 | | × | × | |
| | | | | | | SLv2 | | | × | |
| hrv [ln-transform] | 6.63 | 6.51 | 6.53 | 6.28 | ✓ | BL | × | × | ✓ | Motorway |
| | | | | | | SLv1 | | × | ✓ | |
| | | | | | | SLv2 | | | ✓ | |




*(BAS= baseline, without S-IVIS, Exp= experimental, Visual task)*

**Figure 192 – Average 0.10 Hz component of heart rate variability HRV (LN-transformed)**

With increased mental effort the heart rate variability is reduced.

## 10.7. S-IVIS task performance

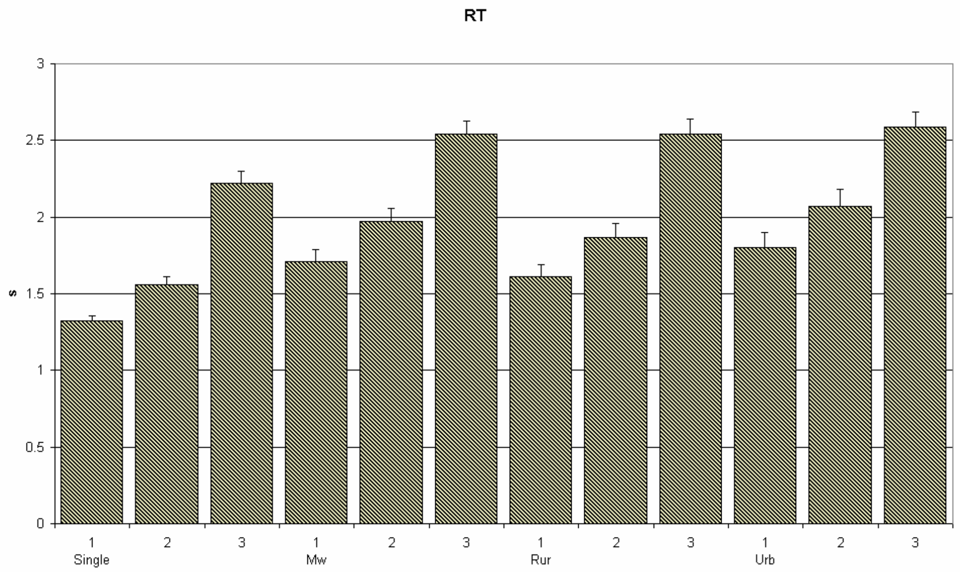
Reaction time (s_rt) in the secondary S-IVIS task was measured in four conditions; as a single task (the static S-IVIS test), while driving on the motorway, on the rural road, and in the urban environment. A main effect of level of difficulty was found; a slower response in the more difficult conditions. See Table 126.

A main effect of Environment was found, and from Figure 193 it is clear that in particular single and dual task performance differ.

**Table 126 –Reaction time (s_rt), Visual task**

| | Mean values | | | Effect | Post Hoc test | | | Road type |
|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv | | SLv2 | SLv3 | |
| s_rt [s] | 1.80 | 2.07 | 2.59 | ✓ | SLv1 | ✓ | ✓ | Urban |
| | | | | | SLv2 | | ✓ | |
| s_rt [s] | 1.61 | 1.87 | 2.54 | ✓ | SLv1 | ✓ | ✓ | Rural |
| | | | | | SLv2 | | ✓ | |
| s_rt [s] | 1.71 | 1.97 | 2.54 | ✓ | SLv1 | ✓ | ✓ | Motorway |
| | | | | | SLv2 | | ✓ | |
| s_rt [s] | 1.33 | 1.57 | 2.22 | ✓ | SLv1 | ✓ | ✓ | Static test |
| | | | | | SLv2 | | ✓ | |

The reaction time variation (st_rt) clearly increased with increased visual demand (S-IVIS difficulty level), in particular in the most difficult condition, Figure 194. Only a few errors were made and stimuli were missed while performing the S-IVIS single task, but in difficulty level 3 misses and errors together increased up to 37 % wrong answers (see Figure 195 and Figure 196).




*Single = static S-IVIS test, Mw = while driving on the motorway, Rur = on the rural road, and Urb = in the Built-up area*

**Figure 193 – Mean reaction time (s_rt) per environment and SLv.**

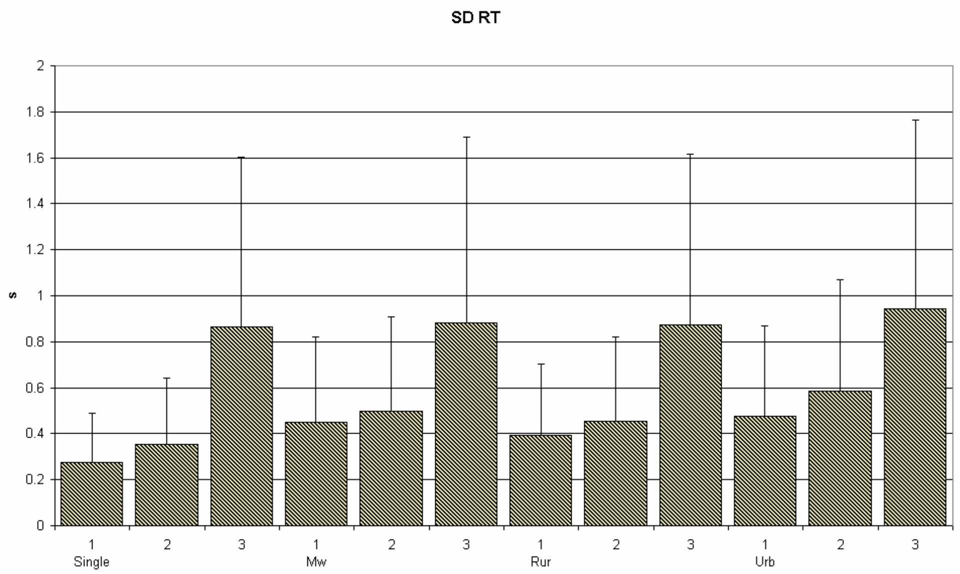
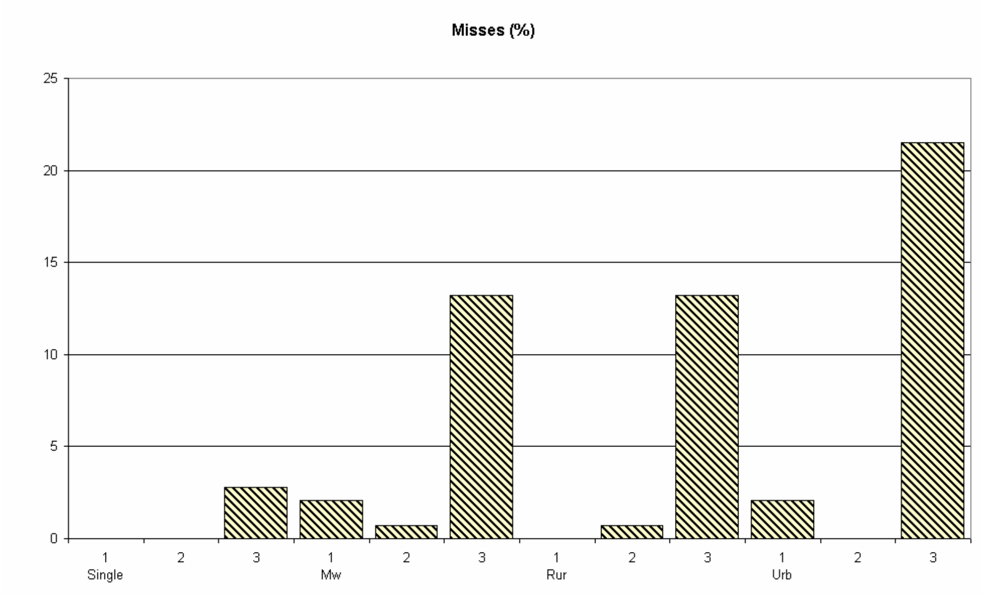
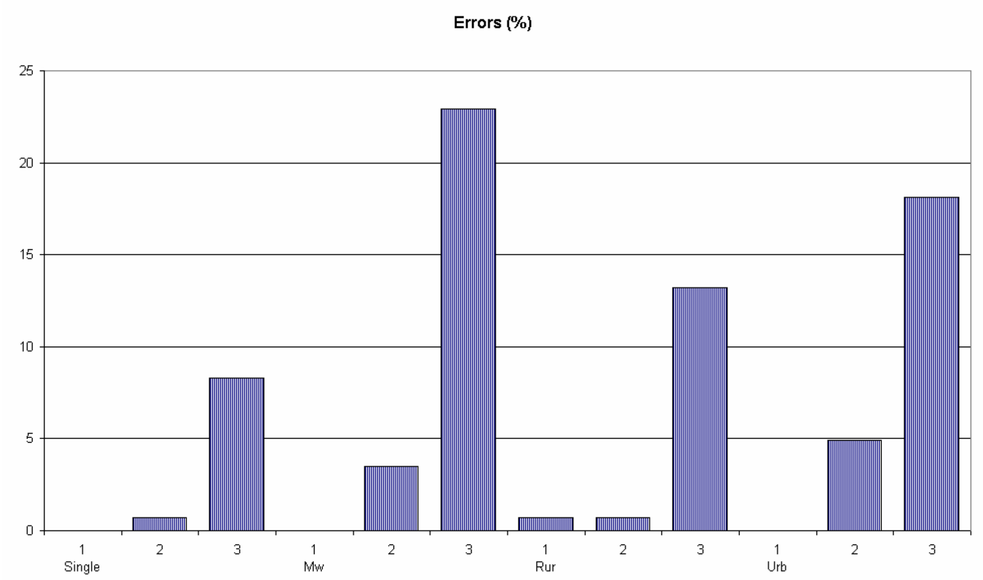



**Figure 194 – Reaction time variation (st_rt) for the different environments, Visual task**




*(Mw= motorway, Rur = rural road, Urb = Urban road, Single = single task performance),*

**Figure 195 – % missed responses (s_missed) by road type and SLv**




*(Mw= motorway, Rur = rural road, Urb = Urban road, Single = single task performance)*

**Figure 196 – % incorrect by road type and SLv**

## 10.8. Measures Summary Table

### 10.8.1. The visual task and Urban road

| | Mean values | | | | Effect | | Post Hoc test | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| **Self reported driving performance** | | | | | | | | | |
| subj_r | 7.60 | 7.09 | 7.01 | 6.66 | ✓ | BL | × | ✓ | ✓ |
| | | | | | | SLv1 | | ✓ | × |
| | | | | | | SLv2 | | | ✓ |
| **Longitudinal control** | | | | | | | | | |
| mn_sp [km/h] | 43.2 | 41.3 | 41.5 | 40.6 | ✓ | BL | × | × | ✓ |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |
| st_sp [km/h] | 5.22 | 4.56 | 4.69 | 4.24 | ✓ | BL | ✓ | × | × |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |
| **Lateral control** | | | | | | | | | |
| lnx_obs [% rides] | 0 | 8 | 10 | 19 | n/s | | | | |
| **Workload** | | | | | | | | | |
| hr [ibi; ms] | 722 | 712 | 714 | 712 | n/s | | | | |
| hrv [ln-transform] | 6.79 | 6.39 | 6.47 | 6.58 | ✓ | BL | ✓ | × | × |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |
| **S-IVIS results** | | | | | | | | | |
| s_rt [s] | | 1.80 | 2.07 | 2.59 | ✓ | SLv1 | | ✓ | ✓ |
| | | | | | | SLv2 | | | ✓ |
| sd_rt | | 0.48 | 0.59 | 0.95 | ✓ | SLv1 | | × | ✓ |
| | | | | | | SLv2 | | | ✓ |
| s_missed [%] | | 2.1 | 0 | 21.5 | n/s | | | | |
| s_incorrect | | 0.0 | 4.9 | 18.1 | n/s | | | | |

### 10.8.2. The visual task and Rural road

| | Mean values | | | | Effect | | Post Hoc test | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| **Self reported driving performance** | | | | | | | | | |
| subj_r | 7.89 | 7.60 | 7.33 | 6.82 | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | SLv1 | | ✓ | ✓ |
| | | | | | | SLv2 | | | ✓ |
| **Longitudinal control** | | | | | | | | | |
| mn_sp [km/h] | 76 | 73.1 | 74.3 | 72.1 | ✓ | BL | × | × | ✓ |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | ✓ |
| st_sp [km/h] | 2.47 | 2.57 | 2.28 | 2.55 | n/s | | | | |
| **Lateral control** | | | | | | | | | |
| Lnx_obs [% rides] | 0 | 15 | 8 | 50 | n/s | | | | |
| st_st [degrees] | 2.24 | 2.74 | 2.19 | 2.53 | n/s | | | | |
| **Workload** | | | | | | | | | |
| Hr [ibi; ms] | 745 | 740 | 745 | 733 | n/s | | | | |
| Hrv [ln-transform] | 6.71 | 6.38 | 6.46 | 6.57 | ✓ | BL | ✓ | × | × |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |
| **S-IVIS results** | | | | | | | | | |
| s_rt [s] | | 1.61 | 1.87 | 2.54 | ✓ | SLv1 | | ✓ | ✓ |
| | | | | | | SLv2 | | | ✓ |
| st_rt | | 0.39 | 0.45 | 0.87 | ✓ | SLv1 | | × | ✓ |
| | | | | | | SLv2 | | | ✓ |
| s_missed [%] | | 0 | 0.7 | 13.2 | n/s | | | | |
| s_incorrect | | 0.7 | 0.7 | 13.2 | n/s | | | | |

### 10.8.3. The visual task and Motorway

| | Mean values | | | | Effect | | Post Hoc test | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| **Self reported driving performance** | | | | | | | | | |
| subj_r | 7.90 | 7.59 | 7.43 | 6.89 | ✓ | BL | ✗ | ✓ | ✗ |
| | | | | | | SLv1 | | ✓ | ✓ |
| | | | | | | SLv2 | | | ✓ |
| **Longitudinal control** | | | | | | | | | |
| mn_sp [km/h] | 122.1 | 115.5 | 116.1 | 115.4 | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | SLv1 | | ✗ | ✗ |
| | | | | | | SLv2 | | | ✗ |
| st_sp [km/h] | 2.17 | 2.36 | 2.65 | 2.65 | n/s | | | | |
| **Lateral control** | | | | | | | | | |
| Lnx_obs [% rides] | 0 | 13 | 10 | 38 | n/s | | | | |
| st_st [degrees] | 2.63 | 2.55 | 2.53 | 2.79 | n/s | | | | |
| **Workload** | | | | | | | | | |
| Hr [ibi; ms] | 737 | 733 | 734 | 727 | n/s | | | | |
| Hrv [ln-transform] | 6.63 | 6.51 | 6.53 | 6.28 | ✓ | BL | ✗ | ✗ | ✓ |
| | | | | | | SLv1 | | ✗ | ✓ |
| | | | | | | SLv2 | | | ✓ |
| **S-IVIS results** | | | | | | | | | |
| s_rt [s] | | 1.71 | 1.97 | 2.54 | ✓ | SLv1 | | ✓ | ✓ |
| | | | | | | SLv2 | | | ✓ |
| st_rt | | 0.45 | 0.5 | 0.88 | ✓ | SLv1 | | ✗ | ✓ |
| | | | | | | SLv2 | | | ✓ |
| s_missed [%] | | 2.1 | 0.7 | 13.2 | n/s | | | | |
| s_incorrect | | 0.0 | 3.5 | 22.9 | n/s | | | | |

## 10.9. Discussion and Conclusions

In summary, the following can be concluded about the different measures and their sensitivity in this experiment.

- Average speed (mn_sp) was very sensitive to S-IVIS and S-IVIS difficulty. Average speed is relatively easy to measure.
- Speed variation (st_sp) was not found to be very sensitive in the present setup
- Lane keeping: In this experiment only video recordings were made of lateral position control. On the basis of the observer's comments, sections with increased swerving were played and time out of lane was recorded. However, driving out of lane (obs_lnx, rated as Seriousness "2") happened very infrequently and accordingly most cells remained zero. As scoring from videotape is very labour intensive this procedure was stopped after analysing three participants finding nothing additional to observer ratings and therefore only observer data were used.
- Steering wheel angle variation (st_st) had a square relation with difficulty level. No clear conclusion about the use of steering wheel measures can be based on the results of this study other than that st_st may be a measure not advanced enough.
- Observer judgements about speed: on high speed roads without S-IVIS too high speed was observed. This is "normal" speeding behaviour that can frequently be observed on motorways. Driving too slow was observed in experimental conditions on the motorway and up to 25% in the urban area. This coincides with the registered driving speed effects. The S-IVIS most frequently affected regularity of speed. This effect did not become very clear in Speed variation (st_sp) but only in observer ratings.
- Workload: IBI is sensitive to task-rest differences, with task either driving or the S-IVIS task. Sensitivity to S-IVIS difficulty level is restricted, possibly due to restricted differences in mental demands of the different task difficulties. The load of the task is mainly visual. The same applies to the 0.10 Hz component of heart rate variability, differences between task and rest, and experimental and baseline conditions, but not within difficulty levels.

# 11. The Swedish Field Experiment

## 11.1. Test site

The experiment was conducted on a motorway outside of Linköping, Sweden. The participants drove a Volvo S80 instrumented car. In the vehicle, speed, lateral position and steering wheel angle were measured. The Seeing Machines faceLAB 3.0 system was used for measuring gaze angle, and the ambulatory digital recorder Temec Vitaport 2 for measuring cardiac and nervous activities. Cameras recorded the face of the driver and the scenery in front of the vehicle. In Figure 197, the vehicle is displayed. In the right image, you can see the FaceLAB cameras through the steering wheel, and the touch screen to the right of the steering wheel.

**Figure 197 – The instrumented vehicle. Left, exterior; right, interior.**

## 11.2. Scenarios and participants

24 drivers participated in the experiment. 12 were male and 12 female. Their average age was 34 years (range 25-46) and the average time they had held their license was 14 years (range 5-27). On average they had driven 15,200 km (range 3,000-30,000) the past 12 months and had an average total mileage of 214,000 km (range 30,000-500,000).

### 11.2.1. Motorway

The motorway had two lanes in each direction. Each lane was 3.75 metres wide. The experiment was conducted to avoid rush hours. The risk of congestion was very low and congestion did not occur during the experiment. Each participant drove twice on the road; once in each direction. The route was not divided into segments of different road complexity levels.

## 11.3. S-IVIS evaluated

Both the visual task and the cognitive task were included. The original three difficulty levels described in 2.4- Surrogate IVIS  were included in the cognitive task, but in the visual task, the simpler alternative was used.

## 11.4. Experimental design

Each participant used both S-IVIS tasks, but no statistical comparisons were made between them. S-IVIS difficulty level (SLv) was a within subject factor. Half of the road stretch in each direction was used as the baseline run (without S-IVIS) and the other one as the experimental run (with S-IVIS). The order of baseline and experimental runs was counterbalanced. The order of the two S-IVIS tasks and S-IVIS difficulty levels were also counterbalanced. The S-IVIS was activated six times per experimental run. For further details about the choice of experimental design, see 2.3.5 -Factors and Levels.

All participants conducted the static S-IVIS test according to 2.3- Experimental design. This test was conducted either before or after driving in each direction of the motorway. The order was counterbalanced.

## 11.5. Procedure

An experimental leader accompanied the participants in the front passenger seat. The experimental leader controlled all equipment, instructed the participants on some occasions, and administered questions on driving performance during the runs.

The participants received written and spoken instructions. Electrodes for physiological measurements were attached to the participant and the gaze detection system was calibrated. Before each drive, the S-IVIS task to be conducted was practiced. The static S-IVIS tests were done either before or after each drive.

There was a distance of 5 km before the experimental route started during which the participants were able to familiarise themselves with the vehicle. Before entering the motorway, the experimental leader briefly repeated the S-IVIS instructions and told the participant whether the S-IVIS would be active during the first half of the drive or not. After half of the drives in both directions, the experimental leader told the participant that the S-IVIS was activated/inactivated.

The road environment and the participant’s face were recorded on video. After driving, the participants signed a document approving/not approving VTI to use the video recordings for scientific purposes.

## 11.6. Measures and analysis method

Speed, lateral position and steering angle were measured. From these, several safety critical indicators were derived, such as lateral position variation, time to line crossing and reversal rate. The self reported measure of driving performance was collected. Also, heart rate, skin conductance and gaze angle were recorded. All measures were implemented according to the specifications in *2.7.2 Indicators*. The effect of the S-IVIS was analysed according to the specification in 2.7.1 Common analysis method. For the S-IVIS tasks, the proportion of correct responses, misses and reaction time was recorded according to the specification in *2.7.3 S-IVIS analysis*. These results were however only compared qualitatively.

# 11.7. Results

## 11.7.1. Effects of the cognitive task

### *11.7.1.1. Self reported driving performance*

The cognitive task difficulty reduced the self rated driving performance (subj_r) significantly from 8.4 for the baseline condition (BL) to 6.6 for the most difficult cognitive task condition (SLv3). See Figure 149. subj_r discriminated between all the cognitive task difficulty levels except between SLv1 and SLv2, and is thus considered a highly sensitive measure.

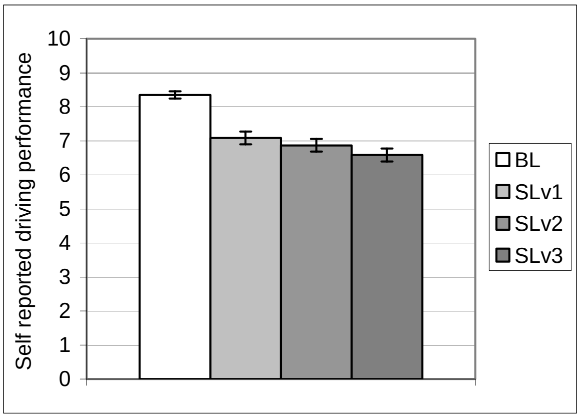



**Figure 198 – Self reported driving performance (subj_r), Cognitive task, Motorway**

**Table 127 – Analysis of self reported driving performance (subj_r), Cognitive task, Motorway**

| | Mean values | | | | Effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| subj_r | 8.35 | 7.09 | 6.87 | 6.59 | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | SLv1 | | × | ✓ |
| | | | | | | SLv2 | | | ✓ |

### *11.7.1.2. Longitudinal control*

Although there were some indications that the speed variation increased and the mean speed decreased as an effect of the cognitive task, these effects were very small (~1km/h) and not significant. Thus neither any compensatory speed reduction nor any indications of deteriorated speed monitoring could be found.

Since there was no equipment in the vehicle for measuring distance to lead vehicles, no car interaction measures could be collected.

### *11.7.1.3. Lateral control*

Several steering activity indicators and lateral position stability indicators were collected. It was found that the cognitive task resulted in an increased steering activity; the reversal rate (rr_st1) increased significantly with the cognitive task difficulty. The reversal rate was 2 reversals per minute higher with the cognitive task than without, which corresponded to a 10% higher reversal rate. See Figure 199 and Table 128. The steering entropy measure (en_st) however indicated that the predictability of the steering behaviour decreased; st_en was 4%

less for with S-IVIS than without. See Figure 200 and Table 129. For neither of the measures was it possible to discriminate between the experimental levels, SLv1, 2 and 3. Since the effects were small and contradictory, and no effects were found in the other steering measures or lateral position measures, the conclusion is that the cognitive task had no safety impact in lateral control.

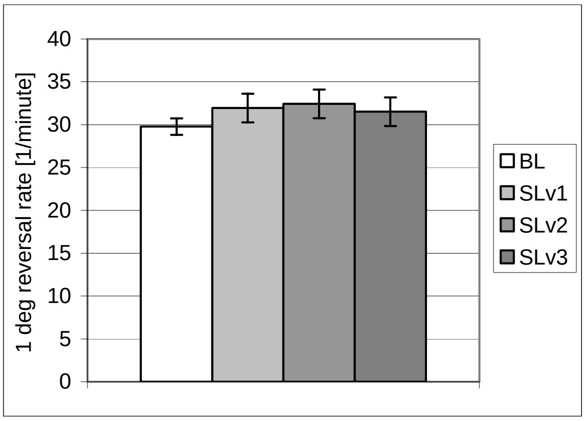



**Figure 199 – One degree reversal rate (rr_st1), Cognitive task, Motorway**

**Table 128 – Analysis of one degree reversal rate (rr_st1), Cognitive task, Motorway**

| | Mean values | | | | Effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| rr_st1 [1/minute] | 29.77 | 31.93 | 32.42 | 31.51 | ✓ | BL | ✓ | ✓ | × |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |

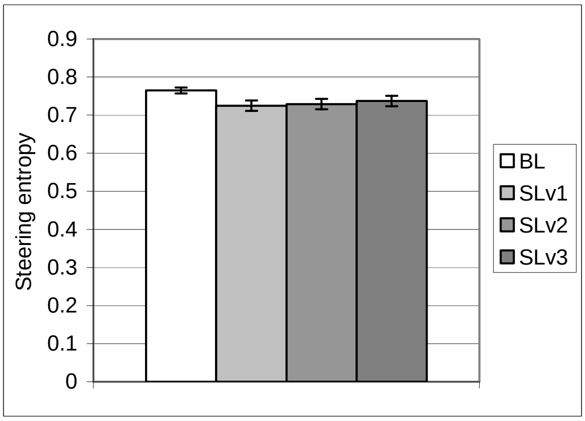



**Figure 200 – Steering entropy (en_st), Cognitive task, Motorway**

**Table 129 – Analysis of steering entropy (en_st), Cognitive task, Motorway**

| | Mean values | | | | Effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| en_st [-] | 0.77 | 0.73 | 0.73 | 0.74 | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |

### *11.7.1.4. Workload*

Inter-beat-intervals (inversed heart rate), heart rate variability, skin conductance level and variation were included as physiological workload indicators. Heart rate variability was not included since it was considered that the S-IVIS tasks were too short for this workload indicator to provide a reliable measure. It was found that the inter-beat-intervals (ibi) was significantly reduced with S-IVIS difficulty, indicating an increased level of stress. See Figure 201 and Table 130. The difference between with/without S-IVIS was 21 milliseconds. The corresponding difference in heart rate was 2.3 beats per minute. In ibi, post hoc test identified differences between the experimental levels and baseline, but not in between the experimental levels. No effects were however found in skin conductance or heart rate variability. The cognitive task thus caused slight increase in stress level.

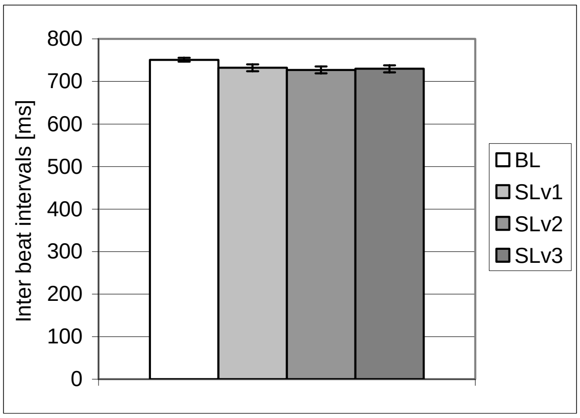
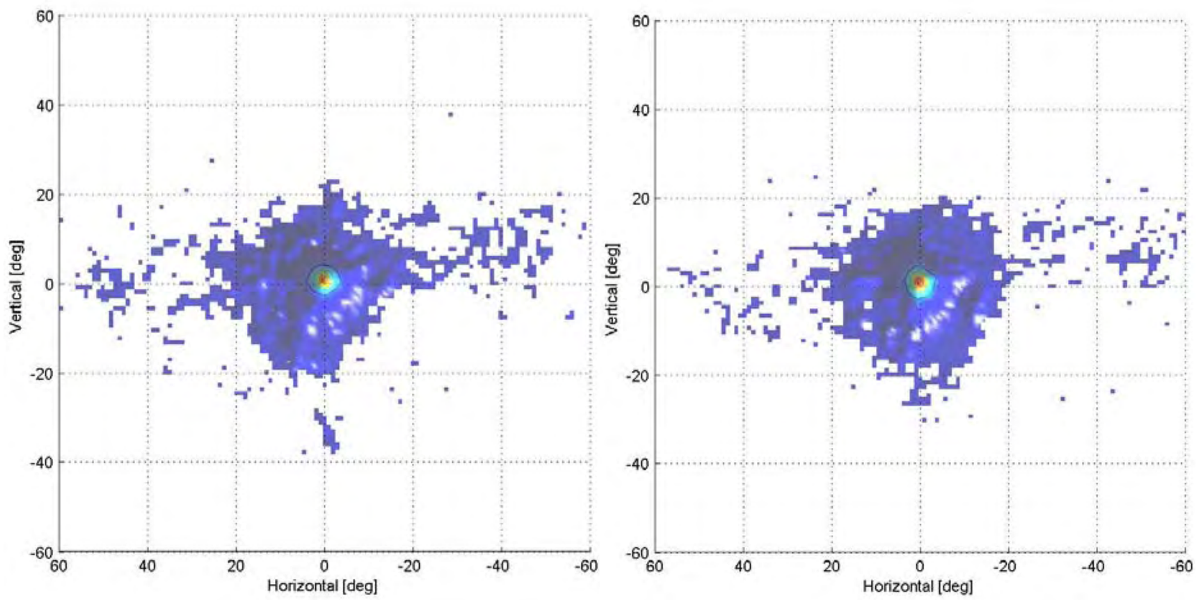



**Figure 201 – Inter-beat-intervals (ibi), Cognitive task, Motorway**

**Table 130 – Analysis of inter-beat-intervals (ibi), Cognitive task, Motorway**

| | Mean values | | | | Effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| ibi [ms] | 750.93 | 732.2 | 727.2 | 729.8 | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |

For the eye movement analysis, 21% of the data were missing due to poor eye-tracking performance (technical difficulties). Figure 202 shows spatial density plots for the gaze directions, comparing baseline and the cognitive task data (all SLv1-3 data). As can be seen in the plot, glances towards the roadside, mirrors and the instrument cluster (probably the speedometer) are less frequent in the cognitive task condition.




*Baseline driving* *Cognitive task (SLv1-3 aggregated)*

**Figure 202 – Gaze data during baseline driving compared to the task, Cognitive task, Motorway**

In order to quantify this effect, the standard deviation of gaze angle (st_ga) was computed. The results from this analysis are given in Figure 203 and Table 131. The analysis indicated a significant decrease in *st_ga* for SLv1 and 3 compared to baseline. For SLv2, there was a very strong trend in the same direction (p=0.052). There were no significant differences between S-IVIS levels. The percent road centre (*prc*) measure yielded similar results, although the effects were weaker. Similar effects were also found in the Volvo simulator experiment. These results support existing studies demonstrating gaze concentration as a result of cognitive load effect (e.g. Recartes and Nunes, 2003).

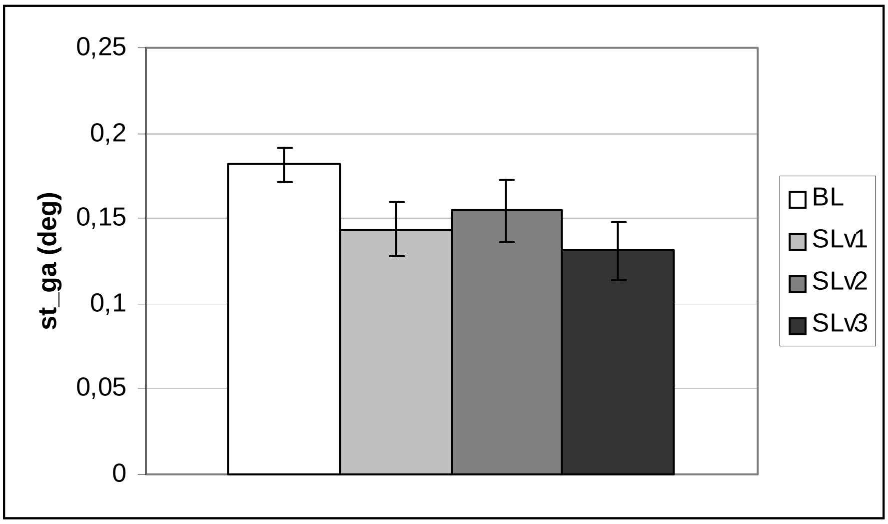



**Figure 203 – Standard deviation of gaze angle (*st_ga*), Cognitive task, Motorway**

**Table 131 – Analysis of standard deviation of gaze angle (*st_ga*) Cognitive task, Motorway**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **st_ga (deg)** | 0.18 | 0.14 | 0.15 | 0.13 | ✓ | n/a | n/a | BL | ✓ | × | ✓ |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | × |

### *11.7.1.5. S-IVIS performance*

The cognitive task performance of course decreased with the cognitive task difficulty. What we also find is that the performance was similarly decreased when used as a single task (static test) and dual task (during the driving experimental condition), although there was a systematic difference between the static and the experimental conditions. See Figure 204 and Figure 205 for the cognitive task results. The cognitive task was prioritised during driving, as was intended. There were no indications of the drivers giving up the cognitive task.

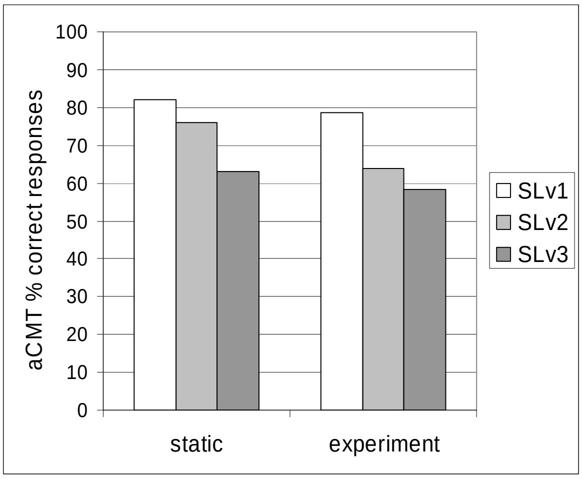



**Figure 204 – % correct responses in static test and in driving, Cognitive task, Motorway**

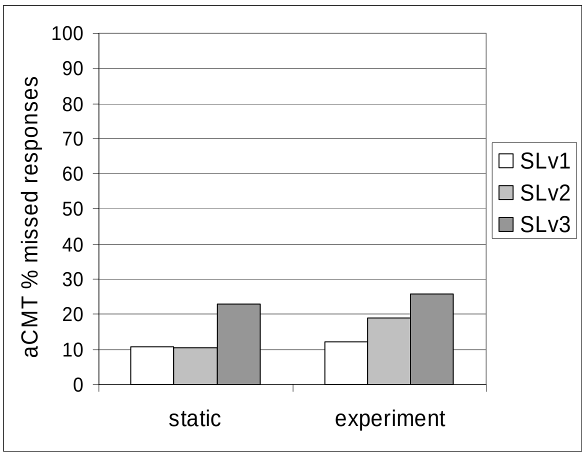



**Figure 205 – % missed responses in static test and in driving, Cognitive task, Motorway**

### 11.7.2. Effects of the visual task

#### *11.7.2.1. Self reported driving performance*

The self reported driving performance (subj_r) was reduced significantly as an effect of the visual task difficulty. The post hoc test showed that all SLvs were significantly different except for between SLv1 and SLv2, as was also the case for the cognitive task. See Figure 206 and Table 132. subj_r was thus also for the visual task found to be a very sensitive indicator of driving performance.

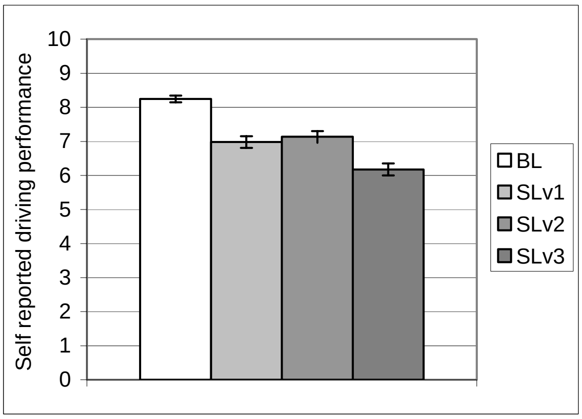



**Figure 206 – Self reported driving performance (subj_r), Visual task, Motorway**

**Table 132 – Analysis of self reported driving performance (subj_r), Visual task, Motorway**

| | Mean values | | | | Effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| subj_r | 8.25 | 6.98 | 7.13 | 6.17 | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | SLv1 | | × | ✓ |
| | | | | | | SLv2 | | | ✓ |

#### *11.7.2.2. Longitudinal control*

For the cognitive task, no effects on speed control were found. For the visual task, however, the results show that the mean speed (mn_sp) was reduced by 3 km/h, and that the speed variation (st_sp) increased by 0.5 km/h with the visual task compared to without. See Figure 207, Figure 208, Table 133 and Table 134. No effect was found in the speed change measure (d_sp). These effects were most likely a result of the drivers compensating for the increased visual demand by reducing the speed. Speed reduction of course also affects speed variation. No safety critical impact of the visual task in speed control was thus found.

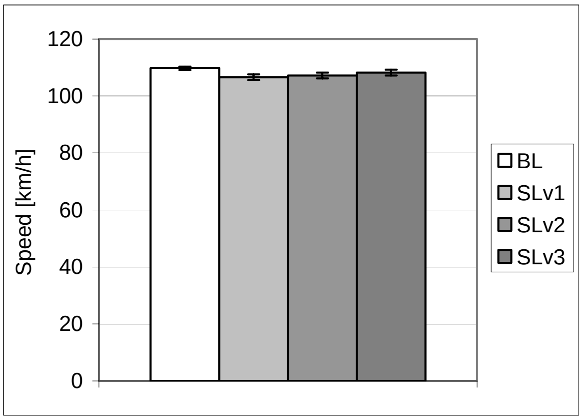



**Figure 207 – Mean speed (mn_sp), Visual task, Motorway**

**Table 133 – Analysis of mean speed (mn_sp), Visual task, Motorway**

| | Mean values | | | | Effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| mn_sp [km/h] | 109.75 | 106.54 | 107.26 | 108.25 | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | SLv1 | | × | ✓ |
| | | | | | | SLv2 | | | × |

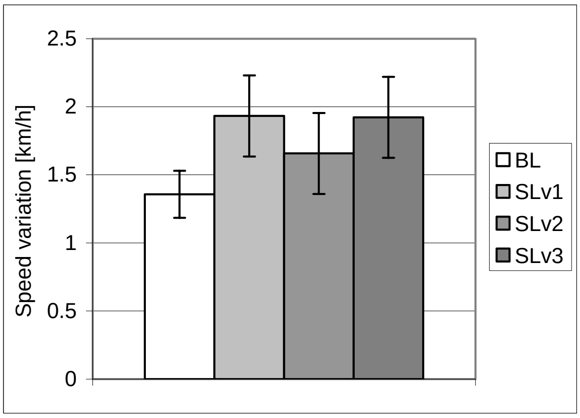



**Figure 208 – Speed variation (st_sp), Visual task, Motorway**

**Table 134 - Analysis of speed variation (st_sp), Visual task, Motorway**

| | Mean values | | | | Effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| st_sp [km/h] | 1.36 | 1.93 | 1.66 | 1.92 | ✓ | BL | ✓ | × | ✓ |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |

### *11.7.2.3. Lateral control*

For the cognitive task, no safety effects were found. For the visual task, however, both steering activity and lane keeping stability was affected.

When the visual task was active, several steering activity measures were increased indicating a more active steering behaviour: Reversal rate (rr_st1) was increased by 13% (Figure 209, Table 135). The high frequency steering component (hi_st) was increased by 32% (Figure 210, Table 136). The 10 deg/sec rapid steering wheel turnings (rswt_10) increased by 69%

(Figure 211 and Table 137). Post hoc tests identified differences between each experimental condition (SLv1-3) and baseline (BL). No differences were however found between the experimental levels in spite of the large effects of the visual task, except for in hi_st (difference between SLv3 and 1). In e.g. The VTI simulator study, the sensitivity was found to be better. This is probably explained by the less controlled driving conditions in the field trial, but also by the visual task that was set to be easier in the field trial than in the simulator study.

The mean time to line crossing (mn_tlc) decreased with the visual task difficulty, indicating a decreased safety marginal to the lane boundaries. See Figure 212 and Table 138. The effect was however very small, less than one second, and only a difference between SLv2 and baseline was identified in the post hoc test. No effect was found in lateral position variation. The effect on lateral position stability was thus marginal.

No effect was found in steering entropy (en_st), which was a setback since en_st proved to be a very sensitive measure in e.g. The VTI simulator study. Also, no effect was found in steering angle variation (st_st) and 40 and 70 deg/sec rapid steering wheel turnings (rswt_40/70).

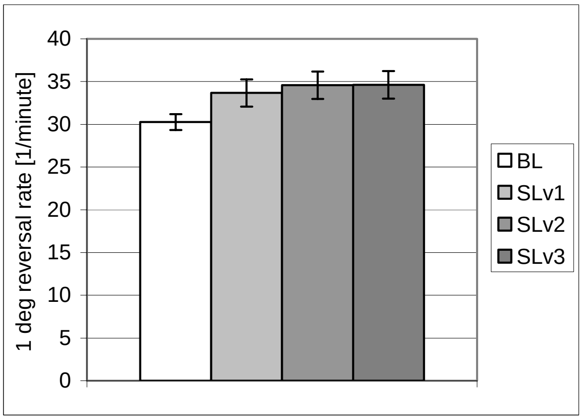



**Figure 209 – One degree reversal rate (rr_st1), Visual task, Motorway**

**Table 135 – Analysis of one degree reversal rate (rr_st1), Visual task, Motorway**

| | Mean values | | | | Effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| rr_st1 [1/minute] | 30.26 | 33.66 | 34.57 | 34.61 | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |

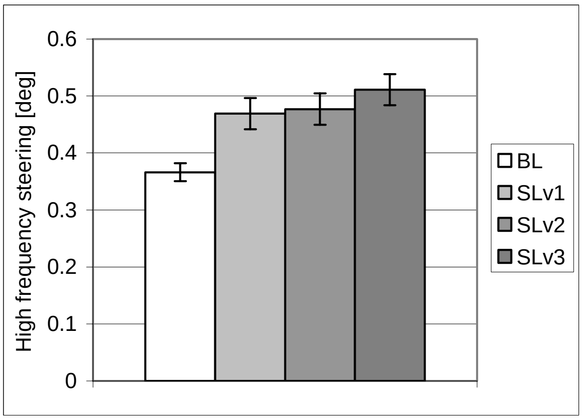



**Figure 210 – High frequency steering component (hi_st), Visual task, Motorway**

**Table 136 – Analysis of high frequency steering component (hi_st), Visual task, Motorway**

| | Mean values | | | | Effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| hi_st [deg] | 0.37 | 0.47 | 0.48 | 0.51 | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | SLv1 | | × | ✓ |
| | | | | | | SLv2 | | | × |

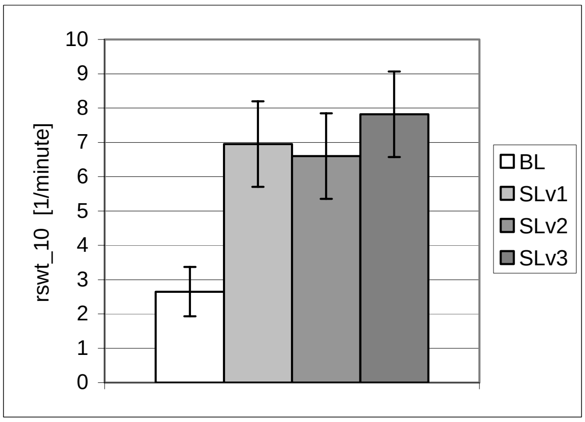



**Figure 211 – 10 deg/sec rapid steering wheel turnings (rswt_10), Visual task, Motorway**

**Table 137 – Analysis of 10 deg/sec rapid steering wheel turnings (rswt_10), Visual task, Motorway**

| | Mean values | | | | Effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| rswt_10 [1/minute] | 2.65 | 6.95 | 6.6 | 7.82 | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |

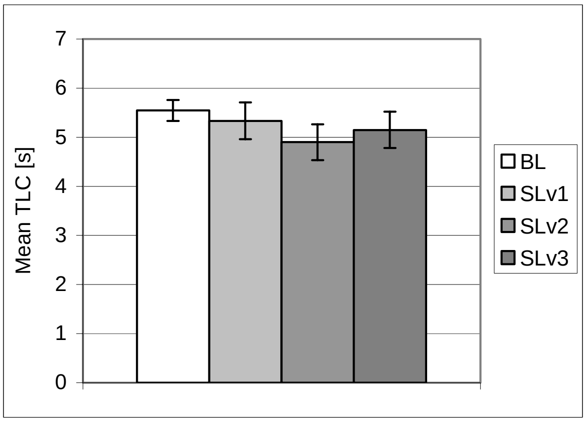



**Figure 212 – Mean time to line crossing (mn_tlc), Visual task, Motorway**

**Table 138 – Analysis of mean time to line crossing (mn_tlc), Visual task, Motorway**

| | Mean values | | | | Effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| mn_tlc [s] | 5.55 | 5.34 | 4.9 | 5.15 | ✓ | BL | × | ✓ | × |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |

### *11.7.2.4. Workload*

**Heart beat and skin conductance measures**

Effects of the visual task were found in inter-beat-intervals (ibi) and in skin conductance level (dc_eda) and variation (ac_eda). The results suggest that the stress and workload levels were increased as the visual task was active. There were significant differences between the experimental levels and baseline, but not between the experimental levels. No effect was found in heart rate variability (hrv), although the mean values indicated that the workload increased (hrv decreased). For ibi and eda results, see Figure 213 and Figure 214.

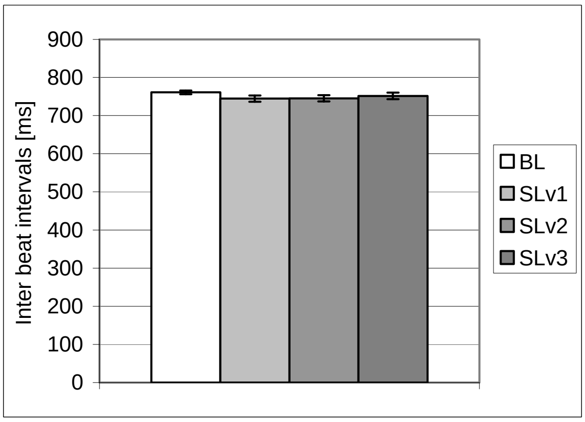



**Figure 213 – Inter-beat-intervals (ibi), Visual task, Motorway**

**Table 139 – Analysis of inter-beat-intervals (ibi), Visual task, Motorway**

| | Mean values | | | | Effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| ibi [ms] | 760.98 | 744.7 | 745.33 | 751.78 | ✓ | BL | ✓ | ✓ | × |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |

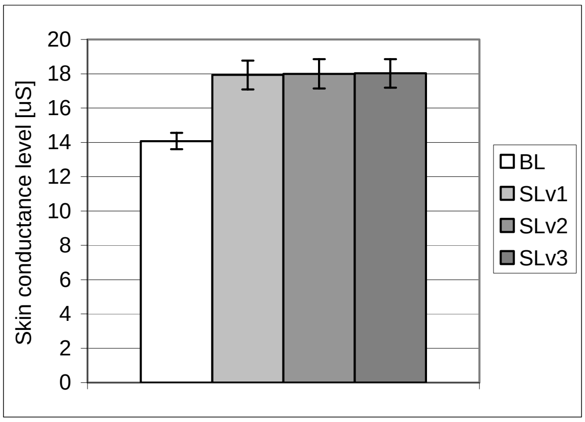



**Figure 214 – Skin conductance level (eda_dc), Visual task, Motorway**

**Table 140 – Analysis of skin conductance level (eda_dc), Visual task, Motorway**

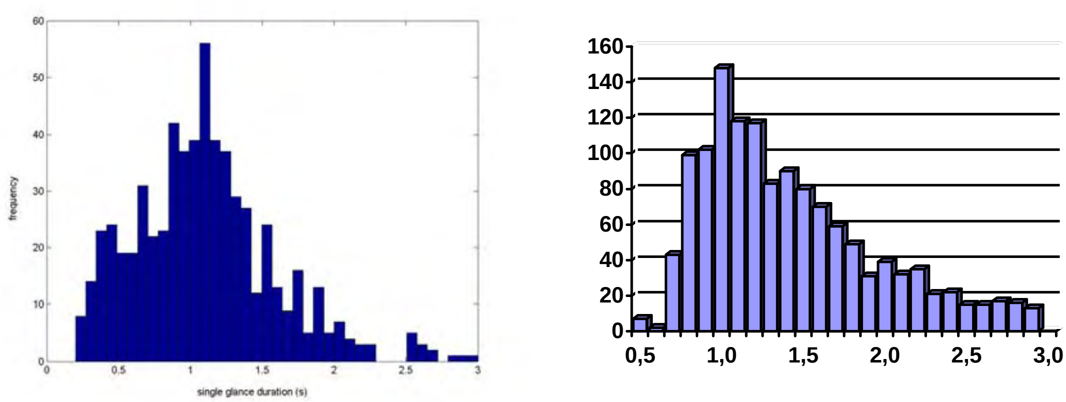
| | Mean values | | | | Effect | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 |
| dc_eda [uS] | 14.08 | 17.92 | 17.99 | 18.02 | ✓ | BL | ✓ | ✓ | ✓ |
| | | | | | | SLv1 | | × | × |
| | | | | | | SLv2 | | | × |

## Eye movement measures

For the visual task, four dependent measures were analysed: number of glances to the S-IVIS display (glance frequency, *n_gl*), the mean single glance duration (*mn_gd*)l, the percentage of total glance time directed to the S-IVIS (*pr_glt*) and the percent road centre (*prc*). For the measures requiring glance segmentation (*n_gl*, *mn_gd* and *pr_glt*), 45% of the data were missing due to poor performance of the eye tracking system.

For the glance-based measures, comparison to a baseline is not meaningful (as there is no reason to expect glances to the S-IVIS display in a no-task condition). Thus, for the visual task, only differences between S-IVIS levels were analysed.

The distribution of single glance durations is plotted in Figure 215. In the corresponding data from the Volvo simulator study, there was a strong peak at about 0.3-0.4 seconds, indicating the occurrence of short “check” glances to the S-IVIS display in order to detect the onset of new arrows images. In the present data, there is a tendency for such a peak, although it is much smaller than in the simulator data. Further analysis is needed to explain this difference.




*Current study* *Rockwell (1988)*

**Figure 215 – Distribution of single glance durations, Visual task, Motorway**

The data is based on a total of 618 glances. Rockwell's data is based on 1230 glances obtained from instrumented vehicle studies on public roads over a ten-year period.

The analysis results for mean single glance duration is presented in Figure 216 and Table 141. SLv3 differed significantly from SLv1 and 2.

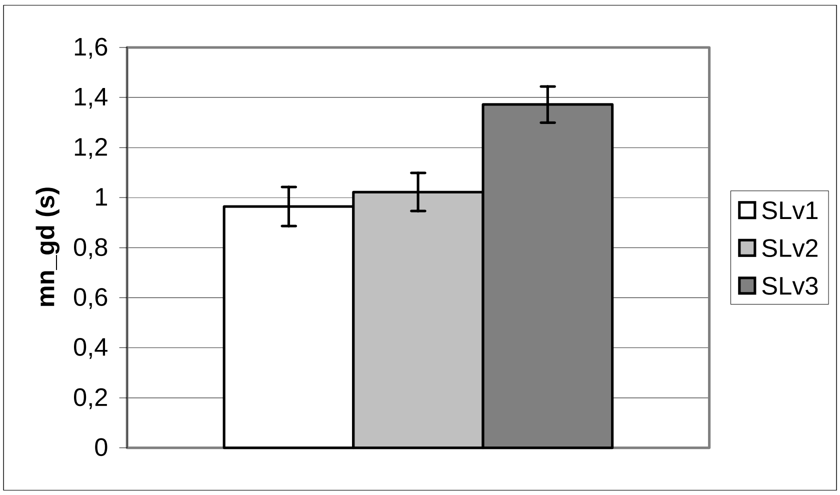



**Figure 216 – Mean single glance duration (*mn_gd*), Visual task, Motorway**

**Table 141 – Analysis of mean single glance duration (*mn_gd*), Visual task, Motorway**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| mn_gd (s) | n/a | 0.96 | 1.02 | 1.37 | ✓ | n/a | n/a | BL | n/a | n/a | n/a |
| | | | | | | | | SLv1 | | × | ✓ |
| | | | | | | | | SLv2 | | | ✓ |

Figure 217 and Table 142 present the results for the number of glances to the S-IVIS display (glance frequency) for the visual task. The only significant difference was between SLv2 and 3.

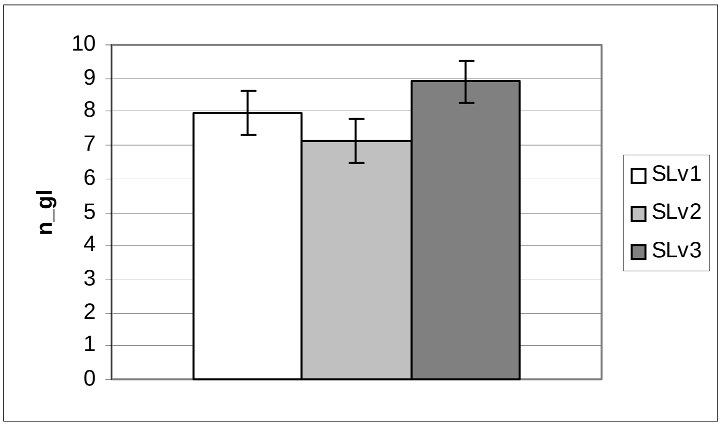



**Figure 217 – The no. of glances to the S-IVIS display (glance frequency, *n_gl*), Visual task, Motorway**

**Table 142 – Analysis of no. of glances to S-IVIS display (glance frequency, *n_gl*), Visual task, Motorway**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| n_gl | n/a | 8 | 7.1 | 8.9 | ✓ | n/a | n/a | BL | n/a | n/a | n/a |
| | | | | | | | | SLv1 | | × | × |
| | | | | | | | | SLv2 | | | ✓ |

The results for percentage glance time to the S-IVIS display (*pr_glt*) are presented in Figure 218 and Table 143. As the results show, SLv3 differs strongly from SLv1 and 2.

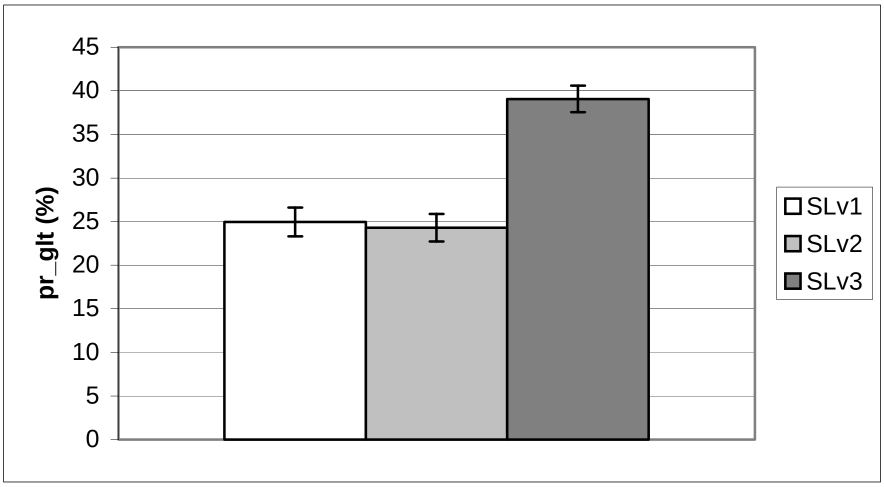



**Figure 218 – % glance time to the S-IVIS display (*pr_glt*), Visual task, Motorway**

**Table 143 – Analysis of % glance time to the S-IVIS display (*pr_glt*), Visual task, Motorway**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **pr_glt (%)** | n/a | 25 | 24 | 39 | ✓ | n/a | n/a | BL | n/a | n/a | n/a |
| | | | | | | | | SLv1 | | × | ✓ |
| | | | | | | | | SLv2 | | | ✓ |

For the *prc* measure, which is computed directly from gaze direction (and thus does not require glance segmentation), 42% of the data were missing due to poor eye tracking performance. In this case, a baseline measure is included. The results from the *prc* analysis for the visual task are presented in Figure 219and Table 144. The SLv1-3 differed significantly from baseline. The only significant difference between S-IVIS levels was between SLv3 and SLv1.

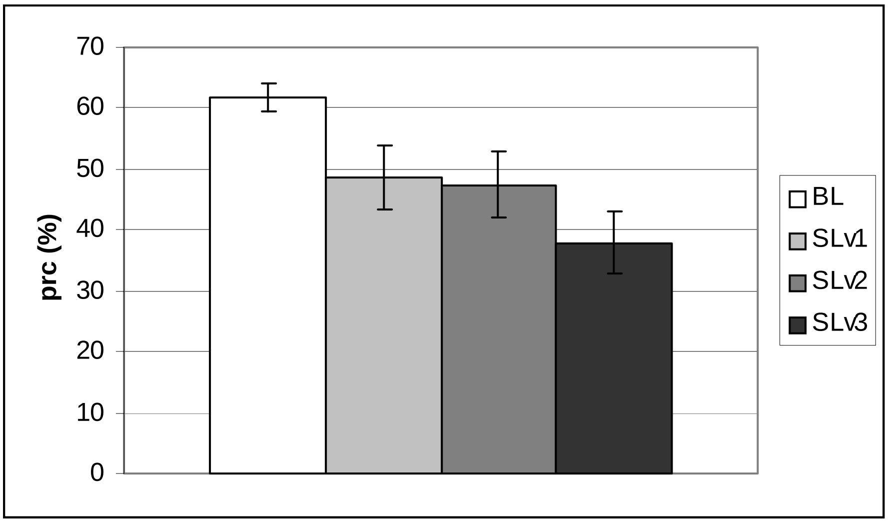



**Figure 219 – Percent road centre (*prc*), Visual task, Motorway**

**Table 144 – Analysis of Percent road centre (*prc*), Visual task, Motorway**

| | Mean values | | | | Significant Effects | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | RLv | SLv*RLv | | SLv1 | SLv2 | SLv3 |
| **prc (%)** | 62 | 49 | 47 | 37 | ✓ | n/a | n/a | BL | ✓ | ✓ | ✓ |
| | | | | | | | | SLv1 | | × | ✓ |
| | | | | | | | | SLv2 | | | × |

Taken together, the results from the visual task analysis indicate that SLv3 induced significantly higher visual demand than SLv1 and 2. No differences were found between the latter.

### *11.7.2.5. S-IVIS performance.*

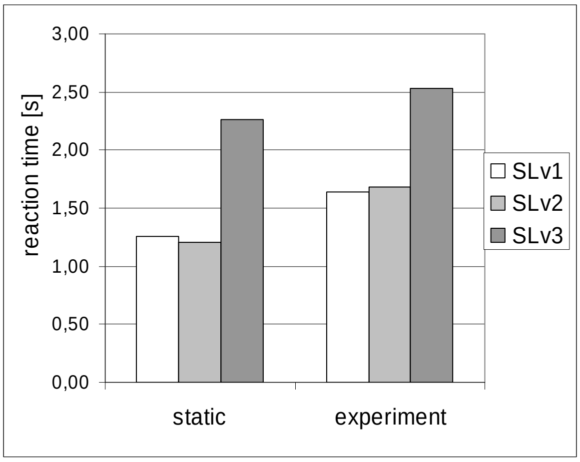



**Figure 220 – Reaction time, Visual task, Motorway**

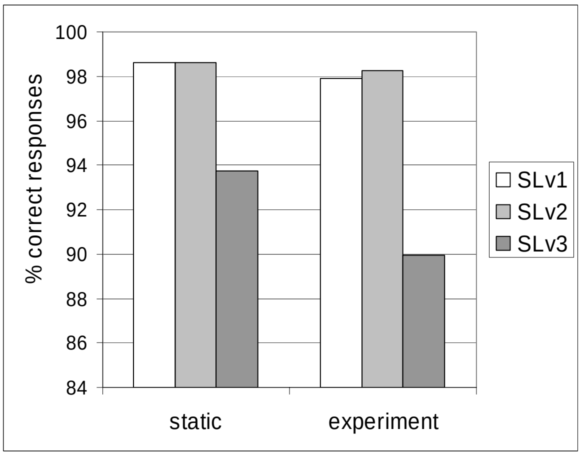



**Figure 221 – % correct responses, Visual task, Motorway**

## 11.8. Summary and conclusions

In this study, similar results were found as in the other WP2 experiments for both S-IVIS tasks. It was found that the visual task affected driving more than the cognitive task. In this experiment, primarily the steering activity was increased as an effect of the visual task and the lateral position stability was somewhat reduced. The results for the cognitive task indicated that the drivers considered their driving performance was poorer with the cognitive task. The cognitive task had a significant effect on the workload indicators, leading to reduced intervals between heartbeats and an increased concentration of gaze towards the road centre. Except for the self reported driving performance, only two measures indicated any effect of the cognitive task on driving at all, and these results were contradictory.

It was hypothesised that the included measures would be sensitive to differences between the S-IVIS difficulty levels (SLvs). For the driving performance and physiological workload measures, however, this was not true. The only exception was the self reported driving performance, which was sensitive to all differences except for between SLv1 and 2.

The most successful driving performance measures in this experiment was self rated driving performance (subj_r), reversal rate (rr_st1), high frequency steering (hi_st), 10 deg/s rapid steering wheel turnings (rswt_10) and steering entropy (en_st), in that order.

## 11.9. Measures summary tables

### 11.9.1. Motorway and the cognitive task

| | Mean values | | | | Main effect | Post Hoc test | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 | |
| **Self reported driving performance** | | | | | | | | | | |
| subj_r | 8.35 | 7.09 | 6.87 | 6.59 | ✓ | BL | ✓ | ✓ | ✓ | |
| | | | | | | SLv1 | | × | ✓ | |
| | | | | | | SLv2 | | | ✓ | |
| **Longitudinal control** | | | | | | | | | | |
| mn_sp [km/h] | 109.24 | 108.85 | 109.29 | 109.01 | ns | | | | | |
| st_sp [km/h] | 1.67 | 2.11 | 1.75 | 1.76 | ns | | | | | |
| d_sp [km/h] | -0.01 | -0.59 | -0.12 | -1.22 | ns | | | | | |
| **Lateral control** | | | | | | | | | | |
| mn_lp [m] | -0.78 | -0.75 | -0.75 | -0.85 | ns | | | | | |
| st_lp [m] | 0.21 | 0.17 | 0.22 | 0.19 | ns | | | | | |
| mn_tlc [s] | 5.65 | 5.87 | 5.67 | 5.66 | ns | | | | | |
| pr_tlc [%] | 11.13 | 11.46 | 12.06 | 11.5 | ns | | | | | |
| rr_st1 [1/minute] | 29.77 | 31.93 | 32.42 | 31.51 | ✓ | BL | ✓ | ✓ | × | |
| | | | | | | SLv1 | | × | × | |
| | | | | | | SLv2 | | | × | |
| st_st | 1.4 | 1.51 | 1.5 | 1.46 | ns | | | | | |
| hi_st [deg] | 0.38 | 0.39 | 0.38 | 0.42 | ns | | | | | |
| en_st [-] | 0.77 | 0.73 | 0.73 | 0.74 | ✓ | BL | ✓ | ✓ | ✓ | |
| | | | | | | SLv1 | | × | × | |
| | | | | | | SLv2 | | | × | |
| rswt_10 [1/minute] | 2.84 | 3.88 | 3.62 | 4.5 | ns | | | | | |
| rswt_40 [1/minute] | | | | | | | | | | not analysed |
| rswt_70 [1/minute] | | | | | | | | | | not analysed |
| **Workload** | | | | | | | | | | |
| ibi [ms] | 750.93 | 732.2 | 727.2 | 729.8 | ✓ | BL | ✓ | ✓ | ✓ | |
| | | | | | | SLv1 | | × | × | |
| | | | | | | SLv2 | | | × | |
| hrv [ms] | 3785.83 | 5364.35 | 5300.94 | 4200.15 | ns | | | | | |
| dc_eda [uS] | 16.69 | 17.14 | 17.92 | 17.51 | ns | | | | | |
| ac_eda [uS] | 0.52 | 0.5 | 0.51 | 0.58 | ns | | | | | |
| st_ga (deg) | 0.18 | 0.14 | 0.15 | 0.13 | ✓ | BL | ✓ | × | ✓ | |
| | | | | | | SLv1 | | × | × | |
| | | | | | | SLv2 | | | × | |

## 11.9.2. Motorway and the visual task

| | Mean values | | | | Main effect | Post Hoc test | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| Measure | BL | SLv1 | SLv2 | SLv3 | SLv | | SLv1 | SLv2 | SLv3 | |
| **Self reported driving performance** | | | | | | | | | | |
| subj_r | 8.25 | 6.98 | 7.13 | 6.17 | ✓ | BL | ✓ | ✓ | ✓ | |
| | | | | | | SLv1 | | × | ✓ | |
| | | | | | | SLv2 | | | ✓ | |
| **Longitudinal control** | | | | | | | | | | |
| mn_sp [km/h] | 109.75 | 106.54 | 107.26 | 108.25 | ✓ | BL | ✓ | ✓ | ✓ | |
| | | | | | | SLv1 | | × | ✓ | |
| | | | | | | SLv2 | | | × | |
| st_sp [km/h] | 1.36 | 1.93 | 1.66 | 1.92 | ✓ | BL | ✓ | × | ✓ | |
| | | | | | | SLv1 | | × | × | |
| | | | | | | SLv2 | | | × | |
| d_sp [km/h] | -0.29 | -2.99 | -0.42 | -1.45 | ns | | | | | |
| **Lateral control** | | | | | | | | | | |
| mn_lp [m] | -0.79 | -0.76 | -0.74 | -0.79 | ns | | | | | |
| st_lp [m] | 0.21 | 0.21 | 0.2 | 0.23 | ns | | | | | |
| mn_tlc [s] | 5.55 | 5.34 | 4.9 | 5.15 | ✓ | BL | × | ✓ | × | |
| | | | | | | SLv1 | | × | × | |
| | | | | | | SLv2 | | | × | |
| pr_tlc [%] | 11.53 | 10.67 | 14.76 | 12.53 | ns | | | | | |
| rr_st1 [1/minute] | 30.26 | 33.66 | 34.57 | 34.61 | ✓ | BL | ✓ | ✓ | ✓ | |
| | | | | | | SLv1 | | × | × | |
| | | | | | | SLv2 | | | × | |
| st_st | 1.36 | 1.46 | 1.49 | 1.5 | ns | | | | | |
| hi_st [deg] | 0.37 | 0.47 | 0.48 | 0.51 | ✓ | BL | ✓ | ✓ | ✓ | |
| | | | | | | SLv1 | | × | ✓ | |
| | | | | | | SLv2 | | | × | |
| en_st [-] | 0.76 | 0.76 | 0.75 | 0.75 | ns | | | | | |
| rswt_10 [1/minute] | 2.65 | 6.95 | 6.6 | 7.82 | ✓ | BL | ✓ | ✓ | ✓ | |
| | | | | | | SLv1 | | × | × | |
| | | | | | | SLv2 | | | × | |
| rswt_40 [1/minute] | | | | | | SLv1 | | | | not analysed |
| rswt_70 [1/minute] | | | | | | SLv1 | | | | not analysed |
| **Workload** | | | | | | | | | | |
| ibi [ms] | 760.98 | 744.7 | 745.33 | 751.78 | ✓ | BL | ✓ | ✓ | × | |
| | | | | | | SLv1 | | × | × | |
| | | | | | | SLv2 | | | × | |
| hrv [ms] | 3466.71 | 2710.44 | 2044.48 | 2152.57 | ns | | | | | |
| dc_eda [uS] | 14.08 | 17.92 | 17.99 | 18.02 | ✓ | BL | ✓ | ✓ | ✓ | |
| | | | | | | SLv1 | | × | × | |
| | | | | | | SLv2 | | | × | |
| ac_eda [uS] | 0.44 | 0.78 | 0.7 | 0.8 | ✓ | BL | ✓ | ✓ | ✓ | |
| | | | | | | SLv1 | | × | × | |
| | | | | | | SLv2 | | | × | |
| mn_gd (s) | n/a | 0.96 | 1.02 | 1.37 | ✓ | BL | n/a | n/a | n/a | not analysed for BL |
| | | | | | | SLv1 | | × | ✓ | |
| | | | | | | SLv2 | | | ✓ | |
| n_gl | n/a | 8 | 7.1 | 8.9 | ✓ | BL | n/a | n/a | n/a | not analysed for BL |
| | | | | | | SLv1 | | × | × | |
| | | | | | | SLv2 | | | ✓ | |
| prc (%) | 62 | 49 | 47 | 37 | ✓ | BL | ✓ | ✓ | ✓ | |
| | | | | | | SLv1 | | × | ✓ | |
| | | | | | | SLv2 | | | × | |

# 12. The VTT Field Experiment

This field study was designed to investigate and compare the potential or sensitivity of selected assessment methods to reflect the effects of different S-IVIS on driver behaviour. More specifically, (1) the data was collected in real traffic, (2) the drivers included so-called average and elderly drivers, (3) the effects of increasing the visual task and the cognitive task workload on driver performance were quantified, (4) the road types included both rural and urban driving and (5) evaluations were based on vehicle data, observations and drivers' reports.

## 12.1. Test site

The instrumented vehicle used in the tests was a 1999 Toyota Corolla sedan with manual transmission. The vehicle was equipped with a hidden PC-based measuring system, differential GPS receiver and a video recording system with two cameras, one in front of the vehicle and one on the dashboard aimed towards the driver's face. The driver's eye movements were recorded with these cameras, as well as the general view in the front of the vehicle. Data collection frequency was 10 Hz for speed and distance data, and for steering wheel angle data. The data was transmitted to the videocassette recorder (VCR) and computer in the trunk.

The visual task was presented by the monitor located on the right side of the steering wheel such that the eye-screen distance was approximately 65 cm for a driver about 180 cm tall.

## 12.2. Scenarios and participants

In total, 54 subjects participated in the study. All were licensed drivers who volunteered for the study. The final data included 48 subjects: two subjects were excluded due to technical problems resulting in insufficient data; one subject was excluded due to sudden heavy rainfall during data collection; and three elderly subjects were unable to hear all the sounds of the S-IVIS task and were excluded after the practice session.

Twenty-four of the final set of subjects were aged between 25 and 59 years (mean 37 years) and 24 between 60 and 73 years (mean 68 years). These age groups corresponded to the *average* and *elderly* driver groups. There were five females and 19 males in each age group. Each subject had driven at least 10,000 km during the previous 12 months and had had their driving licence for at least 5 years. All the drivers owned or regularly drove a vehicle of the same type as the one used in the study.

The test route consisted of two traffic environments: (a) urban and (b) rural. The urban road section consisted of suburban roads in the Helsinki capital area. The posted speed limit ranged from 30 km/h to 60 km/h. The section was 12 km long and included 20 intersections. The S-IVIS was presented at six of these intersections. Each of these intersections had two pedestrian zebra crossings (Figure 222). The driver should yield the right-of-way to potential traffic represented by the narrow lines (traffic on priority streets and pedestrians on zebra crossings).

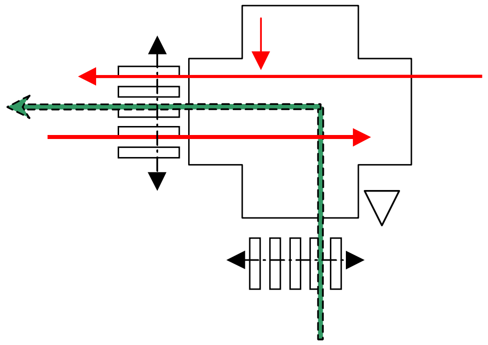


**Figure 222 – Diagram of an intersection with a yield sign where the driver's task was to turn left (thick line).**

The rural road section consisted of one-lane roads in the Helsinki area. The posted speed limit ranged from 60 km/h to 80 km/h. The section was 16 km long. The S-IVIS was presented six times on the straight road sections. In addition to these test routes, drivers drove a practice route of 13.8 km to familiarise themselves with the car and the S-IVIS. They also drove a few kilometres between the urban and rural test routes.

## 12.3. S-IVIS evaluated

Drivers had two S-IVIS; the visual and the cognitive tasks. Both tasks included three difficulty levels (SLv1, SLv2 and SLv3). In the visual task SLv½, SLv1 and SLv2 are referred to as SLv1, SLv2 and SLv3. Drivers had to perform each difficulty level twice in each environment.

On the urban route the S-IVIS task was performed at yielding intersections, where the driver's driving task was to turn either right or left. On the rural route the S-IVIS task was performed at link sections, where the speed limit was either 80 km/h or changed during the S-IVIS task from 80 km/h to 60 km/h or vice versa.

## 12.4. Experimental design

The test route was driven three times, with the visual task, with the cognitive task, and baseline (normal driving). The order of the environments, tasks and task difficulty levels were balanced across subjects within age groups. The timing of the S-IVIS task was determined and controlled by the distance travelled from fixed points (determined with a GPS receiver).

The order of S-IVIS difficulty was counterbalanced over participants. The order of road types was however not. The static S-IVIS test was included. Each participant conducted both S-IVIS tasks, and the order of tasks was counterbalanced.

## 12.5. Procedure

Subjects participated in the experiment individually. They were told that the aim of the study was to investigate what kind of task drivers can safely perform while driving. Particularly, the subjects were instructed to drive safely through the test route and performthe S-IVIS task when it was presented to them.

Since the experiments were conducted in real traffic, an experimenter sat in the front passenger seat equipped with an extra brake pedal. He also gave directions in order to maintain the correct route. An observer, whom the driver believed to be technical support staff, sat in the back. At no time did the observer interfere with the driving.

After completing the drive, subjects were asked about their opinions about the S-IVIS task. Finally they were told that their driving behaviour had been recorded during the experiment, and their permission to use the data was requested.

Experiments were carried out between May 5 and July 2, 2003. The data was collected on weekdays between 9 a.m. and 3 p.m. The experiments were conducted in good weather and road surface conditions; i.e. There was no precipitation or water on the road surface.

### 12.5.1. Measures and analysis method

In the rural route, speed limit information and the driver's speed behaviour were recorded. Only free-flow traffic situations (in which drivers were able to choose their driving speed) were included in the speed analyses (77–80% of all cases). Rapid steering-wheel turns (RSWT) and 2 degrees reversal rate (rr_st2) were computed.

In the urban route, speed behaviour in straight road sections was recorded. Special attention was directed to areas before zebra crossings. Braking jerks of more than 8 $m/s^3$ were counted and these situations analysed.

The effects of S-IVIS difficulty and age group were analysed. However, only a few effects-based vehicle or observational data could be tested because the null hypothesis of Levene's test was usually rejected. Consequently, the obtained differences should be viewed only as possible trends.

The S-IVIS performance was analysed according to *2.7.3 S-IVIS measures and analysis*. Reaction time, correct, incorrect and missed responses were analysed. Driver's self-reported driving quality was asked after each S-IVIS block and at the same locations during the baseline run. In addition, drivers provided several overall assessments after performing the test runs.

In addition to driver behaviour, the accompanying observer coded the driver's performance and the traffic situations with respect to:

- presence of vehicle in front
- presence of oncoming vehicles
- interaction with vehicles in front
- lane keeping behaviour
- speed choice and adaptation
- yielding behaviour
- interaction with vulnerable road users
- signalling behaviour

## 12.6. Results

### 12.6.1. Effects of secondary task in Rural Road driving

#### *12.6.1.1. Traffic conditions*

The traffic conditions were statistically equal in terms of presence of lead vehicles and oncoming traffic. Specifically, 77–80% of the observed sections included no vehicle in front, 79–84% included oncoming vehicles (e.g. at least three groups of oncoming vehicle on the observation section) and 56–65% included oncoming heavy vehicles.

#### *12.6.1.2. Self reported driving performance*

The drivers were asked to rate their driving performance on a scale of 1 to 10, where 1 = "I drove extremely poorly" and 10 = "I drove extremely well". The ratings were asked after each observation section, after S-IVIS task blocks, or after a corresponding section on the baseline route when no S-IVIS task was performed. Drivers rated their driving performance best in baseline conditions (Figure 223). The ratings were higher also for the control sections than while performing the tasks. The ratings were somewhat higher for the cognitive task than for the visual task. Drivers rated their driving performance to be worse as the difficulty of the S-IVIS task increased. Elderly drivers rated their driving performance lower than did average drivers for both environments and tasks.

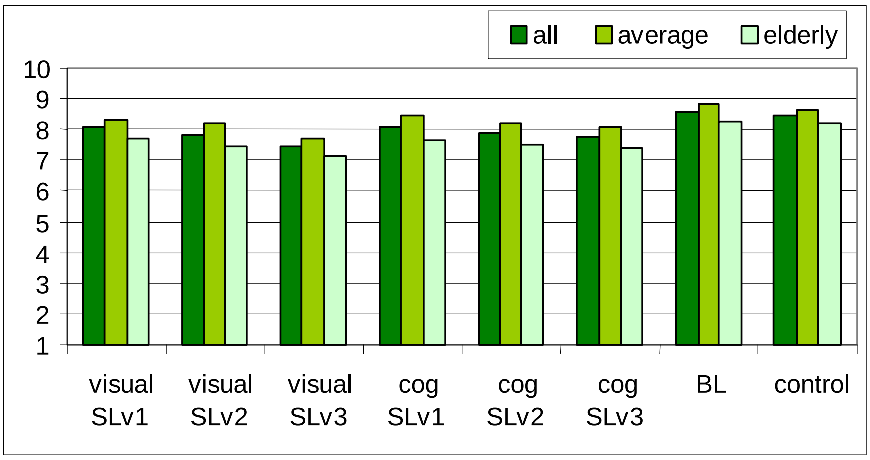



**Figure 223 – Self-reported driving quality on rural road sections by task and difficulty level**

#### *12.6.1.3. Longitudinal control*

The main results for speed behaviour are given in Table 145. For both age groups, the visual task tended to decrease the mean speed somewhat, whereas the cognitive task had practically no effect. However, this tendency was evident only for the comparison of baseline and experiment (not for individual difficulty levels). In addition, both S-IVIS tasks more or less increased the speed variation. This tendency was evident for both age groups.

**Table 145 – Speed behaviour by age group, S-IVIS type and difficulty level**

| | S-IVIS type and level | Mean speed (km/h) | Max speed (km/h) | Min speed (km/h) | Speed variation (km/h) |
|---|---|---|---|---|---|
| Average drivers | Baseline - visual task | 82.4 | 84.5 | 80.3 | 1.2 |
| | Experiment - visual task | 80.9 | 83.2 | 78.7 | 1.3 |
| | SLv1 | 81.0 | 83.5 | 78.9 | 1.3 |
| | SLv2 | 81.2 | 83.3 | 78.8 | 1.3 |
| | SLv3 | 80.5 | 82.9 | 78.3 | 1.2 |
| | | | | | |
| | Baseline - cognitive task | 82.2 | 85.0 | 85.0 | 1.5 |
| | Experiment - cognitive task | 83.0 | 86.5 | 79.2 | 2.0 |
| | SLv1 | 82.4 | 85.6 | 78.2 | 2.1 |
| | SLv2 | 84.1 | 87.9 | 80.1 | 2.1 |
| | SLv3 | 82.6 | 86.0 | 79.4 | 1.8 |
| | | | | | |
| Elderly drivers | Baseline - visual task | 81.9 | 84.7 | 79.0 | 1.7 |
| | Experiment - visual task | 80.9 | 84.7 | 77.4 | 2.2 |
| | SLv1 | 80.6 | 84.5 | 77.3 | 2.2 |
| | SLv2 | 82.1 | 85.6 | 78.5 | 2.2 |
| | SLv3 | 80.0 | 83.7 | 76.2 | 2.1 |
| | | | | | |
| | Baseline - cognitive task | 81.5 | 85.2 | 77.2 | 2.1 |
| | Experiment - cognitive task | 81.6 | 86.0 | 77.2 | 2.7 |
| | SLv1 | 82.4 | 86.4 | 78.9 | 2.3 |
| | SLv2 | 81.0 | 85.6 | 76.1 | 2.9 |
| | SLv3 | 81.5 | 85.9 | 76.6 | 2.9 |
| | | | | | |
| All drivers | Baseline - visual task | 82.4 | 85.0 | 80.0 | 1.5 |
| | Experiment - visual task | 81.0 | 84.0 | 78.0 | 1.7 |
| | SLv1 | 80.8 | 84.0 | 77.9 | 1.8 |
| | SLv2 | 81.7 | 84.5 | 78.6 | 1.7 |
| | SLv3 | 80.3 | 83.3 | 77.3 | 1.7 |
| | | | | | |
| | Baseline - cognitive task | 82.1 | 85.3 | 78.6 | 1.8 |
| | Experiment - cognitive task | 82.4 | 86.2 | 78.2 | 2.4 |
| | SLv1 | 82.4 | 86.0 | 78.5 | 2.2 |
| | SLv2 | 82.6 | 86.8 | 78.2 | 2.5 |
| | SLv3 | 82.0 | 85.9 | 77.8 | 2.4 |

For the visual task, minimum speed (u_sp) was significantly less for elderly drivers and reduced by S-IVIS difficulty level. Post hoc tests showed that the effect was significant between baseline and SLv3. In addition, speed variation (st_sp) was significantly higher for the elderly drivers. For the cognitive task, the minimum speed was significantly less for the elderly drivers compared to the average drivers. Effects on mean speed, maximum speed and speed variation could not be tested with Unianova because the null hypothesis of Levene's test was rejected.

Compared to average drivers, elderly drivers were more often observed to have changes in their speed behaviour (obs_sp_irr). This was the case in all three S-IVIS task conditions. More specifically, the cognitive task had a somewhat greater influence than the visual task on the speed behaviour of average drivers, while there was no remarkable effect S-IVIS task type on the speed behaviour of elderly drivers (Figure 224).

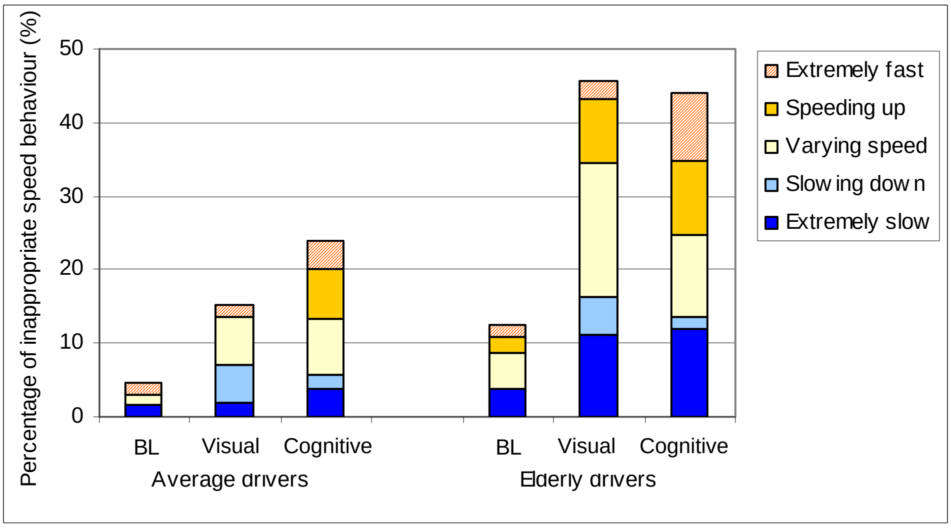



**Figure 224 – Inappropriate speeding by age group and S-IVIS type**

Furthermore, elderly drivers more frequently decreased or varied their speed when an S-IVIS task was performed, especially with the visual task. In addition, for elderly drivers both the visual task and the cognitive tasks were observed to increase the speed (speeding up and extremely fast), whereas with average drivers increasing speed was observed mainly with the cognitive task.

In general, when the S-IVIS task difficulty increased, a greater proportion of drivers were observed to have inappropriate speed behaviour. While involved in the visual task, average drivers were observed to change their speed behaviour only at the most difficult level, whereas the speed of elderly drivers changed at all difficulty levels. While involved in the cognitive task, inappropriate speed behaviour increased with the difficulty of the increasing task, except for elderly drivers whose inappropriate speed behaviour decreased from SLv2 to SLv3 (Figure 225).

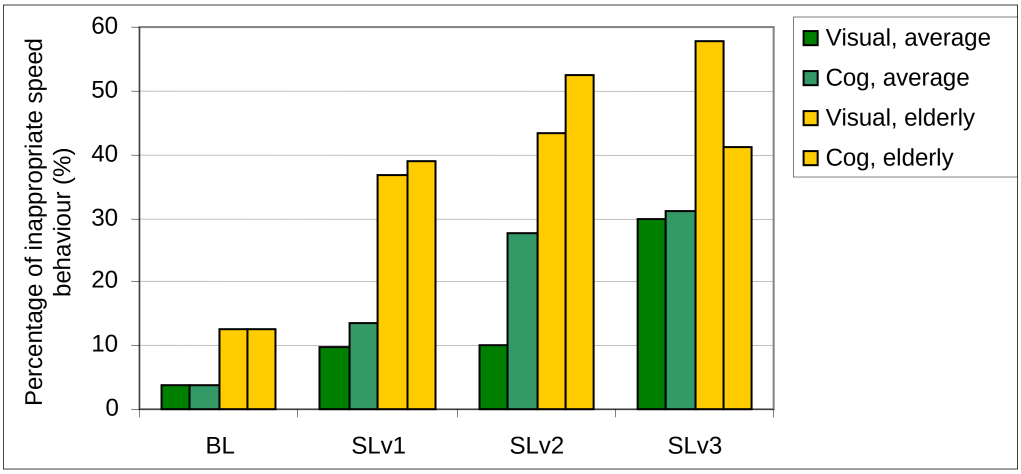



**Figure 225 – % of drivers inappropriately speeding by age group, S-IVIS type and task difficulty level**

The proportion of time driving faster than 5 km/h over the speed limit of 80km/h was 23.0% in baseline conditions. The proportion of time driving slower than 5 km/h below the limit was 3.3% (Table 146). The effects of either task on high speed could not be tested with an Anova because the null hypothesis of Levene's test was rejected. Nevertheless, the S-IVIS task tended to increase the proportions of high and low speed for each age group, except for average drivers performing the visual task (Figure 226). Comparison of the effects by three difficulty levels of the S-IVIS task showed no clear trend.

**Table 146 – Proportion driving faster or slower than 5 km/h above or under the speed limit**

| | | FAST | | SLOW | |
|---|---|---|---|---|---|
| | **S-IVIS type and level** | **5-9.9 km/h** | **10 km/h or above** | **5-9.9 km/h** | **10 km/h or below** |
| **Average drivers** | Baseline - visual task | 25.1 | 5.1 | 2.2 | 0.7 |
| | Experiment - visual task | 10.7 | 1.3 | 4.8 | 0.0 |
| | SLv1 | 6.9 | 3.1 | 5.7 | 0.0 |
| | SLv2 | 12.9 | 0.0 | 4.1 | 0.0 |
| | SLv3 | 12.2 | 0.7 | 4.6 | 0.0 |
| | | | | | |
| | Baseline - cognitive task | 18.0 | 3.8 | 0.9 | 0.5 |
| | Experiment - cognitive task | 25.3 | 8.9 | 6.2 | 0.4 |
| | SLv1 | 21.1 | 9.9 | 7.7 | 1.2 |
| | SLv2 | 31.0 | 7.9 | 0.0 | 0.0 |
| | SLv3 | 23.7 | 8.8 | 10.8 | 0.0 |
| | | | | | |
| **Elderly drivers** | Baseline - visual task | 17.5 | 1.1 | 4.6 | 0.0 |
| | Experiment - visual task | 21.2 | 4.5 | 13.2 | 3.7 |
| | SLv1 | 19.3 | 1.7 | 12.1 | 1.5 |
| | SLv2 | 21.3 | 8.8 | 6.9 | 4.2 |
| | SLv3 | 23.1 | 3.1 | 20.7 | 5.5 |
| | | | | | |
| | Baseline - cognitive task | 20.6 | 1.1 | 2.7 | 1.5 |
| | Experiment - cognitive task | 20.9 | 5.6 | 10.3 | 0.5 |
| | SLv1 | 26.2 | 4.1 | 4.8 | 0.0 |
| | SLv2 | 22.4 | 6.5 | 18.1 | 1.0 |
| | SLv3 | 14.2 | 6.1 | 7.9 | 0.4 |
| | | | | | |
| **All drivers** | Baseline - visual task | 21.2 | 3.0 | 3.4 | 0.4 |
| | Experiment - visual task | 16.2 | 2.9 | 9.0 | 1.9 |
| | SLv1 | 14.1 | 2.3 | 9.4 | 1.0 |
| | SLv2 | 17.2 | 4.6 | 5.5 | 2.2 |
| | SLv3 | 17.3 | 1.8 | 12.1 | 2.5 |
| | | | | | |
| | Baseline - cognitive task | 19.4 | 2.4 | 1.8 | 1.0 |
| | Experiment - cognitive task | 22.9 | 7.1 | 8.1 | 0.4 |
| | SLv1 | 23.6 | 7.0 | 6.3 | 0.6 |
| | SLv2 | 26.8 | 7.2 | 8.8 | 0.5 |
| | SLv3 | 18.2 | 7.2 | 9.1 | 0.2 |

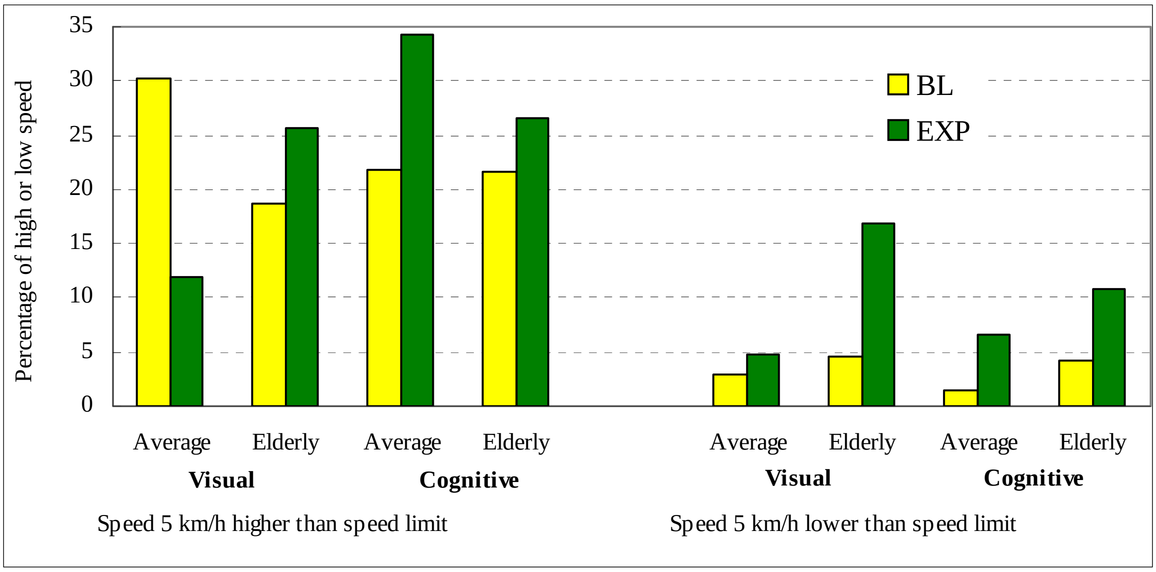



**Figure 226 – Proportion of high and low speeding compared to the speed limit by age group and S-IVIS type**

In the situations where the speed limit changed from 80 to 60km/h, the results showed that the visual task tended to decrease speeding of average drivers and increase that of elderly drivers, while the cognitive task increased speeding of both driver groups (Figure 227).

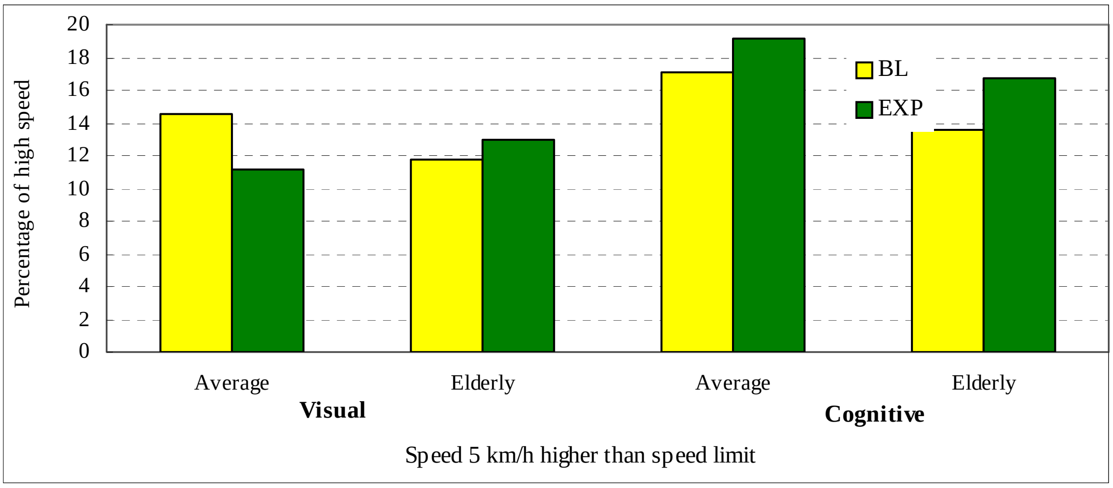



**Figure 227 – Proportion of speeding by S-IVIS type and age group**

Observations showed that in the baseline, only 5% of the drivers were classified to be driving too fast after passing the speed limit sign. The mean percentage was 6 while engaged in the visual task and 16 while engaged in the cognitive task. Compared to average drivers, a greater percentage of elderly drivers seemed to fail the speed limit compliance with less difficult S-IVIS tasks (Figure 228).

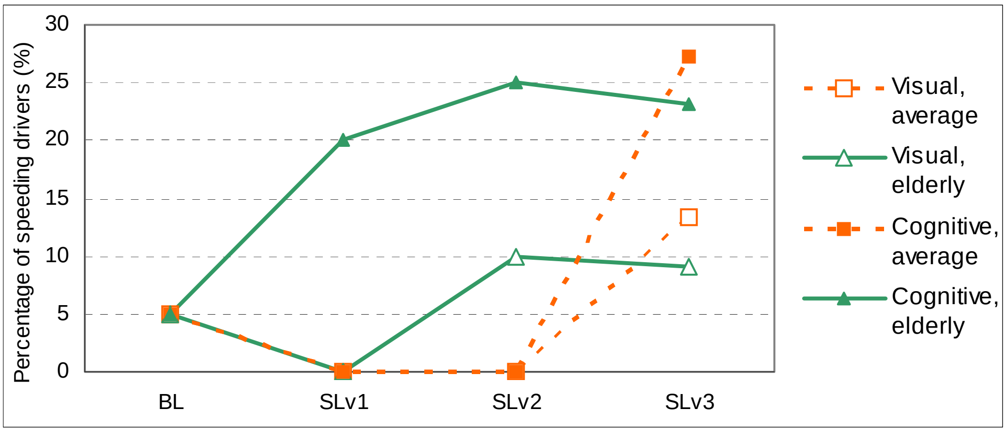



**Figure 228 – % of drivers driving too fast by age group and S-IVIS type**

Approximately 20% of the observation sections included a car-following situation (vehicles travelling in front). In the baseline runs, the drivers were observed to have appropriate headway in 90% of car following situations. The rate was 80% while engaged in the S-IVIS task. Compared to average drivers, elderly drivers more frequently drove too close (Figure 229). They had both momentary close-following situations and continuous close-following situations more often than average drivers did. The cognitive task caused more problems to average drivers and the visual task caused more problems to elderly drivers. However, one should bear in mind that the total number of car-following cases was quite small, only 21 to 30 drivers per S-IVIS task type.

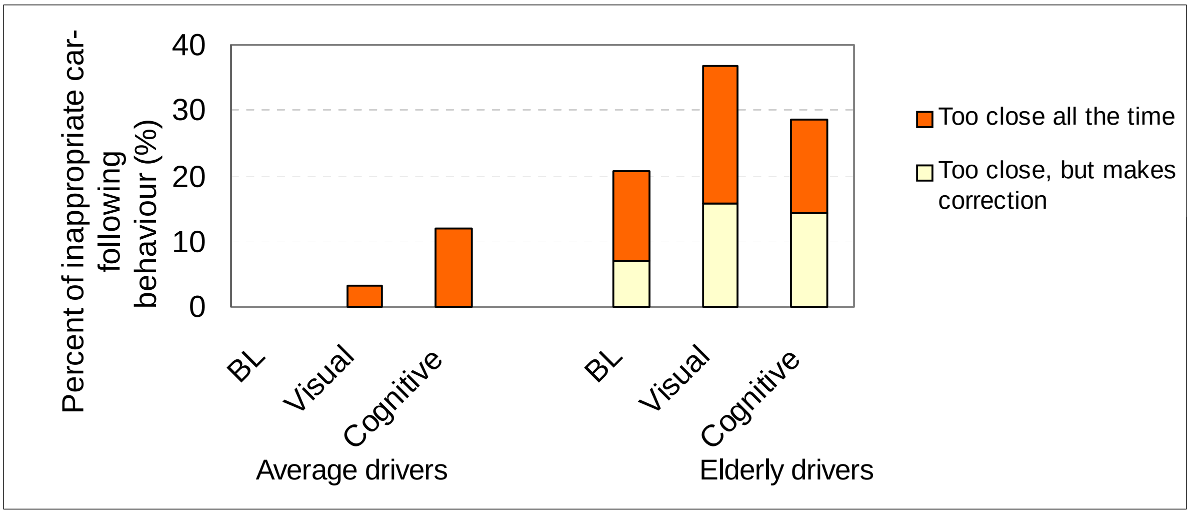



**Figure 229 – % of drivers inappropriately car-following by driver age group and S-IVIS type**

While engaged in the visual task, the percentage of inappropriate car-following behaviour was greater on SLv2 and SLv3 (20–23%) compared to baseline and SLv1 (10%). While engaged in the cognitive task, the percentage of inappropriate car-following behaviour increased with task difficulty (10% in baseline conditions, 17% on SLv1, 18% on SLv2 and 23% on SLv3).

On the rural test route, events where sudden braking was used were very few (11 events). However, there was a slight tendency towards more sudden braking events when the visual task was performed (five events) than with the cognitive task (three events) or with baseline conditions (three events).

### *12.6.1.4. Lateral control*

In baseline conditions the frequency of minor RSWT (40–70 degrees/s) and major turnings (over 70 degrees/s) was approximately zero. However, the visual task increased the frequency of RSWT substantially, and the frequency increased with the difficulty level (Figure 230).

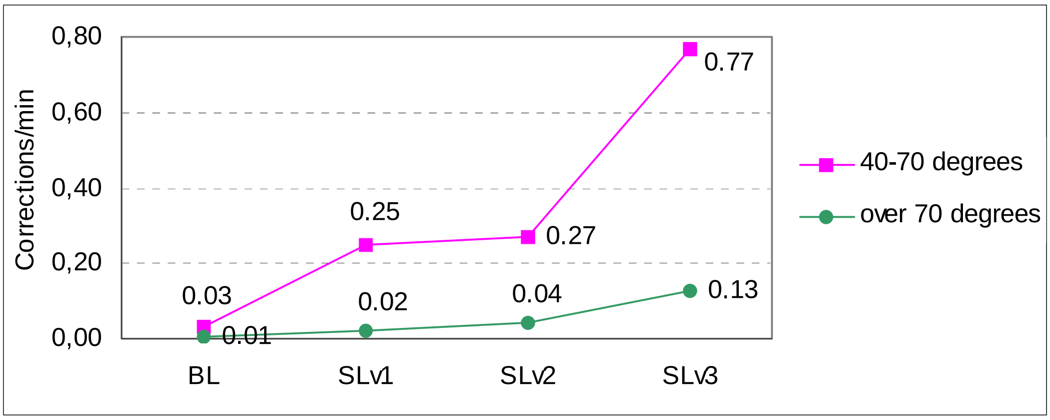



**Figure 230 – Frequency of RSWT by visual task difficulty level.**

The results by age group showed that for elderly drivers the frequency of minor RSWT increased with a less difficult the visual task, whereas for average drivers the increase was evident on more demanding task levels. However, the most demanding the visual task level resulted in approximately the same frequency of minor RSWT to average than to elderly drivers. In addition, major RSWT were found only for elderly drivers (Figure 231). However, the effects of the visual task and the cognitive tasks on RSWT and major RSWT could not be tested with an Anova because the null hypothesis of Levene's test was rejected.

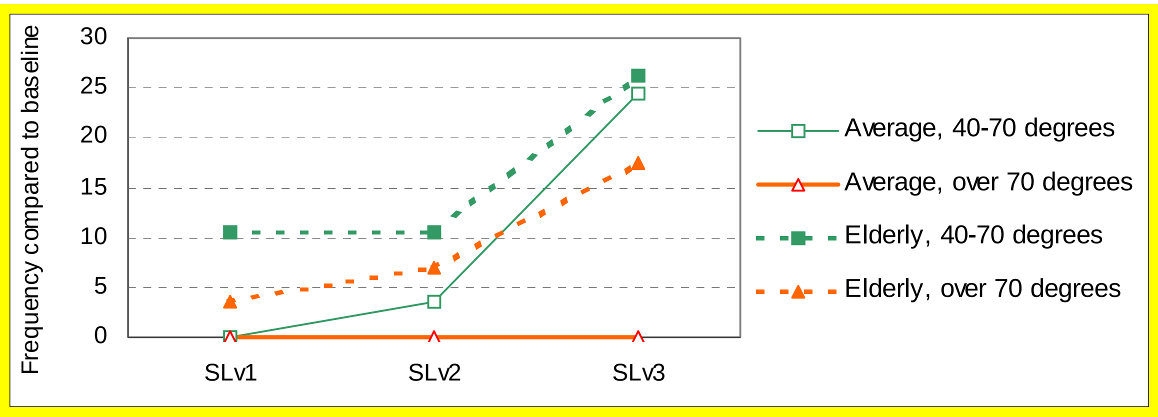



**Figure 231 – Frequency of RSWT compared to baseline difficulty level and age group, Visual task**

The visual task tended to increase the reversal rate (rr_st2), especially with elderly drivers; however, the cognitive task had lower effect on reversal rate than the visual task (Table 147). When comparing the three difficulty levels of the visual task, the results showed that for average drivers only the most difficult task level increased reversal rate. For the visual task, age group and SLv significantly affected reversal rate. Post hoc tests showed that effects were significant between baseline and all the difficulty levels. For the cognitive task, the effect of age group was significant.

**Table 147 – Reversal rate (2 degrees min change) by S-IVIS type, difficulty level and age group.**

| S-IVIS type and level | Average | Elderly | All |
|---|---|---|---|
| Baseline - visual task | 0.29 | 0.32 | 0.30 |
| Experiment - visual task | 0.31 | 0.39 | 0.35 |
| SLv1 | 0.29 | 0.32 | 0.30 |
| SLv2 | 0.31 | 0.39 | 0.35 |
| SLv3 | 0.35 | 0.42 | 0.38 |
| | | | |
| Baseline - cognitive task | 0.30 | 0.34 | 0.32 |
| Experiment - cognitive task | 0.29 | 0.33 | 0.31 |
| SLv1 | 0.28 | 0.34 | 0.31 |
| SLv2 | 0.29 | 0.33 | 0.31 |
| SLv3 | 0.29 | 0.33 | 0.31 |

In the baseline conditions, the observer coded the lateral control as inappropriate in 6% of observations, while the percentage was 59 for the visual task conditions and 4 for the cognitive task conditions. While engaged in the visual task, drivers were most frequently observed to have lateral movement within their own lane or even exceed the lane markings and make a correction. There was also a small proportion of lane exceedences, where the situation was coded as dangerous because of oncoming vehicle(s). Overall, elderly drivers showed inappropriate lane behaviour more frequently than average drivers (Figure 232). Particularly, the visual task seemed to cause severe problems for elderly drivers: the proportion of observed lane exceedences was much higher among elderly (30%) than among average drivers (13%). Also, the potentially dangerous situations all occurred with elderly drivers.

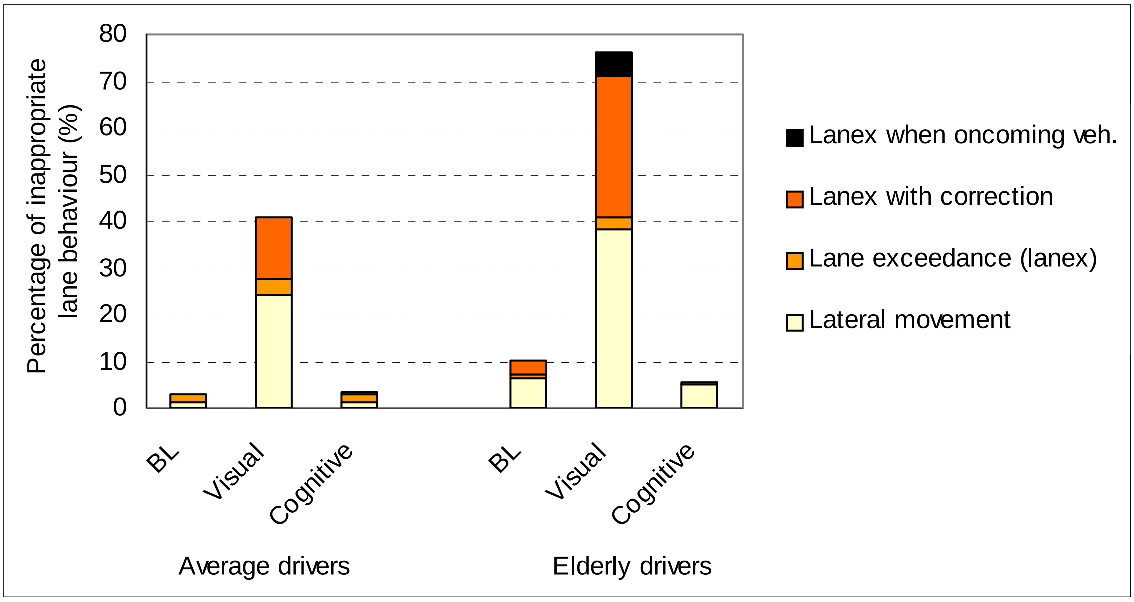



**Figure 232 – Type of observed inappropriate lane behaviour by driver age group and S-IVIS type**

The results by difficulty level of the visual task showed that it affected elderly drivers' lane behaviour substantially on all levels, while the effects on average drivers' lane behaviour increased with the difficulty level (Figure 233).

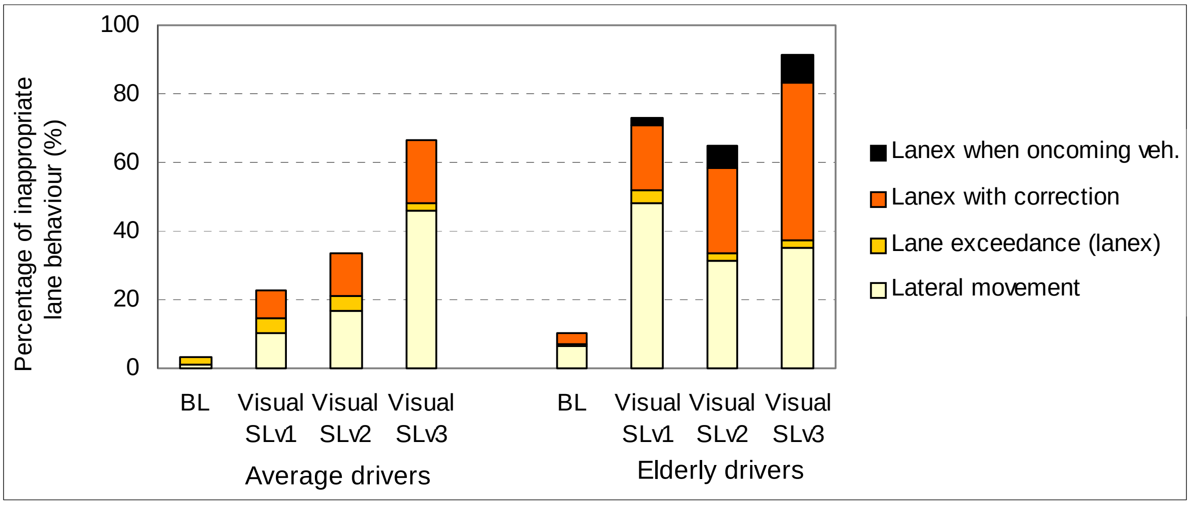



**Figure 233 – % of drivers inappropriately changing lanes by age group and task difficulty level, Visual task**

The results of inappropriate lane behaviour while engaged in the cognitive task showed that the proportion of drivers observed to have inappropriate lane behaviour was as low (4%) as when driving without any S-IVIS (6%). Consequently, no further analyses were performed.

### 12.6.2. Effects of secondary task in Urban Road driving

#### *12.6.2.1. Observed traffic conditions*

The traffic conditions were statistically equal in terms of presence of lead vehicles and oncoming traffic. In 74–76% of the observed intersections, the approaching behaviour was not affected by vehicles travelling in front. In 50–58% of the cases, there were other vehicles at the intersection. However, in 38–44% of all cases, there was a possibility of interaction with other vehicles at the intersection. 15–21% of approaches to the first zebra crossing of the intersection included VRUs (pedestrians, cyclists). The corresponding percentages for the second zebra crossing were 10–12. However, only 4–10% of observed cases included actual interaction with VRUs in the zebra zone.

#### *12.6.2.2. Self reported driving performance*

Drivers rated their driving performance as best in baseline conditions (Figure 234). The ratings were higher also for the control sections than while performing the tasks. The ratings were somewhat higher for the cognitive task than for the visual task. Drivers rated their driving performance to be worse as the difficulty of the S-IVIS task increased. Elderly drivers rated their driving performance lower than did average drivers for both environments and tasks.

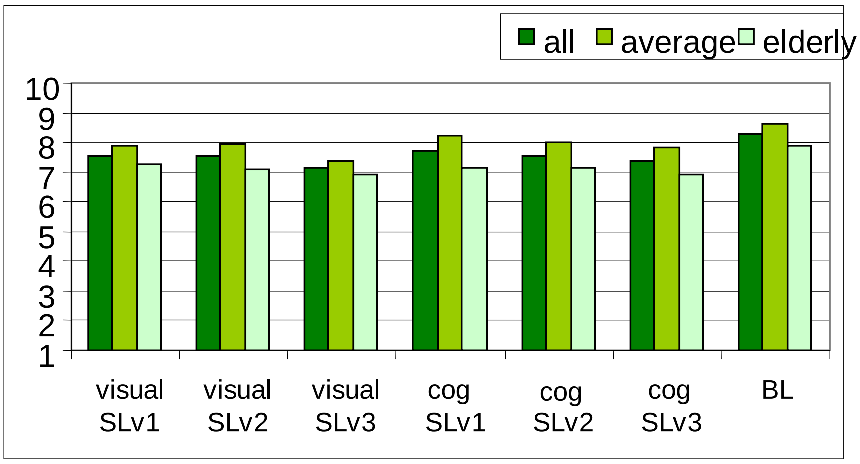



**Figure 234 – Self-reported driving quality on urban road sections by task and difficulty level.**

### *12.6.2.3. Longitudinal control*

Speed outside intersections was measured either before the intersection or after it depending on the street environment. These sections had no curves or zebra crossings that would affect speed behaviour. **Table 148** shows that neither of the S-IVIS tasks affected mean speed (mn_sp). For the visual task conditions, S-IVIS difficulty level resulted in a significant increase in speed variation (st_sp). Post hoc tests showed that the effect was significant between baseline and SLv1. The effects on mean speed, maximum speed and minimum speed were not significant.

**Table 148 – Speed values by S-IVIS type and age group**

| | S-IVIS type and level | Mean speed (km/h) | Max speed (km/h) | Min speed (km/h) | Speed variation (km/h) |
|---|---|---|---|---|---|
| **Average drivers** | Baseline - visual task | 41.0 | 43.1 | 39.0 | 1.3 |
| | Experiment - visual task | 40.9 | 42.6 | 39.2 | 1.1 |
| | SLv1 | 42.6 | 43.7 | 41.4 | 0.7 |
| | SLv2 | 39.5 | 41.3 | 37.6 | 1.2 |
| | SLv3 | 40.4 | 42.4 | 38.2 | 1.3 |
| | | | | | |
| | Baseline - cognitive task | 40.8 | 43.0 | 38.7 | 1.4 |
| | Experiment - cognitive task | 41.1 | 42.8 | 39.2 | 1.1 |
| | SLv1 | 40.3 | 42.1 | 38.5 | 1.2 |
| | SLv2 | 40.6 | 42.6 | 38.7 | 1.2 |
| | SLv3 | 42.1 | 43.6 | 40.4 | 1.0 |
| | | | | | |
| **Elderly drivers** | Baseline - visual task | 39.9 | 42.4 | 37.5 | 1.6 |
| | Experiment - visual task | 40.4 | 41.9 | 38.6 | 1.0 |
| | SLv1 | 40.8 | 42.2 | 39.4 | 0.8 |
| | SLv2 | 38.7 | 40.5 | 36,5 | 1.2 |
| | SLv3 | 41.9 | 43.3 | 40.2 | 1.0 |
| | | | | | |
| | Baseline - cognitive task | 39.9 | 42.4 | 37.5 | 1.6 |
| | Experiment - cognitive task | 41.2 | 42.9 | 39.2 | 1.2 |
| | SLv1 | 42.3 | 44.3 | 39.7 | 1.5 |
| | SLv2 | 40.6 | 42.0 | 39.1 | 0.9 |
| | SLv3 | 40.5 | 42.2 | 38.8 | 1.1 |
| | | | | | |
| **All drivers** | Baseline - visual task | 40.5 | 42.7 | 38.3 | 1.5 |
| | Experiment - visual task | 40.7 | 42.3 | 38.9 | 1.1 |
| | SLv1 | 41.9 | 43.0 | 40.5 | 0.8 |
| | SLv2 | 39.1 | 40.9 | 37.1 | 1.2 |
| | SLv3 | 41.2 | 42.9 | 39.2 | 1.2 |
| | | | | | |
| | Baseline - cognitive task | 40.4 | 42.7 | 38.1 | 1.5 |
| | Experiment - cognitive task | 41.1 | 42.8 | 39.2 | 1.1 |
| | SLv1 | 41.3 | 43.2 | 39.1 | 1.3 |
| | SLv2 | 40.6 | 42.3 | 38.9 | 1.1 |
| | SLv3 | 41.3 | 42.9 | 39.6 | 1.0 |

The mean speed in free-flow traffic situations was calculated 50, 30 and 10 meters before the intersection area (zebra crossing zone) and at the zebra crossing. The effects on mean speeds could not be tested with an Anova because the null hypothesis of Levene's test was rejected. Nevertheless, the following tendencies were identified: when no vulnerable road users were present at the intersection, the S-IVIS task had no effect at distances of 50 m and 30 m, but decreased speed at distances of 10 m and 0 m (Figure 235). However, when there were vulnerable road users at the intersection, the S-IVIS task increased speed before the intersection, especially when there was actual interaction with the VRUs.

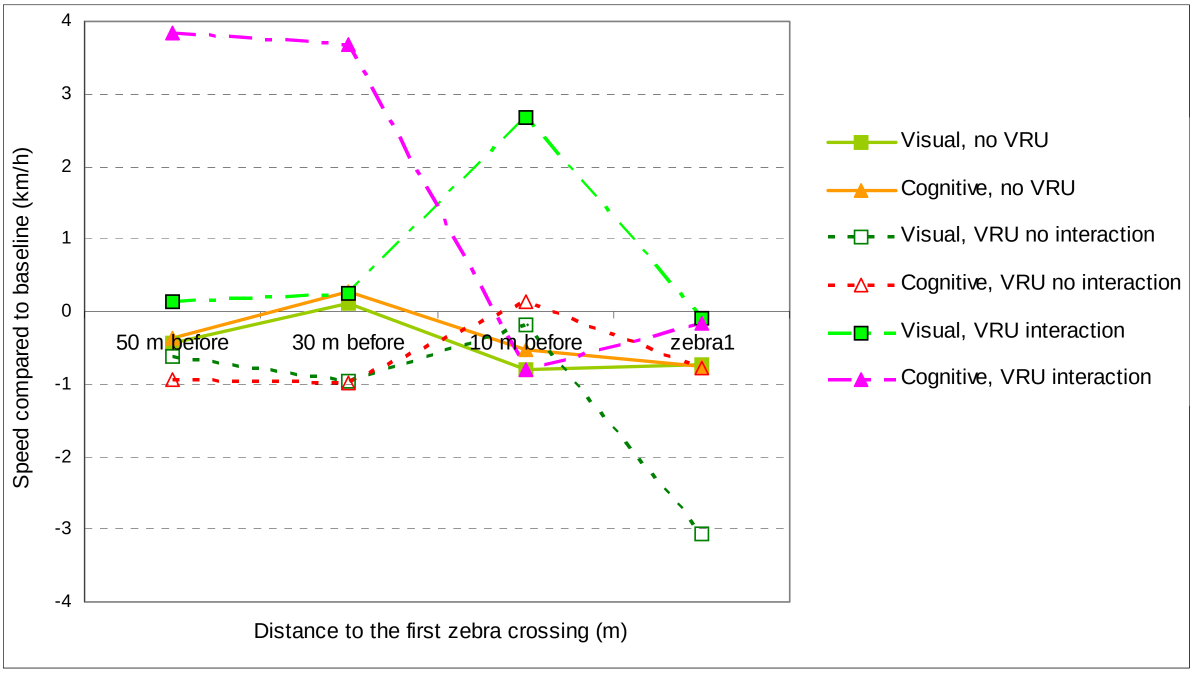



**Figure 235 – Approach speeds to intersections by S-IVIS type and by interaction with VRU(s)**

For driving with no S-IVIS, the observer rated the speed behaviour as appropriate in almost 85% of free-flow traffic situations, while the percentage was 47 for the visual task and 53 for the cognitive task. Both S-IVIS tasks tended to increase all types of inappropriate speed but the proportion of varying speed was especially high for the visual task. In all three S-IVIS task conditions, a greater proportion of elderly drivers were observed to have inappropriate speed behaviour compared to average drivers (Figure 236).

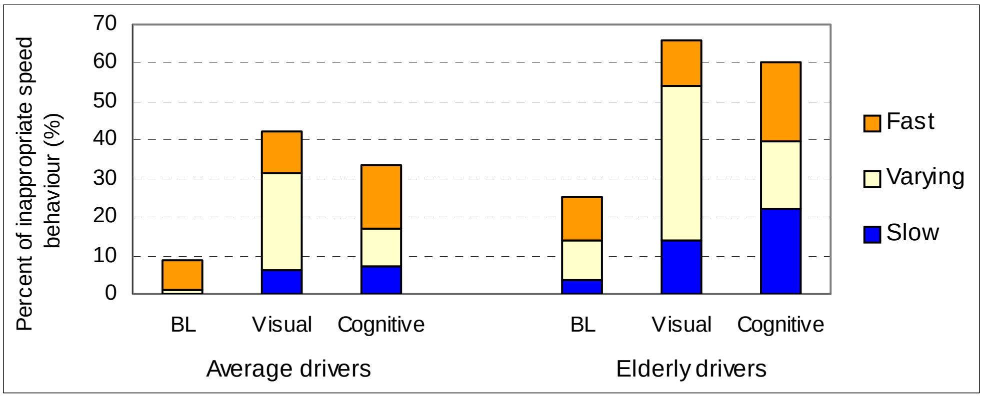



**Figure 236 – Type of observed inappropriate speed behaviour by driver age group and S-IVIS type**

Figure 237 shows the effects of S-IVIS task on speed behaviour by age group and task difficulty level. For average drivers, the difficulty level of the visual task had practically no effect on speed behaviour, while the difficulty of the cognitive task seemed to increase the proportion of inappropriate speed. The effects of different types of S-IVIS task were more alike.

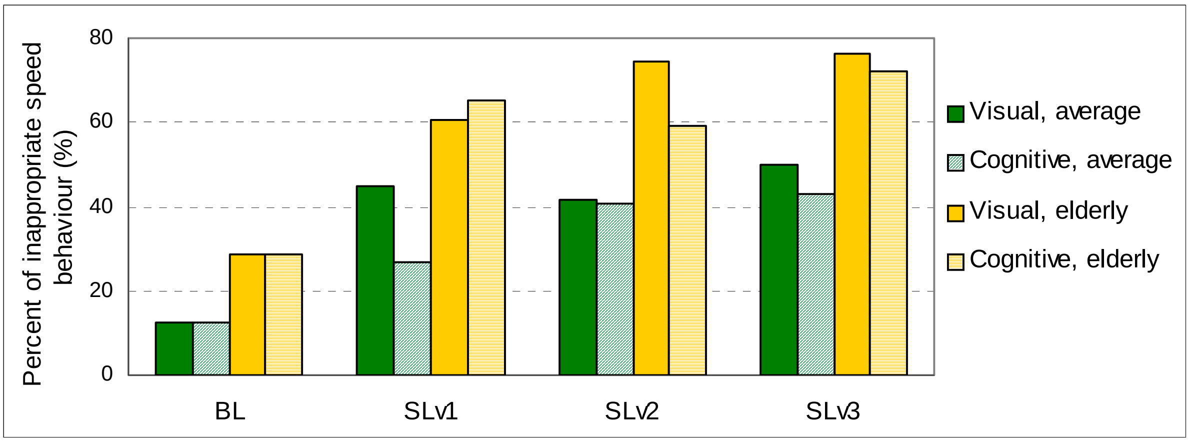



**Figure 237 – % of drivers inappropriately speeding by driver age group, S-IVIS type and task difficulty level**

The total number of sudden braking (jerks) of more than 8 m/s[3] was five (and therefore no test of significance was applied). One jerk happened in baseline conditions to an elderly driver and four happened with the cognitive task to two elderly and two average drivers. All situations including jerks were free-flow traffic situations and there were no vulnerable road users at zebra crossings. The observer in the rear seat registered a sudden braking in all these situations. Three jerks were categorised as a potentially dangerous situation, and all of them happened when the driver was about to drive onto a crossing in the path of a vehicle with the right of way. In one situation the experimenter sitting in the front passenger seat had to push the brake pedal.

### *12.6.2.4. Lateral control*

For driving with no S-IVIS task, the drivers' lane behaviour was coded as appropriate in 87% of all observations, while the percentage was 89 for the cognitive task and 65 for the visual task. For the visual task, drivers more often wandered within the lane (15%), selected a wrong lane (6%) or made a rapid correction (5%). Compared to average drivers, elderly drivers showed inappropriate lane behaviour more frequently. Especially when engaged in the visual task, elderly drivers were often observed to wander within their own lane and make rapid corrections (Figure 238).

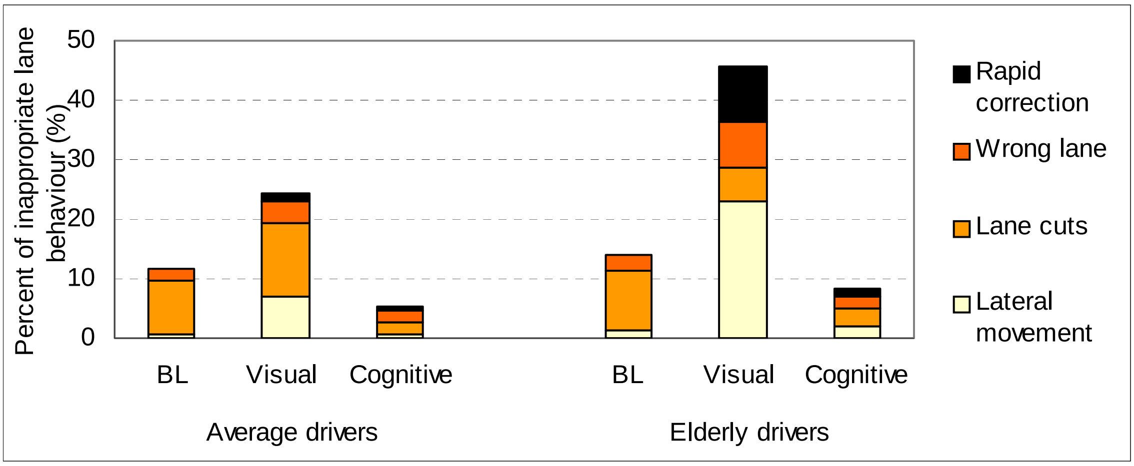



**Figure 238 – Type of observed inappropriate lane behaviour by age group and S-IVIS type**

Increasing the difficulty level of the visual task s had a greater effect on elderly drivers' lane behaviour than on that of average drivers. On SLv1, 63% of elderly driver had inappropriate lane behaviour when the percentage was 55 for SLv2 and 46 for SLv3. The more difficult task level increased e.g. the proportion of rapid corrections from 4% to 17% when the difficulty was raised from SLv1 to SLv3. For average drivers no effect of the difficulty level was evident (Figure 239).

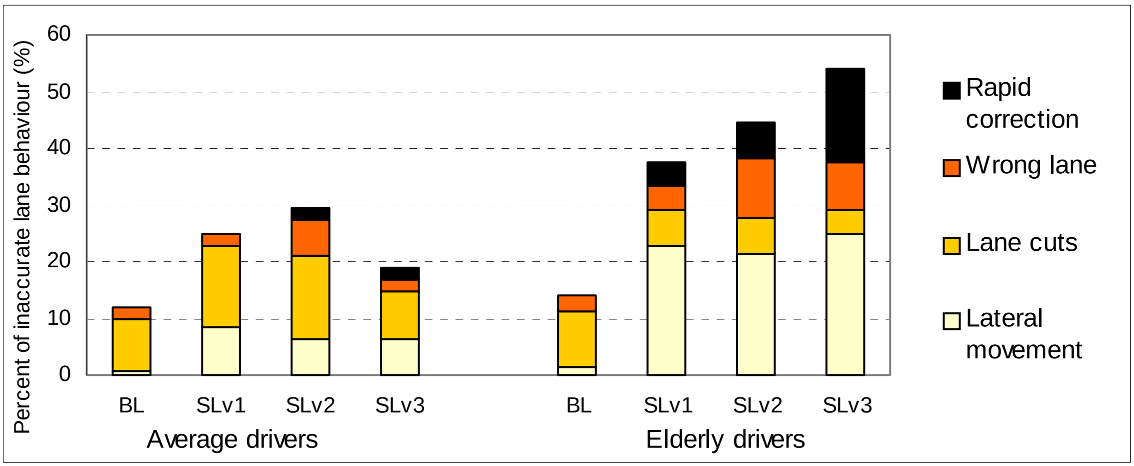



**Figure 239 – Type of observed inappropriate lane behaviour by driver age group and task difficulty level.**

When analysing the type of inappropriate lane behaviour during the cognitive task, the proportion of drivers observed to have inappropriate lane behaviour was as low (11%) as when driving without any S-IVIS task (13%).

### *12.6.2.5. Yielding behaviour*

All observed intersections were give-way intersections. In 38–44% of all cases, drivers changed their driving behaviour because of the possibility of other vehicles being at the intersection. Only these cases are included in further analysis. The proportion of proper yielding behaviour was 88% for baseline conditions, 79% for the cognitive task and 50% for the visual task. The visual task caused substantial unnecessary waiting when there was no other vehicle present or no crossing paths with other vehicles at the intersection. In addition, the proportion of short gap acceptance and potentially dangerous situations (sudden braking etc.) were frequent when engaged in the visual task. The cognitive task increased the proportion of unnecessary waiting and dangerous situations to some degree.

Comparison of yielding behaviour by age group showed that elderly drivers showed inappropriate yielding behaviour more frequently — and that this behaviour was more severe (e.g. acceptance of short gap, potentially dangerous or dangerous situation) — than average drivers (Figure 240). The visual task seemed to cause more unnecessary waiting for average drivers.

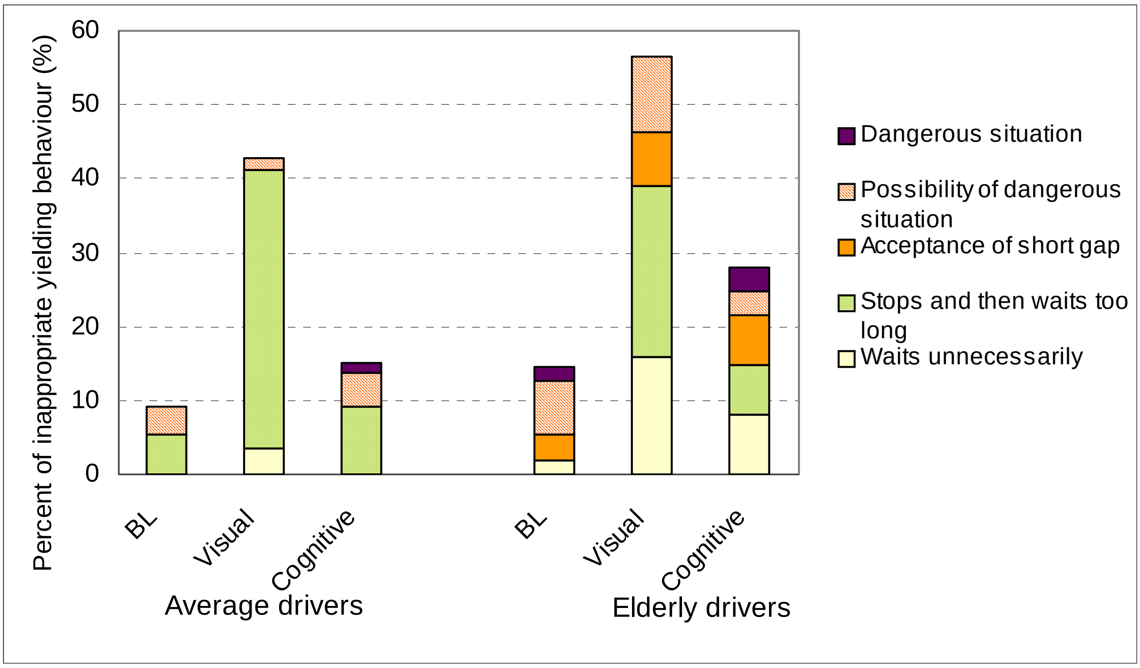



**Figure 240 – Observed yielding behaviour at urban area intersections by age group and S-IVIS type**

### *12.6.2.6. Behaviour towards vulnerable road users*

Yielding to pedestrians was studied at intersections including encounters at two zebra crossings. In 15-21% of the first zebra crossings and in 10-12% of the second zebra crossings there were one or more VRUs (pedestrians, cyclists) present. However, only in 4–10% of all observed cases was the driver's path actually crossing that of the VRUs. Only these cases are included in further analysis.

At the first zebra crossing, the cognitive task seemed to cause inappropriate behaviour towards VRUs much more frequently than the visual task (Figure 241 and Figure 242). In addition, VRUs more frequently seemed to give the right-of-way to drivers when the driver was engaged in the cognitive task than in the visual task or no secondary task. Also the percentage of cases where a VRU was forced to stop to avoid conflict was higher when drivers had the cognitive task (11% of all cases) than when they had the visual task (5%) or no secondary task at all (0%).

At the second zebra crossing, inappropriate behaviour towards VRUs seemed to be frequent in all three S-IVIS task types. VRUs frequently seemed to give the right-of-way to drivers. Especially when the driver was engaged in the visual task, VRUs were forced to wait.

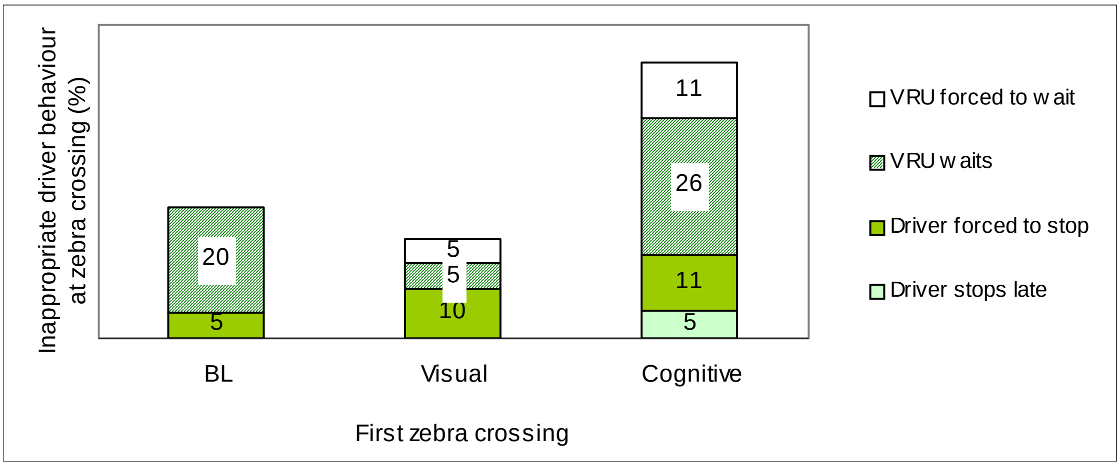



**Figure 241 – Inappropriate behaviour towards VRUs at first zebra crossing by S-IVIS type**

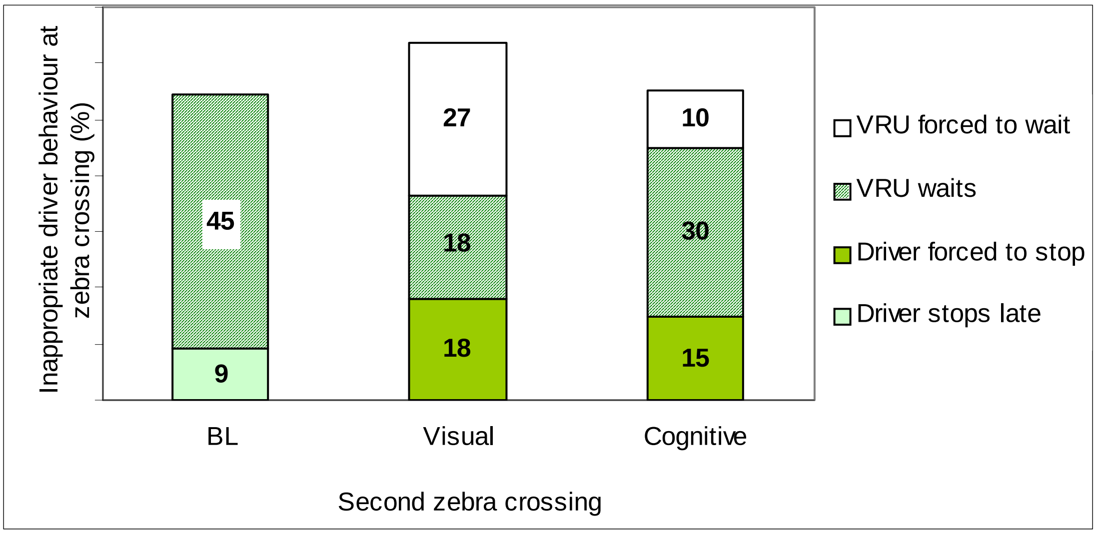



**Figure 242 – Inappropriate driver towards VRUs at second zebra crossing by S-IVIS type**

When the driver had no S-IVIS task, inappropriate behaviour towards VRUs was more frequent among average (27%) than among elderly drivers (22%). Elderly drivers more frequently stopped in front of the zebra crossing, whereas the VRU more frequently gave the right-of-way to average drivers. However, the cognitive task had a greater effect on elderly drivers' zebra zone behaviour. The percentage of appropriate behaviour when engaged in the cognitive task was 57% among average drivers, but only 25% among elderly drivers.

Inappropriate behaviour towards vulnerable road users was even more frequent at the second zebra crossing in all three S-IVIS task conditions. Inappropriate behaviour was more frequent among average (67%) than among elderly drivers (50%) when driving without any task. Compared to elderly drivers, the S-IVIS task seemed to cause more situations for average drivers, where a VRU was forced to give the right-of-way. By contrast, elderly drivers were more frequently observed to be "forced to stop" at the last moment when driving with an S-IVIS task compared to driving without.

#### *12.6.2.7. Stopping and signalling while approaching an intersection*

The S-IVIS task did not affect the stopping behaviour of average drivers. In all three S-IVIS task conditions, the driver stopped completely in approximately 50% of cases, stopped partly in 20% of cases, and drove through in 30% of cases. Among elderly drivers the percentages were 53, 24 and 23, respectively. However, elderly drivers seemed to stop more often (62%) when engaged in the visual task and drove through more often (29%) when engaged in the cognitive task. Especially with the cognitive task, the proportion of partial stops was replaced by a larger proportion of drive-through incidences.

The S-IVIS task had a small effect on signalling. With no S-IVIS task, the use of signals was appropriate in 94% of cases, while the percentage was 85 for the visual task and 81 for the cognitive task. Both S-IVIS tasks increased the category “signalling too late” (baseline 2%, the visual task 10% and the cognitive task 12%). However, among elderly drivers the visual task also increased the proportion of “ambiguous signalling” and the cognitive task slightly increased the proportion of categories “no signalling at all” and ”repeated or corrected direction”.

## 12.7. S-IVIS results

### 12.7.1. The visual task

The analysis of correct responses revealed the following significant main effects and interactions:

| | | |
|---|---|---|
| Main effects | Environment | significant |
| | Level | significant |
| | Age | significant |
| Interactions | Environment*Age | significant |
| | Level*Age | significant |
| | Environment*Level | significant |

The results first showed that the proportion of correct responses was highest for a static situation, followed by rural and urban environments. Second, the proportion of correct responses decreased with increasing task difficulty. Third, the proportion of correct responses was 96% for average divers and 91% for elderly drivers, indicating that the elderly drivers had more problems performing the visual task. The proportions of correct responses by age groups, environments and difficulty levels are shown in Figure 243.

Average drivers performed the task almost as well in a rural environment as in the static test, but in an urban environment the proportion of correct responses decreased. Also the increase of task difficulty level had a greater effect on elderly drivers’ performance than on that of average drivers. Among average drivers the proportion of correct answers decreased (from 99% to 89%) only with the most difficult task level, whereas among elderly drivers the percentage of correct answers decreased already with SLv2 (from 98% to 94%) and especially with SLv3 (to 80%).

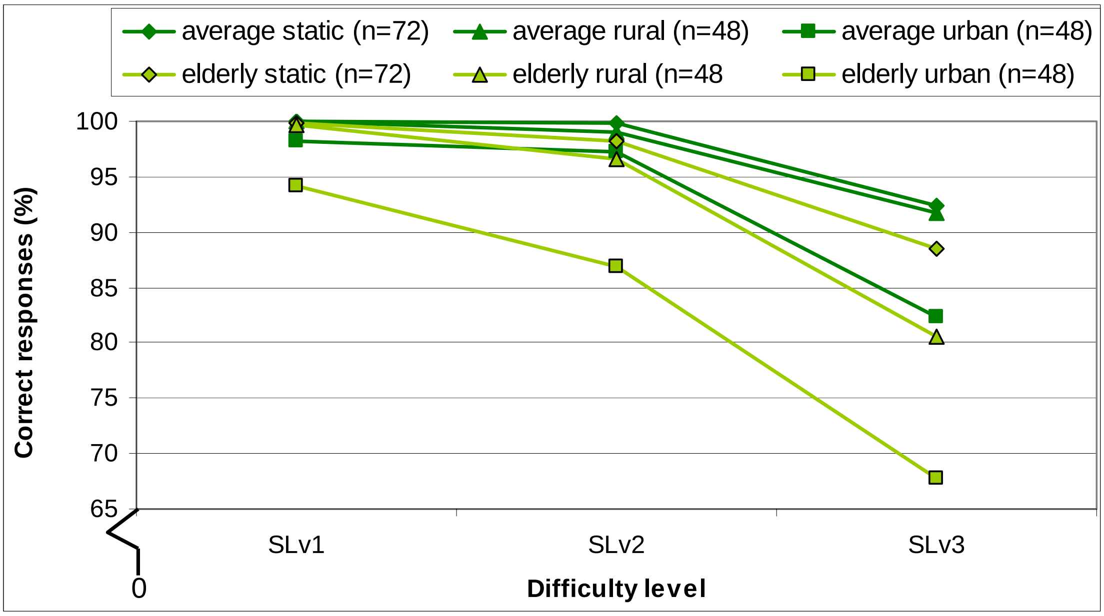



**Figure 243 – % correct responses by age group, environment and difficulty level, Visual task**

The proportion of correct responses with standard error (SE) by difficulty level is shown in Figure 244.

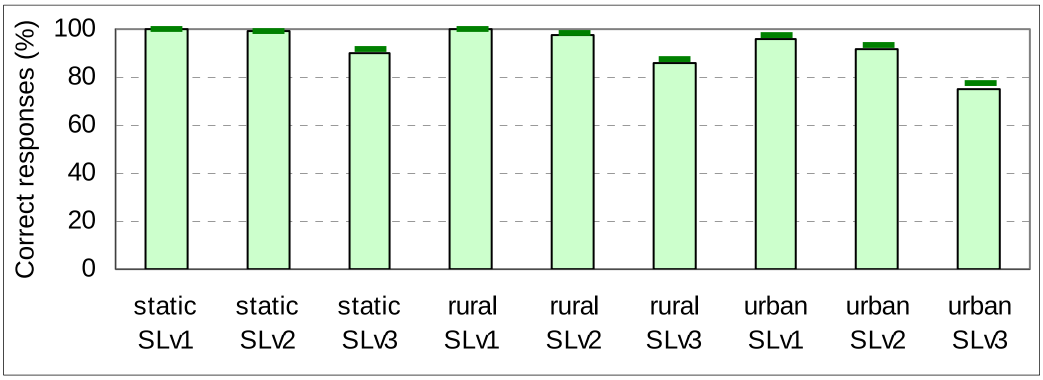



**Figure 244 – % correct responses and SE by environment and task difficulty level, Visual task**

Figure 245, Figure 246 and Figure 247 show the proportions of incorrect responses, missed responses and reaction time with standard error (SE) by difficulty level, followed by the corresponding statistical analysis.

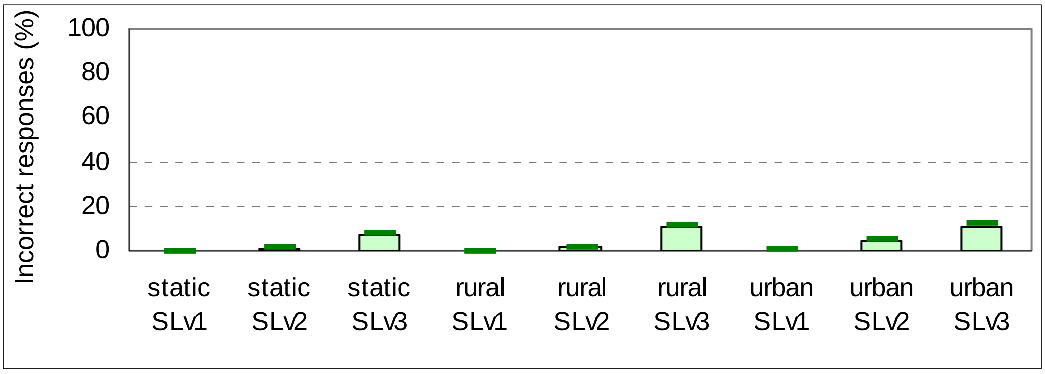



**Figure 245 – % incorrect responses and SE per environment and task difficulty level, Visual task**

For incorrect responses, there were effects of environment, SLv and age group. Interactions were found between SLv and Age, Environment and SLv and between all three factors.

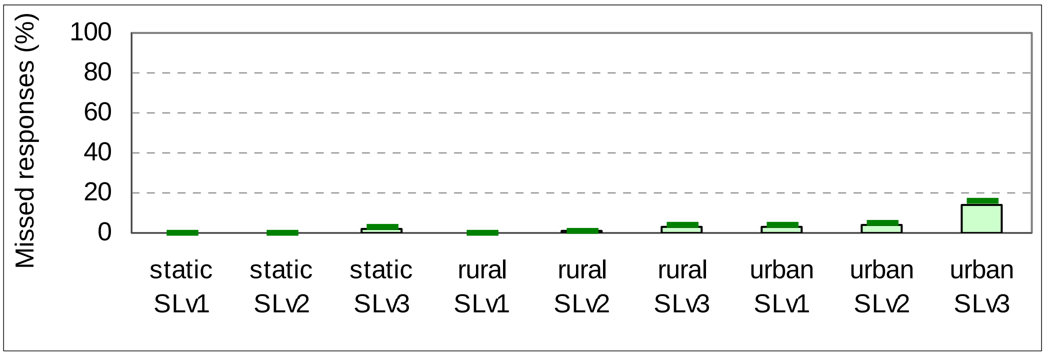



**Figure 246 – % missed responses and SE per environment and task difficulty level, Visual task**

For missed responses, there were effects of environment, SLv and age group. There was an interaction between Environment and SLv. Reaction times were lowest for the static situation, followed by rural and urban environments. The mean reaction time increased with difficulty level from 1.6 to 2.6 s among average drivers from and from 1.7 to 2.7s among elderly drivers. For reaction time, there were effects of environment, SLv and age group. There was an interaction between Environment and SLv.

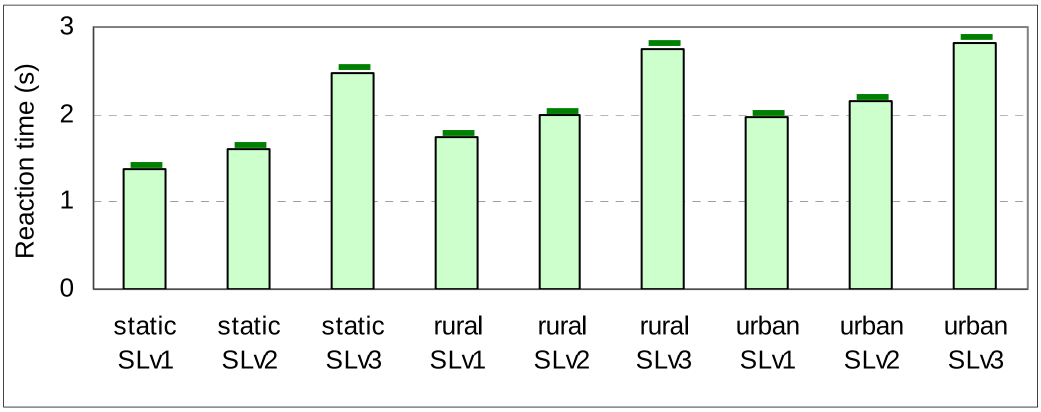



**Figure 247 – Mean reaction time and SE by environment and task difficulty level, Visual task**

In the urban environment the task was performed at intersections with a yield sign and drivers turned either to the right or to the left. The results showed that performance of the S-IVIS task was more difficult when turning left than when turning right. The difference between left and right turns seemed to increase with increased S-IVIS task difficulty, being greatest at SLv3. The S-IVIS task was more difficult for elderly drivers, especially in left turn situations with the most difficult task level. However, the proportion of missed responses was higher for left turns at SLv3 also among average drivers. Reaction times were only slightly longer for left turns than for right turns (Figure 248).

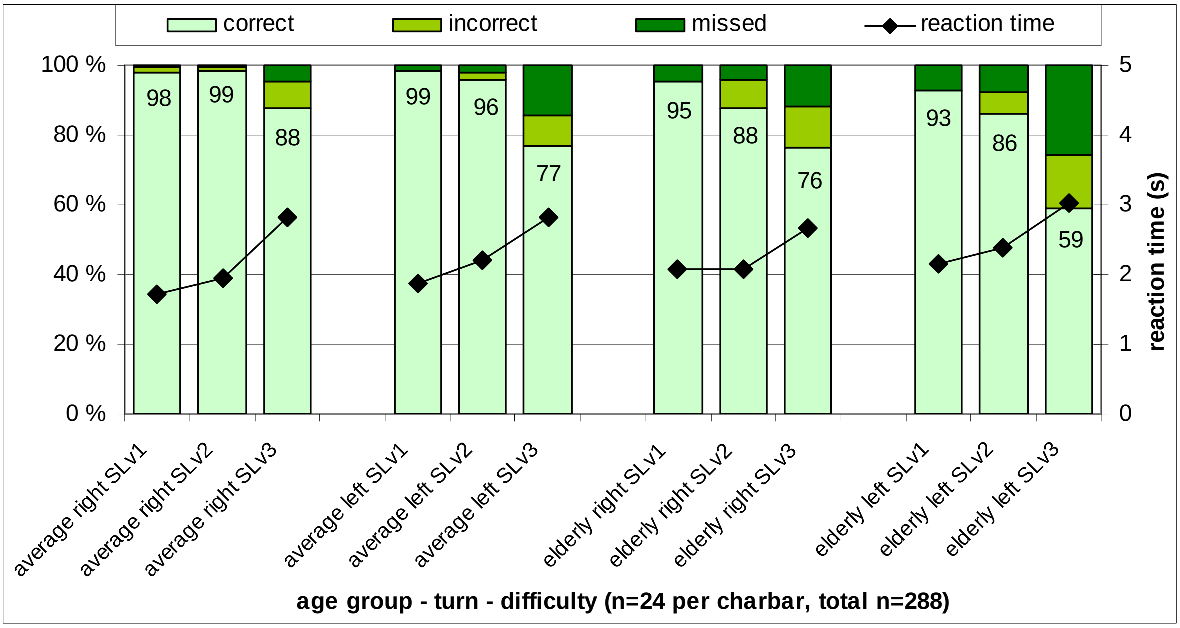



**Figure 248 – Response and reaction time in urban route by age group, turn and difficulty level, Visual task**

### 12.7.2. The cognitive task

For the cognitive task correct responses, there were effects of environment, SLv and age group. No interaction effect was found.

The task was better performed as a primary task than as a secondary task. The number of correct responses was highest for the primary task (78%) and lowest for the S-IVIS task in an urban environment (68%). The task difficulty level affected the performance in each S-IVIS task condition. Elderly drivers performed the cognitive task more poorly than did average drivers. The main effects are presented in Figure 249.

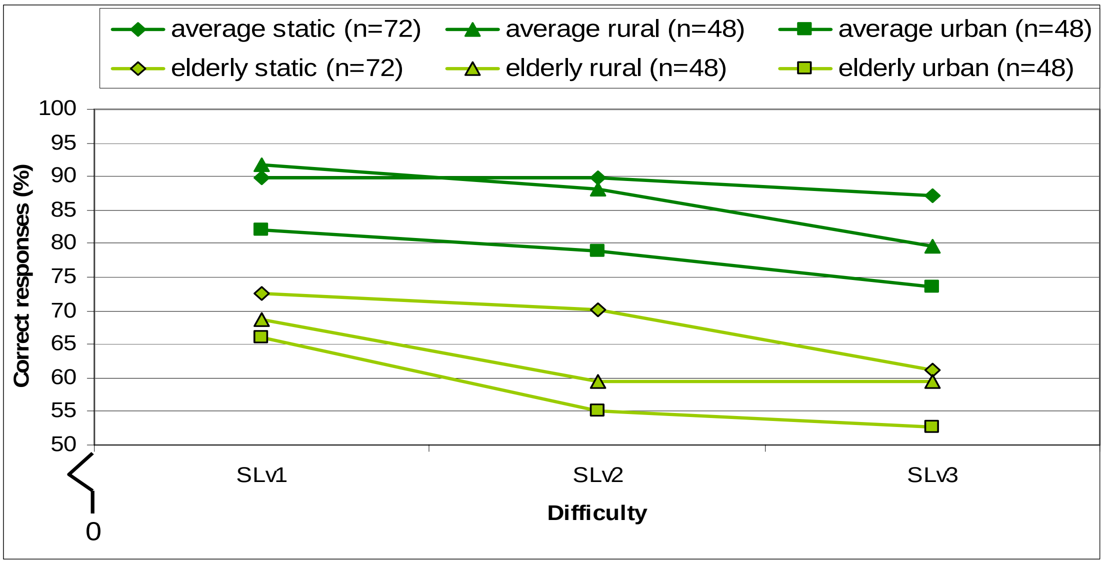



**Figure 249 – % correct responses by age group, environment and number of target sounds, Cognitive task**

The proportion of correct responses with standard error (SE) by difficulty level is shown in Figure 250.

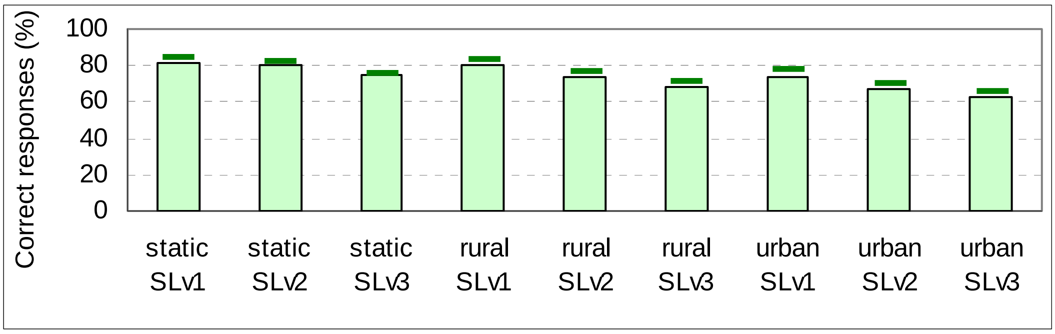



**Figure 250 – % correct responses by environment and number of target sounds, Cognitive task**

Figure 251 and Figure 252 show the proportions of incorrect and missed responses with standard error (SE) by difficulty level, followed by the corresponding statistical analysis.

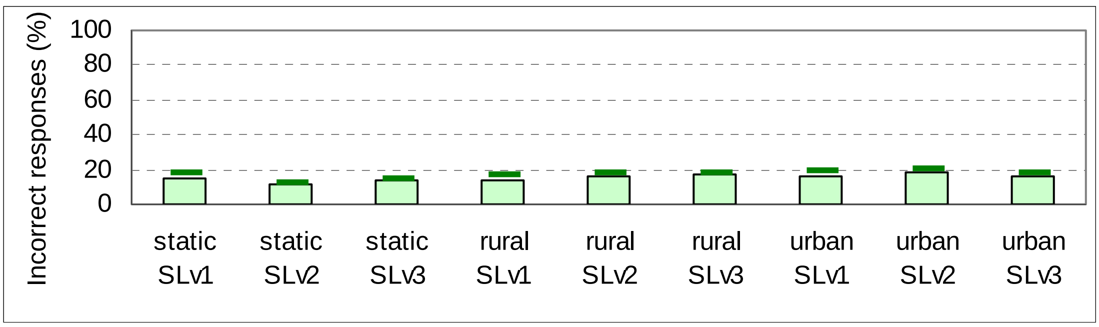



**Figure 251 – % incorrect responses with by environment and number of target sounds, Cognitive task**

For incorrect responses, only the effect of age was statistically significant. None of the interactions was statistically significant.

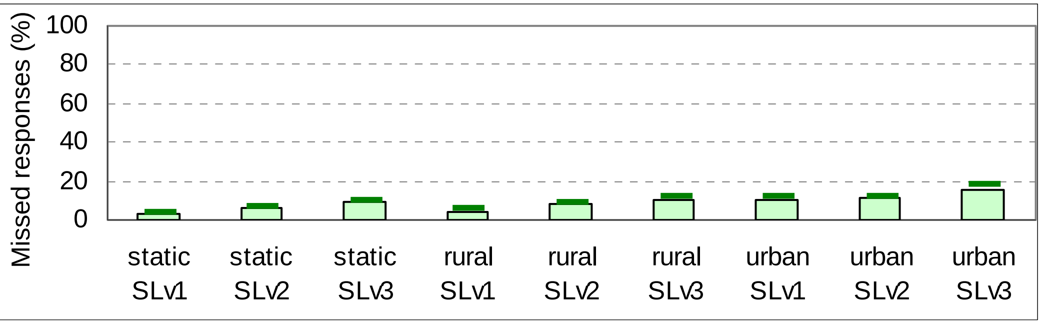



**Figure 252 – % missed responses by environment and number of target sounds, Cognitive task**

In missed responses, there were effects of environment, S-IVIS level and Age group. There were no interaction effects. The proportion of missed responses was 3.0–9.1% for static situation, followed by rural (4.5–10.5%) and (10.4–16.0%) urban environment.

In false responses, there were effects of S-IVIS level and age group, but not environment. The results showed that the difficulty level increased the proportion of false responses, and sound recognition was more difficult for elderly drivers (Figure 253).

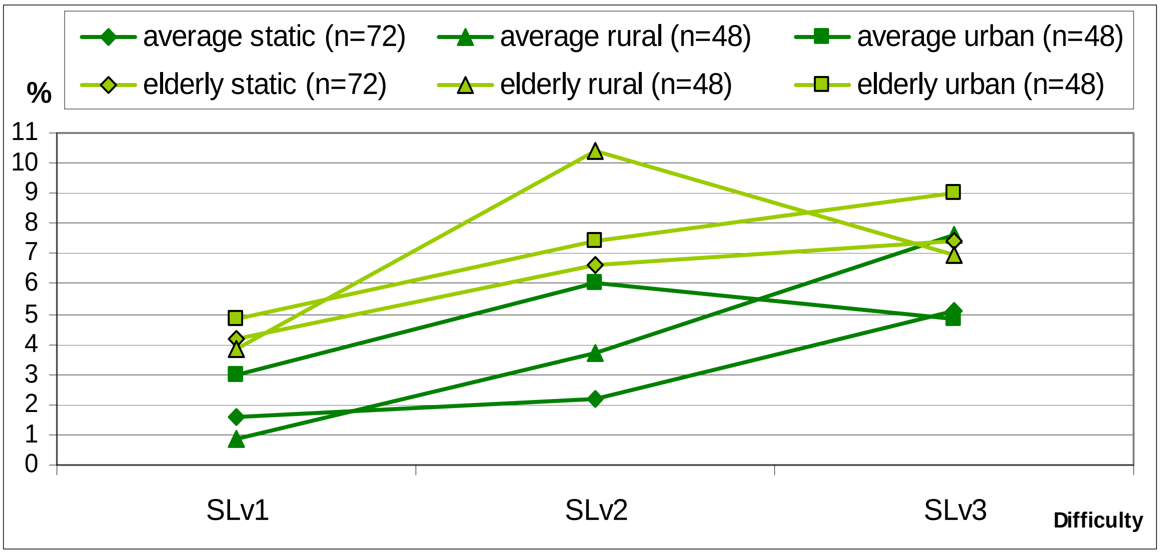



**Figure 253 – % false responses by age group, environment and number of target sounds, Cognitive task**

As earlier in the case of the visual task, the performance of the cognitive task was more difficult at urban left turns than at right turns. When the task was performed with one target sound, the number of correct responses was quite similar despite the direction of the turn. However, the proportion of correct responses was lower with two target sounds at left turns for both age groups. With a right turn the performance did not clearly worsen until three target sounds were given. Meanwhile for a left turn the performance was quite similar with two and three target sounds. Overall, elderly drivers missed more target sounds at left turns than at right turns (Figure 254).

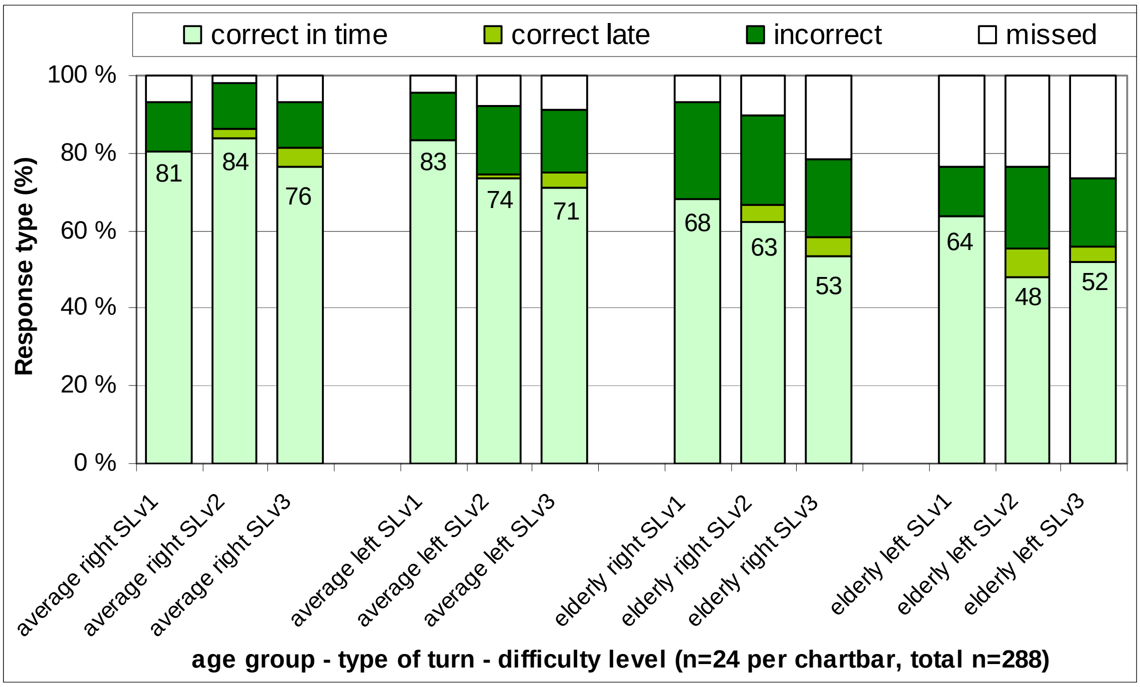



**Figure 254 – Response type on urban route by age group, turn and number of target sounds, Cognitive task**

### 12.7.3. Self-reported assessment of secondary tasks

After driving in all three S-IVIS task conditions, the drivers were asked to assess the them and their performance of the tasks while driving (open questions). They were also asked about possible changes in their driving (listed behavioural changes) that they had possibly identified.

Elderly drivers frequently indicated that the secondary task had been difficult (Table 149). Specifically, the visual task was difficult for 8% and the cognitive task for 29% of elderly drivers. Only 4% of average drivers indicated that the cognitive task was difficult and none that the visual task was difficult. Also the sound recognition was indicated as being difficult more often by elderly (46%) than average (17%) drivers. Only few average drivers mentioned the cognitive task as being difficult (4%) or the most difficult level of the secondary task as being difficult (8%). About 10% of all drivers said that the tasks became easier with practice.

Elderly drivers indicated more frequently than average drivers that the S-IVIS task disturbed their driving. Driving while engaged in an S-IVIS task was indicated as stressful especially by elderly drivers.

**Table 149 – Self-reported assessment of driving with secondary tasks.**

| | average (%) | elderly (%) | total (%) |
|---|---|---|---|
| Cognitive task was difficult | 4 | 29 | 17 |
| Visual task was difficult | 0 | 8 | 4 |
| Recognition of sounds (in cognitive) was difficult | 17 | 46 | 31 |
| Tasks became easier with practice | 13 | 8 | 10 |
| The most difficult levels were difficult | 8 | 0 | 4 |
| Tasks disturbed driving | 25 | 42 | 33 |
| Driving with tasks was stressing | 4 | 21 | 13 |
| Tasks didn't disturb driving | 29 | 17 | 23 |
| Visual task disturbed concentration | 4 | 4 | 4 |

When the drivers were asked if driving with the visual task was different from driving with the cognitive task, 42% of elderly drivers considered driving with the cognitive task more difficult. However, 29% of elderly drivers felt the opposite. The percentages were 33 and 33 for average drivers, respectively.

The drivers were asked also to assess the difficulty of driving with the S-IVIS tasks on a scale from 1 to 10 (where 1= ”driving with task was very easy” and 10= ”driving with task was very difficult”). Overall, drivers considered driving with S-IVIS tasks rather easy. Both age groups agreed that driving with S-IVIS tasks was more difficult in an urban than in a rural environment. Elderly drivers found driving with S-IVIS tasks more difficult than did average drivers. Furthermore, elderly drivers considered driving with the cognitive task more difficult than driving with the visual task, while average drivers indicated driving with the visual task to be more difficult (Figure 255).

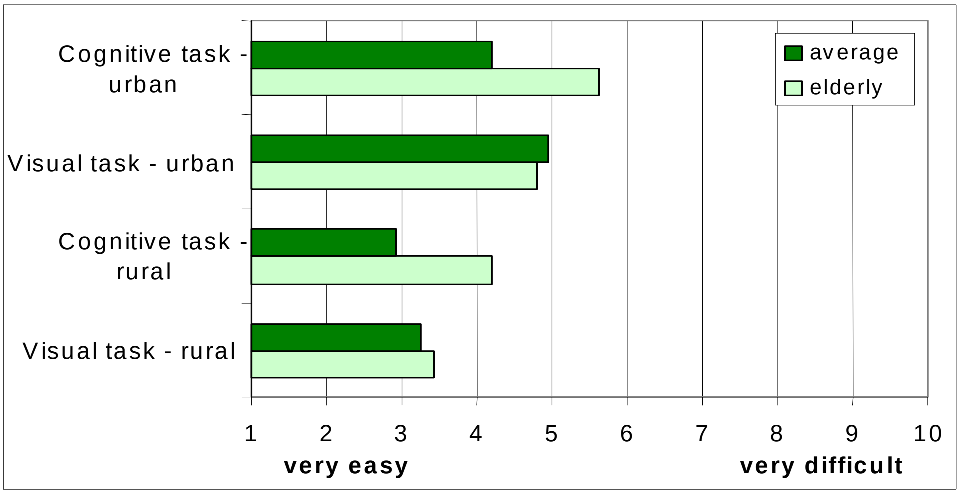



**Figure 255 – Self-reported difficulty of S-IVIS while driving.**

After open questions drivers were asked more specifically if they had noticed some of the listed changes in their driving while engaged in an S-IVIS task. Overall, drivers had noticed more changes while performing the visual task than the cognitive task (Figure 256). When engaged in the visual task, drivers had found that observation of other cars as well as pedestrians and cyclists at intersections became more difficult, for example. Many drivers indicated that they had occasionally lowered their speed unintentionally when engaged in the visual task. The most frequently mentioned change in driving behaviour while engaged in the cognitive task was disrupted observation of other vehicles at the intersection.

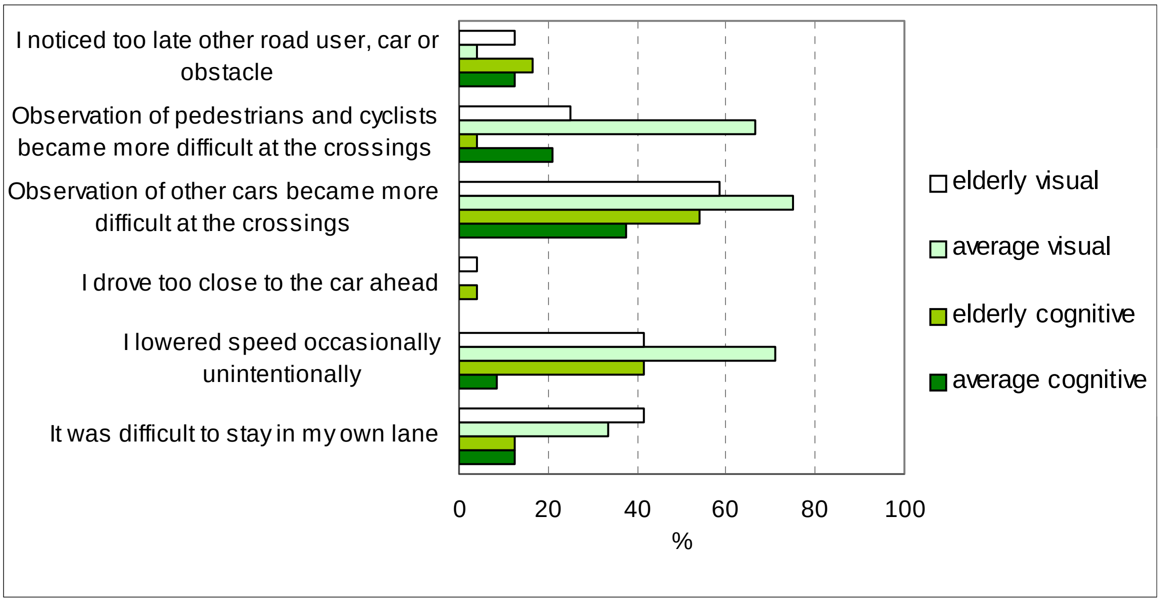



**Figure 256 – Driver assessment of changes while engaged in the secondary tasks by age group and S-IVIS**

In addition to the listed driver behaviour changes, drivers were asked if some other changes had happened while driving and performing S-IVIS tasks. Some drivers mentioned that they had increased speed unintentionally (10% for each task), felt excited, or that perception of traffic signs or other road users had been more difficult.

## 12.8. Summary and conclusions

Drivers rated their driving performance as best in baseline conditions and worse when the difficulty of the S-IVIS task increased. Elderly drivers rated their driving performance lower than average drivers for both environments and tasks. In addition, self-reported assessments of S-IVIS tasks suggested that drivers mostly underestimated the effects of them. However, the differences were relatively small and therefore self-reported assessments of driving cannot be assessed as sensitive measures.

For both age groups, the visual task tended somewhat to decrease *mean speed* in free-flow traffic on rural roads, whereas the cognitive task had practically no effect. However, all differences were very small and showed no tendency at individual difficulty levels. On rural roads, neither S-IVIS task affected the mean speed.

Each S-IVIS task tended somewhat to increase *speed variation* in free-flow traffic on rural roads. This tendency was evident for each age group. However, those tendencies were less evident in an urban environment. In addition, the observations showed that each S-IVIS task increased inappropriate speed behaviour in free-flow traffic situations (extremely fast, speeding up, varying speed, slowing down or extremely slow) in both environments. Compared to average drivers, elderly drivers were more often observed to have changes in their speed behaviour. When the difficulty of the S-IVIS task increased, a greater proportion of drivers was generally observed to have inappropriate speed behaviour.

In a rural environment, the S-IVIS task increased the proportions of *high and low speed compared to the posted speed limit* for each age group and S-IVIS task, except for average drivers performing the visual task. However, the effects of difficulty levels of the S-IVIS task showed no clear trend.

When there were vulnerable road users present at the urban intersection, the S-IVIS task tended to increase *speed before the intersection*, especially when there was some interaction with vulnerable road users.

The visual task increased the frequency of *rapid steering-wheel turnings* substantially in a rural environment, and the frequency increased with the difficulty level. In addition, the measure was more sensitive for elderly drivers than for average drivers. The visual task increased the reversal rate in a rural environment and the measure was sensitive also to difficulty levels of the visual task. However, the cognitive task had no effect on reversal rate.

The total number of *sudden brakings* based on vehicle or observational data was too low for any practical comparison.

*Observed lane keeping* tended to be a sensitive measure for the visual task in both environments and especially for elderly drivers.

*Observed headway distance* in car-following situations seemed to be a rather sensitive measure for both S-IVIS tasks. The effects were more substantial for elderly drivers.

Both S-IVIS tasks tended to decrease the proportion of proper *yielding of the right-of-way to other vehicles* at urban intersections. Elderly drivers showed inappropriate yielding behaviour more frequently and this behaviour was more severe.

The cognitive task seemed more frequently to cause *inappropriate behaviour towards vulnerable road users* than the visual task at urban intersections.

The S-IVIS task did not affect the *stopping behaviour* of average drivers while approaching an urban intersection. However, both S-IVIS tasks decreased the proportion of elderly drivers stopping at the intersections. In addition, both S-IVIS tasks somewhat decreased the *use of signals*.

For both S-IVIS tasks, the percentage of correct responses was highest for the static situation, followed by rural and urban environments; the percentage of correct responses decreased with increasing task difficulty; the proportion of correct responses was somewhat higher among average than elderly drivers, indicating that the elderly drivers had more problems in performing the task. These results suggest that the use of IVIS cannot be evaluated only by the effects on driving, but the effects on performance of S-IVIS tasks should be evaluated as well.

In conclusion, the most successful measure in terms of statistically significant effects by difficulty level was the reversal rate. Specifically, the S-IVIS task increased the reversal rate, especially with elderly drivers. However, this finding was limited to the visual task in a rural environment. Other results showed non-significant trends, frequently because of too large variances in factor levels.

# 12.9. Measures summary tables

## 12.9.1. Rural road and the visual task

| RURAL ARROWS TASK | | Mean values | | | | Main effect | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | **age** | BL | SLv1 | SLv2 | SLv3 | Model | SLv | Age | | SLv1 | SLv2 | SLv3 |
| **Longitudinal control** | | | | | | | | | | | | |
| mn_sp [km/h] | average | 82.4 | 81.0 | 81.2 | 80.5 | ✗ | | | | | | |
| | elderly | 81.9 | 80.6 | 82.1 | 80.0 | | | | | | | |
| st_sp [km/h] | | | | | | | | | BL | ✗ | ✗ | ✗ |
| | average | 1.2 | 1.3 | 1.3 | 1.2 | ✓ | ✗ | ✓ | SLv1 | | ✗ | ✗ |
| | elderly | 1.7 | 2.2 | 2.2 | 2.1 | | | | SLv2 | | | ✗ |
| u_sp [km/h] | | | | | | | | | BL | ✗ | ✗ | ✓ |
| | average | 80.3 | 78.9 | 78.8 | 78.3 | ✗ | ✓ | ✓ | SLv1 | | ✗ | ✗ |
| | elderly | 79.0 | 77.3 | 78.5 | 76.2 | | | | SLv2 | | | ✗ |
| obs_sp_fast [%] | average | 1.5 | 0.0 | 0.0 | 5.0 | - | | | | | | |
| | elderly | 3.7 | 7.3 | 16.2 | 10.5 | | | | | | | |
| obs_sp_slow [%] | average | 0.7 | 3.2 | 7.5 | 15 | - | | | | | | |
| | elderly | 3.7 | 19.5 | 5.4 | 23.7 | | | | | | | |
| obs_sp_irr [%] | average | 1.5 | 6.5 | 2.5 | 10 | - | | | | | | |
| | elderly | 5.1 | 9.8 | 21.6 | 23.7 | | | | | | | |
| **Lateral control** | | | | | | | | | BL | ✓ | ✓ | ✓ |
| rr_st2 [1/minute] | average | 17.4 | 17.4 | 18.6 | 21.0 | ✓ | ✓ | ✓ | SLv1 | | ✗ | ✗ |
| | elderly | 19.2 | 19.2 | 23.4 | 25.2 | | | | SLv2 | | | ✗ |
| rswt_40 [1/minute] (40-70 deg) | all | 0.03 | 0.25 | 0.27 | 0.77 | ✗ | | | | | | |
| rswt_70 [1/minute] (over 70 deg) | all | 0.01 | 0.02 | 0.04 | 0.13 | - | | | | | | |
| obs_lnx [%] | average | 1.8 | 4.2 | 4.2 | 2.1 | - | | | | | | |
| | elderly | 0.6 | 4.2 | 2.1 | 2.1 | | | | | | | |
| obs lateral movement (%) | average | 1.2 | 10.4 | 16.7 | 45.8 | - | | | | | | |
| | elderly | 6.5 | 47.9 | 31.3 | 35.4 | | | | | | | |
| obs lnx with correction (%) | average | 0.0 | 8.3 | 12.5 | 18.8 | - | | | | | | |
| | elderly | 3.0 | 18.8 | 25.0 | 45.8 | | | | | | | |
| obs lnx when oncoming vehicles (%) | average | 0.0 | 0.0 | 0.0 | 0.0 | - | | | | | | |
| | elderly | 0.0 | 2.1 | 6.3 | 8.3 | | | | | | | |
| **Workload** | | | | | | | | | | | | |
| subj_r [-] | average | 8.86 | 8.35 | 8.21 | 7.72 | - | | | | | | |
| | elderly | 8.27 | 7.76 | 7.45 | 7.21 | | | | | | | |
| **SIVIS** | | | | | | | | | | | | |
| s_correct [%] | all | | 99.8 | 97.7 | 86.1 | | | | | | | |
| s_rt [s] | all | | 1.75 | 1.99 | 2.75 | | | | | | | |
| s_missed [%] | all | | 0.2 | 0.7 | 3.5 | | | | | | | |
| s_incorrect [%] | all | | 0 | 1.6 | 10.4 | | | | | | | |

### 12.9.2. Rural road and the cognitive task

| RURAL ACMT TASK | | Mean values | | | | Main effect | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | **age** | BL | SLv1 | SLv2 | SLv3 | Model | SLv | Age | | SLv1 | SLv2 | SLv3 |
| **Longitudinal control** | | | | | | | | | | | | |
| mn_sp [km/h] | average | 82.2 | 82.4 | 84.1 | 82.6 | × | | | | | | |
| | elderly | 81.5 | 82.4 | 81.0 | 81.5 | | | | | | | |
| st_sp [km/h] | average | 1.5 | 2.1 | 2.1 | 1.8 | × | | | | | | |
| | elderly | 2.1 | 2.3 | 2.9 | 2.9 | | | | | | | |
| u_sp [km/h] | average | 85.0 | 78.2 | 80.1 | 79.4 | × | × | ✓ | BL | × | × | × |
| | | | | | | | | | SLv1 | | × | × |
| | elderly | 77.2 | 78.9 | 76.1 | 76.6 | | | | SLv2 | | | × |
| obs_sp_fast [%] | average | 1.5 | 8.1 | 5.6 | 18.8 | - | | | | | | |
| | elderly | 3.7 | 17.1 | 21.1 | 20.6 | | | | | | | |
| obs_sp_slow [%] | average | 0.7 | 2.7 | 8.4 | 6.2 | - | | | | | | |
| | elderly | 1.5 | 14.7 | 18.4 | 7.7 | | | | | | | |
| obs_sp_irr [%] | average | 1.5 | 2.7 | 13.9 | 6.3 | - | | | | | | |
| | elderly | 5.1 | 7.3 | 13.2 | 12.8 | | | | | | | |
| **Lateral control** | | | | | | | | | | | | |
| rr_st2 [1/minute] | average | 18.0 | 16.8 | 17.4 | 17.4 | ✓ | × | ✓ | BL | × | × | × |
| | | | | | | | | | SLv1 | | × | × |
| | elderly | 20.4 | 20.4 | 19.8 | 19.8 | | | | SLv2 | | | × |
| **Workload** | | | | | | | | | | | | |
| subj_r [-] | average | 8.86 | 8.48 | 8.23 | 8.15 | - | | | | | | |
| | elderly | 8.27 | 7.70 | 7.54 | 7.41 | | | | | | | |
| **SIVIS** | | | | | | | | | | | | |
| s_correct [%] | all | | 80.2 | 73.8 | 68.5 | | | | | | | |
| s_missed [%] | all | | 4.5 | 8.2 | 10.5 | | | | | | | |
| s_incorrect [%] | all | | 14.2 | 16.1 | 16.8 | | | | | | | |

### 12.9.3. Urban road and the visual task

| URBAN ARROWS TASK | | Mean values | | | | Main effect | | | Post Hoc test | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | **age** | BL | SLv1 | SLv2 | SLv3 | Model | SLv | Age | | SLv1 | SLv2 | SLv3 |
| **Longitudinal control** | | | | | | | | | | | | |
| mn_sp [km/h] | average | 41.0 | 42.6 | 39.5 | 40.4 | × | | | | | | |
| (straight section) | elderly | 39.9 | 40.8 | 38.7 | 41.9 | | | | | | | |
| | | | | | | | | | BL | ✓ | × | × |
| st_sp [km/h] | average | 1.3 | 0.7 | 1.2 | 1.3 | ✓ | ✓ | × | SLv1 | | × | × |
| (straight section) | elderly | 1.6 | 0.8 | 1.2 | 1.0 | | | | SLv2 | | | × |
| u_sp [km/h] | average | 39.0 | 41.4 | 37.6 | 38.2 | × | | | | | | |
| (straight section) | elderly | 37.5 | 39.4 | 36.5 | 40.2 | | | | | | | |
| obs_sp_fast [%] | average | 8.1 | 10.0 | 11.1 | 11.1 | - | | | | | | |
| | elderly | 11.1 | 12.1 | 11.4 | 11.8 | | | | | | | |
| obs_sp_slow [%] | average | 0.0 | 2.5 | 5.6 | 11.1 | - | | | | | | |
| | elderly | 3.7 | 9.1 | 17.1 | 14.7 | | | | | | | |
| obs_sp_irr [%] | average | 0.9 | 25.0 | 25.0 | 25.0 | - | | | | | | |
| | elderly | 6.5 | 36.4 | 42.9 | 41.2 | | | | | | | |
| **Lateral control** | | | | | | | | | | | | |
| obs lateral movement (%) | average | 1.0 | 8.3 | 6.3 | 6.3 | - | | | | | | |
| | elderly | 1.0 | 22.9 | 21.3 | 25.0 | | | | | | | |
| obs lane cuts (%) | average | 9.0 | 14.6 | 14.6 | 8.3 | - | | | | | | |
| | elderly | 10.0 | 6.3 | 6.4 | 4.2 | | | | | | | |
| obs wrong lane (%) | average | 2.0 | 2.1 | 6.3 | 2.1 | - | | | | | | |
| | elderly | 3.0 | 4.2 | 10.6 | 8.3 | | | | | | | |
| obs rapid corrections (%) | average | 0.0 | 0.0 | 2.1 | 2.1 | - | | | | | | |
| | elderly | 0.0 | 4.2 | 6.4 | 16.7 | | | | | | | |
| **Workload** | | | | | | | | | | | | |
| subj_r [-] | average | 8.65 | 7.89 | 7.96 | 7.40 | - | | | | | | |
| | elderly | 7.90 | 7.24 | 7.10 | 6.95 | | | | | | | |
| **SIVIS** | | | | | | | | | | | | |
| s_correct [%] | all | | 96.2 | 92.0 | 75.0 | | | | | | | |
| s_rt [s] | all | | 1.96 | 2.15 | 2.82 | | | | | | | |
| s_missed [%] | all | | 3.5 | 3.6 | 14.2 | | | | | | | |
| s_incorrect [%] | all | | 0.3 | 4.3 | 10.8 | | | | | | | |

### 12.9.4. Urban road and the cognitive task

| URBAN ACMT TASK | | Mean values | | | | Main effect | | |
|---|---|---|---|---|---|---|---|---|
| **Measure** | **age** | BL | SLv1 | SLv2 | SLv3 | Model | SLv | Age |
| **Longitudinal control** | | | | | | | | |
| mn_sp [km/h] | average | 40.8 | 40.3 | 40.6 | 42.1 | × | | |
| (straight section) | elderly | 39.9 | 42.3 | 40.6 | 40.5 | | | |
| st_sp [km/h] | average | 1.4 | 1.2 | 1.2 | 1.0 | × | | |
| (straight section) | elderly | 1.6 | 1.5 | 0.9 | 1.1 | | | |
| u_sp [km/h] | average | 38.7 | 38.5 | 38.7 | 40.4 | × | | |
| (straight section) | elderly | 37.5 | 39.7 | 39.1 | 38.8 | | | |
| obs_sp_fast [%] | average | 8.1 | 5.4 | 21.6 | 21.6 | - | | |
| | elderly | 11.1 | 20.0 | 21.9 | 19.4 | | | |
| obs_sp_slow [%] | average | 0.0 | 5.4 | 10.8 | 5.4 | - | | |
| | elderly | 3.7 | 22.5 | 12.5 | 30.6 | | | |
| obs_sp_irr [%] | average | 0.9 | 10.8 | 5.4 | 13.5 | - | | |
| | elderly | 6.5 | 12.5 | 18.8 | 22.2 | | | |
| **Workload** | | | | | | | | |
| subj_r [-] | average | 8.65 | 8.25 | 8.00 | 7.85 | - | | |
| | elderly | 7.90 | 7.18 | 7.15 | 6.94 | | | |
| **SIVIS** | | | | | | | | |
| s_correct [%] | all | | 74.0 | 67.0 | 63.1 | | | |
| s_missed [%] | all | | 10.4 | 10.9 | 16.0 | | | |
| s_incorrect [%] | all | | 15.6 | 18.4 | 16.3 | | | |

### 12.9.5. S-IVIS results for the static test and all road types

| | | Mean values | | |
|---|---|---|---|---|
| **SIVIS static** | **age** | SLv1 | SLv2 | SLv3 |
| **Arrows**<br>s_correct [%] | all | 99.9 | 99.0 | 90.4 |
| s_rt [s] | all | 1.38 | 1.60 | 2.48 |
| s_missed [%] | all | 0 | 0 | 2.4 |
| s_incorrect [%] | all | 0.1 | 1.0 | 7.2 |
| **aCMT**<br>s_correct [%] | all | 81.3 | 80.0 | 74.2 |
| s_missed [%] | all | 3.0 | 6.5 | 9.1 |
| s_incorrect [%] | all | 15.3 | 11.5 | 14.0 |

| **SIVIS** | **Main effect** | | |
|---|---|---|---|
| | Environment | SLv | Age |
| **ARROWS TASK**<br>s_correct [%] | ✓ | ✓ | ✓ |
| s_rt [s] | ✓ | ✓ | ✓ |
| s_missed [%] | ✓ | ✓ | ✓ |
| s_incorrect [%] | ✓ | ✓ | ✓ |
| **ACMT TASK**<br>s_correct [%] | ✓ | ✓ | ✓ |
| s_missed [%] | ✓ | ✓ | ✓ |
| s_incorrect [%] | × | × | ✓ |
| s_false [%] | ✓ | ✓ | ✓ |

| | |
|---|---|
| ✓ | **significant effect** |
| × | **absence of effect or can not be tested with Unianova because the null hypothesis of Levene's test was rejected** |
| - | **no statistical tests** |

# 13. Cross test site comparisons

The objective of the cross test site comparisons was to evaluate which measures were the most sensitive and reliable indicators of driving performance and workload. This meta analysis was highly facilitated by the strict standardisation of the included measures, experimental design and scenarios. The meta analysis was conducted by TNO.

## 13.1. Method

The results of the separate studies were combined by means of a meta-analysis of the effects they had produced. A meta-analysis is a quantitative statistical procedure that yields overall estimates of effect sizes that are more accurate and reliable than that of any separate study (e.g., Elvik et al., 2003). A meta-analysis can become quite complicated if effect estimates originate from studies that have used different experimental designs or that differ in their inherent quality (e.g., in the control that has been exerted over confounding variables). In some cases this may mean that available material cannot be used because it can not be combined with the rest of the material. In the present case, however, a meta-analysis should be relatively uncomplicated because so much care had been taken that all studies were identical in their underlying designs.

For each separate study, effect sizes (Cohen's d: Cohen, 1988) were calculated for those effects involving S-IVISs level that were significant at at least the 10 % level. The effect size is the difference score between an S-IVIS level and baseline divided by their common standard deviation (which makes it effectively a z-score). As a convention, the following are used in the literature as descriptive of effect sizes that may occur: 0.2 = small, 0.5 = moderate, 0.8 = large, 1.0 = very large effect. As an illustration of what this would mean for an experimental design, the approximate numbers of Ss required to find this as a main effect (one-sided, i.e. $\alpha = .10$; within-Ss) are ± 300 / 26 / 11 / and 7, respectively. For example, an effect size of 0.5 standard units would be detectable at the .10 level in a design using 26 Ss, while only 11 Ss would be needed to detect the effect if it had a magnitude of 0.8 standard units. Thus, effect sizes have major implications for the design of the experiments to follow in WP 3 in terms of – at least – the numbers of participants required.

## 13.2. Summary of effects

### 13.2.1. Simulator studies

Several available methods for computing combined effects sizes were tried (i.e., inverse-variance method with fixed and random effects), but these procedures gave minimally different results from simple averaging. This was perhaps to be expected given the homogeneity, in terms of experimental design, of the separate studies.

Average effect sizes over studies were computed per parameter when an effect was significant (at least at 10%-level) in all studies that, for a certain methodology and in a certain environment, had used the particular parameter. A further demand was that a minimum of two studies should have used the parameter in order for it to be retained. The exception is the urban environment, for which sometimes only a single study had used all parameters.

Although straight/curved sections were analyzed separately, there was no discernible pattern in the sense that one section type systematically yielded better discriminative power.Thus, the results were collapsed over the straight/curved dimension.

Table 150 shows simple averages over studies (more sophisticated weighing procedures gave minimally different results, which was perhaps to be expected given the standardized way in which the separate experiments had been performed). The separate effects in the table are always based on n = 24.

**Table 150 –Average S-IVIS effect sizes from simulator studies**

| S-IVIS-level | Motorway Visual task | Motorway Cognitive task | Rural Visual task | Rural Cognitive task | Urban Visual task | Urban Cognitive task |
|---|---|---|---|---|---|---|
| **Subjective ratings** | **subj_r** | | | | | |
| 1 | -0.77 | -1.01 | -0.82 | -0.60 | *-0.69* | *-0.29* |
| 2 | -1.43 | -1.12 | -1.36 | -0.67 | *-0.77* | *-0.20* |
| 3 | -1.58 | -1.27 | -1.70 | -0.70 | *-0.78* | *-0.32* |
| | | | | | | |
| **Longitud. Measures** | | | | | | |
| | **mn_sp** | | | | | |
| 1 | -0.33 | NS | -0.40 | NS | -0.38 | -0.25 |
| 2 | -0.49 | | -0.52 | | -0.39 | -0.26 |
| 3 | -0.47 | | -0.53 | | -0.55 | -0.26 |
| | ***st_sp*** | | | | | |
| 1 | NS | NS | NS | NS | NS | *0.35* |
| 2 | | | | | | *0.33* |
| 3 | | | | | | *0.45* |
| | **d_sp** | | | | | |
| 1 | NS | NS | *-0.49* | NS | NS | *0.21* |
| 2 | | | *-0.87* | | | *0.30* |
| 3 | | | *-0.77* | | | *0.38* |
| | **u_sp** | | | | | |
| 1 | *-0.34* | NS | *-0.46* | NS | -0.36 | NS |
| 2 | *-0.34* | | *-0.46* | | -0.34 | |
| 3 | *-0.55* | | *-0.61* | | -0.35 | |
| | | | | | | |
| **Lateral measures** | | | | | | |
| | **st_lp** | | | | | |
| 1 | 0.28 | -0.44 | 0.48 | -0.32 | *0.12* | *-0.12* |
| 2 | 0.70 | -0.37 | 0.84 | -0.89 | *0.31* | *-0.38* |
| 3 | 0.82 | -0.51 | 0.80 | -0.40 | *0.42* | *-0.41* |
| | **mn_lp** | | | | | |
| 1 | NS | NS | 0.10 | 0.28 | 0.07 | NS |
| 2 | | | 0.49 | 0.22 | -0.03 | |
| 3 | | | 0.45 | 0.16 | 0.13 | |
| | **lnx** | | | | | |
| 1 | NS | NS | *0.53* | NS | NA | NA |
| 2 | | | *0.80* | | | |
| 3 | | | *0.68* | | | |
| | **mn_tlc** | | | | | |
| 1 | NS | NS | *-0.31* | NS | *-0.22* | NS |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2 | | | *-0.69* | | *-0.37* | |
| 3 | | | *-0.78* | | *-0.47* | |
| | | | | | | |
| **Headway measures** | | | | | | |
| | **mn_hwt** | | | | | |
| 1 | NA | NA | *0.79* | NS | *0.19* | *-0.32* |
| 2 | | | *0.75* | | *0.30* | *-0.44* |
| 3 | | | *0.95* | | *0.30* | *-0.17* |
| | **sd_hwt** | | | | | |
| 1 | NA | NA | *0.66* | NS | *0.32* | NS |
| 2 | | | *0.77* | | *0.49* | |
| 3 | | | *0.93* | | *0.44* | |
| | **mn_hwd** | | | | | |
| 1 | NA | NA | *NS* | NS | NS | *-0.31* |
| 2 | | | | | | *-0.42* |
| 3 | | | | | | *-0.19* |
| | **sd_hwd** | | | | | |
| 1 | NA | NA | *0.59* | NS | *-0.15* | NS |
| 2 | | | *0.71* | | *-0.28* | |
| 3 | | | *0.94* | | *0.01* | |
| | | | | | | |
| **Steering measures** | | | | | | |
| | **rr_st1** | | | | | |
| 1 | 0.63 | NS | 0.74 | 0.44 | *0.52* | *0.40* |
| 2 | 0.89 | | 0.77 | 0.47 | *0.47* | *0.21* |
| 3 | 0.91 | | 0.95 | 0.52 | *0.52* | *0.30* |
| | **rr_st3** | | | | | |
| 1 | *0.41* | NS | 0.82 | NS | *0.41* | *0.46* |
| 2 | *1.30* | | 1.24 | | *0.48* | *0.34* |
| 3 | *1.40* | | 1.31 | | *0.57* | *0.46* |
| | **rr_st5** | | | | | |
| 1 | *0.54* | NS | *0.70* | NS | *0.52* | *0.47* |
| 2 | *1.20* | | *1.13* | | *0.45* | *0.13* |
| 3 | *1.60* | | *1.25* | | *0.40* | *0.36* |
| | **rr_st7** | | | | | |
| 1 | *0.48* | NS | *0.66* | NS | *0.58* | NS |
| 2 | *1.00* | | *0.91* | | *0.54* | |
| 3 | *1.20* | | *0.95* | | *0.42* | |
| | **rswt_5** | | | | | |
| 1 | *0.55* | NS | NA | NA | NA | NA |
| 2 | *1.20* | | | | | |
| 3 | *1.30* | | | | | |
| | **rswt_10** | | | | | |
| 1 | 1.07 | NS | NA | NA | NA | NA |
| 2 | 1.39 | | | | | |
| 3 | 1.63 | | | | | |
| | **hi_st** | | | | | |
| 1 | 0.23 | NS | *0.74* | *0.34* | *0.37* | NS |
| 2 | 0.46 | | *1.17* | *0.32* | *0.36* | |
| 3 | 0.51 | | *1.13* | *0.35* | *0.22* | |
| | **en_st** | | | | | |
| 1 | 1.24 | NS | *1.23* | *1.64* | NA | NA |
| 2 | 2.38 | | *1.84* | *1.22* | | |
| 3 | 2.43 | | *2.19* | *1.66* | | |

### 13.2.2. Field studies

Table 151 gives the corresponding results for the field studies.

**Table 151 – Average S-IVIS effect sizes from field studies**

| S-IVIS-level | Motorway Visual task | Motorway Cognitive task | Rural Visual task | Rural Cognitive task | Urban Visual task | Urban Cognitive task |
|---|---|---|---|---|---|---|
| **Subjective ratings** | **subj_r** | | | | | |
| 1 | -1.67 | -2.70 | *-0.43* | NA | *-0.69* | NA |
| 2 | -1.59 | -3.16 | *-0.71* | | *-0.79* | |
| 3 | -2.97 | -3.77 | *-1.30* | | *-1.20* | |
| | | | | | | |
| **Longitud. Measures** | **st_sp** | | | | | |
| 1 | 0.44 | NS | NS | *0.35* | -0.49 | NS |
| 2 | 0.32 | | | *0.74* | -0.21 | |
| 3 | 0.51 | | | *0.62* | -0.33 | |
| | **d_sp** | | | | | |
| 1 | NS | NS | *-0.68* | NS | NS | NS |
| 2 | | | *-0.03* | | | |
| 3 | | | *-0.29* | | | |
| | **mn_sp** | | | | | |
| 1 | -1.15 | NS | -0.43 | NS | -0.12 | NS |
| 2 | -0.95 | | -0.32 | | 0.06 | |
| 3 | -0.80 | | -0.55 | | -0.40 | |
| | **u_sp** | | | | | |
| 1 | NS | NS | *-0.50* | NS | *0.40* | NS |
| 2 | | | *-0.33* | | *-0.23* | |
| 3 | | | *-0.65* | | *0.15* | |
| | | | | | | |
| | **mn_lp** | | | | | |
| 1 | NS | NS | NA | NA | NA | NA |
| 2 | | | | | | |
| 3 | | | | | | |
| | | | | | | |
| **Lateral measures** | **st_lp** | | | | | |
| 1 | NS | NS | NA | NA | NA | NA |
| 2 | | | | | | |
| 3 | | | | | | |
| | **mn_tlc** | | | | | |
| 1 | NS | NA | NA | NA | | |
| 2 | | | | | | |
| 3 | | | | | | |
| | | | | | | |
| **Steering measures** | | | | | | |
| | **rr_st1** | | **rr_st2** | | | |
| 1 | *0.85* | *0.52* | *0.53* | NS | NA | NA |
| 2 | *1.07* | *0.64* | *0.65* | | | |
| 3 | *1.08* | *0.42* | *0.95* | | | |
| | **rr_st3** | | | | | |
| 1 | NA | NA | NA | NA | NA | NA |
| 2 | | | | | | |
| 3 | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | **rr_st4-6** | | | | | |
| 1 | NA | NA | *0.41* | NS | | |
| 2 | | | *0.57* | | | |
| 3 | | | *0.93* | | | |
| | **rr_st7** | | | | | |
| 1 | NA | NA | *0.13* | NS | | |
| 2 | | | *0.24* | | | |
| 3 | | | *0.42* | | | |
| | **rswt_10** | | | | | |
| 1 | *0.97* | NA | NA | NA | | |
| 2 | *0.89* | | | | | |
| 3 | *1.16* | | | | | |
| | **hi_st** | | | | | |
| 1 | *1.06* | NA | NA | NA | NA | NA |
| 2 | *1.14* | | | | | |
| 3 | *1.49* | | | | | |
| | **en_st** | | | | | |
| 1 | NS | *-1.18* | NA | NA | NA | NA |
| 2 | | *1.06* | | | | |
| 3 | | *-0.82* | | | | |

### 13.2.3. Laboratory experiments

In the MINHO laboratory experiment (the only laboratory), only rural road was included. Only measures included in the experiment are included in the effect size table (Table 152) below.

**Table 152 – Average S-IVIS effect sizes from the laboratory experiment**

| S-IVIS-level | Motorway Visual task | Motorway Cognitive task | Rural Visual task | Rural Cognitive task | Urban Visual task | Urban Cognitive task |
|---|---|---|---|---|---|---|
| **Subjective ratings** | **subj_r** | | | | | |
| 1 | | | -4.12 | -1.07 | | |
| 2 | | | -3.79 | -1.58 | | |
| 3 | | | -3.70 | -2.00 | | |
| | | | | | | |
| **Longitud. Measures** | **st_sp** | | | | | |
| 1 | | | 2.69 | NS | | |
| 2 | | | 2.13 | | | |
| 3 | | | 2.06 | | | |
| | **mn_sp** | | | | | |
| 1 | | | -1.66 | NS | | |
| 2 | | | -1.58 | | | |
| 3 | | | -1.21 | | | |
| | **u_sp** | | | | | |
| 1 | | | -2.21 | NS | | |
| 2 | | | -1.84 | | | |
| 3 | | | -1.66 | | | |
| | **mn_lp** | | | | | |
| 1 | | | 1.73 | NS | | |
| 2 | | | 1.52 | | | |
| 3 | | | 1.64 | | | |
| | | | | | | |
| **Lateral measures** | **st_lp** | | | | | |
| 1 | | | 2.54 | -1.16 | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2 | | | 3.08 | -1.19 | | |
| 3 | | | 2.85 | -1.31 | | |
| | **lnx** | | | | | |
| 1 | | | 1.95 | NS | | |
| 2 | | | 1.99 | | | |
| 3 | | | 1.58 | | | |
| | | | | | | |
| **Steering measures** | **rr_st1** | | | | | |
| 1 | | | 1.65 | 1.41 | | |
| 2 | | | 1.43 | 1.15 | | |
| 3 | | | 1.57 | 0.92 | | |
| | | | | | | |
| **Headway measures** | **mn_hwt** | | | | | |
| 1 | | | 0.58 | 0.57 | | |
| 2 | | | 0.69 | 0.31 | | |
| 3 | | | 0.78 | 0.26 | | |
| | **mn_hwd** | | | | | |
| 1 | | | 0.38 | NS | | |
| 2 | | | 0.24 | | | |
| 3 | | | 0.61 | | | |
| | **sd_hwt** | | | | | |
| 1 | | | -0.65 | -0.61 | | |
| 2 | | | -0.68 | -0.38 | | |
| 3 | | | -0.91 | -0.24 | | |
| | **sd_hwd** | | | | | |
| 1 | | | -0.36 | NS | | |
| 2 | | | -0.33 | | | |
| 3 | | | -0.63 | | | |

## 13.3. Interpretation of findings from meta-analysis

A sensible step towards interpretation is to only consider those effects which show a clear, i.e. monotonous, relationship with S-IVIS level. That is, the effect should grow with increasing level of S-IVIS difficulty. When this is done the following most differentiating parameters remain per experimental environment/methodology: See Table 153. The most successful indicators were thus self reported driving performance (subj_r), mean speed (mn_sp), lateral position variation (sd_lp), and reversal rate (rr_st1, rr_st1 & rr_st3).

**Table 153 – The most successful indicators**

| **Visual task** | **SIM** | | | **FIELD** | | | **LAB** | | |
|---|---|---|---|---|---|---|---|---|---|
| | *Motorw.* | *Rural* | *Urban* | *Motorw.* | *Rural* | *Urban* | *Motorw.* | *Rural* | *Urban* |
| Subjective | subj_r | subj_r | - | - | subj_r | subj_r | - | subj_r | - |
| Longitudinal | - | - | - | mn_sp | - | - | - | st_sp | - |
| Lateral | st_lp | - | st_lp | - | - | - | - | - | - |
| Steering | en_st; also hi_st or rswt_10 | en_st; also rswt_3 rswt_5 | - | hi_st | rswt_2 or higher | - | - | - | - |
| Headway | - | d_hwd or d_hwt | - | - | - | - | - | mn_hwt | - |
| | | | | | | | | | |
| **Cognitive task** | **SIM** | | | **FIELD** | | | **LAB** | | |
| | *Motorw.* | *Rural* | *Urban* | *Motorw.* | *Rural* | *Urban* | *Motorw.* | *Rural* | *Urban* |
| Subjective | subj_r | subj_r | - | subj_r | - | - | - | subj_r | - |
| Longitudinal | - | - | - | - | - | - | - | - | - |
| Lateral | - | - | - | - | - | - | - | st_lp | - |
| Steering | - | - | - | - | - | - | - | rr_st1 | - |
| Headway | - | - | - | - | - | - | - | sd_hwt or mn_hwt | - |

As a further step topwards defining a minimum effective experiment possibly to be used in WP 3 a cross-methods comparison of effect sizes was then made across (a) simulator, field, and lab; and (b) between the motorway, rural, and urban environments.
Table 154 shows the relevant findings for the simulator studies.

**Table 154 – Range of effects sizes for IVIS levels, sim studies parameters, Visual task**

| | **Range on motorway** | **Range in rural** | **Range in urban** |
|---|---|---|---|
| | | | |
| subj_r | -0.77 / -1.58 | -0.82 / -1.70 | Not retained |
| st_lp | 0.28 / 0.82 | Not retained | 0.12 / 0.42 |
| en_st | 1.24 / 2.43 | 1.23 / 2.19 | NA |
| sd_hwd, sd_hwt | NA | ± 0.60 to ± 0.95 | Not retained |

Effect sizes per retained parameter for the field and lab studies are shown in Table 155 and Table 156, respectively.

**Table 155 – Range of effect sizes per retained parameter, field studies, Visual task**

| | Range on motorway | Range in rural | Range in urban |
|---|---|---|---|
| | | | |
| subj_r | Not retained | -0.43 / -1.30 | -0.69 / -1.20 |
| mn_sp | -0.80 / -1.15 | Not retained | Not retained |
| hi_st | 1.06 / 1.49 | Not retained | Not retained |
| rst1/2 | 0.85 / 1.08 | 0.53 / 0.95 | Not retained |

**Table 156 – Range for lab study (rural only), Visual task**

| | Range in rural |
|---|---|
| | |
| subj_r | - 4.12 / -3.70 |
| sd_sp | 2.69 / 2.06 |
| mn_hwt | 0.58 / 0.78 |

For the cognitive task the corresponding Table 157, Table 158 and Table 159 apply.

**Table 157 – Range of effects sizes for IVIS levels, sim studies parameters, Cognitive task**

| | Range on motorway | Range in rural | Range in urban |
|---|---|---|---|
| | | | |
| subj_r | -1.01 / -1.27 | -0.60 / -0.70 | Not retained |

**Table 158 – Range of effect sizes per retained parameter, field studies, Cognitive task**

| | Range on motorway |
|---|---|
| | |
| subj_r | -2.70 / -3.77 |

**Table 159 – Range for lab study (rural only), Cognitive task**

| | Range in rural |
|---|---|
| subj_r | -1.07 / - 2.00 |
| st_lp | -1.16 / -1.31 |
| rst1 | 1.41 / 0.92 |
| sd_hwt | -0.61 / -0.24 |

Table 160 then appears to be the ‘optimal’ designs for the WP 3 studies. These are based on the following requirements:
The lowest IVIS level should already be significantly different from baseline.
There should be a clear spacing between effects at sucessive IVIS levels.
Coverage of as many underlying dimensions of driving behavior as possible should, at this stage, be maintained (i.e, longitudinal as well as lateral, steering, and headway).

**Table 160 – Specification of optimally effective design per methodology * environment.**

Approximate n: number of subjects required to find the smallest of the effects of the selected measures. For example, in the Arrows/Sim/Rural set-up required n = 20 because of the ‘Headway’ measures (if headway measures were not included n could be smaller).

| | Method | Preferred environment | Parameters | Approximate n |
|---|---|---|---|---|
| **Visual task** | Sim | Rural | SubjR/EnST/Headway | 20 |
| | Field | Motorway | MnSP/HiST or RrST1 or 2 | 11 |
| | Lab | Rural | SubjR/SDSP/MnHWT | 20 |
| **Cognitive task** | Sim | Motorway | SubjR | < 7 |
| | Field | Motorway | SubjR | < 7 |
| | Lab | Rural | SubjR/SDLP/RrST1 | 8 |

A final step could be to select the one and only sufficient combination of tool * environment. However, we have decided that in WP 3 we are going to make one more comparison between methodologies, so this is a step too far.

# 14. Discussion and Conclusions

## 14.1. Study setup

The main objective of this study was to investigate the relationship between on the one hand distraction caused by an IVIS and on the other hand driving performance and safety. The S-IVIS used in these studies were carefully manipulated so that it would occur at particular points on the road and for a fixed duration. They were also manipulated in terms of the type of information and the dose of IVIS that was administered. There were two IVIS types, or rather surrogate IVIS (S-IVIS) types: one to create cognitive load and another to create visual load. The S-IVIS dose always had three levels, plus a baseline (non-SIVIS condition), and the timing of the S-IVIS and the pacing (rate of information flow) were pre-set. The S-IVIS tasks, levels and procedures were extensively pre-tested. Drivers could not choose when to be contacted by the S-IVIS; this was set by the system. Of course, many real-word IVIS systems may allow drivers to retrieve information when they feel comfortable doing so, but others do not allow such flexibility: navigation systems will provide route instructions when they chose and mobile phones may ring at any point. In the experiments, S-IVIS was administered statically (at a workstation) and dynamically (while driving) so as to test whether static performance and dynamic performance of the secondary task were in conformance.

A very large set of experiments was conducted. But in one sense this was one very large multi-national unified and integrated experiment with a common goal, a common experimental protocol and common indicators. For the simulator experiments, the road design and event design was also common within the major road categories of urban, rural and motorway. The overall basic distribution of the experiments across simulator and road category is shown in Table 161. It should be noted that S-IVIS was always a between-subjects factor, so that separate experiments were carried out for each S-IVIS.

**Table 161 – Summary of simulator and laboratory experiments**

| Site | Road Category | | |
|---|---|---|---|
| | Urban | Rural | Motorway |
| Leeds | | ✓ | |
| TNO | ✓ | ✓ | |
| Transport Canada | ✓ | ✓ | |
| Minho | | ✓ | |
| VTEC | | ✓ | ✓ |
| VTI | | ✓ | ✓ |

The rural road served as a kind of reference test, since it was studied in all the simulators. This allowed comparison across the simulators. The urban and motorway drives were investigated along with the rural road driving within single experiments. As a result there were 12 *basic* simulator experiments in total (6 sites x 2 S-IVISs). There were two *additional* simulator experiments. The first was a study of driving by elderly drivers with an S-IVIS (the cognitive task only, since sickness was a severe problem with these subjects using the visual task). The second was a study of British drivers driving with the visual S-IVIS in the Minho laboratory. This last study was conducted to confirm whether differences between what was observed in the Portuguese laboratory and the findings from other sites were attributable to a between-country effect or a between-simulator-and-laboratory effect. There were thus 14 separate simulator and laboratory experiments in total.

The rural road had three levels of difficulty: first straights as the easiest level, next gentle S-shaped curves, requiring more effort than the straights, and lastly a set of discrete critical events, requiring intervention by the driver in the form of a major reduction of speed. These events were different for the two drives performed by the participants — one in the baseline situation and one with the S-IVIS, but they were designed to be matched on type, as shown in Table 162.

**Table 162 – Events for rural roads 1 and 2**

| Road 1 | Road 2 |
|---|---|
| Sheep blocking the road | Road works |
| Crossing lorry | Crossing car |
| Emerging lorry | Emerging car |

The motorway had two levels of difficulty, normal driving and events. Once again there was a need for two sets of events, as shown in Table 163.

**Table 163 – The events on motorways 1 and 2**

| Motorway 1 | Motorway 2 |
|---|---|
| Participant overtakes three vehicles, of which the second cuts in | Participant overtakes three vehicles, of which the second cuts in |
| Road works and vehicle cutting in | Subject overtakes four vehicles, of which the third cuts in |
| Three vehicles in left lane pass subject, of which the second cuts in | Three vehicles in left lane pass subject, of which the second cuts in |

Like the rural road, the TNO urban road had three levels of difficulty:

1. Straight sections, requiring minimal workload compared to other scenarios.
2. Crossings, which required some negotiation by the driver.
3. Discrete events, requiring immediate attention by the driver.

And once again, two roads were constructed with matched events as show in Table 164.

**Table 164 – The events on TNO urban roads 1 and 2**

| Urban road 1 | Urban road 2 |
|---|---|
| Car leaving a bus stop just when the driver arrives | Car leaving its place on the left side of the road |
| Lead car slows down for a pedestrian crossing the street | A car coming from the right, crossing a junction |
| Traffic light stays red until the driver almost comes to a complete stop | Traffic light stays red until the driver almost comes to a complete stop |

The Transport Canada rural road also had three levels of difficulty — straights, curves and events, but the road layout was more typically "North American" as compared to the European layout of the TNO road. The events were also different (see Table 165).

**Table 165 – The events on Transport Canada urban roads 1 and 2**

| Urban road 1 | Urban road 2 |
|---|---|
| Parked car pulls out in front of the driver on the right | SUV pulls out in front of the driver on the right |
| Oncoming car crosses an intersection while the driver is making a left turn | Motorcycle crosses an intersection while the driver is making a left turn |
| Cyclist crosses the road at an intersection while the driver is making a right turn | Pedestrian crosses the road at an intersection while the driver is making a right turn |

For the field (real road) studies, both types of S-IVIS were included in the drives for each participant, with the order of S-IVIS tasks counterbalanced. This was because, for these studies, there was no issue with the drivers learning what might happen in the critical events, since none were staged — all the driving was done in natural settings. The distribution of the field trials across the road types is shown in Table 166. All roadway types were completed in a single session, so that there were three field experiments in total. Thus the overall number of experiments, both simulator and field, was 17. Data for a total of 527 participants were recorded.

**Table 166 – Summary of field experiments**

| Site | Road Category | | |
|---|---|---|---|
| | Urban | Rural | Motorway |
| TRAIL | ✓ | ✓ | ✓ |
| Sweden | | | ✓ |
| VTT | ✓ | ✓ | |

A large number of indicators were collected and most of these were common to the various studies carried out. For the simulator studies, the variables were generally common to all the studies, although in some cases extra data was collected in a particular study, for example the eye movement data in the Transport Canada and VTEC simulator studies. The indicators can be classified into:

- Self-reported driving performance
- Lateral control
- Longitudinal control, i.e. control of speed and distance to a lead vehicle
- Workload, such as physiological measures and gaze behaviour
- Observations of driving performance made by an accompanying expert observer in the field

## 14.2. Major dimensions of the study

The major dimensions of the study were:

- S-IVIS type, visual versus cognitive

  - Within S-IVIS type, S-IVIS level
  - Within S-IVIS type, Static S-IVIS performance versus Dynamic S-IVIS performance
- Simulator and Laboratory studies versus. Field Studies
  - Simulator/Laboratory type
- Road category (urban, rural, motorway)
  - Within Road category, Road level
- "Average" drivers versus Elderly drivers
- UK drivers versus Portuguese drivers

The findings across each of these dimensions are discussed below.

## 14.3. S-IVIS Type

The two types of S-IVIS had quite different effects on driving performance. The visual task had pronounced effects in terms of steering and lateral behaviour. With increased task load there was a tendency for more steering reversals and higher standard deviation of lateral position, i.e. more wandering in the road. In some of the studies, more high-frequency steering and a reduction in time to line crossing were also found. The steering reversal behaviour is an indication that, with their eyes off the road, there was a tendency for the drivers to allow the vehicle to deviate from the intended path and then to jerk on the steering wheel when they realised they were off-tracking. The interaction with the visual S-IVIS was accompanied by a speed reduction (not affected by S-IVIS level, however) and an increase in headway. The two are almost certainly related. This phenomenon of a speed reduction when engaged with an IVIS has been noted in numerous studies, but should not be interpreted as necessarily compensating for other safety-related impacts.

The cognitive task caused reduced lateral deviation; in other words it "improved" steering behaviour, though there was also a tendency for drivers to compensate for the task load by shifting away from the road edge. This "improvement" in steering behaviour was accompanied by an increase in glance focus on the roadway straight ahead, at the expense of the periphery. The concentration on the road straight ahead probably explains the reduction in lateral deviation. There were indications in some of the results that the predominant negative effect of the cognitive task on driving performance was on longitudinal control in car following. For example in one experiment, a reduction in minimum distance headway was found. This was noticeable for the elderly drivers, particularly at the highest level of S-IVIS demand. The effects of the cognitive task on speed were mixed, i.e. not consistent across the studies. The meta-analysis indicated that the only reliable measure for the cognitive task impact, across all the rural road and motorway simulator studies and the motorway field studies was the subjective rating of driving performance by the drivers.

## 14.4. S-IVIS level

The important question with S-IVIS level is whether safety-related driving performance became progressively worse with increased demand, or alternatively whether drivers were able to manage the situation by dropping the S-IVIS task where and when required. In this latter scenario, there would be a ceiling effect such that performance on the primary task would be worst as S-IVIS level 1 or level 2, performance on the S-IVIS task would be significantly worse at levels 2 and 3 or at level 3 alone as compared with level 1. Such a ceiling effect would mean that even a highly distracting IVIS was not a problem. There are indications in the findings that drivers were doing some "management" of the task load. S-IVIS performance tended to be worst when the task demand in driving was highest, i.e. in the events. For the elderly drivers, the proportion of incorrect responses to both the visual task and the cognitive task, tended to increase steadily with driving difficulty. But drivers were not always able to manage the trade-off and there were many indications of driving performance being worst when secondary task demand was the highest. For example, in the VTI simulator experiment, lateral deviation with the visual task was highest at S-IVIS level 3 in the most demanding rural road situation, namely the events. Here the trade-off failed and it failed in the worst possible situation, when driving was most difficult.

## 14.5. Static S-IVIS Performance vs Dynamic Performance

If performance on the S-IVIS task was the same in the static and dynamic situations and did not vary across driving difficulty, then there would be strong arguments for testing an IVIS without any need to resort to driving simulators or real-road driving. The static test would pick up any problems and thresholds could be set in terms of glance durations or task time. The latter is exactly what has been proposed in the U.S. with the "15 second rule". Generally, the studies here found that there was an interaction between S-IVIS performance across the baseline (static) and three levels of dynamic situation (i.e. the three levels of road difficulty). This confirms the HASTE approach of requiring driving context to be considered in assessing IVIS. Static performance did not reliably predict dynamic performance.

## 14.6. Simulator vs. Field

It has not in the end proven feasible for the field studies to serve as some kind of validation of the simulator studies. The roads used did not really correspond, the data collected was not always the same (due to the equipment on the instrumented cars lacking, for example, measurement of lateral deviation) and the real roads did not have corresponding difficulty levels to the experimental roads.

But what has emerged is that the field studies are complementary to the simulator evaluations. The field studies tended to pick up somewhat different effects of the systems than the simulator studies. One example is the interaction with pedestrians at the zebra crossing in the Helsinki drives (see section 12.6.2.6), where the cognitive task resulted in substantially poorer and therefore more dangerous interaction, particularly in the form of delayed response or lack of response to the situation. This may be attributable to the reduced mental processing available when under the cognitive load, leading to a situation in which the driver is unable to interpret pedestrian intention. It may also be related to the already noted tunnel vision induced by the cognitive task. Thus a future test regime may well have to incorporate both simulator and real-world driving. An alternative would be to ensure that the type of scenarios and events where the field studies proved particularly revealing, can be incorporated in a simulator environment. Such scenarios could perhaps take the form of detecting objects in the periphery or detecting changes in the peripheral scene.

Additionally, it has not proved possible to test elderly drivers with the visual task in Leeds simulator, because of simulator sickness. This again shows the value of the field tests. There were clear indications from the Helsinki drives that elderly participants had substantially more problems as a result of S-IVIS use. Evaluation of this effect can only practically be done in real-world driving, since many real IVISs will impose both visual and cognitive loads. On the other hand, consideration will need to be made of the fact that elderly drivers driving with and

IVIS on unfamiliar roads may get into dangerous situations. Thus there may be practical and ethical considerations to be taken into account.

## 14.7. Simulator Type

The broad conclusion is that the type of simulator or laboratory used in the assessment did not have an effect. This is indicated by the meta-analysis (chapter 13) which shows that, in the rural road analysis, the variables that were found to be significant in the Portuguese laboratory were generally the same as those found to be significant in the more elaborate simulators. The effect sizes were also broadly in line; indeed in many cases they were larger in the Portuguese study, perhaps as a result of the generally more risky driving by the Portuguese drivers.

## 14.8. Road Category

In the simulator studies, the rural road was the most diagnostic and the motorway the least diagnostic, i.e. the effect sizes from the rural road were generally larger. This can be seen from
Table 150 in chapter 13. The urban road did not pick up any additional information that was not provided by the rural road. This means that, for simulator and laboratory assessments, the rural road can be used as the sole road category in the later work of HASTE assessing real IVIS systems, as well as in the final HASTE test procedure.

In the field studies with the cognitive task, the motorway produced one indicator with a consistent effect, namely Subjective Rating (the driver's self-assessment); the other roads produced no indicator that discriminated consistently between S-IVIS level. With the visual task, the rural road performed as well as the motorway.

## 14.9. Road Level

Road level was an important factor. It will obviously be sensible in the later work of the project to investigate whether the easiest level of the road can be dispensed with. It is, however, improbable that one would only want to retain the most difficult level of the rural road. The curved sections allow the investigation of safety-related steering behaviour. Additionally, if only relatively high risk situations are included, the drivers may well respond by slowing down and adopting short headways in order to manage their risk. Some easier sections can help to lull them into greater complacency about their risk.

## 14.10. "Average" vs Elderly Drivers

The findings have confirmed the hypothesis, advanced in HASTE Deliverable 1 (Roskam et al., 2002), that there would be severe problems for elderly drivers in using IVIS while driving, particularly at higher levels of task demand. Not only were the impacts of task demand greater for the elderly drivers; there were also indications that they had fewer mental resources available for managing attention between primary and secondary tasks. Evidence for this is found in the fact that there were fewer signs of a ceiling effect for the elderly drivers than for the younger drivers, especially when most stressed, i.e. when the driving task was most difficult (see section 5.6.4). This is a very strong indication that the S-IVIS level 3 is beyond their capability. Evidence from the field studies, on for example interaction with pedestrians when engaged in the cognitive task, confirmed this.

However, the experience with elderly drivers has also highlighted a problem for the future assessment protocol. The elderly drivers suffered from severe simulator sickness when performing the visual task in the Leeds simulator. As a result, this part of the investigation had to be abandoned. It is clear that investigation of elderly performance with visual tasks will, almost certainly have to be restricted to real road assessment.

## 14.11. UK vs Portugal

The controlled comparison of the British and Portuguese (section 4.8) showed the expected effect: the Portuguese drivers exhibited riskier driving behaviours. But, reassuringly, the ANOVA analysis revealed there was no interaction effect of the “country” factor. In other words, results obtained with Portuguese drivers should be as reliable as those obtained with drivers from northern Europe.

## 14.12. Methodological issues

The results obtained from this very large set of studies confirm some of the initial decisions made in formulating the HASTE approach. There was clear value to the focus on *dynamic* evaluation, i.e. of looking at interaction with an IVIS while driving and of identifying the effects of that interaction on driving. Static testing cannot predict how an IVIS will affect steering behaviour or interaction with other road users. The different road levels proved their worth, particularly levels 2 and 3 of the rural road. There is also clear value to the inclusion of events (road level 3), but there is also some scope for improving the events so that the drivers are less able to adapt to their occurrence, by for example slowing down as the lead vehicle comes closer to them.

There may also be scope for the inclusion of peripheral detection tasks (PDTs) in the driving, in order to gain a better understating of drivers’ ability to assimilate information in the periphery, which is crucial to safety maintenance. However, there are also some potential problems here: a PDT will become a tertiary task, in addition to the primary task of driving and the secondary task of interaction with an IVIS. Thus there is the potential for the PDT to distort the findings. This will require further investigation.

The results also confirm the value of using a very large number of indicators. Some of these indicators have turned out to be non-diagnostic and therefore can be abandoned in the next phase of the project. Others have turned out to be superfluous in that they what they reveal overlaps with the diagnosis provided by other indicators. One of the most useful outcomes from the meta-analysis in chapter 13 is the ability to sift though the indicators for the ones that are the most powerful. As a result, it will be possible to substantially reduce the number of participants in the next set of experiments.

Do the results confirm the exponential increase in risk with increased task load that was initially hypothesised? Perhaps not, or at least not generally. To some extent drivers were able to trade off secondary task performance against primary task performance. But not always and not always with total success. The results with the elderly drivers give grave cause for concern, particularly the elderly drivers’ performance with the cognitive task.

## 14.13. Summary of some major findings

Important conclusions from the studies are:

- The effect of the S-IVIS visual task on driving is very clear: increased distraction leads to problems in lateral control.

- The effect of cognitive task is more complex, in that some driving parameters, particularly related to steering control and lateral position appear to improve. However, this improvement seems to be an artefact of greater concentration on the road straight ahead at the expense of information acquired from the periphery. Thought needs to be given to tasks or tests that might capture this loss of information acquisition from the periphery.

- Motorway driving in the various simulators and the laboratory was generally less diagnostic.

- Elderly drivers exhibited very risky driving while performing IVIS tasks

- The field studies provided some information that was not provided by the simulator assessments. The subsequent work in the project should consider simulator tasks that can provide analogous information.

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# Appendix 1: List of indicators

| Complete indicator name | Abbreviation |
|---|---|
| **Self reported driving performance** | |
| self reported driving performance | subj_r |
| **Longitudinal control** | |
| speed [km/h] | mn_sp |
| speed variation [km/h] | st_sp |
| speed change [km/h] | d_sp |
| min speed [km/h] | u_sp |
| min Time To Collision [s] | u_ttc |
| mean of TTC minima [s] | mn_ttc |
| proportion TTC minima < 4s [%] | pr_ttc |
| proportion if time where TTC < 4s [%] | tet |
| mean distance headway [m] | mn_hwd |
| mean of distance headway minima [m] | u_mn_hwd |
| proportion of distance headway minima < 20m [%] | pr_hwd |
| distance headway variation [m] | sd_hwd |
| min distance headway [m] | u_hwd |
| mean time headway [s] | mn_hwt |
| mean of time headway minima [s] | u_mn_hwt |
| proportion of time headway minima < 1s [%] | pr_hwt |
| time headway variation [s] | sd_hwt |
| min time headway [s] | u_hwt |
| brake reaction time [s] | rt_br |
| abrupt onset of brakes [-] | j_br |
| observed speeding [%] | obs_sp_fast |
| observed too slow driving [%] | obs_sp_slow |
| observed irregular speed [%] | obs_sp_irr |
| observed *fill in behaviour* [%] | obs_... |
| **Lateral control** | |
| lateral position [m] | mn_lp |
| lateral position variation [m] | st_lp |
| mean TLC minima [s] | mn_tlc |
| min TLC [s] | u_tlc |
| proportion TLC minima < 1s [%] | pr_tlc |
| proportion of time outside lane, lanex [%] | lnx |
| 1 deg reversal rate [1/minute] | rr_st1 |
| 2 deg reversal rate [1/minute] | rr_st2 |
| 3 deg reversal rate [1/minute] | rr_st3 |
| 5 deg reversal rate [1/minute] | rr_st5 |
| high frequency steering [deg] | hi_st |
| steering entropy [-] | en_st |
| rapid steering wheel turnings > 10deg [1/minute] | rswt_10 |
| rapid steering wheel turnings > 40deg [1/minute] | rswt_40 |
| rapid steering wheel turnings > 70deg [1/minute] | rswt_70 |
| observed lane exceedences [%] | obs_lnx |
| observed *fill in behaviour* [%] | obs_... |
| **Workload measures** | |

| | |
|---|---|
| glance frequency | n_gl |
| glance duration [s] | mn_gd |
| glance duration variation [s] | sd_gd |
| IVIS glance duration proportion [%] | pr_glt |
| gaze angle variation [deg] | st_ga |
| inter beat intervals [ms] | ibi |
| heart rate variability [ms] | hrv |
| skin conductance [uS] | dc_eda |

| | |
|---|---|
| skin conductance variation [uS] | ac_eda |
| self reported workload | subj_wl |
| **S-IVIS** | |
| Correct responses | s_correct |
| Reaction time | s_rt |
| missed responses | s_missed |
| incorrect responses | s_incorrect |

# Appendix 2: Detailed report on included indicators

## Contents



## Introduction

The aim of this report is to present the measures that are to be included in the WP2 pilots. There are measures that cannot be included in all pilots due to technical shortcomings. A set of measures is mandatory, which means those measures shall be included if possible.

The aim is further to provide strict definitions of the measures in order to assure that the collected measure in the different pilots are comparable. However, still the definitions leave some room for site specific solutions concerning data recording, filtering and other data processing. Therefore, it should be described in the pilot reports how data has been collected and processed.

## Mandatory driving performance measures

### SPEED

#### Definition

Speed is defined as the travel speed in km/h relative to the road surface [km/h].

#### Value

Increased speed during the influence of distracting factors has been used as an indicator of decreased speed control. Since increase in speed correlates to increase in accidents, an increase in speed can be used as in indicator of decreased performance. The value of speed as a performance measure is based on the assumption that the measured speed is driver paced. However, in high traffic density speed is affected by other road users to a higher extent than if the traffic density is low. The driver may reduce the speed as a compensatory action due to increased mental load or distraction by e.g. an IVIS. This is however more often used as an indication of increased mental load rather than change in driving performance.

### Technical considerations

It should be possible to relate the vehicle's speed to current signposted speed limits. Table 167 describes requirements for speed data.

**Table 167 – Description of speed data**

| | |
|---|---|
| Measurement range | 20 km/h to 180 km/h |
| Accuracy | ± 2km/h |
| Precision | 2 km/h |
| Sampling rate | 100 ms (10 Hz) |

## SPEED VARIATION

### Definition

Speed variation is defined as the speed standard deviation [km/h].

### Value

Speed variation is often used as a measure of driving performance for driving on high way and rural road. High variation has been considered as an indicator of poor driving performance that reflects involuntary speed variation; speed instability. Variation is usually calculated as standard deviation. A deficiency of this parameter is that it does not differ between involuntary speed changes and speed variation due to the interaction with other road users or adaptation to the road conditions (curvature, visibility).

### Technical considerations

See Table 167 for data requirements. Speed standard deviation should only be calculated over sections of equally signposted speed limits.

## LATERAL POSITION

### Definition

Lateral position is defined as the distance between the right hand part of the front right wheel to the left part of the right hand lane marking [m]. When the line is crossed, the lateral position it becomes negative. The lane boundaries are defined as the inner edges of the lane markings. Left-hand wheel and left-hand lane marking are used in the UK.

### Value

Lateral position reflects strategy. For instance, Brookhuis found that under the influence of sedative drugs drivers drove more towards the relatively safe emergency shoulder compared with a control condition (i.e. They adapted their safety margins).

### Technical considerations

Lateral position is used to calculate both lateral position variation and TLC and thus, it is important to get precise data. Target accuracy for on-the-road pilots is set to ± 10 cm. In driving simulators will be at least ten times better. See Table 168 for data requirements.

**Table 168 – Description of lateral position data**

| | |
|---|---|
| Measurement range | From 0 m to lane width |
| Accuracy (while driving ; including yaw, roll, pitch, height variations ) | ± 10 cm or better when LP is within lane width |
| Precision (while driving) | 5 cm or better when LP is within lane width |
| Rate | 100 ms (10 Hz) |
| Marked line characteristics : | Well marked White/yellow continuous or dashed lines. |

## LATERAL POSITION VARIATION

### Definitions

Lateral position variation is defined as the lateral position standard deviation [m]. Lateral position variation is derived from lateral position data.

### Value

Less lateral control may be observed as an increase in lateral position variation. In several studies, driver deprivation (drugs, sleepiness) and time on task have been shown to cause increase in SDLP; the steering control has become less stable. However, SDLP is influenced by take-overs and voluntary changes in lateral position due to road curvature; effects that may not be related to driving performance

## LANE EXCEEDENCES

### Definition

A lane exceedence (LANEX) is defined as the proportion of a time any part of the vehicle is outside the lane boundary [%]. The lane boundaries are defined as the inner edges of the lane markings. The vehicle boundaries are defined as the outer edges of the front wheels.

### Value

LANEX has been used as a measure of lateral control, e.g. by Tijerina et al (1999).

### Technical considerations

Lateral position data is required.

## TIME TO LINE CROSSING

### Definition

Time to line crossing (TLC) is defined as the time to cross either lane boundary with any of the wheels of the vehicle if speed and steering wheel angle are kept constant. As the vehicle approaches the line TLC will decrease until it reaches a minimum. Under "normal" conditions this will occur when the motion of the car is changed from going towards one line to the other. During this change the car will pass a situation where it momentarily will not move toward any of the line but follow the road perfectly this will result in an indefinite or undefined TLC. In order to determine the safety margins we have to look for the TLC minima, which is also the case for TTC. A TLC min value is defined as the min TLC within a TLC waveform. See Figure 257. TLC values higher than 20 seconds are ignored. Also TLC waveforms of duration less than one second are ignored. The graph shows how TLC values less than 20 seconds and TLC wave duration > 1 second are defined. Time to cross the right line is represented by negative values.

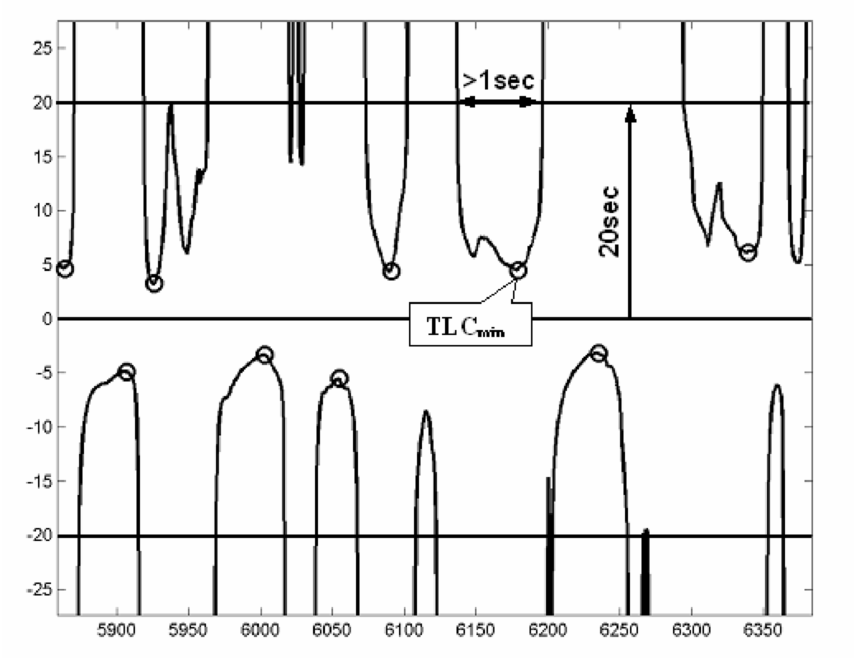


**Figure 257 – Principles used to identify relevant TLC $_{min}$ values**

Included measures are:

- *The proportion of TLC min values less than one second [%]*
- *Mean value of the min TLC values [s]*

## Value

Time to Line Crossing was first proposed by Godthelp and Konings (1981) to describe steering behaviour. According to Godthelp et al, TLC reflects the time available for error neglecting, assumed a fixed steering strategy. In other words; TLC reflects a lateral control safety margin. Godthelp's proposed calculation of TLC included a complex mathematical definition, based on vehicle speed, steering wheel angle, heading angle and lateral position. In this calculation, it is assumed that the road is straight. Van Winsum et al (1996) proposed an alternative method of calculating TLC that considered road curvature. Due to problems achieving all necessary data for exact calculation, approximations are often used based on lateral position and lateral velocity and in simulator studies also lateral acceleration in relation to the road.

## Calculations

Within the HASTE project one trigonometric method and two approximations of TLC will be used in the simulator experiment, and one or if possible both approximations in the field experiments. The lane boundaries are defined as the inner edges of the lane markings. The vehicle boundaries are defined as the outer edges of the front wheels.

For the trigonometric method, TLC is based on the vehicle speed and the instantaneous circular path of the vehicle. At the intersection of this curve and the edge/centre line distance to line crossing (arc segment length) is calculated. Then this arc segment length is divided with travel speed in order to get TLC. The calculations are based on the instantaneous curve radius. The calculations are described in van Winsum et al (van Winsum, Brookhuis, & de Waard, 1997).

The first approximation (TLC1) assumes that the lateral motion is linear. Thus, TLC is calculated as lateral distance divided by lateral velocity. The lateral distance to line in the TLC calculation will be different depending on which direction the vehicle is moving (towards the right or left line (lane) marker. When the lateral velocity is:

- *Negative (moving to the right), then the lateral distance to right line will be equal to lateral position as previously defined.*
- *Positive (moving to the left), then the lateral distance to left line will be defined as (lane width - (lateral position + vehicle width)),*
- *Zero, then TLC is infinite.*

The second approximation (TLC2) includes road relative lateral acceleration and is calculated as the lateral distance to line divided by the sum of lateral velocity and acceleration. The lateral distance to line in the TLC calculation will be different depending on which direction the vehicle is moving (towards that right or left line (lane) marker. When (lateral velocity + change in lateral velocity) is:

- *Negative (moving to the right), then the lateral distance to right line will be equal to lateral position (see footnote).*
- *Positive (moving to the left), then the lateral distance to left line will be defined as (lane width - (lateral position + vehicle width)).*
- *Zero, then TLC is infinite.*

### Technical considerations

Of course, the measurement of lateral position is crucial for TLC. In simulator experiments, this should not be a problem.

## REVERSAL RATE

### Definition

Reversal rate is defined as the number of changes in steering wheel direction per minute [turns/minute]. An angle difference of around 2$^{o}$ between steering end values is required for the reversal to count. See Figure 258. Higher values may be used, but smaller reversals may be neglected.

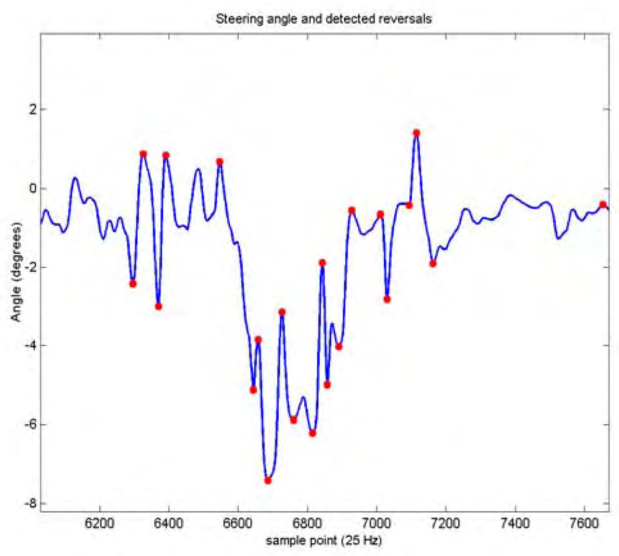


**Figure 258 – Steering angle (blue) and reversals (red). Threshold 2 degrees.**

Reversal rate is calculated as follows. First, the steering signal is low pass filtered with a second order Butterworth low pass filter of cutoff frequency 0.6 Hz. Then, local minima and maxima are identified with a peak detection algorithm; within a moving window of 0.8 seconds length, the values have to increase/decrease monotonically towards the centre value to classify the centre value as a local maximum, and of course the opposite to be a minimum. Then the differences between adjacent minima and maxima are calculated. If the difference is larger or equal to the threshold value, then there is one reversal. Note that it is actually the peaks that are counted.

### Value

The number of changes in steering wheel rotational direction reflects the frequency of steering corrections, not the magnitude.

### Technical considerations

Care has to be taken in the calculation of this indicator so that only driver-induced changes in steering wheel angle are recognised and not artefacts caused by noise. Technical specifications for the measurement of steering wheel angle are listed in Table 169.

**Table 169– Description of steering wheel angle data**

| | |
|---|---|
| Measurement range | ± 45° or more |
| Accuracy | ± 0.5° |
| Precision | 0.5° |
| Sampling Rate | 100 ms (10 Hz) |

## TIME TO COLLISION, TIME HEADWAY AND DISTANCE HEADWAY

### Definitions

Time To Collision (TTC) [seconds] is defined as the distance to the lead vehicle (bumper to bumper) divided by the speed difference to the lead vehicle. TTC is only defined if the distance between the vehicles decreases. As with TLC, TTC generates wave formed data. TTC values larger than 15 seconds are ignored. Also TTC wave forms of duration less than one second are ignored.

Time Headway [seconds] to lead vehicle is defined as the distance to the lead vehicle (from bumper to bumper) divided by own momentary travel speed. Distance Headway [metres] to a lead vehicle is defined as the distance to lead vehicle, defined as the distance from bumper to bumper. Time headway values larger than 3 seconds are ignored. Distance headway values larger than 50 metres are ignored.

TTC and headway are measures of longitudinal risk margin. Included measures are:

- Proportion of time of which the TTC is less than 4 seconds. This measure is called *Time Exposed Time-to-collision* (TET).
- The proportion of TTC local minima less than 4 seconds.
- Mean of TTC local minima.
- The proportion of time headway local minima less than 1 second.
- Mean of time headway local minima
- The proportion of distance headway local minima less than 20 meters.
- Mean of distance headway local minima

### Value

The closer and faster a subject travels behind a lead vehicle, the less is the chance to manage avoiding a collision in case of the lead vehicle reduces the speed. For a small TTC or headway, the time a subject may be distracted by another task without a highly increased risk of accident is much less than if the time headway is large.

### Technical considerations

Requirements on headway data is listed in Table 170.

**Table 170 – Description of distance headway data**

| | |
|---|---|
| Measurement range | From 0 to 50 meters |
| Accuracy | ± 0.5 m |
| Precision | 0.1 m |
| Sampling Rate | 100 ms (10 Hz) |

## BRAKE REACTION TIME

### Definition

Brake reaction time is defined as the time from the appearance of a hazardous event to the onset of the brakes [ms].

### Value

Driver reaction time (RT) to such as obstacles and sudden firm braking of a lead vehicle is a straightforward measure of speed control performance.

### Technical considerations

Data on the unexpected events and the use brake pedal are required for RT-calculation. Automatic measurement of unexpected events in field trials is very difficult. If the events are decoded from video recordings, an accuracy of 40 ms (25 Hz sample rate) is achieved - if the use of brake is measured also with at least 25 Hz and if the data are synchronised. Still, 40 ms accuracy is barely acceptable. Brake reaction time is thus not a feasible performance measure in field trials. In a simulator/lab it is feasible and the accuracy should be at least 20 ms (50 Hz sample frequency). Requirements on headway data is listed in Table 171.

**Table 171 – Description of reaction time data**

| | |
|---|---|
| Measurement range | From 0 to 2 seconds |
| Accuracy | ± 20 ms |
| Precision | 5 ms |
| Sampling Rate | 20 ms (50 Hz) |

## OBSERVER RATINGS

### Definition

Observer rating is a method for rating driving performance on a tactical level (Michon’s driver model). The method as used in WP2 is based on the Wiener Fahrprobe by Risser (1985). The method originally requires two accompanying persons, who are trained on the ratings. Standardised ratings for specific locations along the route, and non standardised ratings for the overall driving, are made. In HASTE, we include only the standardised part, containing driving performance variables such as yielding behaviour and speed choice. We thus only need one observer. The situations have to be chosen for which ratings are to be made. In simulator experiments, observer ratings have to be made via video observations. The specific observation forms are included in the relevant WP2 reports.

# Optional driving performance measures

## SPEED CHANGE

### Definition

Speed change during attention to IVIS [km/h]. The least-square-method is used for adapting a straight line to the speed profile. Speed change is calculated as the end value minus the start value for the adapted line.

### Value

Speed change may better reflect the impact of IVIS on speed behaviour than mean speed since it reflects the adaptation of speed during the time period of distraction.

## STEERING ANGLE VARIATION

### Definition

The steering angle variation is defined as the standard deviation of the steering angle [deg].

### Value

This measure is very easy to calculate and may provide a simple measure on steering corrections. It will however only reflect steering corrections if the road is not very curvy. This measure is thus not feasible in urban environments.

## HIGH FREQUENCY COMPONENT OF STEERING WHEEL ANGLE VARIATION

### Definition

The high frequency component of steering is defined as the ratio between the power of the 0.3-0.6 Hz component and all steering activity.

High_steering shall be calculated as following. The steering signal is filtered with a second order Butterworth low pass filter with cutoff frequency 0.6 Hz. This results in the “all steering activity” signal. The signal is further filtered with a 0.3 Hz second order Butterworth high pass filter, which results in the high frequency steering component. The power of the signals is calculated as the root mean square.

### Value

As with the standard deviation, the proportion of the high frequency component of steering wheel angle reflects steering corrections. However, this method aims at excluding the effect of open loop behaviour and only focus on corrections. McDonald and Hoffman (1980) support that steering corrections are reflected by high frequency components.

### Technical considerations

For all frequency related calculations, the tolerance for artefacts is low, but this should not be a problem since measuring steering wheel angle is not very difficult.

## RAPID STEERING WHEEL TURNINGS (RSWT)

### Definition

Number of RSWT within the interval a specified interval, e.g. $40 < RSWT \leq 70$ degrees per minute.

### Value

When in highly critical situations, the driver may perform rapid steering wheel turnings to avoid driving off the road or colliding into other vehicles. RSWT may be sensitive to this behaviour.

## STEERING ENTROPY

### Definition

The behavioural entropy is calculated on the basis of prediction errors of vehicle signals. The predictions are obtained using some predictive filter as a driver model. For example, in Nakayama et al. (1999), the predictions were obtained by performing a second-order Taylor expansion using the samples at the three previous time steps.

The entropy of the signal is then calculated on the basis of the distribution of these errors. This involves dividing the errors into a finite number of bins, where nine bins were used in the present work. The bin-ranges are obtained by calculating the error value α at the 90:th percentile of the *null distribution*, i.e. The error distribution obtained from a baseline condition. The bin edges are then chosen as +/-(0, 0.5α, α, 2.5α and 5α). In Nakayama et al (1999), individual null-distributions were calculated for each subject using all the data collected for that subject. The proportions $p_i$ , i=1, 2, ..., I, where I is the number of bins, is then calculated. The entropy *h* of the signal for a given time-period is finally given by

$$h = \sum_i p_i {}^I log\ p_i\ .$$

### Value

The basic hypothesis is that secondary task demands not only affect the magnitude and/or variance of vehicle control parameters, but also leads to more disruptive, and hence less *predictable*, control behaviour. One approach, developed at Nissan Cambridge Basic Research, is to quantify this predictability in terms of the *behavioural entropy*, as described in Nakayama et al. (1999) and further developed in Boer (2000). The method has been shown sensitive to workload induced by visual as well as cognitive distraction, in simulated and real world environments (op. cit.)

### Technical considerations

This indicator requires a baseline measurement of each subject's steering behaviour, which have influence on the design of the study.

### ABRUPT ONSETS OF BRAKES

#### Definition

An abrupt onset of the brakes is defined as the occurrence of a deceleration change higher than 10 $m/s^3$, induced by braking. The applied measure is the number of abrupt onsets of brakes per km. The threshold value is based on the findings in Magnus Nygård's findings (1999).

#### Value

An abrupt and intense beginning of the deceleration caused by braking indicates the occurrence of a critical situation (Nygård, 1999). This measure can be used as a measure of driving performance; high rate of jerks indicates higher risk and less performance. However, it should be taken into account that another road user may cause the critical situation. In this case, this measure may indicate a correct action. This measure is feasible in high traffic density environments where jerks are most likely to occur.

#### Technical considerations

Change in deceleration is the second derivative of speed, or the first derivative of deceleration. It should be assured that speed/deceleration data is of such precision that no noise is amplified to seriously affect data quality.

## Mandatory workload measures

### SELF REPORTED DRIVING PERFORMANCE

#### Definition

After each S-IVIS block or at the corresponding road sections in the baseline drive, the participants are asked to report their driving performance. The scale is vertical from 1 to 10, where 1 corresponds to extremely poor and 10 to extremely well. Response is verbal.

#### Value

This measure is very simple to use and takes advantage of the fact that the driver in most situations have an opinion about his/her own driving performance. A deficiency is of course that the driver's opinion may not reflect actual risk of accident. The driver may be unaware of the risk, which is supported by the fact that speeding is a quite common behaviour although strongly linked to risk of accident.

### GLANCE FREQUENCY

#### Definition

Glance frequency is defined as the number of glances to a target during a pre-defined task, where each glance is separated by at least one glance to a different target.

#### Value

Depending on the complexity of the task, typically between 1 and 7 glances are needed to acquire and process the information. Because it is related to the overall complexity of the display, it is a highly sensitive measure of visual attention or visual workload

### Technical considerations

The SAE J-2396 standard provides the glance definition '*A glance is considered as a series of fixations at a target area until the eye is directed at a new area*'. However, it does not consider fixations, smooth pursuits and saccades which are the bricks forming a glance. For the glance frequency measure, a smooth pursuit is to be classified as a fixation (smooth pursuits are series of short fixations separated by short, to many systems immeasurable, saccades).

## GLANCE DURATION

### Definition

The time from the moment at which the direction of gaze moves toward a target (e.g. The interior mirror) to the moment it moves away from it. This includes the transition time, the time of the saccade initiating the glance, to that target.

### Value

Long glance durations associated with a target may be indicative of high workload demand, posed by that location (or task involving that location). Also, the sum of all glance durations associated with a target provides a measure of the visual demand posed by that location. Glance duration shall always be considered together with Glance.

### Technical considerations

The same technical considerations as for glance frequency apply to glance duration.

## S-IVIS PERFORMANCE

### Definition

S-IVIS performance is defined as how well the participant manages the S-IVIS task, of course. Included measures are:

- Reaction time [s]
- Correct responses [%]
- Missed responses [%]
- False responses [%]

### Value

The S-IVIS performance measures are included in order to evaluate how the drivers prioritise the S-IVIS tasks in comparison to the driving task.

### Technical considerations

A separate laptop has been chosen to control the S-IVIS and to record the responses. If the response is manual (such as pressing a micro switch on the finger) this will be easy. If the response is vocal, however, it is problematic to measure the reaction time.

## Optional workload measures

### INTER-BEAT-INTERVALS AND HEART RATE VARIABILITY

#### Definition

The Inter-Beat-Intervals (IBI) measure is defined as the mean time interval between the heart beats, identified in electrocardiogram data. Heart Rate Variability is the variation of Inter-Beat-Intervals and is calculated as the mean value of the 0.07-0.14 Hz component of the IBI spectral density.

#### Value

Inter-Beat-Intervals are affected by emotional factors such as stress and fear of failing a test (Jorna, 1992). If a task of varying difficulty is performed, the risk of fail is consequently influenced by task difficulty. According to Wilson and Eggenmeier (1991), IBI can be considered a global measure of general arousal. Since arousal and stress may be the results of mental workload, IBI may be used as an indicator of mental workload. The inter beat intervals (IBI) is more normally distributed compared to the more commonly mentioned Heart Rate (Jennings, Stringfellow, & Graham, 1974).

Heart rate variability (HRV) is a measure of the variation of the inter-beat-intervals (IBI), but there is a wide range of methods for calculating it (Mulder, 1988; Task-Force-Members, 1996). It has been found that HRV decreases with increased task demand and driver fatigue (Kalsbeek & Ettema, 1963; Mulder, 1988; Wilson, 1992). Wilson and Eggenmeier (1991) emphasize that HRV most likely reflects cognitive effort, not general arousal. HRV seems to be sensitive to changes in mental workload especially in the 0.1 Hz band of IBI (e.g. Egelund, 1982; Van Winsum, Van Knippenberg & Brookhuis, 1989).

#### Technical considerations

IBI requires ECG data recorded with at least 256 Hz sample frequency. HRV require at least 1000 Hz (Mulder, 1992). The recording is preferably done with a separate recording device. Be sure to synchronise the ECG data with the driving data.

### SKIN CONDUCTANCE

#### Definition

Skin conductance is the inversed electrical resistance of the skin. Included measures are:

- Skin conductance level [uS]
- Skin conductance variation [uS]

Skin conductance level is calculated as the power (root mean square) of the 0 – 2.0 Hz component of the skin conductance signal. Skin conductance variation is calculated as the power of the 0.5 – 2.0 Hz component of the skin conductance signal. Second order Butterworh filters are used.

#### Value

Sympathetic nervous system (SNS) activation causes wave formed changes in skin conductance, so called skin conductance responses (SCR) or galvanic skin responses (GSR). Since arousal and stress activates the SNS, the skin conductance is sensitive to changes in stress and arousal (Wang, 1959). But also the level of skin conductance is affected by arousal and stress.

### Technical considerations

Interpersonal variations in sensitivity to stimuli, baseline drift, and occurrence of movement artefacts cause difficulties analysing skin conductance.

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# Appendix 3: Analysis plan

## Analysis of effect of S-IVIS difficulty and Road Complexity

The effects of S-IVIS and road complexity on the included dependent variables were analysed. In the different experiments, the number of road complexity levels differed, as did also the number of experimental factors; if only one RLv was included, this was not considered a factor of course. The number of S-IVIS blocks, and consequently data points, also differed. In the field trials, 6 S-IVIS blocks were included, and 9 in the simulator and laboratory experiments. Finally, depending on the scenarios and the included measures, some analyses included a subset of the road complexity levels. E.g. speed was not feasible to include in the analysis of the events situations. In the simulator motorway experiment 9 S-IVIS blocks were included, but there were only two road complexity levels. The different designs and analysis models for the different scenarios are reported in Appendix 3.

Design 1 (Table 172) was used if three road complexity levels were included in the analysis, which was true typically for lateral control measures. Design 2 in Table 173 if two levels were included, such as for speed measures (Events excluded).

**Table 172 – Design 1 (3 RLv x 4 SLv). Number of data points per participant**

| | **S-IVIS level** | | | |
|---|---|---|---|---|
| **Road complexity level** | **BL** | **SLv 1** | **SLv 2** | **SLv 3** |
| **RLv 1** | 3 | 1 | 1 | 1 |
| **RLv 2** | 3 | 1 | 1 | 1 |
| **Events** | 3 | 1 | 1 | 1 |

**Table 173 – Design 2 (2 RLv x 4 SLv)**

| | **S-IVIS level** | | | |
|---|---|---|---|---|
| **Road complexity level** | **BL** | **SLv 1** | **SLv 2** | **SLv 3** |
| **RLv 1** | 3 | 1 | 1 | 1 |
| **RLv 2** | 3 | 1 | 1 | 1 |

The included factors were

- S-IVIS level (SLv), 4 levels
- Road complexity level (RLv), 3 levels (design 1) or 2 levels (design 2)
- Study object ($\alpha$), 24 levels

The model was defined as

$$y_{ijk} = \mu + SLv_i + RLv_j + \alpha_k + (SLv \times RLv)_{ij} + (SLv \times \alpha)_{ik} + (RLv \times \alpha)_{jk} + \varepsilon_{ijk}$$

Design 3 in Table 174 was to be used for test of effect of S-IVIS on dependent variables only applicable in one RLv where there were repetitions within each cell, which was true for e.g. all measures in the motorway simulator experiments and motorway field trials.

**Table 174 – Design 3 (1 RLv x 4 SLv)**

| **S-IVIS level** | | | |
|---|---|---|---|
| **BL** | **SLv 1** | **SLv 2** | **SLv 3** |
| 6 | 2 | 2 | 2 |

The included factors were

- S-IVIS level (SLv), 4 levels
- Study object (α), 24 levels

The model was defined as $y_{ij} = \mu + SLv_i + \alpha_j + (SLv \times \alpha)_{ij} + \varepsilon_{ij}$

Design 4 in Table 175 was to be used for analysis of effects of S-IVIS in critical events only.

**Table 175 – Design 4 (1 RLv x 4 SLv. For the analysis of critical events)**

| **S-IVIS level** | | | |
|---|---|---|---|
| **BL** | **SLv 1** | **SLv 2** | **SLv 3** |
| 3 | 1 | 1 | 1 |

The included factors were

- S-IVIS level (SLv), 4 levels
- Study object (α), 24 levels

The model was defined as $y_{ij} = \mu + SLv_i + \alpha_j + \varepsilon_{ij}$

### Optional test of S-IVIS tasks

In this step, statistical comparisons between S-IVIS tasks (Arrow vs the cognitive task) were included, although the rationale for this was rather questionable; we do not know if the tasks were comparable. This uncertainty and a between groups design (on S-IVIS task) resulted in nested analysis models. This analysis step was optional. SLv 0 (baseline drive) was not included in the design, of course, since S-IVIS was not active for this condition.

Only an example of a design and model is given here, to be used if three road complexity levels were included in the analysis design. See Table 176.

**Table 176 – Design 5 (2 ST x 3 RLv x 3 SLv)**

| **ST1, ST2** | **S-IVIS level** | | |
|---|---|---|---|
| **Road complexity level** | **SLv 1** | **SLv 2** | **SLv 3** |

| | | | |
|---|---|---|---|
| **RLv 1** | 1, 1 | 1, 1 | 1, 1 |
| **RLv 2** | 1, 1 | 1, 1 | 1, 1 |
| **Event** | 1, 1 | 1, 1 | 1, 1 |

The included factors in the analyses were

- S-IVIS task (ST), 2 levels
- S-IVIS level (SLv), 3 levels
- Road complexity level (RLv), 3 or 2 levels, or not included
- Study object ($\alpha$), 24 levels

For S-IVIS task as a between subjects factor, the model was defined as:

$$y_{ijkm} = \mu + RLv_i + ST_j + \alpha_{k(j)} + SLv_{m(j)} + (RLv \times ST)_{ij} + (RLv \times \alpha)_{ik(j)} + (RLv \times SLv)_{im(j)} + (\alpha \times SLv)_{km(j)} + \varepsilon_{ijkm}$$

If S-IVIS task was a within subjects factor, the model was defined as:

$$y_{ijkm} = \mu + RLv_i + ST_j + \alpha_k + SLv_{m(j)} + (RLv \times ST)_{ij} + (RLv \times \alpha)_{ik} + (RLv \times SLv)_{im(j)} + (\alpha \times SLv)_{km(j)} + (ST \times \alpha)_{jk} + \varepsilon_{ijkm}$$

where $SLv_{m(j)}$ means that S-IVIS level is nested within S-IVIS task

# Appendix 4: Analysis and measures table for the rural road simulator experiments

| Analysis | Measures |
|---|---|
| Effect of S-IVIS (4 Lvs) and Road complexity (3 Lvs) (Design 1) | **Mandatory measures**<br>self reported driving performance (subj_r)<br>lateral position and lateral position variation (mn_lp, st_lp)<br>1, 3, 5 & 7 degree reversal rate (rr_st1, 3, 5, 7)<br>mean time-to-line-crossing (mn_tlc)<br>proportion of TLC minima<1 second (pr_tlc)<br>mean time-to-collision (mn_ttc)<br>lane exceedences (lnx)<br>proportion of time TTC < 4s (tet)<br>minimum TLC<br><br>**Additional measures**<br>glance duration (mn_gd) and glance frequency (n_gl).<br>power of high frequency steering component (hi_st)<br>steering entropy (en_st)<br>40 and 70 deg/s rapid steering wheel turnings (rswt_40, rswt_70)<br>inter-beat-intervals (ibi)<br>heart rate variability (hrv)<br>skin conductance level and variation (dc_eda, ac_eda). |
| Effect of S-IVIS (4 Lvs) and Road complexity 2 Lvs) (Design 2) | **Mandatory measures**<br>speed and speed variation (mn_sp, st_sp)<br>minimum speed (u_sp)<br>mean of time and distance headway (mn_hwt, mn_hwd)<br>Time and distance headway variation (st_hwt, st_hwd)<br>speed change over S-IVIS blocks (d_sp) |
| Effect of S-IVIS in Events (Design 4) | **Mandatory measures**<br>proportion of time TTC < 4s (tet)<br>proportion of TTC minima < 4 seconds (pr_ttc)<br>mean time and distance headway (mn_hwt, mn_hwt)<br>mean of time and distance headway local minima (u_mn_hwt, u_mn_hwt)<br>proportion of time/distance headway < 1s/20m (pr_hwt, pr_hwd)<br>Time/distance headway variation (st_hwt, sd_hwd)<br>minimum time/distance headway (u_hwt, u_hwd)<br>brake reaction time (rt_br)<br>minimum TTC (u_ttc)<br>minimum speed (u_sp)<br>mean speed (mn_sp)<br><br>**Additional measures**<br>brake jerks (br_j) |

| | |
|---|---|
| Effect of S-IVIS task type (Design 5) for 3 Road Complexity Levels | **Mandatory measures**<br>self reported driving performance (subj_r)<br>lateral position and lateral position variation (mn_lp, st_lp)<br>1, 3, 5 & 7 degree reversal rate (rr_st1, 3, 5, 7)<br>mean time-to-line-crossing (mn_tlc)<br>proportion of TLC minima<1 second (pr_tlc)<br>lane exceedences (lnx)<br>proportion of time TTC < 4s (tet)<br>minimum TLC<br><br>**Additional measures**<br>glance duration (mn_gd) and glance frequency (n_gl).<br>power of high frequency steering component (hi_st)<br>power of high frequency steering component (hi_st)<br>steering entropy (en_st) |
| Effect of S-IVIS task type (Design 5) for 2 Road Complexity Levels | **Mandatory measures**<br>speed and speed variation (mn_sp, st_sp)<br>minimum speed (u_sp)<br>mean of time and distance headway (mn_hwt, mn_hwd)<br>Time and distance headway variation (st_hwt, st_hwd)<br>speed change over S-IVIS blocks (d_sp) |
| Effect of S-IVIS task type in Events (Design 5) | **Mandatory measures**<br>proportion of time TTC < 4s (tet)<br>proportion of TTC minima < 4 seconds (pr_ttc)<br>mean time and distance headway (mn_hwt, mn_hwt)<br>mean of time and distance headway local minima (u_mn_hwt, u_mn_hwt)<br>proportion of time/distance headway < 1s/20m (pr_hwt, pr_hwd)<br>Time/distance headway variation (st_hwt, sd_hwd)<br>minimum time/distance headway (u_hwt, u_hwd)<br>brake reaction time (rt_br)<br>minimum TTC (u_ttc)<br>minimum speed (u_sp)<br>mean speed (mn_sp)<br><br>**Additional measures**<br>brake jerks (br_j) |

The designs attributed in the table are previously described in Appendix 3.

# Appendix 5: Analysis and variables table for the simulator motorway experiments

### Analysis plan

| Analysis | Measures |
|---|---|
| Effect of S-IVIS in Normal Driving Conditions (Design 3) | **Mandatory measures**<br>self reported driving performance (subj_r)<br>speed and speed variation (mn_sp, st_sp)<br>lateral position and lateral position variation (mn_lp, st_lp)<br>1 degree reversal rate (rr_st1)<br>mean time-to-line-crossing (mn_tlc)<br>proportion of TLC minima<1 second (pr_tlc)<br>proportion of TTC minima<4 seconds (pr_ttc)<br>mean time-to-collision (mn_ttc)<br>mean of time and distance headway local minima (u_mn_hwt, u_mn_hwd)<br>glance duration (mn_gd) and glance frequency (n_gl)<br><br>**Additional measures**<br>speed change over S-IVIS blocks (d_sp)<br>lane exceedences (lnx)<br>power of high frequency steering component (hi_st)<br>steering entropy (en_st)<br>40 and 70 deg/s rapid steering wheel turnings (rswt_40, rswt_70)<br>proportion of time TTC < 4s (tet)<br>inter-beat-intervals (ibi)<br>heart rate variability (hrv)<br>skin conductance level and variation (dc_eda, ac_eda). |
| Effect of S-IVIS in Events<br>(Design 4) | **Mandatory measure**<br>brake reaction time (rt_br) |
| Effect of S-IVIS task, optional (Design 7) | Same as for Effect of S-IVIS in Normal Driving Conditions |

Design 3, 4 and 7 and corresponding analysis models are previously described in Appendix 3.