Evaluation of methods for the assessment of minimum required attention

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Abstract

The empirical methods eye tracking while driving, visual occlusion while driving, think aloud while driving, expert judgement in the laboratory and think aloud while watching video are evaluated for their usefulness to assess driver attention in real traffic. Using a within-subjects design, six driving instructors drove three 14-kilometre-laps on a motorway per driving condition. Additional participants took part in sub-sets of the conditions. The methods were evaluated both with respect to practical implications and to the results that could be obtained with them.

Glance behaviour and self-paced visual occlusion varied between different manoeuvre types (lane change – two directions, driving in left or right lane) and also between drivers. For the assessment of the attentional requirements of different traffic situations it is recommended to identify “situational prototypes” and related manoeuvres. The attention assessment should then be made with eye tracking in combination with visual occlusion, complemented with the think aloud technique. It is important to consider inter-individual variations in the process of identifying general attentional requirements for a prototypical situation/manoeuvre combination.

Information about surrounding traffic needs to be obtained for a correct assessment. Preliminary results indicate that it is important to adopt a manoeuvre-oriented view, for example when identifying visual targets, instead of using a static gaze target classification scheme.

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De empiriska metoderna; ögonrörelsemätning under körning, visuell ocklusion under körning, berättande körning, samt expertbedömning i labb och berättande ”körning” medan man tittar på en inspelad körning på video, bedöms med hänsyn till lämpligheten att mäta förarens uppmärksamhet i verklig trafik. Sex trafiklärare körde en 14 kilometer lång sträcka på motorväg tre gånger per betingelse under användning av inomgruppsdesign. Ytterligare deltagare var med i en delmängd av betingelserna. Metoderna bedömdes både med hänsyn till praktiska aspekter och till de erhållna resultaten.

Blickbeteende och den självinitierade visuella ocklusionen varierade mellan olika manövertyper (byte av körfält till vänster och höger, körning i vänster eller höger fil), och även mellan förare. För att ta fram uppmärksamhetskrav för olika trafiksituationer rekommenderas att identifiera ”situationsprototyper” och relaterade manövrar. Uppmärksamhetsbedömningen görs sedan med ögonrörelsemätning i kombination med visuell ocklusion, med berättande körning som komplement. Det är viktigt att beakta interindividuella variationer under framtagningen av uppmärksamhetskrav för en situationsprototyp-manöver-kombination.

Information om omgivande trafik behövs för en korrekt bedömning. Preliminära resultat visar att det är viktigt att använda sig av ett objektorienterat synsätt vid identifikationen av visuellt uppmärksammande objekt, istället för att utgå ifrån ett statiskt klassifikationsschema.

Titel: Utvärdering av metoder för att mäta minimala mängden uppmärksamhet som krävs under bilkörning
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Preamble

During the past years, while working with different projects concerned with the subject of attention in traffic, we have had intensive discussions about the topic. We became more and more convinced that a new perspective was needed, that we needed to start with the assumption that humans often employ behavioural strategies that get them to their goals, and that different strategies can be equally successful. Therefore we appreciated it enormously, when the opportunity came along to dig deeper into this topic on a theoretical level, but especially to start with the first empirical data collection investigating the possibilities to measure “minimum required attention”.

Linköping, August 2015

Katja Kircher
Project leader

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Quality review

Review seminar was carried out on 17 June 2015 where Prof. Dr. Torbjörn Falkmer, Curtin University, Australia, reviewed and commented on the report. First author Katja Kircher has made alterations to the final manuscript of the report. The research director Jan Andersson examined and approved the report for publication on 24 September 2015. The conclusions and recommendations expressed are the author’s/authors’ and do not necessarily reflect VTI’s opinion as an authority.

Kvalitetsgranskning

Granskningsseminarium genomfört 17 juni 2015 där Prof. Dr. Torbjörn Falkmer, Curtin University, Australien, var lektor. Förste författaren Katja Kircher har genomfört justeringar av slutligt rapportmanus. Forskningschef Jan Andersson har därefter granskat och godkänt publikationen för publicering 24 september 2015. De slutsatser och rekommendationer som uttrycks är författarens/författarnas egna och speglar inte nödvändigtvis myndigheten VTI:s uppfattning.
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Summary

Evaluation of methods for the assessment of minimum required attention

by Katja Kircher (VTI) and Christer Ahlström (VTI)

This report evaluates different methods for their usefulness to assess attention, namely visual occlusion, eye tracking, expert judgements, verbal protocol and situation awareness probes. Which method to choose depends on the definition of attention used for the study in question, but also on practical considerations, for example whether a certain type of equipment can be used in the planned study procedure.

In addition to the theoretical summary, a subset of the discussed methods was evaluated with empirical data. Six driving instructors participated as experts in the trials that included driving during the day and at night with eye tracking, driving while thinking aloud, driving with self-paced occlusion glasses, and providing written expert statements as well as conducting a film-based think aloud session. Expert judgements have also been acquired from a larger set of driving instructors (n = 85). Results are reported for each attention assessment method separately and discussed comparing their advantages and disadvantages. Data from different methods are also triangulated in order to combine the strengths of individual methods.

Attentional patterns differ for different driving manoeuvres and between drivers. Mirror glances are more frequent in manoeuvres that involve interaction with other road users, and speedometer glances are more frequent in manoeuvres that involve speed changes. The mean glance duration to those peripheral targets is quite constant across manoeuvres, however. The manoeuvre that has the lowest attention demand characteristics is driving in the right lane (right hand traffic). Here, participants had the lowest glance frequency to peripheral targets and the highest percentage of self-paced visual occlusion.

Driving on the motorway is a proactive task, which involves the anticipation of and proactive adaptation to other road users’ behaviour. Therefore, drivers experience it as important to have a good overview of what is going on around them from far in front of the vehicle to behind the vehicle.

The occlusion technique provides a direct measure of the minimum available spare capacity in different manoeuvres. It works reliably, but care has to be taken to provide suitable instructions, and it is recommended to use a safety backup in the form of a co-driver with dual command. Occlusion data can be enriched in a valuable way by adding eye tracking during the occlusion condition. In comparison to driving with eye tracking only it becomes visible how and where drivers cut down on their information intake. Further, concurrent thinking aloud adds information about the cognitive processes behind the observable behaviour. However, verbalising one’s attentional distribution also influenced the visual behaviour, therefore it is recommended not to use the think aloud technique during the whole trial period. Verbal/written statements made off-line, that is, through the reproduction of declarative memory, is not recommended as a technique to assess attentional distribution while driving. It does not appear possible to access the procedural capability of ‘driving’ well enough with this type of method.

For the assessment of the minimum required attention for a certain situation and manoeuvre it is recommended to use a combination of methods consisting at least of driving with occlusion goggles and eye tracking. Data that can be used for manoeuvre identification have to be collected as well. The think aloud method can give access to additional cognitive information.

While first suggestions for the rules on which the minimum required attention algorithm should be built can be made based on the collected material, more data are needed to establish concrete values.
Sammanfattning

Utvärdering av metoder för att mäta minimala mängden uppmärksamhet som krävs under bilkörning

av Katja Kircher (VTI) och Christer Ahlström (VTI)

Den här rapporten sammanfattar och utvärderar olika metoder för att mäta förares uppmärksamhet. De inkluderade metoderna är visuell ocklusion, ögonrörelsemätning, expertbedömningar, verbala protokoll och sonder/prober för att mäta situationsmedvetenhet (situation awareness probes).

Rapporten innehåller en teoretisk sammanställning av de olika mätmetoderna, och några av metoderna utvärderas även i småskaliga försök. Sex trafiklärare deltog som försökspersoner i experimentet, där de fick köra en instrumenterad bil på motorväg under fyra olika betingelser: körning i ljus och mörker, berättande körning samt körning med ocklusionsglasögon. I samtliga betingelser samlades data från bilen in tillsammans med GPS, radar, ögonrörelsemätning samt film framåt och bakåt.

Försöksdeltagarna fick även lämna skriftliga expertbedömningar samt göra berättande "körning" medan de tittade på en inspelad film från sin körning i dagsljus. Expertbedömningar har även gjorts av en större grupp trafiklärare (n=85).

I rapporten presenteras resultaten från varje mätmetod separat, men data från olika metoder integreras även för att dra nytta av individuella metoders fördelar och minska deras respektive nackdelar.


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1. Introduction

Many definitions of driver inattention and distraction have been proposed over the years, but inconsistencies and construct validity issues are commonplace among them. A number of issues have been pointed out and discussed before (Kircher & Ahlstrom, submitted; R. A. Young, 2012a, 2012b). An important underlying assumption found in a number of definitions is the idea that a driver is distracted as soon as he or she attends to something not ‘relevant for driving’. Alternatively, distraction is only considered to be present if this type of attention allocation leads to a situation ‘critical for safe driving’.

The existing definitions of distraction do not lend themselves to operationalisation, as this would require a hindsight-free and consistent definition. Interestingly, the so-called distraction detection algorithms that do exist (for reviews see Ahlstrom & Kircher, 2010; Lee, et al., 2013) are not based on the definitions of distraction provided in the literature. Generalising very roughly, they are designed such that they expect the driver to glance at the forward roadway for most of the time, and only when the driver glances away from that region too often or for too long they issue a distraction detection. Thus, implicitly some glances to other targets are accepted before the driver is considered to be distracted.

Another commonality among the distraction detection algorithms is that they state explicitly when the threshold is reached, but there is no explicit description of how the ‘grey zone’ should be treated, in which drivers do look away from the forward roadway, but not enough to warrant a distraction detection. Those glances could either be directed at objects that actually are relevant for driving, like interacting traffic outside of the forward area, or at objects that are completely unrelated to driving. It is not clear whether this ‘grey zone’ is considered to be a theory-free buffer that prevents the occurrence of too many distraction detections, or whether it is there for a reason – theory driven and representing a certain type of glance behaviour that is considered to be acceptable – even though the glances are not directed at the forward roadway. Most algorithms do not take into account where those ‘grey zone’ glances are directed.

One way to tackle this ‘grey zone’ and the resulting uncertainty in how to treat those glances is to start out not by defining driver distraction, but rather by defining driver attention. Following the reasoning that drivers are considered to follow a satisficing instead of an optimising approach (Boer, 1999; Summala, 2007), it is desirable to identify the minimum required attention in a given situation. When enough attention is devoted to the situation, the benefits outweigh the costs (Goodrich, Stirling, & Frost, 1998), and the possibly remaining capacity can either be devoted to traffic anyway, probably with the effect to enhance the current mental model, or it can be devoted to something else, with the current model still being ‘good enough’.

As traffic is dynamic, the current mental model becomes more and more outdated over time. One way to describe this information decay has been suggested by Senders, Kristofferson, Levison, Dietrich, and Ward (1967). Even though a number of aspects of this model can be criticised, the underlying idea is that the driver only has to acquire updated information when the available information has become so outdated that the perceived uncertainty becomes too high for comfort or experienced safety. Depending on the information density in the scene and the rate of information decay this can be more or less frequently.

This view also implies that drivers typically have spare time or spare capacity, which can be devoted to other things without leading to a direct threat to safety. Different types of studies have been conducted to show this. Participants drove with an occlusion helmet (Senders, et al., 1967), or reported verbally where they directed their attention (Hughes & Cole, 1986; K. L. Young, Salmon, & Cornelissens, 2013), or had their glance behaviour tracked and analysed (e. g. Falkmer & Gregersen, 2005; Mourant & Rockwell, 1972; Rockwell, 1988; Serafin, 1994; Underwood, 2007). The findings show that drivers spend time attending to objects that are not relevant for driving, that expert drivers
do so to a larger extent than novices, and that more attention is directed at traffic in more complex situations. Thus, spare capacity varies both with situational complexity and the driver’s capability.

Further, possibly more subjective indications that drivers actually do have spare capacity in many occasions are the facts that it is possible to drive for hours at a time without getting exhausted, that it would be possible in many cases to exceed the posted speed limit, which leads to a faster information decay and therefore requires resources, and that drivers are known to execute additional tasks frequently without ending up in a safety critical situation.

These points indicate that drivers have a possibility to regulate the situational demands by adjusting their speed, choosing their manoeuvres and selecting when and where to drive. Thus, it can be argued that there are attentional requirements inherent in a situation given that a certain manoeuvre is being executed. Within this manoeuvre the driver can influence part of the information decay by regulating the own speed and trajectory, and part of the information decay is dependent on the presence, the speed and the trajectory of other vehicles.

The so-called Minimum Required Attention (MRA) approach offers a new take on how to define driver distraction (Kircher & Ahlstrom, submitted). It is intended to take varying situational demands, the possibility of spare glance capacity and the driver’s partial self-regulation into account. The basic idea behind MRA is to formalise requirements for when and how often a driver is required to sample certain information in different traffic situations. If these requirements are violated, the driver is considered distracted. However, if the requirements are fulfilled, the driver can use potentially available spare capacity to attend to other things without being considered distracted. The situational demands in combination with the driver’s tactical behaviour in the situation determine the amount of available spare capacity.

The overall aim of this report is to evaluate different methods for their usability in identifying the necessary information to set up the first set of rules for one particular traffic environment – a dual-lane motorway. Different attention allocation assessment methods are considered and evaluated theoretically to acquire the information needed to establish the rules: visual occlusion, eye tracking, expert judgements, verbal protocol and situation awareness (SA) probes. The most promising methods are then to be evaluated in an empirical pilot study. The whole process from data acquisition, data reduction and analysis is scrutinised, as any useful methodology has to be practically feasible and deliver reliable data. Those data need to have the potential to contribute to the understanding and assessment of the minimum required attention.
2. **Attention assessment methods**

We present and discuss a number of assessment methods which are expected to cover different aspects of attention distribution and evaluation of possible spare capacity. For each method advantages and disadvantages are highlighted and its usefulness for an operationalisation of driver attention is discussed.

2.1. **Visual occlusion**

![Figure 1. A set of commercially available occlusion glasses in transparent and occluded mode.](image)

Visual occlusion is a method that has been used in many different ways to assess visual aspects of driving (Figure 1). Common to all studies is that the participant wears a set of glasses that can be rendered transparent or opaque, for example with liquid crystal occlusion shutters, or mechanically opened and closed on demand. Opening/closing of the shutter can be controlled either by the experimenter or by the participant, and the duration of the transparent and opaque phases can be fixed or variable. The occlusion technique has been used in real traffic to assess the visual demands of different traffic environments (Senders, et al., 1967), to simulate glances to traffic in a parked car to evaluate in-car technology (Baumann, Keinath, Krems, & Bengler, 2004; Gelau & Krems, 2004), to simulate distraction while driving on a closed course (Brown, 2005), and to assess the influence of a secondary task in driving situations of varying complexity in a simulator (Tsimhoni, 2003). Hoedemaker and Kopf (2001) used a variation of the occlusion technique by only blocking central vision, but allowing peripheral vision, in order to assess the effect of adaptive cruise control (ACC) on visual information demands in the central region. The occlusion technique has been introduced by the International Standards Organisation (ISO) as a standard for assessing visual demand from in-vehicle systems (ISO, 2007). However, the technique has been found to overestimate resumability by not including a task during occlusions (Monk & Kidd, 2007).

2.1.1. **Advantages**

- Occlusion glasses provide a clean and objective measure of when the driver does not see anything of the surroundings. If the driver controls the shutter, and if the driver follows the instructions and operates the glasses safely, the occluded time snippets provide a (minimum) indication of the spare glance capacity on the current road type in the current situation.

- If the driver controls the shutter, the driver him/herself decides when not to look, that is, the spare glances are based on the driver’s own assessment.

- Real-time measurements can be acquired in a real traffic situation.
2.1.2. Disadvantages

- The setup can be considered dangerous. It might not receive ethical approval\(^1\).
- Total occlusion does not correspond to a driver’s looking away from the forward roadway. A driver who looks at a tourist sign or a mobile phone still has some peripheral vision to track one’s course, therefore total occlusion is more ‘strict’ than a glance away from traffic. This means that the spare glance estimation with this method is conservative.
- The conscious decision to operate the shutter with the finger is probably much more cognitively demanding and artificial than blinking with the eyes or glancing away. This means that the spare glance estimation with this method is conservative.
- The driver might feel pressed to render the glasses opaque more frequently than he or she feels comfortable. This would mean that the spare glance estimation with this method is too generous.
- The glasses have heavy frames, obscuring the periphery of the visual field also in the transparent state.
- The glasses may feel uncomfortable to wear.
- No information about the traffic situation is logged.

2.2. Eye tracking

*Figure 2. On the left hand side a remote eye tracker is in the process of being mounted in a test vehicle. On the right hand side an eye tracker that is worn like a pair of glasses is shown.*

Eye tracking is used in traffic research both to investigate glance direction and eye blinks (Figure 2). Within attention and distraction research the glance direction is of most interest. Knowing where the foveal vision is directed gives a good indication of what the driver’s attention is directed at (Theeuwes, Kramer, Hahn, & Irwin, 1998).

Glance behaviour has been evaluated in numerous ways. One possibility is to investigate for how long and how often a driver glances at a secondary task (Donmez, Boyle, & Lee, 2006; Donmez, Boyle, & Lee, 2007). Eye movements have also been analysed for experienced and inexperienced drivers, in order to find out about possible differences between the two groups (Crundall, et al., 2012; Underwood, Chapman, Bowden, & Crundall, 2002). Further, algorithms have been developed that consider glance behaviour from the recent past to form an estimation of the driver’s present attentional

\(^1\) The regional ethical committee in Linköping, Sweden, approved of a study using visual occlusion on the motorway. Preconditions were that a co-driver with a secondary set of controls sits in the front passenger seat for safety reasons.
Eye tracking can be done with the help of remote or head-mounted eye trackers. The first setup includes an eye tracker that is mounted in for example the vehicle. With the help of cameras it monitors the driver’s face and eyes, which are typically illuminated with IR light. Based on the films the glance direction is computed. The number and position of attached cameras determines the visual angle that can be tracked. When the driver turns the face out of sight of the cameras, tracking is lost. Remote eye trackers have a fixed and known position in the system they are attached to, e.g., within the vehicle. That means that the gaze direction in relation to fixed targets can be determined automatically. This requires the use of at least two cameras and the establishment of a ‘world model’. However, targets that move relative to the system in which the cameras are mounted have to be coded manually and require that an additional scene camera is integrated with the eye tracking system.

Head-mounted eye trackers work in a similar fashion, except that they are attached to the head of the participant, meaning that they will follow the participant’s head direction wherever it is turned. Typically a scene camera is present, as head-mounted eye trackers do not have a fixed position in the world. Analysis is usually done frame-by-frame, which is cumbersome and time intensive, even though software has been developed to make the process somewhat easier.

In general, the tracking quality improves when the driver does not wear glasses, heavy make-up (especially mascara) or a beard. Sun glare can also disturb eye tracking. For remote trackers glance tracking is usually the better the more (well calibrated) cameras can see the driver’s face.

Glance behaviour has also been evaluated based on off-line manual frame-by-frame coding of video sequences of the driver’s face (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006; Klauer, et al., 2014; Stutts, et al., 2005). This method yields data similar to that collected from an eye tracker with forward view, but without the advantages of being real-time and at least providing possibilities for semi-automatic analysis, which is much cheaper and faster than completely manual analysis. This approach will not be discussed here.

2.2.1. Advantages

- With a well calibrated and well working system a rather accurate gaze direction can be calculated real-time at any point in time. This allows an assessment of what the driver looks at or in which direction the driver is looking and for how long.

- Glance behaviour is quite automated and therefore not easily influenced on purpose.

2.2.2. Disadvantages

- Spare glances have to be inferred via interpretation. Labelling is done by the experimenter instead of by the driver. A glance at a billboard can be labelled as ‘not traffic relevant’ without too much controversy, but this is not necessarily the case for all targets. Also, a glance to a traffic relevant target may temporarily become less acutely relevant after a short period of time. Long glance durations to the forward roadway are often not due to continued intensive monitoring of the road, but rather due to the fact that the face points forward, which makes it comfortable to look ahead.

- The underlying assumption is that attention and gaze direction are linked and that attention therefore is overt. This is assumed as the dynamic task of driving demands a frequent intake of new visual information, which, in turn, does not give much leeway for covert attentional processes. It is also assumed that what is looked at foveally is somehow ‘seen’, meaning that it is processed enough to be either retained or dismissed on a meaningful basis.
• Eye tracking provides information about the foveal gaze direction, but not about the intake of information via the periphery.

2.3. Expert judgement

Expert knowledge encompasses what qualified individuals know with respect to their technical practices, training and experience. Expert judgements are biased in the sense that they are affected by the process used to gather the information, have uncertainty, and are conditioned on various factors (such as question phrasing, information considered, assumptions and problem solving (Kirkeboen, 2009)). It is therefore up to the analyst to extract tacit knowledge from the thoughts and believes of the experts.

Examples of recommendations for eye scanning rules given by US experts are cited in Zwahlen (1991). They encompass tips like ‘having a wide picture’, to ‘keep the eyes moving’, to ‘scan the entire traffic scene’, to ‘centre the gaze on the travel path’, to ‘look at mirrors and instruments’, to ‘centre on a target 12 seconds ahead’ and to ‘employ an orderly visual search pattern’. Interestingly, analyses of the actual scanning behaviour of six semi-experienced drivers showed that not all of the recommendations were applied while driving in real traffic. This may mean that the experts were wrong or that the drivers were not employing the best glance strategy, or also that there are many ways to reach the same goal. When proposing rules for glance behaviour, Zwahlen states that ‘it would be highly desirable that the need for such rules as well as the conditions for which they apply would be carefully researched and justified and that such rules would be carefully developed and validated on the basis of driver eye scanning behaviour studies conducted in representative driving environments under representative conditions with a sufficiently large group of representative drivers’ (p. 21 f.).

2.3.1. Advantages

• Provides information according to best practice (prior knowledge, experience, the law book) about how to construct a mental model of the surroundings.

• Can cover situations that do not occur during test drives.

• Allows for a different perspective compared to the academic driver distraction research community.

• Low cost.

2.3.2. Disadvantages

• The quality of information that is retained depends on the knowledge and expertise of the experts.

• The results rely on subjective judgement and intuition.

• It is difficult to verbalise spare capacity, especially in off-line verbal recommendations.

2.4. Verbal protocol

The think-aloud method is described as a method that gives access to information present in the participants’ short-term memory (Ericsson & Fox, 2011; Ericsson & Simon, 1980, 1993). Think-aloud protocols involve participants’ verbalising their thoughts as they are performing a set of specified tasks. It is different from introspection as it does not require any ‘looking into our own minds and reporting what we there discover’ (James, 1890, p. 185), but only requires the participant to act as if he or she were alone in the room, speaking to oneself, instead of trying to explain one’s thoughts.
(Ericsson & Fox, 2011). Ericsson and Simon (1993) provide a thorough discussion on how verbal protocol data should be collected.

The drivers are asked to explain whatever they are looking at, thinking, doing, and feeling while driving. The original purpose of the verbal think aloud protocol was to gain better understanding on how people solve problems. By asking them to verbalise their thoughts as they come into mind it is ensured that no hindsight rationalisation occurs, and that intermediate steps in the process, especially those that do not lead to a solution, are not forgotten. According to van Someren, Barnard, and Sandberg (1994) it is less difficult than it seems to think aloud, and in general it does not interfere with task performance (Fox, Ericsson, & Best, 2011).

Verbal reports of short term memory tend to be complete unless the participant is under high cognitive load (major task-directed processes tend to take priority over the process of verbalisation). However, proceduralisation of the task may be an issue (Anderson, 1987). For example, if the driver does not consciously attend to the object of regard, as may be the case in an automated driving task, the focus of regard will no longer be active in working memory, and thus not necessarily available for vocalisation.

Hughes and Cole (1986) compared verbal reports obtained while participants drove along a route of about 22 km and while watching a film recorded on the same route. The instruction was to report everything that attracted the participants’ attention. In the instruction it was stated specifically that there might be times when there was little to report and that at other times the participants would be very busy reporting. The reports obtained were classified into eight categories, four of which were considered traffic relevant (road related, traffic control devices, vehicles, people) and four were considered not to be immediately relevant to traffic (immediate road surroundings, general surroundings, vegetation, advertising). It was found that the number of reports was 21% greater in the laboratory than while driving, but that the percentage of reported classes was similar in both environments. In-depth analyses showed that mainly ‘traffic control devices’ and ‘vehicles’ were reported more frequently in the laboratory. The authors come to the conclusion that verbal reporting based on film is a good enough approximation of driving the route. However, it was not stated anywhere whether the drivers reported anything seen in the rear-view mirrors, and whether the mirrors were visible in the film.

2.4.1. Advantages
- Enables the observer to see first-hand the process of task completion rather than only the final outcome.
- Compared to expert judgements, there is less discrepancy between the verbal think aloud response and what the driver actually thinks since there is no need to retrieve information from long-term memory (thoughts generated from the long-term memory are often tainted by perception).
- Can disambiguate glances with two possible targets on the same axis (pedestrian and truck behind; head-up display or car behind, etc.).
- The verbal protocol has been reported not to affect task performance (Fox, et al., 2011).

2.4.2. Disadvantages
- Think aloud utterances are often incoherent, but this may be alleviated by synchronised videos of the surroundings.
- Information could be lost due to the inherent slowness of speech (events that happen in fast succession cannot be covered due to time constraints).
Some participants are not very good at verbally communicating their thoughts. Also, the cognitive load of problem solving and speaking may be too difficult for some participants (Branch, 2000).

There is a possibility that not all processes are verbally accessible. However, there is some evidence (Gugerty, 1997) that the driver's mental model or SA is constructed of explicit knowledge, that is largely accessible to verbal report.

2.5. Real-time situation awareness probes

Some research has investigated the effect of driver distraction on SA (reviewed in K. L. Young, et al., 2013). The general finding is that SA decrease when drivers converse on mobile phones. However, SA has also been found to increase when drivers use adaptive cruise control (ACC; Ma & Kaber, 2005) which could lead to the following interpretation: Drivers adapt to the situation, when they do something they are not familiar with (driving with ACC) they monitor the environment more closely to be able to act as soon as it is necessary. When they do something they know how to deal with (mobile phone) they reduce SA to the degree that is (hopefully) still sufficient.

Conventionally, two different methods are used to measure SA. Either the task is frozen when the probing questions are asked, such as in the Situation Awareness Global Assessment Technique (SAGAT), or the task continues to run, such as in the Situation Present Assessment Method (SPAM). Real-time probes, without freezing, have been suggested to objectively and unobtrusively measure SA in highly dynamic operating environments, such as driving. Probes are developed based on a goal-directed task analysis within the specific domain, and are formulated to target the three levels of SA, including perception, comprehension and projection (Endsley & Garland, 2000). They can also be targeted at specific driving goals, including operational, tactical and strategic goals (Kaber, Liang, Zhang, Rogers, & Gangakhedkar, 2012; Michon, 1985). Operator response accuracy and time latency between a probe and response are collected as SA measures. Since the probes are used in real-time, they are less dependent on memory than conventional SA measures.

Real-time SA probes are typically posed to drivers through conversation by an experimenter riding along in the car. The probes have different levels:

1. SA level 1: Probes about the current status of events. Example: ‘What was the last posted speed limit you saw?’

2. SA level 2: Probes about comprehension of events. Example: ‘Is the lead vehicle speeding up, slowing down, or traveling at a constant speed?’

3. SA level 3: Probes about anticipation. Example: ‘Will the lead vehicle slow down, change lane or do nothing to facilitate for an entering vehicle in the approaching entrance to the motorway?’

2.5.1. Advantages

- Real-time assessment of SA.
- Reduced intrusiveness as no freeze in the task under analysis is required.

2.5.2. Disadvantages

- Real-time probe queries may serve to direct attention to the required elements in the environment, resulting in biased data.
• Difficult to come up with a sufficient amount of relevant probes on monotonous roads such as motorways.

• Probes on Level 2 and 3 are situation dependent. For some drivers/trials, perhaps only Level 1 probes can be used.

2.6. Dual task paradigm

It is very common to ask drivers in an experimental setting to conduct secondary tasks while driving (Strayer & Johnston, 2001; Zhang, Kaber, Rogers, Liang, & Gangakhedkar, 2014). This so-called ‘dual task paradigm’ even led to the development of artificial in-vehicle tasks (Jamson & Merat, 2005; Östlund, et al., 2004) with the purpose to simulate different aspects (visual load, cognitive load, etc.) of real-world tasks that are executed while driving. In most cases the driver steers a vehicle either in a simulator, on a test track or in real traffic while executing an additional in-vehicle task. The instructions are in most cases to prioritise driving, but it has been argued that the instruction should be to prioritise the additional task while driving ‘good enough’, if realistic conditions are to be reflected (Ahlstrom, Kircher, et al., 2012).

Both performance in the driving task and in the additional task are typically analysed for decrements when the tasks are combined. The performance in the driving task is normally compared to baseline driving, that is, driving without any additional task. It is less common to collect data for baseline additional task performance, that is, additional task execution without driving.

In most cases the secondary task is system-paced, that is, the experimenter determines when the participant has to execute the task. This is for increased experimental control, but may not necessarily reflect naturalistic behaviour. Also, it can be required to keep a constant speed or headway, which prevents the driver from naturalistic compensatory behaviour, which has been found to occur both for self-paced and system-paced tasks in a semi-controlled field study (Kircher, Ahlstrom, Palmqvist, & Adell, 2015) as well as in a simulator study (Eriksson, Lindström, Seward, Seward, & Kircher, 2014). If the opportunities for self-regulation are reduced, it is likely that possible performance impairments are overrated.

2.6.1. Advantages

• Additional tasks may feel natural to execute.

• Especially the dedicated surrogate tasks allow an exact assessment of secondary task performance.

• The paradigm is well-known and often used.

• Both system-paced and user-paced options are available.

• The peripheral vision is probably comparable to naturalistic dual-task performance.

2.6.2. Disadvantages

• The setup may be considered dangerous. It may not receive ethical approval and it may even be illegal.

• It is not self-evident which additional task should be used.

• The participant needs to understand that the additional task should be executed in a fashion that does not impair driving performance, but while using the maximum excessive capacity.
3. Theoretical evaluation of the described methods

As shown above, all of the described methods have their own set of advantages and disadvantages. In addition to those factors, for the project at hand considerations involving uniqueness of the method, costs and practicality were made (see Table 1). This evaluation led to the conclusion to proceed with the methods visual occlusion, eye tracking, expert judgement and the verbal protocol both based on video and while driving.

The real time SA probes were dropped, as the current setting made it hard to implement such a test successfully. It has been shown that people do not reliably remember things they have passed that are not relevant to their driving at the moment (Johansson & Rumar, 1966), but this does not mean that the drivers have a low awareness in general – only that it is selective and guided by top-down processes. However, if probing for relevant things, the number of potential probes on the experimental road section is very low indeed. Also, the generalisation of the method to other traffic situations may be harder and for the other methods discussed.

The dual task paradigm was dropped as well, as it resembled the occlusion technique in principle, but with some drawbacks. The occlusion technique is much closer to affecting vision only as any dual task concept can be. To solve an additional task, mental processes have to be involved, and it is difficult to tell how these processes influence driving in general. It may be possible that the participant still considers the secondary task while looking at the traffic, therefore it is not clear that attention is directed at traffic when the eyes are directed there. However, when using the occlusion technique the instruction will be that the participant should close the glasses as soon as he or she feels it is possible to do so safely, such that the assessment of spare visual capacity is as clean as possible.

It was also decided to test these methods with a limited number of participants who should be expert drivers. The choice fell on driving instructors for several reasons. Firstly, they should be experts in driving and should therefore know how attention should be distributed. Secondly, in the visual occlusion condition it was planned to have a safety backup by having an experienced person ride in the passenger seat with dual commands. As driving instructors are used to this setup, they would be ideal backups for each other. Also, driving instructors are used to thinking aloud while driving, as this technique is part of their methods when teaching beginner drivers.
**Table 1. Overview of some of the theoretical evaluation criteria for the methods that were considered for the assessment of the minimum required attention.**

<table>
<thead>
<tr>
<th>Visual occlusion</th>
<th>Eye tracking</th>
<th>Expert judgement</th>
<th>Verbal protocol</th>
<th>Real-time SA probes</th>
<th>Dual task paradigm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main expected contribution</td>
<td>relatively pure measure of spare capacity</td>
<td>rather clean way to assess glance distribution</td>
<td>cheap off-line instrument</td>
<td>assessment of mental model underneath the ‘tangible’ surface</td>
<td>assessment of spare capacity</td>
</tr>
<tr>
<td></td>
<td>Main expected complication</td>
<td>ethical and legal issues, danger</td>
<td>cumbersome evaluation; high level of proficiency with eye tracker data necessary; time consuming when analysing video material</td>
<td>reality may be far from judgement, very subjective</td>
<td>some people may have difficulties with verbalising their thoughts</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost for trial</td>
<td>purchase or development of glasses, adaptation of log equipment</td>
<td>high one-time cost when purchasing equipment, installation can be time consuming</td>
<td>development of necessary paper material</td>
<td>recording equipment</td>
<td>probes need to be identified and experimenters trained in probing for them</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost in repeated usage</td>
<td>rather high: car, logging equipment and occlusion glasses needed</td>
<td>high: car, logging equipment and eye tracker needs to be available</td>
<td>low: paper material</td>
<td>low to medium when using film, higher when a vehicle is needed</td>
<td>car and trained experimenter needed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Practical implications</td>
<td>ethical approval needed, equipment still needs to be improved and built more sturdily for more frequent usage</td>
<td>important to be very precise with the calibration procedure, otherwise well-known and straightforward method</td>
<td>easy to use, simple and short, but possibly difficult for participants to produce useful rules</td>
<td>easy to use, but possibly difficult for participants to make realistic estimates – also, if only one picture is used it is possible that the level of abstraction is not high enough</td>
<td>difficult to find meaningful probes, especially when the same section of road should be repeated three times</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instruction to participant</td>
<td>Visual occlusion</td>
<td>Eye tracking</td>
<td>Expert judgement</td>
<td>Verbal protocol</td>
<td>Real-time SA probes</td>
</tr>
<tr>
<td>----------------------------</td>
<td>------------------</td>
<td>-------------</td>
<td>------------------</td>
<td>----------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>close the glasses as soon as it feels safe to do so, but do not take risks – use them as an indication of when you do not need any additional visual information and could have looked at the radio, your phone, etc.</td>
<td>just drive the way you usually would</td>
<td>please write down how a good driver/how you would allocate his or her attention in a setting like the one investigated</td>
<td>verbalise all the thoughts about how you distribute your attention that go through your head – we are interested in anything you might direct your attention at (a longer instruction was available)</td>
<td>answer the questions asked by the experimenter as best you can</td>
<td>process the additional task as much as possible without taking any risks in your driving</td>
</tr>
</tbody>
</table>

| Evaluation | as ethical approval was obtained, the method was selected to be taken into consideration, due to its pureness and the promising results presented by Senders (1967) | this method was selected, because it seems to be self-evident that eye movements should be logged when investigating attention; also it can be used as reference between the different conditions | this method was selected, as it is very low cost, and because it is complementary to visual occlusion and eye tracking, as it is offline and more based on insight and reflection than actual behaviour | this method was selected because it is complementary to visual occlusion and eye tracking, and as it provides expert judgement in direct connection to the traffic environment at hand | similar to verbal protocol, but less pure, more preconceptions involved, therefore not included in the methods selected for testing | similar to visual occlusion, but less pure, therefore not included in the methods selected for testing |
4. Method

4.1. Design and procedure

For a group of six ‘core’ participants the design was within subjects. Each participant completed six different method conditions as described in Table 2, distributed over two different days. During the conditions ‘car eye tracking daylight’ and ‘car eye tracking darkness’ the participants were not aware of the purpose of the study. Those two conditions were run during Day 1, always with the daylight trial first. The remaining conditions were run during Day 2. The lab conditions were run first, and the ‘car’ conditions were balanced. This was mainly due to practical reasons. A more detailed description including the log equipment is given in Section 4.4 Conditions and equipment below.

As the participants were not informed immediately about the full purpose of the study, but received information gradually for each condition, separate informed consent forms were filled in for each condition.

Table 2. Overview of the method conditions. The participants were unaware of the purpose of the study in conditions ‘car eye tracking daylight’ and ‘car eye tracking darkness’. Conditions with ‘car’ were conducted in the field, conditions with ‘lab’ were conducted in the laboratory.

<table>
<thead>
<tr>
<th>Day 1</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>car eye tracking daylight</td>
<td>The participant drove the test route in daylight. The instructions were to drive the test route as usual on a private trip without particular hurry.</td>
</tr>
<tr>
<td>car eye tracking darkness</td>
<td>The participant drove the test route in darkness. The instructions were to drive the test route as usual on a private trip without particular hurry.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Day 2</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>lab expert judgement</td>
<td>The participant was asked to explain in free text how one should distribute one’s attention on a motorway like the test route, in order to drive well. In addition, the participant was asked to fill in percentages of recommended attention distribution on a drawing of a forward view.</td>
</tr>
<tr>
<td>lab think aloud</td>
<td>The participant watched video clips (forward and mirror view) from his or her own daylight and darkness drives and was asked to think aloud how he or she distributed attention.</td>
</tr>
<tr>
<td>car think aloud</td>
<td>The participant drove the test route with the instruction to think aloud how he or she distributed attention.</td>
</tr>
<tr>
<td>car occlusion glasses</td>
<td>The participant drove the test route with occlusion glasses. The instruction was to close the glasses as soon as the participant felt that no further visual information was needed for the time being.</td>
</tr>
</tbody>
</table>

4.2. Test Route

The test route consisted of a motorway section of about 7 km in length. Within each ‘car’ condition each participant drove this section three times in each direction. There were two lanes in each direction, after about one third of the section there was an exit with an off- and on-ramp, and the speed limit was 110 km/h on the whole section. Traffic was low to medium.

One participant encountered snow and mud on her daytime and darkness drive with eye tracking only. In all other cases the road was clear. Some participants experienced grey skies and some precipitation, others had sunshine. In all cases visibility was good enough to proceed unhindered at the posted speed limit.
Figure 3. Overview of the test route. The actual measurements were taken on the motorway section going east-west. This road section was approximately 7 km long and lies between Linköping Tift and Linköping East. Map data ©2015 Google.

4.3. Participants

Six driving instructors (two female, four male) participated in all conditions of the study – they are labelled the ‘core participants’. Their mean age was 35 years (std = 7.2 years), with an age range between 27 and 46 years. All participants had several years of experience as driving instructors. They were all very familiar with the route driven. Each of the core participants received 2000 SEK for participation in all conditions.

Even though the main purpose of the study was an evaluation of the methods used, as opposed to providing statistically sound content results, additional participants were included where this was possible and feasible, partly because technical issues led to some data loss, and partly to provide more power for at least some of the results.

For most of the conditions, additional data were collected from different populations. For the condition ‘lab expert judgement’ written descriptions were obtained from 68 additional driving instructors and another 17 participants who had almost completed their education to become driving instructors. No demographical information about those participants is available. A subgroup of this population (25 driving instructors) also filled in the additional form on the estimated attention distribution in percent. Another group of 85 experienced drivers also provided written descriptions. Exact demographic data for those people are not available, but most were above 50 years of age and had accumulated many years of driving experience. The additional driving instructors and candidates did not receive any reimbursement, and the experienced drivers received reimbursement within another project.

The six core participants filled in the form on the attention distribution in per cent twice – once upon arriving for the test session on the second day, and once after the ‘car occlusion glasses’ condition.

Another six experienced drivers participated in the ‘car occlusion glasses’ condition. Their mean age was 45 years (std = 12.6 years, range 30-64 years). All drivers were familiar with the route. Two of those drivers also completed the full ‘car eye tracking daylight’ condition, the other four completed...
one lap with eye tracking only instead of three, immediately following the ‘car occlusion glasses’ condition. These participants did not receive any monetary reimbursement. A tabular summary of which participants contributed to which conditions can be found in Table 3.

Table 3. Tabulation of participants per condition.

<table>
<thead>
<tr>
<th>Field</th>
<th>Lab</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Day</td>
</tr>
<tr>
<td>6 core participants</td>
<td>x (2 eye tracking files corrupt)</td>
</tr>
<tr>
<td>6 experienced drivers</td>
<td>x (2 full drives, 4 drove one lap)</td>
</tr>
<tr>
<td>68 driving instructors</td>
<td></td>
</tr>
<tr>
<td>17 driving instructor students</td>
<td></td>
</tr>
<tr>
<td>85 experienced drivers</td>
<td></td>
</tr>
</tbody>
</table>

4.4. Conditions and equipment

In this section the experimental conditions are described in more detail, including the necessary equipment and the instructions given.

4.4.1. Laboratory

Written explanation

As a first task in the laboratory the participants explained in writing how one’s attention should be distributed when driving on a two-lane motorway. The instruction was: ‘Imagine that you drive on a normal motorway with two lanes per direction. Please explain how a driver should allocate his or her attention in order to drive well. Please explain as well how the driver’s attention should be distributed when passing an off-ramp and an on-ramp.’ In addition to the free verbal description the participants were shown a schematic drawing of a forward view while on a motorway. They should indicate which percentage of attention they would allocate to different targets when driving well, including the mentioning of possible spare capacity that could be allocated to other things (Figure 4). The participants could take as much time as they wanted to in order to fill in the forms.
Figure 4. The schematic picture of a motorway drive on which the participants indicated their suggested distribution of attention in per cent.

Video-guided verbal protocol

Also in the laboratory, the participants watched a film on a laptop in the software Movie Maker. The films consisted of the forward view (including the car’s bonnet) with an inset showing the mirrored rearward view (Figure 5). The viewing angle for both views was 170 degrees – the wide angle setting of the GoPro Hero3 Black Edition camera with which the film was recorded. An external microphone was connected to the laptop to record the participants’ voice, which was added as ‘narration’ to the film to keep the verbal report and the film synchronised.

Figure 5. One frame of a video to which the think-aloud protocol was recorded. A mirrored rear-view recording was inserted in the frontal picture to resemble the view in the central rear-view mirror.

Each participant viewed and thought aloud to the first two daylight and darkness stretches of the westward direction of the test route. This was a compromise between keeping a reasonable time for the task and still acquiring material for a within-subjects analysis. Replaying each of these stretches took approximately five minutes, depending on the original driving speed. After each stretch the participant
was offered to take a break if desired. An experimenter was in the room while the participant commented on the film to operate the equipment and to answer possible questions.

4.4.2. Field
The experiment vehicle was equipped with a GPS receiver, a VBox (RaceLogic, Buckingham, UK), a car area network (CAN) logger from CTAG (Porriño, Spain) that records vehicle data such as pedal usage, direction indicators and speed. The logger also records data from external sensors such as a universal medium range radar (UMRR Type 29, Smart Microwave Sensors GmbH, Braunschweig, Germany) and time synchronisation information from a five camera eye tracker (SmartEye Pro 6.1, Gothenburg, Sweden) supported by two scene cameras. The actual eye tracking data were stored as raw video and the tracking was acquired by post-processing at a later stage. Additional cameras (GoPro Hero3 Black Edition) record the forward and backward scene. The recordings will be used for the lab-based trials on the second day. The forward camera was also used to record sound in the ‘car think aloud’ condition. A part of the logging equipment can be seen in Figure 6. In addition to the logging equipment, a second brake and clutch pedal was built in to be operated from the passenger seat. This was a safety measure for the ‘car occlusion glasses’ condition.

Figure 6. The logging equipment mounted in the trunk of the car (left) and the three of the eye tracking cameras, the two cameras for the forward scene belonging to the eye tracker as well as the camera used for recording the scene for the film-based think-aloud protocol.

Eye tracking daylight and darkness
Two drives were conducted with eye tracking only, one during daylight and one during evening when it was dark outside. A SmartEye Pro 6.1 system (SmartEye, Gothenburg, Sweden) with five cameras and two scene cameras was used for that purpose. Four of the eye tracking cameras were arranged across the dashboard and the fifth was placed on the right side of the middle console. The scene cameras were placed on the left and right side of the rear-view mirror and covered approximately 160 degrees of the forward view when they were merged. For analyses the glance direction could be overlaid over the scene, in order to indicate the glance target. A 3D world model of the car was used to track glances directed at car-related targets like mirrors, the speedometer, etc.

The participants were instructed to drive as they normally would on a road like this and to pretend that they were alone in the car. An experimenter sat in the right back seat of the car to monitor the recording equipment but would not talk to the participant when on the test route, except to answer possible questions related to the study.

Instead of tracking the participant’s glance in real time, the participant’s face was recorded on film for off-line tracking. This procedure allowed for more accurate profile generation and ensured that the latest available tracking algorithm could be used for all data. Eye tracking was also used during the occlusion drive and the think aloud drive, employing the same tracking procedure.
Occlusion glasses

Mechanical occlusion glasses built in-house were used for the study (Figure 7). The reasons for designing a new pair of glasses were that:

1. There was a bug in the commercially acquired glasses which sometimes caused them to freeze while occluded. This made them unreliable for our research purposes.

2. It was difficult to time synchronise the data from the commercially acquired glasses with the other data streams (CAN, eye tracking etc.).

3. Mechanical shutters were preferred instead of liquid crystal occlusion shutters since it was possible to design mechanical shutters that automatically switched to open in case of power failure.

4. It was possible to use a material in the mechanical shutters which is dark but yet permeable to IR-light. This means that the eye tracker works even when the shutters are closed, making it possible to assess how the participants moved their eyes during the occlusion phases. It also leads to more stable eye tracking in general, as the eyes do not have to be redetected after every occlusion occasion.

The default state of the glasses was open. The participant had a microswitch attached to his or her left index or middle finger (Figure 8). When this switch was pressed, the occlusion glasses closed mechanically and remained shut as long as the switch was pressed. When the switch was released, the glasses opened up again. The left hand was used, as gear changing, which requires a hand movement away from the steering wheel, was done with the right hand. The microswitch could be pressed against anything for activation, like for example the steering wheel or the thumb of the same hand. The participant was instructed to make sure to take in all the visual information needed, and under this precondition to close the glasses as often as possible. The participant was also instructed that closing the glasses was not meant to be a competition, and one should never feel pressed to keep the glasses closed ‘just a little bit longer’.

During the occlusion condition either another driving instructor or an experienced driver was seated in the passenger seat. This person was instructed to act as safety backup, even though it was stressed that the participant had full responsibility for driving at all times. An experimenter sat in the right hand back seat of the car to monitor the logging equipment.

The eye tracker was activated during the occlusion drive. It was planned that the information collected with the occlusion glasses could be enriched that way.
Figure 8. The participant regulated the occlusion glasses in a self-paced manner by pressing and holding a microswitch attached to a finger of the left hand for shutting the glasses, and releasing the switch for opening the glasses.

**Think aloud**

The think aloud method requires proper training of the participants. In this project, a 3-step training programme developed at The Monash University Accident Research Centre (MUARC) was used:

1. After the first test day the participants were handed a sheet explaining the think aloud task and encouraging them to practice thinking aloud before arriving to the next test day.

2. When the participant came for the session on the second day the think aloud technique was discussed with the participant and then employed in the laboratory session.

3. The third step was to have participants practice thinking aloud in real traffic as they drove to the start location of the trial (Tift roundabout).

The participants of this study were well practiced in the think aloud task, as ‘narrative driving’ is part of the methods used by driving instructors to teach their students. During the think aloud session the participant drove the test route while reporting on what he or she paid attention to while driving. The narration was recorded on the GoPro camera track with an external microphone that was attached to the participant’s clothes (Figure 9). Eye tracking was active during the think aloud condition.

The instruction was to drive like one would normally do in the given situation, and to report verbally where the attention was placed throughout the drive.

During the trial an experimenter sat in the right back seat of the car to monitor the logging equipment and to prompt the participant to continue thinking aloud, in case of prolonged periods of silence. This turned out not to be necessary, however.
Figure 9. During the think-aloud condition while driving the participant wore a microphone attached to the GoPro camera that recorded the forward scene.

4.5. Data description and data reduction

For all ‘car’ conditions glance behaviour and vehicle data like speed, headway, GPS position, etc. were logged. Video of the forward and backward roadway was recorded. In the ‘car occlusion glasses’ condition the occlusion periods were logged as well, and in the ‘car think aloud’ condition the verbal report of the participant was recorded together with the forward film. In the ‘lab expert judgement’ condition, the participants’ notes on paper were collected, and in the ‘lab think aloud’ condition the verbal report of the participant was added as soundtrack to the film. All think aloud material was transcribed close to verbatim, leaving out disfluencies and filler sounds.

For all ‘car’ conditions the manoeuvres executed by the participant were logged according to the scheme in Table 4. The lane change manoeuvre from the right to the left lane was always started five seconds before an actual vehicle movement was visible, because it was assumed that the participant already prepared for the manoeuvre during this time.
Table 4. Manoeuvre classification for motorway driving.

<table>
<thead>
<tr>
<th>Manoeuvre</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entering motorway</td>
<td>always in the beginning, ends when the entire car body is on the motorway</td>
</tr>
<tr>
<td>Exiting motorway</td>
<td>starts when the first movement to the right is noticeable</td>
</tr>
<tr>
<td>Lane change left to right</td>
<td>starts when the first movement to the right is noticeable, ends when car fully positioned in the right lane (rightward movement is finished)</td>
</tr>
<tr>
<td>Lane change right to left</td>
<td>starts five seconds before the first movement to the left is noticeable, ends when car fully positioned in the left lane (leftward movement is finished)</td>
</tr>
<tr>
<td>Driving in right lane</td>
<td>starts when any of the line crossing manoeuvres is finished, ends when any of the line crossing manoeuvres begins</td>
</tr>
<tr>
<td>Driving in left lane</td>
<td>starts when any of the line crossing manoeuvres is finished, ends when any of the line crossing manoeuvres begins</td>
</tr>
</tbody>
</table>

4.6. Data reduction

4.6.1. Vehicle data

Of the data logged directly from the vehicle only speed was used for the present analyses. Speed was logged directly from the CAN bus.

4.6.2. Eye movement data

![Figure 10](image)

Figure 10. The view of the five cameras watching the participant’s face. The head rotation, the glance direction and the eye opening is indicated by the SmartEye Pro system.

Of the eye movement data only glance direction related data were used (see also Figure 10). The world model of the experimental car (Figure 11) was used to determine whether the participant glanced at or through any of the targets listed in Table 5.
Figure 11. The SmartEye Pro world model of experimental car. Each square and sphere indicates a target that can be looked at or through (if it is transparent, like the windows). The yellow dots indicate the position of the IR flashes and the small green/blue/red-markers indicate the positions of the five cameras.

Table 5. The targets marked up in the world model of the experimental car.

<table>
<thead>
<tr>
<th>Target</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windscreen</td>
<td>transparent – if the glance vector cuts the centre mirror first, the windscreen is not counted as looked through</td>
</tr>
<tr>
<td>Left window</td>
<td>transparent – the left mirror can be looked at through the left window</td>
</tr>
<tr>
<td>Right window</td>
<td>transparent – the right mirror can be looked at through the right window</td>
</tr>
<tr>
<td>Centre mirror</td>
<td>the objects representing the outer mirrors are somewhat bigger than the real objects, to compensate for noise in the eye tracking system</td>
</tr>
<tr>
<td>Left mirror</td>
<td></td>
</tr>
<tr>
<td>Right mirror</td>
<td></td>
</tr>
<tr>
<td>Frontal area underneath windscreen</td>
<td>includes the whole area underneath the windscreen down to the feet, but additional areas of interest are marked up and are located in front of this area in the world model</td>
</tr>
<tr>
<td>Instrument cluster</td>
<td>includes the rectangular area around the speedometer and the rpm meter and is somewhat bigger than the real object to allow for noise in the eye tracking system</td>
</tr>
<tr>
<td>Speedometer</td>
<td>these objects are somewhat bigger than the real objects to allow for noise in the eye tracking system</td>
</tr>
<tr>
<td>Rpm meter</td>
<td></td>
</tr>
<tr>
<td>Middle console</td>
<td>the area containing the controls for the heating system, the radio, etc.</td>
</tr>
</tbody>
</table>
Given that the participant looked through the windscreen, the scene cameras in combination with the overlay of the eye glance direction provided an indication of where the participant’s foveal vision was located. This information had to be coded manually. A coding scheme, combining the in-car targets and defined targets in the traffic scene was developed (Table 6). It was decided to start out with a relatively detailed coding scheme for data reduction to keep the options open.

*Table 6. Glance targets of the coding scheme developed for manual data reduction (‘outside’), as well as the relevant targets from the automatically logged ‘world model’ in the vehicle.*

<table>
<thead>
<tr>
<th>Dynamic (outside)</th>
<th>Static (outside)</th>
<th>Static (world model)</th>
</tr>
</thead>
<tbody>
<tr>
<td>first car ahead in left lane</td>
<td>left lane near</td>
<td>centre mirror</td>
</tr>
<tr>
<td>1+x car ahead in left lane</td>
<td>left lane far</td>
<td>left mirror</td>
</tr>
<tr>
<td>first car ahead in right lane</td>
<td>right lane near</td>
<td>right mirror</td>
</tr>
<tr>
<td>1+x car ahead in right lane</td>
<td>right lane far</td>
<td>instrument cluster</td>
</tr>
<tr>
<td>vehicle to the left (side by side)</td>
<td>object in emergency lane</td>
<td>middle console</td>
</tr>
<tr>
<td>vehicle to the right (side by side)</td>
<td>emergency lane</td>
<td>everything else</td>
</tr>
<tr>
<td>moving vehicle in emergency lane</td>
<td>outside of road, left</td>
<td></td>
</tr>
<tr>
<td>moving vehicle on entrance ramp</td>
<td>outside of road, right</td>
<td></td>
</tr>
<tr>
<td>moving vehicle on exit ramp</td>
<td>speed limit signs etc.</td>
<td></td>
</tr>
<tr>
<td>oncoming traffic</td>
<td>all other signs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>barrier (left)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>barrier (right)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>entrance ramp</td>
<td></td>
</tr>
<tr>
<td></td>
<td>exit ramp</td>
<td></td>
</tr>
</tbody>
</table>

The forward view recorded with the SmartEye system, merged with the glance vector and annotated with the frame number looked like shown in Figure 12. As described above, the forward view was recorded with two cameras whose pictures were then merged. Due to this reason a slight offset between the cameras is visible in the forward view for longer distances.
In order to evaluate the functionality of the coding scheme, one half lap for one participant was coded manually. It became clear that such a target related coding scheme, that at the same time is free of meaning and context, does not really fulfil the needs of the envisaged algorithm. For example, an overtaking vehicle will first be coded as ‘centre mirror’ or ‘right mirror’, then as ‘vehicle to the left (side by side)’ and then as ‘first car ahead in left lane’. It can change label more often if it overtakes more cars and then changes lanes back to the right lane. Therefore, the necessity to develop a more context- and meaning-filled coding scheme was identified – for example it may be more meaningful to identify glances to ‘the overtaking vehicle’, possibly with enriched information as to how this vehicle moves in relation to the own vehicle.

Within the given framework it was not possible to develop and test such a coding scheme. Some basic empirical groundwork has been laid, however, such that the development of a meaningful classification scheme can be started there. It has to be noted, though, that manual or semi-manual video analysis always is tedious, and in the present case hardware as well as software issues made the coding even more complex.

4.6.3. Occlusion data

The log data of the occlusion glasses are a continuous indication of whether the glasses currently are open or closed. This information is time synchronised with the remaining log data. Closing time, opening time, durations and frequency can be derived from this log. No additional data reduction was performed.

4.6.4. Think-aloud data

All think-aloud protocols were transcribed. The transcription method used was not completely word for word, but staying close to the spoken word and capturing the meaning, while leaving out repetitions and disfluencies. This was done partly to make it easier to read the text and partly to improve accuracy for word counts, etc.

Analysis of the transcribed texts was done based on Trickett and Trafton (2007), using the Natural Language Toolkit 3.0.3 (Bird, Loper, & Klein, 2009) framework in Python 2.7.7. Speech tagging was performed with Hunpos 1.0 using a Swedish model trained on the Stockholm Umeå Corpus (Halacsy,
Kornai, & Oravecz, 2007; Megyesi, 2008; SUC, 1997). Frequency distributions of nouns, verbs and collocations (a sequence of words that co-occur more often than would be expected by chance – here only sequences of two words were considered) were extracted. Nouns were extracted to quantify what the participants paid attention to, verbs to quantify what the participants were doing, and collocation were extracted to get a grasp of what the participants were doing in relation to what object.

For the collocation analysis, the text was preprocessed by applying the Swedish Snowball stemmer (to reduce inflected or derived words to their word stem) and by removing Swedish stop words (common words such as by, to, that, and, at). All analyses were conducted on the Swedish text and the results were subsequently translated to English for the report. It was sometimes necessary to use several English words to capture the meaning of one single Swedish word.

Extracted nouns, verbs and collocations were merged manually when they contained similar information. For example, ‘see [the] car’ and ‘looking [at] [the] vehicle [ahead]’ were merged to ‘check vehicle’. A cut-off at 20 occurrences in the field trials and at 7 occurrences in the lab trials was set to avoid rare words and phrases. The different cut-offs were due to the latter trials’ shorter duration.

4.6.5. Written description

The written descriptions were transferred into digital format. The analysis was conducted using a content analysis of the digital data material. Content analysis seeks to identify themes in a text or audio recording, and describes the key messages (Bryman, 2012). A content analysis approach normally starts with careful reading of the material in order to get an overview. Thereafter follows a categorisation of statements that are considered meaningful with respect to the research questions. After this a condensation of categories into different themes follows, which will usually later be described in the results section. The analysis process in this part of the study followed this set-up. Sometimes, however, the categorisation and thematisation was done in the same step, because specific research questions could be formulated based on the general aim, before the analysis begun.

The strength of the qualitative approach lies in its ability to capture a deeper understanding of a conception or notion of a phenomenon, rather than to come up with statistically generalisable results. The quotations presented in the results section are intended to express the unified picture rather than a specific participant’s expressions. On some occasions, however, some informant's perceptions substantially differed from the common picture. In those cases this is highlighted.

4.6.6. Written percentage distribution

The numbers written on the paper sheets were coded according to the scheme in Table 6. Four out of the 25 participants who had filled in the sheets had, by drawing a circle round the whole forward view, indicated the percentage for a larger target area at once. Therefore the target category ‘forward in general’ was added.
5. Performance indicators

For glance behaviour and occlusion behaviour the performance indicators (PIs) specified in Table 7 were computed per:

- participant
- condition (day, darkness, think aloud, occlusion)
- direction (eastbound, westbound)
- lap (first, second or third)
- manoeuvre (whole section, driving in right lane, driving in left lane, lane change left to right, lane change right to left, entering motorway, exiting motorway)

Therefore the maximum number of cases produced per participant is 168. Four of the additional participants only drove one daytime round and three occlusion rounds, in two cases the eye tracking equipment failed before the end of the trip was reached, and on 10 segments no overtaking manoeuvres took place. The additional participants did not drive the darkness and think aloud conditions. For some analyses the data from one or two participants had to be included for different conditions, as the data quality was not sufficient. Therefore the actual number of cases used varies across analyses.

Most vision related PIs are based on glances. A glance is defined based on the glance targets defined in Table 5. The start of the glance is when the gaze direction first intersects a zone and the end of the glance is the last data point before the gaze direction leaves the zone. Some analyses are done on fixations, which were determined in a two-stage segmentation process based on 2D velocity and dispersion, originally developed to suit remote eye tracking data from complex environments (Ahlstrom, Victor, Wege, & Steinmetz, 2012). The 2D velocity of vertical and horizontal gaze data was calculated using Savitzky-Golay smoothing and differentiation (Nyström & Holmquist, 2010; Savitzky & Golay, 1964). The polynomial order of the filter was set to 3 and the window width was set to 0.2s. The velocity threshold was set to 10°/s. The velocity threshold was deliberately set too low in order to make sure that all saccades were detected. The false detections were then removed in the dispersion step of the algorithm by checking whether the fixation candidates were spatially close. Since remote eye trackers have much worse accuracy, precision and availability in peripheral regions compared to the central forward view (Ahlstrom & Dukic, 2010; Beinhauer, 2006), the threshold for what is defined as spatially close is dependent on where the driver is looking. Here the threshold was defined such that the dispersion area becomes small in the central region and then gradually increases for more peripheral areas according to:

\[
\begin{align*}
1.5 & \left(0.54-0.46\cos\left(\frac{2\pi d}{80}\right)\right) & -3^\circ \leq d \leq 3^\circ \\
17 & & -40^\circ < d < -3^\circ, 3^\circ < d < 40^\circ \\
& & d \leq -40^\circ, d \geq 40^\circ
\end{align*}
\]

The PIs are based on the data available within each case. Data availability depends on manoeuvre length and the participants’ behaviour. For short manoeuvres like ‘entering motorway’ the absolute number of glances to different targets is much smaller than for manoeuvres of longer duration, for example ‘driving in right lane’. In Table 8 the total number of glances to different glance targets is provided for orientation.
Table 7. The performance indicators computed per participant, condition, direction, lap and manoeuvre.

<table>
<thead>
<tr>
<th>Performance Indicator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Driving behaviour</strong></td>
<td></td>
</tr>
<tr>
<td>Data segment length</td>
<td>The accumulated length in km driven in a certain manoeuvre.</td>
</tr>
<tr>
<td>Mean speed</td>
<td>The mean velocity for the segment in question.</td>
</tr>
<tr>
<td>Number of overtakings per minute</td>
<td>The number of overtaking manoeuvres (lane change from right to left, followed by driving in the left lane, followed by a lane change from left to right) were calculated per minute.</td>
</tr>
<tr>
<td>ACC activation</td>
<td>The percentage of the data segment with ACC active.</td>
</tr>
<tr>
<td><strong>Eye movement based</strong></td>
<td></td>
</tr>
<tr>
<td>Number of glances to target X per minute</td>
<td>The number of glances per minute to a certain target. Each glance to a target started when the filtered signal crossed into the target area and ended when the signal left the target area.</td>
</tr>
<tr>
<td>Mean duration of glances to target X</td>
<td>The average duration of the time during which the signal rested in the area of target X without leaving it.</td>
</tr>
<tr>
<td>Percentage of time spent looking at target X</td>
<td>The percentage of time spent in total with the gaze dwelling on a certain target. It is a combination of the number of glances and the mean glance duration.</td>
</tr>
<tr>
<td>... away from target X ...</td>
<td>To compute indicators related to glances away from a certain target, the duration from the end of one glance to the target to the beginning of the next glance to the target. In the occlusion condition an occlusion period is subsumed under ‘away’.</td>
</tr>
<tr>
<td>prc8</td>
<td>Percentage of glances directed at a circle with a radius of 8 degrees around the modal point computed for a sliding window of 1 minute duration.</td>
</tr>
<tr>
<td><strong>Occlusion based</strong></td>
<td></td>
</tr>
<tr>
<td>Number of occlusions per km</td>
<td>The average number of times per kilometre for which a participant activated the occlusion glasses.</td>
</tr>
<tr>
<td>Mean duration of occlusions</td>
<td>The average duration of each single occlusion.</td>
</tr>
<tr>
<td>Percentage of time occluded</td>
<td>The percentage of time spent occluded in total. It is a combination of the number of occlusions and the mean duration of occlusions.</td>
</tr>
<tr>
<td>Max occlusion duration</td>
<td>The maximum occlusion duration within one case.</td>
</tr>
</tbody>
</table>
Table 8. The total number of glances to the different gaze targets defined in the world model (Table 5) per manoeuvre and condition.

<table>
<thead>
<tr>
<th>Target</th>
<th>Day</th>
<th>Dark</th>
<th>Occlusion</th>
<th>Verbal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windscreen</td>
<td>313</td>
<td>218</td>
<td>219</td>
<td>219</td>
</tr>
<tr>
<td>Right window</td>
<td>1</td>
<td>2</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Left window</td>
<td>258</td>
<td>154</td>
<td>326</td>
<td>215</td>
</tr>
<tr>
<td>Right mirror</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Left mirror</td>
<td>194</td>
<td>117</td>
<td>270</td>
<td>151</td>
</tr>
<tr>
<td>Centre mirror</td>
<td>45</td>
<td>8</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Speedometer</td>
<td>101</td>
<td>109</td>
<td>169</td>
<td>77</td>
</tr>
<tr>
<td>Cluster</td>
<td>25</td>
<td>16</td>
<td>40</td>
<td>9</td>
</tr>
<tr>
<td>Total</td>
<td>937</td>
<td>624</td>
<td>1317</td>
<td>1317</td>
</tr>
</tbody>
</table>

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In Figure 13 the log from one participant on one segment is shown. In the first half of the segment the participant conducted three overtaking manoeuvres in short succession, and in the second half he remained in the right lane. The occlusions occur mostly while in the right lane, and their frequency decreases in the end of the right lane driving – before a lane change or exiting the motorway is initiated. Speedometer glances are most frequent when entering the motorway, but occur throughout the trip. Mirror glances are frequent, perhaps especially so close to lane changes.

Figure 13. The log of one segment of one participant. The grey line indicates the manoeuvres, the blue line indicates occlusions and the orange line indicates the gaze targets.

Figure 14 is a magnification (duration one minute) of the middle section of Figure 13. It starts out with driving in the right lane, then an overtaking manoeuvre occurs, and the section ends with driving in the right lane. The participant occluded his vision once while in the left lane, in the end of changing lanes back to the right lane, and several times while in the right lane. Mirror glances were most frequent when preparing for the lane change from right to left, and also during the lane change.

Figure 14. The same log as in Figure 13, but zoomed in to one minute of driving.

In the following section occlusion behaviour, glance behaviour and the verbal comments about attention distribution will be analysed and put into relation to each other. All inferential statistical analyses were conducted with an alpha level of .01. This was done to compensate for mass
significance as well as to avoid an over interpretation of effects. However, given the small number of participants especially during the darkness and the think aloud conditions, the results should be taken more as indications of trends than as hard facts.
6. Results from pilot study

A number of different methods were employed to collect different types of data that were hoped to give information about the proper attention allocation in the situation in question. The main purpose of this study was to evaluate these different methods for their suitability of assessing attention distribution, both with regard to the data collection procedure and the data quality and analysability. To this end the following steps were evaluated:

- acquisition, installation and usage of equipment etc.
- data collection procedure
- data reduction procedure
- data analysis

In the beginning of each section the practically experienced advantages and disadvantages experienced with each method are discussed, such that a context is provided for the interpretation of the results.

6.1. Driving behaviour

First analyses compared a number of driving parameters across conditions, to investigate whether the general conditions were comparable between the different conditions.

The distance spent in all manoeuvres specified in Table 4 was compared across conditions, direction and lap for all participants. There were no significant differences for any of the investigated factors (F(17, 1146) = 0.43; p > .01). The distance spent in the different manoeuvres is presented in Table 9.

Table 9. Distances driven and percentage of total distance for the different manoeuvres.

<table>
<thead>
<tr>
<th>Manoeuvre</th>
<th>Distance</th>
<th>Percent of total distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entering motorway</td>
<td>0.26 ± 0.09 km</td>
<td>4%</td>
</tr>
<tr>
<td>Exiting motorway</td>
<td>0.16 ± 0.10 km</td>
<td>2%</td>
</tr>
<tr>
<td>Lane change left to right</td>
<td>0.39 ± 0.37 km</td>
<td>5%</td>
</tr>
<tr>
<td>Lane change right to left</td>
<td>0.59 ± 0.35 km</td>
<td>8%</td>
</tr>
<tr>
<td>Driving in right lane</td>
<td>4.27 ± 1.95 km</td>
<td>60%</td>
</tr>
<tr>
<td>Driving in left lane</td>
<td>1.50 ± 1.18 km</td>
<td>21%</td>
</tr>
</tbody>
</table>

An analysis of speed showed that the participants drove slightly, but significantly (F(3, 170) = 4.2; p < .01) slower (99.8 km/h) on average during the darkness condition than during the other conditions (day: 102.0 km/h; occlusion: 102.9 km/h; think aloud: 103.0 km/h). There was a tendency to drive more slowly in the westbound direction (102.2 km/h) than eastbound (103.9 km/h), which may be due to the main wind direction coming from the west. There is practically no difference in ascent and descent in each direction, and as the manoeuvres were distributed similarly, it can be assumed that traffic was not too different, either.

The number of overtakings per kilometre did not differ between conditions, for direction or lap number (F(23, 170) = 0.68; p > .01) and lay at 0.43 overtakings/km on average. The distribution of the different manoeuvres across the test area over all conditions is shown in Figure 15. The frequency of
left lane driving is slightly reduced in the area between the off-ramp and the on-ramp, but increases again in the area of the on-ramp.

Figure 15. Distribution of manoeuvres (%) across the test track per direction over all conditions, participants and laps. Map data ©2015 Google.

The average usage of ACC was slightly but significantly $F(3, 1096) = 3.8; p < .01$) higher during the occlusion (30.1%) than during the darkness (19.1%) condition. The day (24.7%) and think aloud conditions (24.0%) did not differ significantly from any other condition. The main variation was with the type of manoeuvre, however, with ‘entering motorway’ and ‘exiting motorway’ showing an ACC activation of about 0-8% and the other four conditions showing an activation of 25 to almost 50% ($F(5, 1096) = 31.9, p < .01$). It was also found that within each manoeuvre type the ACC was either on for more than 75% of the time or less than 25% of the time. Therefore, the ACC variable was split up into the two categories on, comprising the former group, and off, comprising the latter group.

6.2. Glance behaviour

A quality check was conducted for the eye tracking data, to make sure that only reliable data were included in the following analyses. In the present case film recordings of all participants’ trips existed. As the data reduction procedure required numerous manual steps, which also included a visual inspection of each of the recorded films, it was a natural step in the procedure to check for the quality of the data by viewing the film and making a subjective judgement. This is a very reliable, but time consuming method to identify instances of bad tracking. To a human observer it is immediately obvious whether a recording is of high or low quality, even though it may be complex to parse this implicit knowledge into pattern recognition algorithms.

The visual inspection showed that one participant had to be excluded for the conditions Day and Darkness. In those conditions the automatically generated ‘profile’ did not lock onto the correct facial features reliably, but shifted and jumped between different positions, which led to an erroneous and erratic glance tracking. The resulting glance data were useless and had to be discarded. No such problems occurred for the other two conditions, and the gaze data from all other participants were of good quality.
6.2.1. Method related

The eye tracker used was a high-end remote system (Smart Eye Pro 6.1) with five cameras and two scene cameras. As suggested by the manufacturer, instead of tracking eye movements in real time it was decided to record a film of the trip, such that tracking would be done as a second step. This was meant to ensure a higher data quality, as more adjustments and improvements would be possible with this setup. However, it turned out that the software still contained a bug, with the consequence that the recorded films contained a non-neglectable number of black frames, which disturbed the off-line eye tracking. A number of patches had to be implemented, such that eventually the procedure to arrive at tracked eye movement data was very time consuming, cumbersome and error-prone. In addition, recording film from five cameras demands a lot of storage space, which leads to substantial investments in hard disks and further exacerbates the complications, as working with the data requires numerously swapping hard drives. Thus, in hindsight real-time tracking should have been used and is recommended for further studies.

Installing the hardware is technically demanding, and it takes both time and proficiency to set up all cameras correctly. The car has to be measured in relation to the system, such that a ‘world model’ of the car can be associated with the data (see also Figure 11). The scene cameras need to be installed and aligned with the coordinate system of the eye tracking software. Once the hardware is installed in the car, however, the procedure to start the recording/logging is simple and straightforward. For most people the resulting data are of good quality, and the usage of a five camera system prevented data loss even in extreme gaze directions, for example when looking at the right wing mirror or down at the middle console. However, certain types of glasses, especially with heavy frames, and eye make-up can disturb the eye tracker and reduce the quality of the recorded data.

6.2.2. Behaviour analysis

One objective of the study was to investigate the variance in glance behaviour within and between participants per manoeuvre, because this has effects on the usefulness of the method and investigated PIs for building a general required glance pattern. The investigated glance targets were traffic relevant targets outside of the forward view (mirrors and speedometer) as well as the forward view (window in general and prc8 more specifically). In Table 10 an overview is provided showing which factors and interactions were significant for which PIs per condition. Analyses were made using the GLM with the factors participant, manoeuvre and lap including all two-way interactions. Per condition and glance target a separate GLM was computed.

Table 10. Overview of how the factors participant, lap and manoeuvre as well as their interactions influence the performance indicators used mainly in the glance behaviour analysis.

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Day</td>
<td>**</td>
<td>***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Darkness</td>
<td>*</td>
<td>**</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Occlusion</td>
<td>***</td>
<td>***</td>
<td>*</td>
<td>**<em>(</em>)</td>
<td></td>
<td>(*)</td>
</tr>
<tr>
<td>Verbal</td>
<td>***</td>
<td>***</td>
<td>*</td>
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</tbody>
</table>

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<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Day</td>
<td>***</td>
<td>(*)</td>
<td>*</td>
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### Glance Duration and Percentage of Time Spent Looking at prc8

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*** = p < .001; ** = p < .01; * = p < .05; (*) = p < .10

Different participants have varying glance strategies for different manoeuvres

Overall there is a large difference between the participants in how many glances they directed at any of the investigated targets, how long these glances were, and which percentage of time they spent looking at the targets. The number of glances to the investigated targets, in many cases their duration, as well as the percentage of time spent looking at them is also highly dependent on the type of manoeuvre made. The glance duration to the speedometer is slightly less dependent on the manoeuvre type. In general it can be said, however, that the manoeuvre type has a large influence on how often, for how long and with which percentage of the total glance time the targets are glanced at, and there is also frequently an interaction between manoeuvre type and participant. This indicates that different participants have varying glance strategies for different manoeuvres. However, for the targets speedometer and mirror the participants’ behaviour seems to be quite consistent across laps – there are not many interactions with lap and any other factor either. For the forward view related targets the dependence on lap seems to be slightly higher, mainly in interaction with the factor ‘participant’, which can be due to different distributions of manoeuvre types across laps within one participant.

Glance behaviour is consistent within each participant and manoeuvre

Generally, it can be said that the glance behaviour with respect to the investigated targets and PIs seems to be consistent within each participant and manoeuvre, such that ‘lap’ and therefore ‘learning’ will not be considered in the following analyses. Even though ‘participant’ shows clear effects, it will not be taken into account in the following analyses either. This is partly due to the fact that not all participants contributed to all conditions, and that the low number of participants in general does not afford a meaningful analysis of inter-individual differences. The main reason is, however, that this is mainly a methods test, investigating whether it is possible to describe the minimum required attention
for motorway driving independent of the driver. Therefore, it is necessary to find effects that persist over and above inter-individual differences.

**Glance duration, but not glance frequency, is reduced during occlusion**

Further GLM analyses with the factors ‘manoeuvre’ and ‘condition’ were conducted separately for each glance target, always using the mean number of glances, the mean glance duration and the percentage of glances to the target as dependent variables. All multivariate tests were significant, and the between-subjects effects are explained in more detail below.

In Figure 16 the mean values are presented per PI, the glance targets ‘all mirrors’ and ‘speedometer’, manoeuvre type and condition. Mirror glances were generally least frequent during darkness and most frequent while thinking aloud (F(3, 839) = 10.0, p < .01), with no difference between day and occlusion. In the occlusion condition the mirror glances were shortest, followed by driving in darkness, but overall the differences were not large across conditions or manoeuvres, with the average mirror glances lasting between 0.3 to 0.5 s except while thinking aloud in the right lane, where the average mirror glance duration was 0.65 s. The percentage of time spent looking in the mirrors was comparable across conditions and manoeuvres with the exception of the think aloud condition, in which about 5% more time was invested into the mirror in all manoeuvres.

**Glance frequency, but not glance duration, is affected by manoeuvre type**

The type of manoeuvre had a larger effect on the number of glances than on the mean duration of glances. The highest share of mirror time (ca. 15–20%) occurred when entering the motorway, the lowest share (around 7% for all conditions except think aloud) was found for driving in the right lane, which did not require any active interaction with other traffic. Overall, the percentage of mirror glancing time was not shorter in the occlusion condition than during daytime or darkness.

**Drivers spend 5% of their time checking mirrors during normal driving**

For those ten segments in which no overtaking manoeuvres occurred, the average percentage of mirror glances when driving in the right lane lay at 4.8%. Thus, even though no overtaking manoeuvres were conducted at all, the participants still paid some attention to the traffic behind them.

**Type of manoeuvre affects the time spent looking at the speedometer**

For the speedometer glances the durations tended to be shorter during darkness than during the day (F(3, 769) = 2.9, p < .05). The overall percentage of time spent looking at the speedometer was not influenced by condition, but it was by manoeuvre (F(5, 769) = 11.4; p < .01). ‘Exiting motorway’ led to the highest speedometer glance time in all daylight conditions with about 11–12%.

No interaction effect between manoeuvre and condition existed for speedometer glances, but mirror glances were longer on average when driving in the right lane in the think aloud condition (F(15, 839) = 3.1, p < .01).
Time spent looking forward is significantly reduced in the occlusion condition

Not only glances away from the forward view, but also glances towards the forward view were analysed. The regions of interest were the whole window as well as prc8, that is, the small region around the most frequent focus point. Figure 17 shows the mean values for the investigated PIs per glance target, manoeuvre type and condition.

The occlusion condition deviates clearly from the remaining conditions. The mean glance duration to the windscreen is similar within manoeuvre across conditions, except for the occlusion condition in the manoeuvres ‘driving in right lane’ and ‘exiting motorway’, where it is about 0.5-1 s shorter than for the other three conditions – the interaction effect for mean glance duration is significant at the .01-level for ‘window’, but not significant for ‘prc8’. For the resulting percentage of time spent looking at the windscreen or prc8, a significant interaction effect between condition and manoeuvre appears (windscreen: F(15, 949) = 3.9, p < .01; prc8: F(15, 949) = 2.6, p < .01), where the time spent looking forward is significantly reduced mainly for driving in the right lane in the occlusion condition, and where drivers spend most time looking forward in the darkness condition.
Windscreen

mean number of glances per minute

- day
- night
- occlusion
- think aloud

mean glance duration (s)

- day
- night
- occlusion
- think aloud

pre8

Condition

- day
- night
- occlusion
- think aloud
Windscreen

Figure 17. Mean values of the three investigated PIs for glances to the window and prc8 per condition and manoeuvre.

Glances that last longer than over a distance of 80 to 100 m are very rare

Histograms showing the number of fixations per glance and the glance duration in metres for the forward view glance targets during the different manoeuvres across all conditions are shown in Figure 18. These curves show that most of the windscreen glances consist of 6 fixations or less. More than 12 fixations per windscreen glance are extremely rare. For prc8 the figures are slightly smaller, with about 4 fixations per glance and rarely more than 8 fixations.

Most often the glances do not last longer than the time needed to cover 40 m, and glances that last longer than over a distance of 80 to 100 m are very rare. There are some variations across manoeuvres, where ‘entering motorway’ is the clearest exception with a higher frequency of short glances and a lower frequency of long glances to the forward view targets.
Not enough to look at the average number of glances

When attempting to set up rules for how often a certain target needs to be attended to it is not enough to look at the average number of glances alone. If the targets are not glanced at with regular intervals, but possibly twice in a row with a following longer break, this does not show in the mean values. Therefore a plot of the frequency distribution of the distance covered in between glances to the targets can provide additional information (Figure 19). The plots show that very short distance intervals between glances to mirrors are very frequent in all manoeuvre types. The pattern is similar for the speedometer, except that the typical interval between glances is slightly longer. However, the two manoeuvres driving in left lane and especially driving in right lane also contain a number of longer intervals, and the frequency of very short intervals is much lower for these two manoeuvres.

Mirrors and speedometer are usually checked every 300 meters

Therefore, all glances with inter-glance intervals of less than three seconds were clustered and treated as a single glance. The underlying assumption is that these repetitive glances belong to the same ‘attention action’. In Figure 20 the histograms for the distance covered between glance clusters are
shown. For mirror glances entering motorway and the lane change manoeuvres disappear completely, as all mirror glances end up in the clusters. For the remaining manoeuvres it is more common with shorter between-cluster intervals between mirror glances when exiting the motorway than when driving in the right or left lane, which is also connected to the fact that the manoeuvre in itself was shorter. When driving within one lane the most common inter-cluster distance is around 300 m, and when driving in the right lane longer intervals are somewhat more frequent.

For the speedometer, glances clustering leads to a disappearance of the two lane change manoeuvres, because all glances end up in the clusters. Distances between clusters are shorter when exiting the motorway than when entering. When driving in either of the lanes the distances between clusters are distributed very similarly. They have a small peak between 200 m and 300 m, but intervals between 100 m and 700 m are common.

**Figure 20.** Histograms for the distance covered (in m) between glance clusters towards the mirror and the speedometer per manoeuvre across participants. Repetitive glances to the mirror or speedometer are clustered into one glance for inter-glance intervals of less than 3 s.

**Forward glances within clusters are shorter than forward glances in general**

Within each mirror or speedometer glance cluster, the participant looked forward in between the target glances. It is assumed that those glances mainly serve the purpose to check that the situation in front of the car is as expected, while the main attentional focus is still in the mirror or on the speedometer. The average duration of forward glances within clusters is therefore an indication for the minimum duration needed to collect information from the forward scene when under slight pressure to sample the rearward scene or the current speed.

For the mirror clusters the average glance duration forward was 1.1 s, and there were no differences between the four conditions (F(3, 681) = 2.3; p > .01). A difference for manoeuvre type was found (F(5, 681) = 3.4; p < .01), however, as can be seen in Figure 20, this is mainly due to the means in the exiting motorway manoeuvre, where the number of clusters was small (see Table 8).

The forward glances within the speedometer clusters were with an average of 1.2 s of a similar duration. There was a significant difference between conditions (F(3, 466) = 16.4; p < .01), but not for manoeuvre (F(5, 466) = 0.8; p > .01). As visible in Figure 20, the within-cluster forward glance duration is slightly longer in the night condition and slightly shorter in the occlusion condition, and the larger spread of values in the exiting manoeuvre is likely due to the small number of speedometer glances and therefore glance clusters while exiting.
Figure 21. Mean durations of forward glances within mirror and speedometer clusters per condition and manoeuvre.

Looking straight ahead is the visual default mode

The average number of glances away from the window corresponds very closely to the average number of glances to the window, indicating once more that drivers typically glance through the windscreen after every glance away from it, instead of moving the glance from one other target to the next. Looking straight ahead can be seen as a visual default mode where all other gaze directions emanates from. The average duration of glances away from the windscreen lay below one second, even in the occlusion condition when driving in the right lane. Given that the average occlusion duration was almost two seconds in this condition (see below), the occlusions have to be a small percentage of all glances away from the windscreen, and the typical glances away are much shorter on average. During daytime the average glance duration away from the windscreen lay at 0.5 to 0.6 s (average 0.57 s), during darkness the average duration was significantly shorter (F(3, 924) = 37.1, p < .01) with about 0.4 to 0.5 s (average 0.45 s; Figure 22).
The time spent on ‘other targets’ increases during occlusion

It was also analysed how much time was spent glancing at targets that are not the windscreen, the speedometer or any of the mirrors. This includes glances through the side windows, to other objects inside of the car, and, in the occlusion condition, also the occluded periods (Figure 23). A first analysis with the factors participant, condition, lap and direction showed that there are individual differences between participants (F(10, 1022) = 13.1, p < .01) as well as between conditions (F(3, 1022) = 44.2, p < .01), with the occlusion condition leading to a much higher share of glances to ‘other targets’ (15% instead of 6–8%). Neither lap (F(2, 1022) = 2.1, p > .01) nor direction (F(1, 1022) = 2.2, p > .01) had any effect on the percentage of glances to the remaining targets. The only significant interaction was found between participants and condition (F(15, 1022) = 10.8, p < .01).

An analysis with the factors condition and manoeuvre showed a significant interaction between the two factors (F(15, 1081) = 8.1, p < .01), which partly explains the significant difference in manoeuvre. For all manoeuvres ‘other targets’ were glanced at with a higher percentage during the occlusion condition (F(3, 890) = 95.4, p < .01), but the effect was most pronounced when driving in the right lane and when changing lanes back into the right lane.
Figure 23. Mean percentage of glances directed at ‘other targets’ per condition and manoeuvre.

Glance behaviour during lane change manoeuvres

As expected, the data show that drivers devote more time to look into the mirrors when changing lanes as compared to driving straight on. Figure 24 shows that the mirror glances increase to about 30 to 40% of all glances around 50 m before the lane change is actually initiated, and the centre mirror is more and more abandoned for the left mirror. During that time speedometer glances are rather uncommon, but they increase in likelihood already during the lane change and comprise about 10% of the glances at about 100 m after the initiation of the lane change. The most common glance target during the whole manoeuvre is the road centre (radius 8 degrees). About 400 to 200 m before the lane change is initiated, the frequency of lost eye tracking is comparatively high at about 15 to 20%. This is likely a result of glances over the shoulder on the left hand side. This area was out of range for the eye tracker, and the systematic increase of lost tracking in similar locations across conditions supports this interpretation.

The most obvious differences between conditions are the larger presence of centre mirror glances in the think aloud condition. Particularly after the lane change initiation the centre mirror glances are more frequent. In the occlusion condition the speedometer glances appear somewhat more frequent especially also just before the lane change is initiated, while mirror glances occupy a smaller area than in the other conditions. Occlusions occur throughout the manoeuvre, possibly with a slight reduction just around the initiation of the lane change and around 200 m before that moment.
Figure 24. Glance distribution (in %) for the 400 m before a lane change from right to left was initiated (at point 0) to 200 m after the lane change was initiated across all right-to-left lane changes and all participants.

In Figure 25 the glance distribution for the lane change back into the right lane is shown. Here, the centre and right mirror are checked just before the manoeuvre is initiated, and the peak is much narrower than for the lane change into the left lane. Speedometer glances are rare around the actual lane change initiation, but rather common afterwards, when the vehicle is back in the right lane, which typically happens about 100 to 150 m after the initiation of the manoeuvre.
Spatiotemporal glance behaviour

It is not only of interest to analyse how the drivers’ glance behaviour varies with manoeuvre. The variation with the physical location can give information as to whether certain glances appear to be required in certain geographical locations. Figure 26 shows the distribution for driving eastward and Figure 27 for driving westward. These figures are mainly included to show the potential of a location based presentation. In the present study the number of participants was too small to produce smooth patterns. Still, in the eastward direction an increase of window glances outside of the prc8 area can be observed at around 3000 m and in the westward direction at about 5000 m. This is likely connected to the presence of the motorway entrance.
Figure 26. Glance distribution (in %) across targets for the whole road segment in the eastern direction, across all laps and participants.
Figure 27. Glance distribution (in %) across targets for the whole road segment in the western direction, across all laps, participants and manoeuvres.

To follow up on this, a plot showing the glance frequency to the right window or mirror was overlaid on a map (see Figure 28). This plot indicates clearly that glances to the right are much more frequent around on-ramps, where drivers watch for vehicles entering the motorway.
Drivers look less at the speedometer when using cruise control

The test vehicle was equipped with an ACC system, which could be used as desired by the participants. Plots of the duration between speedometer glances and between speedometer glance clusters are shown in Figure 29. Both with and without clustering it is apparent that drivers let the intervals between speedometer glances get longer when ACC is switched on. The most frequent distance driven between speedometer glance clusters lies at around 150 m to 400 m, and inter-glance distances of 1000 m or more are rare.

Figure 29. Distance (m) between speedometer glances across all participants, laps, conditions and manoeuvres, depending on whether ACC was on or off.
6.3. Visual occlusion

6.3.1. Method related

The main advantages of the occlusion glasses used in the study are presented in the methods section under “Conditions and equipment” on page 27. A drawback of the self-built glasses was that they were rather fragile and required careful handling. There were also some minor issues that always could be solved quickly by the constructor of the glasses, but for more intensive usage it will be necessary to build a sturdier version.

The glasses covered the forward view completely, but the peripheral vision was not shut off completely. It is possible that this construction leads to an occlusion behaviour that differs from glasses that totally shut off vision, but on the other hand it can be argued that drivers who look away from the forward scene often have limited peripheral vision available. Thus, the glasses used in this study possibly correspond more to the natural experiences of ‘looking away from the forward roadway’.

The participants’ answers to the short questionnaire about the occlusion condition are listed in Table 11. All participants reported a strategy, which basically contained the plan to close the glasses when it felt safe to do so. Most participants reported that they could have closed the glasses more often, that they felt not or slightly uncomfortable during the closing phase, and that their driving did not become substantially more dangerous, given that they themselves could choose the closing occasions.

Table 11. All 12 occlusion condition participants’ answers to four short questions about the occlusion situation (translated from Swedish).

<table>
<thead>
<tr>
<th>Did you have any strategies for when and how you closed the glasses?</th>
<th>Do you think you could have closed them more often, or where you on max? Which percentage of the ‘closing possibilities’ did you use?</th>
<th>How did it feel during the closing phase?</th>
<th>Would you say that your driving became more dangerous than when driving normally?</th>
</tr>
</thead>
<tbody>
<tr>
<td>When I did not have any cars close by, both in front of me and behind. Straight road. Good visibility around.</td>
<td>40%</td>
<td>Rather uncomfortable, no control over what is happening. I did not want to close the glasses for any longer period of time.</td>
<td>Maybe a bit more dangerous, because in normal driving I would not have chosen to lose focus on the road and traffic that often.</td>
</tr>
<tr>
<td>When I saw that it was calm around me I closed the glasses. When it was very calm I closed them with a higher frequency.</td>
<td>To feel completely safe this was max. I could have closed the glasses a bit more, running the risk that lateral control would have suffered.</td>
<td>Because I used the occlusion when everything was calm, it felt fine.</td>
<td>No.</td>
</tr>
<tr>
<td>I closed when I felt I knew what was going on.</td>
<td>95%</td>
<td>Totally ok, one learns when it is ok to close. When closing for too long the eyes started focusing straight ahead without having to think about it.</td>
<td>It got a little more dangerous, but not much.</td>
</tr>
<tr>
<td>My strategy for closing the glasses was to close in those occasions when I could continue in my lane undisturbed. When I did not plan to overtake myself, was overtaken or was close to somebody else.</td>
<td>I could have closed the glasses a lot more often, I closed them about 40% of the capacity. I could have flickered with them several times per minute!</td>
<td>It didn’t feel troublesome at all during the closing phase. All other senses got sharper, like hearing, the feeling in the body with steering wheel movements, and to keep up the current speed.</td>
<td>I don’t think that my driving became more dangerous at all. I only closed the glasses at selected moments.</td>
</tr>
</tbody>
</table>
I looked around and closed the glasses when I considered the risk for a deviation from my course as small. I waited with closing the glasses when I saw that other cars were on their way to overtake me. I could have closed more often. But I considered this to feel unusual. It would have felt like I only closed them ‘just because …’. I used about 70% of the possibilities. It felt quite fine. But I did not want to close them for too long because of the lateral positioning. But I never experienced it as uncomfortable.

No.

When I felt I knew what was going on, that is, I had checked speed and course and the surrounding traffic. I could probably have closed them more often and a little longer in a few cases. About 70 to 80%. A little uncomfortable, but I got used to it, and in the end it felt fine. Possibly in a few occasions, but probably only a feeling. In reality my driving is probably more dangerous in normal life, when I am not especially focused, like in this case on the experiment.

Before closing them I checked for possible cars that could get into my lane. I also checked my distance with the car in front, my lane position and the proximity of any exit (because cars in front could slow down …) Yes, I could have closed more often. I think I closed them an 80% of the possible total time. Relaxed and confident. Under normal conditions and with no ‘unexpected’ events I consider my driving almost as good as my normal driving.

When it was free in front of me. I also had a lot of help from the ACC which adjusts the distance to the car in front. I think I closed about 30% [of the whole driving time], but 50% [of the whole driving time] should have been possible. It didn’t feel as bad as I’d have thought before. No! Traffic was quite calm.

Yes. When it felt safe I closed them. When it started to feel insecure I opened them again. I think I could have closed them more often. I was not on my maximum, maybe at 75% I would think. Scary when they were closed. That is, increasingly scary with increasing closing time. Yes – but only marginally, because I closed them when I was sure!

My strategy was to close them when I felt confident in the situation; how the traffic was, whether the road was straight or not, no overtakings etc. … I probably could have closed them more often, mainly because traffic on that day was really calm and the road conditions were good, but at the same time I did not want to close them for too long, it’s a difficult balancing act. Used maybe 85% of the possibilities. It felt fine, I only closed for short moments, so it never felt like any danger. It would have been worse when there had been more traffic, slippery roads or in an inner-city situation. No. I don’t really think so, but I was more tense when I drove with the glasses compared to when I drove without them.

I checked that it was quite ‘empty’ around me and the road straight (also for motorway conditions, where there aren’t really any ‘curves’), and how it looked a bit further ahead (and maybe behind). One invests probably more effort into choosing one’s ‘closing situation’ compared to just looking away in normal driving. I could have closed them more often. Used maybe 75% of the ‘possibilities’. Unfamiliar, but not especially dangerous or uncomfortable. No, one probably assumes (!?!?) that one has acceptable control when one chooses to close. In some occasions I did not realise that I drifted off laterally.

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6.3.2. Behaviour analysis

Two participants had misinterpreted the instructions and also stated in the follow-up questionnaire that they had only used about 40% of the occasions for occlusion. Thus, their data were removed from further occlusion analyses.

Spare capacity when driving on the motorway is at least about 12%

The number of occlusions per km, the average occlusion time and the percentage of time occluded were analysed per manoeuvre type. The mean values and standard deviations are shown in Table 12. The overall percentage of time driven with occluded vision was 11.8% across all manoeuvres and participants. Drivers occluded their vision most when driving in the right lane, followed by the exiting motorway manoeuvre. They chose to occlude their vision the least when entering the motorway or changing from the right into the left lane.

Table 12. Mean values and standard deviations for the performance indicators number of occlusions per km, mean occlusion duration and percentage time occluded per manoeuvre and for complete segments. The data are not normally distributed.

<table>
<thead>
<tr>
<th>Manoeuvre</th>
<th>Number of occlusions per km</th>
<th>Mean occlusion duration (s)</th>
<th>Percentage time occluded (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>whole segment</td>
<td>4.1 ± 2.8</td>
<td>1.9 ± 0.64</td>
<td>11.4 ± 5.5</td>
</tr>
<tr>
<td>entering motorway</td>
<td>0.80 ± 1.8</td>
<td>1.6 ± 1.0</td>
<td>1.6 ± 3.8</td>
</tr>
<tr>
<td>exiting motorway</td>
<td>1.5 ± 3.5</td>
<td>1.1 ± 0.43</td>
<td>2.2 ± 5.3</td>
</tr>
<tr>
<td>lane change left to right</td>
<td>3.8 ± 3.6</td>
<td>1.7 ± 0.74</td>
<td>9.6 ± 7.0</td>
</tr>
<tr>
<td>lane change right to left</td>
<td>1.8 ± 2.7</td>
<td>1.4 ± 0.89</td>
<td>3.7 ± 5.3</td>
</tr>
<tr>
<td>driving in right lane</td>
<td>4.7 ± 2.9</td>
<td>1.9 ± 0.63</td>
<td>14.0 ± 7.4</td>
</tr>
<tr>
<td>driving in left lane</td>
<td>2.7 ± 3.7</td>
<td>1.4 ± 0.67</td>
<td>5.4 ± 6.7</td>
</tr>
</tbody>
</table>

Little spare capacity left when passing entrances/exits

The box plots in Figure 30 clarify the relationship between the number of occlusions, the average occlusion duration and the percentage occluded per condition. Occlusions occur rarely when entering or exiting the motorway and are most frequent when driving in the right lane or when changing lanes from left to right. These two manoeuvres are also associated with the longest mean occlusion durations, therefore the time spent occluded is pronouncedly larger in those two manoeuvres, and especially when driving in the right lane, than in other manoeuvre types.
Drivers have different occlusion strategies

A multivariate general linear model with the dependent variables number of occlusions per km, the average occlusion time and the percentage of time occluded and the factors manoeuvre and participant was run, showing that both factors (participant: F(27, 380.3) = 14.0; p < .01; manoeuvre: F(15, 359.3) = 5.8; p < .01), but not their interaction (F(99, 390.1) = 1.4; p > .01) significantly influenced the combination of variables. Overall, this indicates that there is variation between participants in how frequently and for how long they occlude themselves, and that the manoeuvre plays a role for the occlusion behaviour. Most participants did not occlude their vision at all when entering and exiting the motorway.

Figure 31 shows histograms for the distance and time that passed between two occlusions within the same manoeuvre, that is, it indicates the length of the opening intervals. Rather short opening intervals are relatively seen most frequent for the manoeuvres ‘lane change left to right’ and ‘exiting motorway’, followed by ‘driving in the right lane’ and ‘driving in the left lane’. For ‘entering motorway’ and ‘lane change right to left’ not many short occlusion intervals exist.
The plots in Figure 32 indicate that some participants chose to occlude themselves more often than others, but that those participants with a higher occlusion frequency showed a lower mean occlusion duration. When the factors ‘participant’ and ‘manoeuvre’ are controlled for, the partial correlation coefficient between the number of occlusions and the mean occlusion duration equals $r = -0.44$ ($p < .01$), which means that in general there is an inverse relationship between the two – when longer occlusions are used, they are not as frequent as compared to shorter occlusions. Therefore, the effect of manoeuvre type is most interesting to analyse for the percentage of occlusions, which is a combination of the other two PIs.

Figure 32. Occlusion duration (s) vs. number of occlusions per participant and per manoeuvre.

More likely to occlude in connection to lane change from left to right and driving in left lane

Furthermore, it was investigated how long before the beginning of the next manoeuvre the last occlusion ended (Figure 33). The manoeuvre ‘exiting motorway’ was excluded, as the data collection ended during the exiting manoeuvre. For the lane change left to right and for driving in the left lane it was quite common that occlusions ended in close proximity to the next manoeuvre, or that they continued into the next manoeuvre. When driving in the right lane or entering the motorway it was more common not to occlude one’s vision in close proximity to the following manoeuvre. When changing lanes from the right to the left there is no clear peak – occlusions are equally likely to finish both close to the following manoeuvre or earlier on.
Figure 33. Distance from the ending of the last occlusion occasion to the beginning of the next manoeuvre, per manoeuvre that is currently performed, across all participants.

Occlusion frequency and duration increases when using cruise control

A t-test showed that usage of ACC is associated with an increased frequency of occlusion occasions ($t(337) = 6.6, p < .01$) and with an increased percentage of time occluded ($t(337) = 7.4, p < .01$), as can be seen in the probability distribution illustrated in Figure 34. However, neither the mean occlusion duration ($t(178) = -.98, p > .01$) nor the maximum occlusion duration ($t(178) = .52, p > .01$) were influenced by ACC usage, showing that the drivers allow themselves to close down vision more often, but not for longer at a time.

Figure 34. Distribution of the distance driven between two occlusions.
Spatiotemporal occlusion analysis

In principle it is of interest to investigate where drivers choose to occlude their vision, and especially whether there are any locations where drivers specifically choose not to occlude their vision. In Figure 35 the location based occlusion frequency is plotted per direction over all participants and laps. The plot does not allow a reliable conclusion about locations where drivers systematically avoid visual occlusion, but it is possible that a larger number of participants would change this, as the changes in frequency produced by random factors would be smoothed out.

Figure 35. Occlusion frequency for both driving directions across all participants, laps and manoeuvres. Map data ©2015 Google.

6.4. Expert judgement - written description

6.4.1. Method related

In this condition more than 200 participants contributed altogether, as the form was administered also during different courses and seminars with groups of driving instructors, as well as to a group of experienced drivers, who participated in a different study at VTI. Overall administration is very easy, and many participants can be reached at the same time. It is not even necessary for the participants to be in a certain place, the form can be mailed home to them.

The participants had a very varying level of proficiency in verbalising (in written form) their attention allocation while driving. Some wrote only a few words, while others produced up to two pages of text. In many cases the participants rather explained how they behaved than how they allocated their attention.

6.4.2. Data analysis

A qualitative data analysis was performed on the data provided by the driving instructors. The experienced drivers were not included, as they may have qualitatively different views of the matter. This was assumed, because driving instructors receive a formal education on how to transfer knowledge to their students.
The driving instructors expressed that the foundation, or the primal starting point, for motorway driving is to have one’s gaze and attention directed far ahead. The gaze should, however, be continuously moving around and not fixed at a certain point, in order to collect as much necessary information about the current situation as possible. This base foundation was illustrated by one participant as:

*The ‘baseline glance’ should be far ahead. However, be active in your search, don’t let the gaze stay at a certain point and pay special attention to risky places, for example [motorway] entries.*

A concrete figure was expressed in this context. The distance where the basic view should be directed is between 300-500 meters ahead. It is also of importance to check the rear mirrors now and then to see what is happening behind the own vehicle. The common notion was that this should be done roughly every ten seconds:

*Also look into the rear window every 8-10 seconds but also sometimes into the side mirrors. Behind the car as much is happening as in front of it.*

An agile scanning behaviour based far ahead was motivated such that it helps to control the position and speed of the car, to gather information about what other traffic is doing, and because it helps to anticipate unexpected events. To be able to foresee what is about to happen in the traffic environment in order to be prepared for the unexpected seemed to be of high importance. The need to keep a certain amount of attention directed at what is happening behind the car was not justified in the same way as the forward glances. What came through was that it was important to check the mirrors in order to get SA, but no motivation was expressed why this was important, and why it was important to check every 10 seconds. As exemplified in the quotation above, ‘much is happening behind the car’, but why that is of significance to know is not explained in detail. There might exist a sort of common sense understanding among driving instructors that regular rearward glancing is of importance for general SA, but not necessarily why this is so.

When passing an exit from the motorway the participants expressed that the attention should mainly be directed at the vehicles in front, in order to be prepared and facilitate if someone is exiting.

*When I pass by an exit I check if the traffic ahead or behind is intending to leave the motorway.*

The facilitation could be achieved by means of either reducing speed or making a lane change. It was also pointed out that it was of importance to raise the attention level in order to be able to act if a driver ahead makes a last minute decision to exit:

*When passing by an exit it’s good to observe possible braking manoeuvres if other drivers are late in their planning. However, braking should be done after exiting the motorway.*

Some attention should also be directed rearward. Numbers that were mentioned on how to divide the attention was 75% ahead, 10% rear, 10% on the exit and 5% in the left mirror. According to the participants, when passing an on-ramp, it is important to scan already at an early stage, and to be attentive to what happens in the vicinity of the acceleration lane. If someone is about to enter the motorway, either a speed reduction or a lane change has to be conducted:

*When passing an entry I devote a big part of my attention to scan for vehicles that will need space in order to enter the motorway. Mainly, I try to control my speed to avoid changing lanes. But I have also already checked traffic behind me if I need to make a lane change.*
The participant above suggests that it is more appropriate to reduce speed than to change lanes when making room for a vehicle entering the motorway. However, this opinion was not expressed by any other participant. In general, no particular tactic was favoured over another. Numbers on how to distribute one’s attention when passing an exit were not commonly expressed, but one suggestion was to direct around 60% of the attention forward and 40% backward.

With regard to passing a motorway exit it was pointed out that it was important to be extra attentive to the vehicles in front, in case they decide to exit. If needed, one could either reduce speed or change lanes in order to facilitate exiting for the vehicle in front. Also here it is obvious that the aim of directing the gaze towards the vehicle(s) in front is to gather information, foresee and prepare for a possible manoeuvre. The rational for directing the gaze and pay increased attention to the vehicles in front can be understood as the deployment of previous experience. The participants know that when passing exits, one needs to pay more attention to that situation. From experience they have learned that manoeuvring actions are commonplace there and in order to be prepared for them, so they concentrate their attention. It was also mentioned that a part of the attention should be directed rearward when passing an exit. No reason for this was elaborated on, however, but most probably it can be seen as a part of the preparation for a possible manoeuvre, like a lane change or speed reduction.

6.5. Expert judgement – written attention distribution

6.5.1. Method related

All in all, filling in one’s estimate about attentional distribution for an example scene does not appear to be promising. Even though the method is very low cost and the form can be administered to many people at the same time, it is not intuitively understood. A number of test participants also reported that they found it difficult to estimate how much attention they devoted to different areas of the driving scene.

The participants were instructed to fill in the form considering a driver who drives well. In hindsight it would probably have been better to ask drivers to fill in the form considering how they usually do, and have the underlying assumption that this is a successful behaviour. The given instruction might have created a conflict between how one typically does and an imagined ‘ideal’ driver, which makes it likely that certain targets are exaggerated.

Further, it appears to be difficult for drivers to imagine the possible presence of spare capacity. This can be connected to the point made above, that an ‘ideal’ driver directs all attention to traffic. It may also be the case that drivers either do not actively remember how many other things they attend to while driving, or that they do not want to admit it. This illustrates that it is very important to give clear instructions.

The percentage distribution was elicited with an example image on a paper. As it was a still image showing three other cars, a traffic sign and a few houses, the participants got rather locked to the scene at hand. While some participants indicated somewhat larger target areas by drawing circles, others indicated the percentages exactly attached to the present objects. This makes it difficult to generalise the results, and it can also create difficulties for the analyst to interpret correctly which targets the participant head in mind.

As the participants filled out a paper form, they had to keep track of having the numbers add up to 100 per cent. While most participants did not have any difficulties with this, some made calculation errors, and some just put ordinal numbers on the sheet, making a priority ranking of targets.

For further attempts to assess the attention distribution with the help of this method it is recommended to be very careful about the instruction, and to ask drivers to indicate how they actually behave, instead of asking about a driver who drives well.
Also, it can be worth testing not to show an actual image, but rather let the participants produce a list of things to which they attach numbers, or to present a written list of targets that is based on the empirical results obtained from other parts of this study. A further possibility would be to let the participants watch a number of short video scenes from different manoeuvres made on motorways and then ask about their attention distribution based on a list of targets. However, this method is in general unlikely to elicit realistic answers on the percentage of attention directed ‘elsewhere’, if the participants are not explicitly instructed to consider this aspect.

When analysing the data, it appears more meaningful to keep to larger categories than to split the targets into single vehicles, especially if the method is used as is. It has to be explored which targets will be produced spontaneously, if corresponding instructions are given.

6.5.2. Data analysis

The data of the core participants and of the other group of driving instructors who only had filled in the written lab forms were analysed separately. This was done partly because the participant groups had different preconditions, as the core participants had been driving such a motorway in their previous experimental session and had received more detailed information about the purpose of the investigation than the other group. Also, five core participants filled in the percent distribution sheet once more after having driven with occlusion glasses.

As mentioned, the percentages noted by the participants were classified according to the coding scheme in Table 6. While it was tried to do this as objectively as possible, a certain degree of interpretation by the data reductionist was unavoidable. The detailed classification was also reduced to the three larger categories found in Table 6 as well as the following categories ‘forward in general’, which included both static and dynamic targets in the forward scene, ‘mirrors in general’, which included all mirrors, ‘inside of car’, which is equal to ‘world model’ except the mirrors and ‘outside of road’, which include the right and left side outside of the motorway. When participants gave one overall value for the ‘forward scene in general’, then no splitting into dynamic and static objects was possible. Table 13 summarises the results for the larger categories for the core participants before and after having driven the occlusion condition, as well as for the other participants.

As the number of core participants is small, the results have to be treated with caution. For the same reason no inferential statistics are computed.

In general the forward scene receives the largest percentage of attention, but the variance is high. Much of the remaining percentage is devoted to the mirrors, whereas objects inside the car (instrument cluster, middle console, other) receive about five per cent of the total attention, with a rather small variance. The area to the left of the motorway did not receive any attention, and the area on the right side received only a small portion, with a small variance. It can be noted that the core participants indicated a higher value for the area outside of the road after having driven with occlusion glasses.

Also, the indicated reserve capacity was larger for the core participants after having driven with occlusion glasses than before. Of the 25 other participants, twelve indicated the presence of reserve capacity. One person noted a reserve capacity of 45 per cent, which had a large influence on both the mean value and the standard deviation. If this person is excluded, the mean value is reduced to 8 ± 6 per cent, which is exactly equal to the number given by the core participants before the occlusion condition.

When splitting the scenario into dynamic and static objects, the dynamic objects receive substantially more attention than the static objects, even though the variance of the indicated values is rather high. Again, the percentages given by the core participants before occlusion and the other participants are comparable for dynamic objects. Two core participants report a much lower value for the dynamic objects after having used the occlusion glasses, the other three reverted to giving an overall value for the forward scene, therefore not allowing a split into dynamic and static objects.
### Table 13. Mean values (in per cent), standard deviations (in per cent) and number of counts for several larger target categories for lab task of indicating the attention distribution in per cent in written form. The lower part of the table illustrates a different way to structure the targets, where ‘world model car’ represents all targets that would belong to the world model that is incorporated in the used eye-tracker. The values do not add up to 100% as each target can appear in more or none of the categories shown.

<table>
<thead>
<tr>
<th></th>
<th>Core participants</th>
<th>Other participants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before occlusion condition</td>
<td>After occlusion condition</td>
</tr>
<tr>
<td>Forward in general</td>
<td>59 ± 15 (n = 6)</td>
<td>55 ± 21 (n = 5)</td>
</tr>
<tr>
<td>Mirrors in general</td>
<td>29 ± 11 (n = 6)</td>
<td>28 ± 16 (n = 5)</td>
</tr>
<tr>
<td>Inside of car (excl. mirrors)</td>
<td>5 ± 2 (n = 6)</td>
<td>4 ± 2 (n = 5)</td>
</tr>
<tr>
<td>Outside of road</td>
<td>2 ± 2 (n = 6)</td>
<td>5 ± 4 (n = 5)</td>
</tr>
<tr>
<td>Reserve capacity</td>
<td>8 ± 6 (n = 3)</td>
<td>13 ± 3 (n = 3)</td>
</tr>
<tr>
<td>Dynamic outside</td>
<td>50 ± 17 (n = 5)</td>
<td>33 ± 18 (n = 2)</td>
</tr>
<tr>
<td>Static outside</td>
<td>8 ± 8 (n = 5)</td>
<td>10 ± 0 (n = 2)</td>
</tr>
<tr>
<td>World model (car)</td>
<td>35 ± 13 (n = 6)</td>
<td>32 ± 16 (n = 5)</td>
</tr>
</tbody>
</table>

*8 ± 6 (n = 11) when excluding one outlier at value 45%*

### 6.6. Verbal protocol

Driving instructors are very proficient at thinking aloud. Both while watching the film in the laboratory and during actual driving they kept on talking and did not have to be reminded to think aloud.

The quality of the recording in the laboratory was good and was, due to the choice of software, directly linked to the viewed film. In the field the soundtrack is linked to the forward view, as the recordings were made on the GoPro camera. The sound quality was not as good as in the laboratory, however, even though a dedicated microphone attached to the participants clothing was used.

All verbal recordings were transcribed by a professional transcriber. In a few instances the transcriber could not understand a few seconds of what was being said in the driving condition.

### 6.6.1. Method related

In a previous experiment, we had large difficulties with getting truck drivers to talk continuously while driving. Despite careful instructions and training, it just did not come naturally to them to narrate their own driving. We were therefore worried that the drivers in this study would find it difficult as well, thus leaving us with insufficient data to work with. However, the driving instructors were very good at narrating their driving, probably because it is an instruction technique, which is specifically taught to driving instructors, and which is used frequently in practice with the students.

Natural language processing is a difficult task since there are so many nuances, ambiguities and meanings to a verbal description. Even though part of speech tagging, word counts etc. can be made
automatically, manual intervention is necessary to summarise the text protocols and to infer meaning to the results. A additional qualitative approach could possibly enrich the conclusions presented below, as it might help in identifying ‘attention chunks’, that is, how the drivers possibly structure their trip into tactical manoeuvres.

6.6.2. Data analysis

Frequency distributions of nouns, verbs and collocations were extracted using the Natural Language Toolkit 3.0.3 (Bird, et al., 2009). A histogram of the most common nouns during the field trials is shown in Figure 36. The nouns can be subdivided into three categories:

1. **Traffic**: Cars, trucks, traffic.

2. **Road environment**: Road, exit, lane, traffic, entrance, sign, distance.

3. **Interior of the vehicle**: Mirrors, speedometer.

Half of the nouns mentioned during the think aloud condition are related to the surrounding traffic. Nouns related to the road environment and to the interior of the vehicle are distributed evenly with 25 % of the nouns each.

![Figure 36: Histogram of the most common nouns.](image)

The three most dominant verbs are ‘see’, ‘will’ and ‘check’, see Figure 37. Seeing usually refers to the passive act of just looking at whatever happens in front of the driver while checking refers to a more active search of information. ‘Will’ often indicates a planned act of something the driver is going to do. These three verbs are followed by a long list of words that describe the typical course of events entailed by driving on a motorway; drive, overtaking, approaching, using the turning indicators etc. These verbs are mixed with other words that are naturally frequently occurring in descriptive natural language, for example; do, try, need, want and take. As expected, the enlisted verbs reflect the facts that (i), driving is a highly visual task, (ii) that drivers try to predict and anticipate upcoming events, and (iii), that driving is an active task.
Figure 37: Histogram of the most common verbs.

Figure 38 shows a histogram of the most common collocations. These phrases can roughly be divided into four categories:

- **Anticipate some future event.** This includes looking *far ahead* in order to predict and consequently be able to adapt to *vehicles behind, vehicles ahead*, and other upcoming events. This also includes *staying in the right lane*, since the driver is *approaching* an exit and monitoring vehicles that probably *will turn*.

- **React to some ongoing event.** This includes *checking vehicles* that behave as if they are about to do something (such as *changing lanes*), adjusting one’s speed *a little*, in order to adapt to vehicles that *catch up* with the driver or that the driver *catches up with*.

- **Monitor the surroundings.** This includes *checking the mirrors, the speedometer* or just having a general *check on the surroundings*.

- **Actively check something before performing some manoeuvre.** This includes checking the *right lane* and the *blind spot* before making a lane change, and keeping an eye on a truck while *overtaking* it.

The concordance of each collocation was checked manually, and the interpretations above are based on their most common meanings. About half of the collocations are devoted to strategically plan one’s actions in order to facilitate a smooth and worry-free travel path. This provides interesting evidence against especially the earlier driver models where the driver simply acts as a stimulus-response machine (e.g. Shinar, 1993). About 25% of the collocations were related to the reaction on a current event (stimulus-response), 20% to monitoring and the remaining 10% routine checks before commencing a manoeuvre.
Comparison between field and lab data

The think aloud protocol was also used in a lab session where the participants had to describe what they saw when watching a film of their own motorway driving (both in the daylight and in the darkness condition). Figure 39 illustrates differences in the nouns that the drivers used to describe their driving on the motorway compared to watching a film. Trucks are mentioned less frequently during darkness, which is a consequence of the lower prevalence of trucks in the evening. There is also less mentioning of the speedometer in the lab situation as the speedometer was not visible on the film. Mirrors were mentioned a lot more in the lab sessions, probably as a consequence of a lack of other things to look at. The mirror has a very central role in the shown film (see Figure 5). When it comes to the verbs that drivers use to describe their driving, there is a great resemblance between thinking aloud while driving and watching a film (see Figure 40).

Collocations differ more between the two settings (see Figure 41). The two areas that are visible in the lab setup are the forward path of travel and the centre rear view mirror. Phrases directly associated with these two areas are accentuated in the lab setting compared to actual driving, i.e., looking far ahead and checking the mirror. At the same time, there are fewer mentionings of vehicles behind. This indicates that the drivers change their vocabulary in the lab setting, by simply stating that they look at the mirror instead of explicitly stating what they see in the mirror. As was the case for the nouns, the drivers do not report about checking the speedometer in the lab setting, because there is no speedometer to check.

Figure 38: Histogram of the most common collocations.
Figure 39: Histogram of the most common nouns, comparing thinking aloud while driving on a motorway in daylight with watching a film of motorway driving in daylight and darkness.

Figure 40: Histogram of the most common verbs, comparing thinking aloud while driving on a motorway in daylight with watching a film of motorway driving in daylight and darkness.
Figure 41: Histogram of the most common collocations, comparing thinking aloud while driving on a motorway in daylight with watching a film of motorway driving in daylight and darkness.
7. Discussion

The present study was mainly set up as methods evaluation, which is the main reason why the number of core participants was low. Where possible it was tried to increase the number of participants, for example with the help of associated projects or during workshops and seminars. The number of participants was in all cases sufficient to test the feasibility of the methods used and the feasibility and time requirements of the data reduction and analyses. The actual results have to be treated with caution, though, especially for those parts of the study where the number of participants was low. They are included, anyway, as they are likely to point in the general direction of what can be expected from larger studies, and they provide a picture of what can be done with the data obtained.

Even though we assume the existence of ‘spare mental capacity’, we do not propagate that mental capacity of an individual is constant over time, or across individuals. Rather, mental capacity can expand and shrink based on outer circumstances (M. S. Young & Stanton, 2002) or based on inner motivation (Platten, Schwalm, Hülsmann, & Krems, 2014), but we assume a certain individual and situational upper limit that can be sustained comfortably over an extended period of time. When discussing the MRA requirements we assume a comfortable level of attentional effort, and we also assume that the drivers who participated in this study held this level for most of the time. This suggests that future MRA rules imply that for a short period of time and under temporary high mental load an even lower amount of attention directed at the driving task may be sufficient.

7.1. Number of participants

Zwahlen (1991) recommended to use a ‘sufficiently large group of representative drivers’ (p. 22) to conduct research on general rules and recommendations based on eye tracking. For MRA we deviated slightly from these recommendations, as we decided to employ expert drivers (driving instructors) in our tests. The reason for this is that we want to increase our chances to collect recommendable strategies. Professionals like taxi drivers or experienced high-mileage drivers like travelling salesmen could also have been options of choice. The reasons for only using a small sample are given above, even though we realise the importance of a ‘sufficiently large group of drivers’. Depending on the method employed, an increase of the number of participants can either mean large or smaller additional costs, both in relation to data collection and data processing. If more participants can be tested at the same time, and the more automated the data analysis is, the smaller are the additional costs per each additional participant.

7.2. Experimental setup

As mentioned previously, the main purpose of the present study was to test the employed methods. As with most studies in experimental cars, the drivers were not familiar with the test vehicle. However, the vehicle is a common type in Sweden, the participants were driving instructors and other experienced drivers used to driving different vehicles, and the data collection only started after about 12 to 14 minutes of driving, such that at least a short practice phase was provided.

Throughout the study the participants were accompanied by an experimenter. While driving, the experimenter sat in the back seat, and in the lab conditions the experimenter was in the room while the tasks were executed. This might have put some pressure on the participants, such that they did not behave completely naturally. It is likely that they would have executed more additional tasks while driving if they had not been observed by an experimenter and a host of cameras, and it is also possible that the glance behaviour in itself was affected.

The experimental design was not completely balanced, because it was intended to keep the participants as ‘naïve’ as possible at least for the day and darkness conditions. This may have led to learning effects, and it can be argued that a different level of information in the different conditions may have systematically influenced behaviour. The results of the analyses presented here speak against obvious
learning effects, however, as the factor ‘Lap’ did not have any effect on most tested variables. As there is no learning effect within conditions it is likely that there is not any learning effect between conditions either. The results also indicate that it is more likely that the effects found between the conditions are connected to the condition specific features instead of to the overall information level provided. This assumption is made, because the differences between conditions can be logically connected to the condition specific features. Also, the think aloud and the occlusion condition were order-balanced between participants, and no specific order effects could be found.

7.2.1. Eye tracking quality

In many studies eye tracking is done in real time, such that the output is made up of data log files with gaze vectors. In some cases these data are combined with a video of the forward view. Typically, eye tracking output also contains a quality signal, giving an estimate of the reliability of the detected signal. Obviously, for larger amounts of data an automated procedure that investigates gaze data quality is needed, but it has to be kept in mind that eye tracking is context dependent, and that relying on the quality signal alone is not enough, due to several reasons:

- It is possible, like in the present study, that the profile used for locating the eyes and consequently the glance direction does not lock onto the correct facial features. This leads to a useless gaze vector signal, even though the estimated quality still may be high – as the eye tracker software is not aware of the erroneous profile placement.

- Lost tracking can be indicative of a bad signal. It can also mean that the view of the face is obstructed. This can happen when the driver places something in front of his face, for example a hand when blowing one’s nose, or for any other reason. This type of data loss may occur more or less randomly distributed across a trip, and it depends on the research question how much of it can be tolerated. There can also be systematic data loss, as observed in the present study just before changing lanes, especially from right to left. Here the data loss very likely indicates a glance over the shoulder, such that the driver’s face was turned away from the eye tracking cameras far enough to render glance detection impossible. In such a situation data loss can be filled with meaning and interpreted as a necessary part of executing a lane change.

When no recording of the eye tracking cameras’ view is available for ocular verification of profile placement, a visual inspection of the gaze overlay over the viewed scene, or at least of the raw gaze direction time series, is recommended. If that is not possible due to a lack of such material, or impractical for other reasons, a thorough data quality check is highly recommended, otherwise the final results can be contaminated from instances of bad tracking. It can be meaningful to check for multiple modes in histograms of gaze direction data. If there are several large peaks it indicates that the 3D model fitted to the drivers face is erroneous. It could also be worthwhile to check for an unproportionally large amount of very short fixations, and also to check if saccades are in line with the saccadic main sequence (Ahlstrom, Victor, et al., 2012).

7.3. Time based versus distance based PI computation

In this study we calculated the number of glances per minute, but it is thinkable to use distance in the denominator instead. As it was easier to compute the PI per minute, as the speed did not vary much across situations, and because it is more common in the literature to use time in the denominator, this approach was used here. However, considering the goal of formulating rules for the minimum required attention, using distance in the denominator has a number of interesting implications that should be taken into account. As has been shown before, it is quite common for drivers to reduce speed when workload is increased, for example when executing an additional task. This basically lets the driver buy time to perform the task while still being able to pay sufficient attention to the environment. This would imply that ‘minimum required attention’ rules that are based on time do not acknowledge speed
reduction as an effective compensational mechanism, as they still require the same amount of attention to be paid to different targets within a certain time window. If the requirements are distance based, a speed reduction would free time. This is also quite intuitive – if a car travels at a certain angle to the lane boundary it will cross the boundary in the same place, regardless of the travel speed – higher speeds only lead to the road being crossed earlier in time, but not closer to the current position. Therefore, a slow speed affords a larger time window to correct one’s actions. This is illustrated in Figure 42.

![Figure 42. Relationship of speed and the available time to act.](image)

Based on this reasoning it would be sensible to use distance in the denominator for rules that describe for example the number of glances to a certain target. This holds up for all static objects, as speed in relation to stationary things is under the control of the driver. However, as soon as other moving road users come into play, the driver does not have complete control over the relative speed between the own vehicle and other objects. Therefore, time needs to be integrated into the rules as well, to account for movement that happens independently of the driver’s control. Exactly how this relationship between time and distance in the denominator should look needs to be determined based on more data.

7.4. Off-line versus real-time use

The final goal of the efforts undertaken here is to find the best method for how to build an operationalisable algorithm for minimum required attention, and, in extension of that, of course also to develop this algorithm. The specifications of this algorithm are described in detail (Kircher & Ahlstrom, submitted), but the actual application of the algorithm can vary, and this can entail additional requirements and characteristics.

The MRA algorithm considers manoeuvres performed by the driver and is therefore mainly intended for off-line use. This is because manoeuvre coding is done after the fact. In the present analysis lane changes from the right to the left were defined as starting five seconds before the actual lane change was initiated with a vehicle movement. If this definition is kept, future manoeuvre type knowledge is necessary to apply the algorithm correctly.

Possible application areas for an off-line use of the algorithm are for example distraction identification (for past behaviour), black spot identification and accident classification. In those cases the manoeuvres are known, and the driver’s behaviour can be compared with the MRA algorithm. For black spot identification a possible accumulation of detected cases of insufficient attention can indicate either a difficult spot in which drivers do not manage to fulfil all the requirements in the available amount of time, or a spot that is difficult to ‘read’ and therefore leads to many drivers’ not following the algorithm requirements. Instead of linking the occurrences of algorithm requirement violations to locations, they can also be linked to drivers or to the occurrence of accidents. More detailed classifications are possible, considering which rule was violated in which way.
The MRA algorithm can in principle also be used in real time, like for attention status assessment, distraction detection and possibly manoeuvre prediction, but not for all of them at the same time. If the algorithm is meant to be used for real-time attention assessment or distraction detection, then the manoeuvres have to be defined such that no future knowledge is needed. For the motorway scenario described here this applies only to the lane change right to left, which might instead be assumed to start when the driver activates the turn indicator, or based on the relative speed and distance to the vehicle in front.

However, as gaze data are manoeuvre dependent, they could also be used to predict overtaking manoeuvres. In this case the assumption is that a driver basically follows the MRA rules, which might enable the identification of a lane change before it actually takes place. This information could then be used to adapt other information, warnings, etc.

7.5. Visual occlusion

Visual occlusion as it was used here – where the default state is ‘open’ and where drivers themselves choose when and for how long to occlude themselves – did not lead to any compensatory driving behaviour as for example fewer overtakings or reduced speed. The reason is most likely that there is no inherent attraction in driving with occluded vision, therefore drivers see no reason to ‘create more room’ for occlusions, in contrast to what can be observed for nomadic device usage (Ahlstrom, et al., 2015; Kircher, et al., 2015). The absence of compensatory behaviour in driving is good news for the use of the technique as a pure method to assess spare capacity. For further corroboration additional data should be collected for a number of different traffic environments.

A comparison of the present occlusion data with Senders, et al. (1967) data is difficult due to several reasons. The current data collection happened at a speed of approximately 110 km/h (the speed limit on the motorway), while the speed limit on the public road used by Senders et al. was somewhere around 55 to 60 mph, which equals approximately 90 km/h. Also, and even more important, in Senders et al.’s study the default condition was occluded vision, which needed active intervention from the drivers for opening the visor. Then, the visor only stayed open for a predetermined time. In the fixed-speed conditions the opening frequency could be regulated by the driver at will. On the other hand, the default setting in the present study was open glasses, and the drivers were allowed to regulate both the occlusion frequency and duration at will. Even though the drivers in the present study had the possibility to adapt speed as well, they did not do so, such that we can assume a fixed speed for reasons of simplicity.

With a viewing time of 0.5 s and a fixed speed of 60 mph (96.5 km/h) the reported mean voluntary occlusion time for two participants was 1.48 s respectively 1.84 s. Not much information about the road, other traffic, manoeuvres made or exits passed is available, except that the road was the interstate I-495 in Massachusetts, and that it was ‘essentially straight’ (p. 22). The mean voluntary occlusion duration for the present study over all participants and all manoeuvres was $1.9 \pm 0.64$ s, which is slightly longer while driving at a higher speed. Senders et al. used a viewing time of 0.5 s, as they had not found a substantial difference when using 1.0 s instead. However, in the present study viewing times were self-selected and could therefore not only be longer, but the drivers also had the possibility to a much larger extent to adapt both viewing and occlusion times to the situational demands. While we recognise that the closing-strategies varied markedly between participants, it can be assumed that a higher level of control over viewing and occluded periods will lead to longer single occlusion periods, as drivers will occlude themselves when it is ‘worthwhile’, that is, when they feel that they have ample time to do so. It would be interesting to investigate further how behaviour would change if the default was to have the glasses closed, but still allowing the participants to open them with self-selected frequency and duration.

As mentioned, drivers employed different strategies for their occlusion behaviour. Participants who occluded themselves more often did so for a shorter amount of time per occasion and the other way
around. The percentage of time for which each participant was occluded was therefore quite similar across participants. Thus, if the ‘occlusion affordance’ of a road stretch should be assessed, it is recommended to use the percentage of time occluded instead of either the number of occlusions or the mean occlusion duration, as the former PI appears to be more stable across different people.

The drivers occluded their vision to a different extent for different manoeuvres. The percentage was lowest for manoeuvres that are associated with merging into faster traffic, as when the driver enters the motorway or changes lanes from right to left. When changing back into the slower lane the percentage of occlusions was higher, probably because other traffic was overtaken and therefore ‘accounted for’, leading to a higher predictability. Driving in the left lane is associated with a much lower percentage of occlusions than driving in the right lane. The reason for left lane driving is typically to overtake slower traffic, which means that there is often a vehicle close by, which is likely to reduce occlusions. Also, monitoring the traffic behind is more essential when driving in the left lane.

The occlusion paradigm was used as a clean way of assessing the ‘least amount of spare capacity’. It is unclear whether occlusion glasses also provide the ‘minimum required attention’, as drivers probably try to be on the safe side. The answers in the questionnaire where most drivers indicated that they did not use the occlusion glasses at maximum supports this notion. The occlusion technique is also likely to be on the conservative side due to the fact that it only allows for a very limited amount of peripheral vision. When viewing traffic irrelevant in-vehicle or out-of-vehicle targets in normal driving, it depends on the viewing angle how much peripheral vision is left. There are a number of indications in the literature that peripheral vision is important for lane keeping, but not useful for hazard detection (Horrey & Wickens, 2004).

Visual occlusion can be related to glance behaviour when interacting with self-paced additional visual tasks. The main difference is that for most visual tasks the drivers do not only have to ‘stop looking ahead’, but also to focus on something else, often in the near-focus range, and often involving a head movement. Also, typically some cognitive engagement is connected to the execution of visual additional tasks. Unfortunately, additional tasks are usually not separated into self-paced or system-paced tasks, which would be of value, as it has been shown for cyclists that self-paced tasks lead to significantly longer mean glance durations than system-paced tasks (Ahlstrom, et al., 2015). However, for controlled experiments the setup is often described in enough detail to allow a categorisation of the tasks executed.

### 7.5.1. Comparison to other studies

The tasks in a study by Rockwell (1988) were connected to radio operation and can be classified as self-paced. The participants drove on a motorway with light to moderate traffic at a speed of approximately 80 km/h, and they were told to execute the tasks only when they felt it was safe and convenient to do so. Except for the adjustment of the volume, which led to an average glance duration of 1 s, most other operations led to average glance durations to the radio of 1.5 s. In contrast, the overall mean occlusion duration in the present study was with 1.9 s somewhat longer, but did not involve any head movements.

In a study by Hada (1994) drivers were asked to look at three visual targets in the forward area inside the car for ‘as often as, and as long as’ they felt safe to do so (p. 19) – also essentially a self-paced task, possibly with some external pressure to please the experimenter. The mean glance duration lay at 1 s. Glances were slightly longer (1.1 s) when the target was straight ahead than when the head had to be moved, and glances were longer on the expressway than on smaller roads, giving rise to the assumption that the expressway was a more predictable environment.

The mean frequency with which drivers looked at the targets on expressways was approximately 0.36, which corresponds to 22 glances per minute – and at a speed of approximately 100 km/h, which
corresponds to the 65 mph speed limit in the research area, this would result in ca. 13 glances per km. This is substantially more than the average of 4.1 occlusions per km recorded in the present study.

The percentage of time spent looking at the targets in the Hada-study was between 35 and almost 40% on the expressway, which is about three times as much as drivers occluded themselves in the present study. Of course a number of possible explanations exist for the differences, like different traffic conditions and a differing experienced pressure to look at the targets/occlude oneself. It is also possible that occlusion feels more threatening and is therefore applied more conservatively, which would mean that the values obtained in the present study really reflect the absolute minimum of available spare capacity. This is supported by the statement that most drivers indicated that they could have occluded themselves more often than they actually did.

While occlusion behaviour is interesting in itself, there is much to learn from combining it with glance behaviour and the comparison of glance strategies across the different driving conditions.

### 7.6. Glance behaviour

A preparatory analysis showed that participants differ in their glance behaviour from one another. They also differ in their glance behaviour between different manoeuvres, but are consistent within themselves over time and comparable locations (in this case operationalised by driving direction). The within-subjects consistency shows that there are reliable patterns, and that learning effects are not likely to be expected over the time of an experiment. However, the inter-individual differences need to be considered when attempting to build a ‘required glance pattern’. As mentioned, the number of participants in the present study was low, and not all participants completed all conditions. Therefore, the present data are probably not suitable for a detailed analysis of between-subjects differences. It is strongly recommended to enhance the data with a larger amount of drivers that participate in all conditions. This may both reduce the between-subjects variability and lead to more stable data in general.

As glance behaviour was recorded during all four driving conditions, the main factors analysed were condition and manoeuvre type. The comparison of the PIs ‘number of glances to target X’ and ‘mean duration of glance to target X’ in addition to the resulting ‘percentage of time looked at target X’ allowed for a number of interesting observations, especially when combined with the results of the occlusion behaviour.

As expected, drivers spent most of their time looking out of the windscreen. This is especially true for manoeuvres that do not require any direct and active interaction with other traffic, namely driving in the right or left lane and exiting the motorway. During these manoeuvres approximately 80–85% of the time is spent looking out of the windscreen, and most of those glances are directed at a small circle straight ahead (pc8). The notable exceptions are ‘driving in the right lane’ and to some extent ‘lane change left to right’ in the occlusion condition, which will be discussed below.

The visual default mode, i.e., looking straight ahead, is the most common glance direction. However, the average glance duration to the forward view is rather short and lies at about 2.5 to 3 s for the manoeuvres that do not require active interaction with other traffic. In the other manoeuvres the mean glance duration forward decreases to about 1.5 to 2 s, and within mirror and speedometer clusters to just slightly above 1 s. The glance frequency to the forward view and to the targets speedometer and mirror indicates that drivers employ an active scanning pattern, never resting the glance in the same position for a long time. The frequencies also indicate that it is likely that drivers use the forward view as ‘base’, such that they in most cases look from the forward direction to another target, then back to forward, then to the next target, then back to forward and so on.

The data show that driving in darkness leads to a slightly different glance behaviour than driving in daylight. For example, in darkness the drivers spent somewhat more time looking forward than in the other conditions, independent of the manoeuvre performed. They also look somewhat more frequently
at the speedometer when on the motorway, but the mean glance duration to the speedometer is shorter than in the other conditions. The mirrors receive a smaller percentage of glances, while the forward view is looked at more. The glances to the speedometer become more frequent but shorter, thus, the overall percentage remains comparable to the other conditions. The ‘other targets’ receive approximately the same amount of glances in darkness as in the other conditions, thus, those are unlikely to be glances to the scenery. Possibly it is more difficult to estimate one’s speed in darkness, as the visual flow impression is less pronounced. This may lead to more frequent glances to the speedometer, but then a short dwell time probably is sufficient, as the glance mainly constitutes a confirmation of the fact that the current speed is still within one’s accepted limit.

While for glances to the forward view a manoeuvre-based pattern is visible both for glance frequency and glance duration, this is different for the targets ‘mirror’ and ‘speedometer’. For the glance frequency a dependence on manoeuvre that is rather independent of condition can be observed, perhaps with the exception of speedometer glance frequency during darkness. The glance duration, however, does not appear to have any dependence on manoeuvre, and its variation is rather small, in the range of 0.3 to 0.5 s both for mirror and speedometer glances. This is only about a fifth to a third of the shortest average duration of glances to the forward scene. It is likely that the forward glances comprise of several fixations on either the same or different objects, while for glances to the mirror or speedometer one fixation is sufficient.

The occlusion condition differs from the other conditions mainly for the ‘driving in the right lane’ and ‘lane change left to right’ manoeuvres, and the difference is more pronounced for forward glances than for glances to the speedometer and the mirrors. This leads to the assumption that those mirror and speedometer glances that are executed during normal driving in fact are experienced as necessary and important and do not only happen out of habit, such that they cannot be reduced substantially at will. Glances to the forward roadway appear to include more spare capacity when in the right lane or heading back there. Even though changes in front of the car typically have a larger and faster impact on how to proceed safely, the drivers seem to experience that the uncertainty in the environment at the given speed is smaller than the time available to scan the environment – therefore they can occlude their vision in this scenario while still feeling that they have control. This appears not to be the case for the other manoeuvre types, except possibly to a small extent.

Interestingly, an increased glance frequency and duration, and thus also percentage of time spent looking at the mirrors was found for the think-aloud condition, however, no such effect appeared for the speedometer. Possibly the verbalisation of one’s attention distribution intensifies the scanning of the safety critical targets. All participants in the think-aloud condition were driving instructors, and therefore it is likely that they are used to stressing the importance of mirror glances. Speedometer glances are presumably more automated and less safety critical – and possibly less associated with certain manoeuvres, and therefore they are not dealt with on a conscious level. A further indication for this interpretation is that speedometer checks are mentioned much less often while thinking aloud than mirror glances are.

The distance- and location-based data analysis shows that it is important to split the viewing area into meaningful target areas. The plots presented in Section 0 do not separate the windscreen into different sections except for the prc8 area. However, it may be meaningful to make more detailed subdivisions, and it can be considered whether those divisions should change depending on the type of manoeuvre performed. A dynamic adaptation of the target areas depending on manoeuvres may enhance accuracy and interpretability for each manoeuvre, but will make comparisons across manoeuvres more difficult. A solution could be a stable set of relatively detailed target areas that can be regrouped depending on the manoeuvre in question. This allows flexibility, but still gives the possibility to make comparisons.

In order to present the data in percent the different target areas need to be mutually exclusive, and the subdivisions should not be too small, as there will be a certain tracking error that has to be taken into account.
7.6.1. Comparison to other studies

The glance data found here were compared to the results obtained by other on-road studies. Unfortunately, for most studies on glance duration in real world traffic glance parameters to traffic related targets are not reported – the focus lies on glances to additional tasks. In a study of eye movements while driving on a highway with and without performing two additional tasks it was found that about 4% of the glance fixations are directed at the speedometer (Recarte & Nunes, 2000), which can be related to about 4–8% of the time spent looking at the speedometer in the present study. In the present study the mirrors were glanced at for about 4–6% of the time when driving in the right lane (excluding the think aloud condition), and in the Recarte and Nunes study the participants directed about 3–5% of their fixations at the left and centre mirror together. Additional spatial imagery tasks reduced the number of speedometer and mirror glances substantially to below 1% (speedometer) or around 2% (mirror), however, no classification into driving manoeuvres was made. Two more experiments by the same authors found that 1.8% respectively 1.3% of all fixations were directed at the mirrors and 2.1% respectively 3.4% at the speedometer (Nunes & Recarte, 2002).

American studies found speedometer glances to last on average 0.62 s (Dingus, Hulse, Antin, & Wierwille, 1989) respectively 0.8 s (Rockwell, 1988). The latter study found an average duration of 1.0 s for mirror checks – more than twice as long as in the present study. Thus, the data from the present study correspond well to what was found by Recarte and Nunes (2000), while the glance durations at the speedometer and mirrors in the American studies are substantially longer and more in the range of additional task glances. In the Dingus-study participants were asked to report the current speed, which may explain the unusually long glances to the speedometer. We do not have an immediately plausible explanation for the other differences with the American studies, except that the data were collected 25 years ago on a different continent, which may be the reason for structural changes that we are not aware of.

Hada (1994) found that the intervals between glances to a visual target inside the car were 2.9 s on an expressway. There is no direct comparison value in the present study, but it can be assumed that drivers need to look through the windscreen as well as into the mirrors and the speedometer while also performing an additional task. Therefore, the occlusion condition which yields windscreen glances of approximately 1.5 s and a mirror and speedometer glance frequency of about 10 respectively 7.5 glances per minute may roughly equal this value. In a simulator study Tsimhoni (2003) found that while performing an additional task that required multiple glances, the participants looked back at the road for 0.75 s on straight roads, for 0.85 s on moderate curves and for 1 s on sharp curves. These glances are even shorter than the windscreen-glances in the occlusion-condition, however, in a simulator the frequency of mirror glances may be lower, and also, the glances measured by Tsimhoni are from ‘inside’ the execution of an additional task. It is likely that drivers want to finalise the task and then allow themselves a number of shorter on-road glances, which may be followed by longer on-road glances once the task is completed. Therefore, in addition to mean glance durations through the windscreen the distribution should be analysed as well.

The values found in the present and other published studies can be set in relation to findings from the large naturalistic driving study SHRPII (Victor, et al., 2015). The comparison is rough and speculative, as the SHRPII-data are categorised differently, and manoeuvre type is not accounted for. Also, the only crash type investigated was rear-end, and the data are not limited to motorway driving. These limitations have to be kept in mind when interpreting the following findings.

In the SHRPII study it was found that during baseline driving, that is, when no crash or near-crash occurred, drivers typically do not look forward for about 20 to 25% of the time – instead they look at mirrors, through the windows on the left and right, at the instrument cluster, the middle console, at passengers, interior objects and so on. This is very similar to what was found in the present study, where drivers look through the windscreen for approximately 70 to 80% of the time. For crashes and to some extent for near crashes a higher percentage of off-road glances was found, with values
reaching approximately 50% of the time in the last seconds before the crash. Glances to the interior of the car accounted for about 30% of the total. It can be noted that the drivers in the occlusion condition in the present study looked through the windscreen for more than 60% when driving in the right lane, and more during the other manoeuvres. Thus, on average they do not reach the level of off-road glances that was found for drivers who had crashed.

Further, in the SHRPII study it was analysed which percentage in the time window from 5 s before to 1 s after a crash or near-crash was spent looking away from the forward roadway. This was then compared to baseline driving. Only when the accumulated glance time off the forward roadway amounted to 2 s or more (i.e., 33% of the time or more), a significantly increased risk for crashes or near crashes was found. In the occlusion condition drivers chose to keep their gaze off the forward roadway for about 35% of the time when in the right lane, and less for all manoeuvres together. The mean occlusion duration in the right lane was 1.9 s – just below 2 s. The data material in the present study is small compared to SHRPII, and the studies were conducted on different continents and with widely varying methods and preconditions – but still, the participants in the present study, who drove safely on the selected route, demonstrated glance behaviour that kept clear of the behaviour associated with crashes in the SHRPII study.

7.6.2. Implications

Overall it is possible that there are two types of glances – those used for confirmation of facts, which can be really short (e.g. to the mirrors or the speedometer), and those used for uncertainty reduction, where new information is gathered and interpreted. The windscreen glances are included in the latter group, and of course it is likely that each glance to the windscreen is made up of a number of fixations, while the mirror and speedometer glances likely contain fewer fixations. When occluded, the participants reduce the glance duration to a value close to the minimum needed for the type of glance. The mean duration of glances to the window is about 1.5 s in the lane change manoeuvres in all conditions. Probably 1.5 s is more or less the necessary minimum for assessing what is happening in front of the vehicle, as these manoeuvres also require a lot of active glancing to the mirrors and the side windows. When driving in the right lane the average window glance duration is 1 s longer for all conditions but the occlusion condition, where the value lies at 1.5 s. This may mean that participants can ‘rest’ during normal driving in the right lane, but in the occlusion condition they use this resting time to occlude themselves whenever they feel they can safely do so. Thus, it seems meaningful to require a minimum average glance duration to the forward traffic scene of approximately 1.5 s independent of manoeuvre type, while glance durations to other targets do not have to be that long – here the frequency appears to be more important than the duration.

The within-cluster glances to the forward view are with an average of around 1.1 s even shorter than the 1.5 s discussed above, which shows that in situations under slight pressure to look somewhere else, and for a limited amount of time, it is possible to make do with even shorter forward glances. However, for the development of the algorithm it is recommended to use figures that do not involve pressure and therefore a possibly heightened level of mental effort that cannot be sustained over a longer period of time.

While gaze tracking is a useful method to indicate where a driver directs his or her foveal vision, it always has to be kept in mind that the eye can see much more than the foveal information, and makes use of peripheral vision as well. The objects further in the periphery are represented more blurry, but motion can for example be detected quickly and easily. There have been studies that showed that only very rough information of the visual scene, which is assumed to correspond to human pre-attentive vision, is enough for rather successful navigation (Pugeau & Bowden, 2011; Rudzits & Pugeault, 2015). Therefore, even though the foveal gaze was not directed at a particular target, the driver may very well be aware of the presence of that target.
7.7. Verbal information

Verbal information existed both in written and in spoken form. For the analysis of the written text a more qualitative approach was taken, while the written figures denoting the estimated percentage of attention to a certain target were analysed quantitatively. Also the verbal protocol data were analysed with a quantitative approach. The reason for using different methods were twofold – first of all, the written text was difficult to submit to a quantitative analysis, due to the widely varying ways in which the participants had responded. Secondly, it was hoped that a qualitative analysis would touch upon aspects in the material that might be difficult to catch in a purely quantitative approach.

A general issue with verbal material, which is consciously produced, is the fact that there will be no or only limited reporting of behaviour that is highly automated and therefore likely to happen unconsciously. On the other hand, however, it is likely that the consciously experienced part of the observed behaviour will be enriched with information, and further behavioural aspects, that were not observed and measured, may come to light.

The qualitative analysis of the written material suggests that for driving on the motorway it is important to scan the surroundings both in front of and behind the own vehicle continuously and collect necessary information. The information gathered is essential in order to both be able control the own vehicle, but also, and equally important, to be able to foresee what will happen, such that appropriate decisions in the interaction with other drivers can be made. Thus, driving on the motorway is experienced as an action that requires proactive behaviour and anticipation. Other vehicles’ manoeuvres need to be predicted based on their present behaviour, such that the own behaviour can be adapted in time, to enable a smooth continuation without major disruptions of the travelling flow. Interestingly, there was no mentioning of driver support systems like ACC, which could possibly be strategically activated or deactivated in certain driving scenarios.

In the written descriptions the participants did not mention how they dealt with their possible spare capacity. This can partly be a consequence of how the question was phrased, namely that good driving should be described, and it can also be connected to the fact that most people do not consider the execution of additional tasks as part of driving, even though they may be related to navigation or the manipulation of in-car controls. It may be necessary to prompt for spare capacity in a second step, to make sure that this aspect is not simply forgotten.

On the sheets based on which the attentional distribution should be estimated in percent there was an explicit prompt for the estimation of spare capacity. The value indicated for spare capacity was relatively close to the percentage during which participants drove occluded, even though the variance was quite large. However, this was also the case for the between-subjects variation in occlusion behaviour. The core participants, who filled in the percentage sheet both before and after driving the occlusion condition, increased their estimate of spare capacity after having driven with occlusion. This can also be seen as an indication that it is difficult to estimate such values without any anchor to base the estimate upon. Mirror glances were generally heavily overestimated by about factor 2, while at the same time underestimating the percentage of time spent looking at the forward roadway.

Generally, the quality of the information given depends on the knowledge and expertise of the driving instructors. There is a risk that the driving instructors overestimate the minimum required attention since it may be their firm belief that it is necessary to monitor traffic relevant events all the time. This may also be true for novice drivers, but most likely not for expert drivers.

For future analyses of verbal protocols it is recommended to split the material into different manoeuvres. This will provide insight as to whether reported attentional distributions are manoeuvre dependent just as visual behaviour is. On top of that, it might also work as a rough indicator of invested mental load per manoeuvre. Not only a word count per distance or time, or a similar count of
disfluencies, but also a content analysis of the spoken material may provide clues on how much effort the driver currently invests, and how this investment changes over time.

7.8. Think aloud

Apparently glance behaviour is influenced to some extent when thinking aloud. The strongest indication for this is the increased duration and intensity of mirror glances especially when driving in the right lane. The more frequent mentioning of the mirrors in combination with this effect is interesting when seen in comparison to the lack of such an effect for speedometer glances. Possibly, when actively talking about one’s (good) driving it is important to stress the safety critical mirror glances, which might lead to an exaggerated execution of exactly those glances. Speedometer glances may be seen as less relevant for safety, which may either lead to a prioritisation when mentioning targets of attention in a time-constrained setting, or which may reflect the more automated nature of speedometer glances. The latter means that they would be less consciously accessible, which is the reason for their being mentioned less often. Overall, when both glance behaviour and a verbal report are to be collected, it is advisable not to do so during the same driving session, as the eye tracking results may be affected by the conscious thought process.

Based on the differences between think aloud data obtained in the field compared to in the lab setting, especially for collocations, we conclude that the level of detail available in the lab setting is insufficient. Both the lack of realism and the restricted amount of available information contribute to the differences. Interestingly, this finding contrasts with the conclusions drawn by Hughes and Cole (1986), who compared driving a course to watching a film of the same course. One reason for the differing conclusions could be that in our study the categorisation was more fine-grained, which may have revealed differences that were covered by the rougher categorisation used in Hughes and Cole’s study. Also, we found the main differences in the collocations, which were not analysed by Hughes and Cole. The comparability of real driving and film in think-aloud output may also depend on the setup used, for example whether mirrors and especially their content are visible on film, and whether a speedometer is present or not. In addition, it may also depend on how the instructions are phrased.

The think aloud technique is valuable in any case, however, because it provides direct and participant-generated information about why a certain behaviour is displayed, and whether a chain of actions belongs to the same ‘attentional episode’, like for example an overtaking manoeuvre. Verbal information obtained through thinking aloud during the action is more likely to access the procedural aspects of driving and appears to be more valuable than off-line reproduction of declarative knowledge.

7.9. Suggested improvements for data collection

The instrumentation of the test vehicle was high and advanced, but it is still possible to suggest improvements for future trials.

- As there is an experimenter in the car, the manoeuvres performed could be logged during the data collection instead of off-line from video. This would speed up the process as well as it might possibly help to identify better the moment in which a driver initialises an overtaking manoeuvre. The usage of a lane tracker may also aid in manoeuvre identification.

- The addition of a rearward radar and/or the synchronisation of the cameras monitoring traffic with the remaining data stream would be very beneficial. This would be possible with the usage of a Vbox that can record camera signals. It is also recommendable to include a view of the driver.

- In the present study the eye movements were not logged in real time, but off-line from film. This caused a substantial amount of additional work and possibly a slightly reduced data
quality. Therefore it is recommended to use real-time eye tracking in future studies. The experimenter in the car can monitor the tracking in real-time if a screen is available, such that possible problems can be addressed immediately in the field.

- The construction of the occlusion glasses needs to be improved to make them more robust.
- It should be considered whether it should be attempted to measure mental load in future studies. It has to be ensured, however, that this does not disturb glance behaviour.
8. Conclusions

Based on the practical experience with the tested methods and the results obtained from the limited number of participants a recommendation is given on which methods to use for the assessment of the minimum required attention in a certain location, and which aspects of attentional distribution the algorithm should incorporate.

8.1. Recommended methods

The occlusion method is considered to be the central method to assess spare capacity, and additional methods can be used to enhance the information.

A think-aloud session could be used to provide a better picture of when it is acceptable to occlude and why. However, the think-aloud part should be separated from the pure occlusion drive, as it was shown that thinking aloud while driving influences glance behaviour, which may very well carry over to occlusion behaviour. It is possible to either let the drivers think aloud or motivate their occlusions based on a video-confrontation after driving, or to use part of the drive to obtain the verbal motivations.

The addition of eye tracking, like it was done in the present study, is valuable, as more precise information is available with respect to which glances are redundant. It was shown here that the number of speedometer and mirror glances was not affected by visual occlusion, and it can be assumed that this result holds up over different situations. However, it is important to continue with content analyses of the objects outside of the car, and how the glance frequency to those is affected by occlusion.

To enhance this, it is also recommended to add radar not only to the front but at least also to the rear, or to operate with video and image recognition. Glance as well as occlusion behaviour is much more meaningful in relation to the current situation than exclusively related to the fixed features of the own vehicle.

Eye tracking is valuable to get an idea about the typical glance distribution across different targets, which will provide a sort of baseline especially for the number of glances to specific targets that are outside of the forward view. However, for the forward view eye tracking is not enough, as it cannot be differentiated between necessary and ‘default’ forward glances. When used in conjunction with occlusion it provides additional information about which targets receive less attention in the occlusion condition, and it is a good method to get at glance targets that are so automatised that they will not be mentioned in a think-aloud protocol.

Expert judgement as a stand-alone method does not appear to be very promising. In addition to the problems experienced with describing partially automatised behaviour and to deliver meta-knowledge about one’s highly overlearned skills, the problem may be related to the fundamental difficulty to convey procedural knowledge via language. While experts may be very proficient at driving a car, they may not be as good at verbalising it, especially when it comes to the more automatised parts of driving. Driving instructors may be an exception, as it is part of their job description to teach others to drive, but even for them it was more difficult to describe driving while not driving at the same time. Driving is more than just applying a limited set of rules, as it involves (pro)active consideration of the situation at hand, which at the same time enables the driver to change the situation. Thus, it does not lend itself very well to a meaningful static off-line description.

Also, the analyses of the collected data showed that it is important to partition driving on the motorway into different manoeuvres. Different rules apply for lane changes and for driving straight on, therefore they should not be lumped together. One possible solution to address the partitioning and the procedurality would be to show people a film of a certain manoeuvre and ask how they would
distribute their attention in this clip if they had been the driver. It may be necessary to prompt specifically for spare capacity.

The think-aloud method is a good complement to driving, as it provides insights into content and motivation that cannot be accessed directly from observational methods only. While thinking aloud appears to modify glance behaviour, it should be explored further for its capability to integrate observed glance behaviour into higher-level tactical procedures, which may help both for the development of the algorithm and for the prediction of MRA requirements in new situations.

However, it appears to be necessary to be immersed in the actual driving situation as compared to only thinking aloud while watching a video. In the latter setting much information was lost, even though the participants had the advantage to comment on videos from their own driving, not too long after having done the trip in question. Commenting on a video of somebody else’s driving may be even more difficult, producing results that are even further away from real driving.

All in all, there is not one single method that is enough to establish the minimum requirements of attention in a given situation, however, the occlusion method plays a central role. Using this, the minimum spare capacity availability can be assessed, and an enrichment with eye-tracking and think-aloud in combination with good and automatically analysable data about the surrounding traffic would be very valuable for the development of the algorithm.

8.2. Analysis method/strategy/approach

Based on theory and on preliminary analyses of the collected data set, the following aspects proved to be of importance for the interpretation of the results.

First of all, it is important to identify the manoeuvres that are thinkable in the investigated area. The attentional distribution differed clearly between manoeuvres, which means that the demand characteristics vary as well. When defining manoeuvres it is important to keep them general enough to avoid hindsight bias, but to get specific enough to be able to isolate the important aspects of behaviour for each particular type of manoeuvre. It may be better to be somewhat over specific in the beginning, because manoeuvres that turn out to have the same demand characteristics may be merged again later on.

Also, it is important to consider that glances to peripheral targets like the mirrors, the speedometer, but likely also road signs or other road users may and often do consist of ‘clusters’ of glances, that is, the target is fixated again very soon after just having been fixated. When scanning for clusters we used 3 s as cut off for in-between glance durations, but the mean in-between glance duration in clusters proved to be much shorter than that, indicating that the repeated glances actually are part of the same ‘attention action’. The hypothesis is that there is a base frequency of glances to peripheral targets to keep oneself informed about the situation, and if there is new or dense information additional repeated glances to the same peripheral target may be used for sufficient uncertainty reduction. Therefore, the required glance frequency to peripheral targets should be based on the frequency of clusters rather than single peripheral glances.

Loss of tracking does not necessarily mean that the section is void of information. Systematic loss of tracking in certain manoeuvres can also mean that the drivers systematically turn their head so much that the eye tracking cameras cannot see it any more. One example for this is the glance over the shoulder before changing lanes, which is illustrated in Figure 24. Thus, an analysis of the occurrence of systematic tracking loss may be indicative of certain behavioural tactics.

It soon emerged that it was not meaningful to glance code based on a static coding scheme. A content based scheme needs to be developed, and the data from the current project could serve as a base for such a scheme. The actual development and the coding of the available data is considered to be a future step of high importance. Such a scheme also needs to consider that drivers typically attend to
something behind the car when the glance is directed at the mirror – the mirror itself is rarely the target of attention. In a content based coding scheme it will be necessary to incorporate the information that objects behind the own vehicle can turn into objects in front of the own vehicle and vice versa.

8.3. Results applicable to the MRA algorithm

Based on the analysis of the data set obtained in this study a number of aspects that are of relevance for algorithm development could be identified. They are listed here as bullets with a short description.

- Occlusion provides the minimum spare capacity in each manoeuvre type, based on the assumption that drivers only occlude themselves when they feel completely safe to do so.

- Occlusion only (slightly) affected glance duration, not the frequency, to peripheral targets. It is assumed that the glance frequency is more important for information intake. Therefore for peripheral targets it is recommended to only implement glance frequency but not duration in the demand characteristics.

- Minimum forward glance duration is 1.5 s, perhaps shorter in situations where other target areas are in the main attentional focus. The combination of the eye tracker with the occlusion glasses allows an assessment of where the driver looks when only focusing on the ‘necessary’ glances. This way it is hoped that especially the ‘necessary’ duration of forward glances can be determined objectively. The present data suggest that the average minimum time drivers want to look forward is approximately 1.5 s. This forward glance duration can be reduced within clusters for a short period of time.

- Manoeuvres produce qualitatively different glance patterns and strategies and have to be considered in an algorithm.
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