Measuring information demand of a dynamic in-vehicle display while driving – a study evaluating the MARS (Masking Action Relevant Stimuli) method

Lena Rittger[1], Katharina Reinmueller[2], Andrea Kiesel[3]

[1]Adam Opel AG, Bahnhofsplatz, 65423 Ruesselsheim, Germany

[2]University Wuerzburg, Roentgenring 11, 97070 Wuerzburg

[3]University Freiburg, Engelbergerstraße 41, 79085 Freiburg, Germany

Manuscript type: Full length research article

Address information for Lena Rittger (corresponding author):

Adam Opel AG

IPC S4-01, Bahnhofsplatz

65423 Rüsselsheim

Tel: +49(0)6142769912

Fax: +49(0)6142775759

Lena.rittger@opel.com

Abstract

The novel MARS (Masking Action Relevant Stimuli) method assesses information demand for dynamic stimuli while driving. The action relevant stimulus is masked and the driver presses a button to unmask the stimulus for a limited period. We interpreted button presses as information demand. Following our previous research (Rittger, Kiesel, Schmidt, & Maag, 2014), the current study further evaluates the method. We applied the MARS method to a dynamic in-vehicle display containing recommendations from a traffic light assistant. In a driving simulator, drivers approached intersections with different traffic light phasing. The display either presented simple or complex information. In half of the drives, the participants used the MARS method. The study had a full within subjects design and fixations were recorded in all conditions. The results showed that the information demand varied according to the information in the display and the traffic light phase. A comparison of button presses with fixations showed that one unmasking interval came along with one fixation on the display. As a conclusion, the MARS method can distinguish between conditions with high and low information demand for the display. Button presses relate to fixations on the display. Hence, the MARS method is a promising tool to assess the information demand in dynamic environments and could be applied as an extension or alternative for eye tracking.

Keywords: Driver behavior, information processing, decision making, human-machine-interface.

1. Introduction

In complex dynamic situations like driving, it is efficient to focus attention to specific task relevant information (Shinoda, Hayhoe, & Shrivastava, 2001). The information demand for stimuli inside and outside the vehicle relates to their action relevance. The information demand describes that in order to come to the correct decision on appropriate driving behavior, drivers attend to stimuli that are relevant for this decision. Consequently, the investigation of the human information demand for certain stimuli serves as valuable input for understanding the driving task, and driver's decisions and behaviors. It further supports to design traffic systems and in-vehicle devices.

Information needed for solving the driving task is mainly visual (Gelau & Krems, 2004; Van der Horst, 2004). Drivers use visual strategies and search patterns (Engström, 2011). Therefore, eye tracking has been a standard method for measuring information demand in transportation research. A large number of research demonstrated the relation between attention for a stimulus and fixations on that stimulus (e.g., Corbetta, 1998; Horrey, Wickens, & Consalus, 2006; Just & Carpenter, 1980; Konstantopoulos, Chapman, & Crundall, 2010; Pradhan et al., 2005; Shinar, 2008; Sullivan, Johnson, Rothkopf, Ballard, & Hayhoe, 2012; Underwood, Chapman, Bowden, & Crundall, 2002). Senders, Kristofferson, Levison, Dietrick and Ward (1967) mentioned that the driver's attention is not continously directed to the road. Between observations, the uncertainty about one's position increases until it exceeds a threshold and leads the driver to look on the road again.

Yet, there are limitations to the eye tracking method. First, while a specific stimulus is fixated, the attention might be allocated elsewhere (inattentional blindness or the looked-but-failed-to-see error; Mack, 2003; Greenberg et al., 2003). A driver who fails to notice information might show the same gaze behavior as a driver who processes the fixated information (Galpin, Underwood, & Crundall, 2009). Second, even if the driver fixates and attends to a stimulus, the eye tracking cannot determine whether the fixations occur because of action relevance, or because the driver simply has to look somewhere in the road scene ("convenience glances", Kircher, Fors, & Ahlstrom, 2014). Third, attention can shift towards a stimulus without fixating it (Posner, 1980). Consequently, depending on the position and relevance of the stimulus, measuring fixations might fail to measure action relevance of a stimulus. Fourth, eye tracking comes along with some technical and practical disadvantages. For example, it is necessary to calibrate the eye tracker for each participant. During the experiment, certain movements or participant characteristics (e.g., eye color, glasses) might interrupt the data recording. The data analyses is especially challenging for dynamic environments or small stimuli with close proximity.

Due to these limitations, we presented the MARS (Masking Action Relevant Stimuli) method for measuring information demand for stimuli in the driving scene (Rittger, Kiesel, Schmidt, & Maag, 2014). This method is easily applicable when investigating behavior in a driving simulator. The concept is based on occlusion, i.e. the visual obscuration of parts or the whole driving scene (Senders et al., 1967). With the MARS method, relevant information of a single dynamic stimulus in the driving environment is masked. Drivers unmask the stimulus by pressing a button. The unmasking remains for a fixed interval, before the masking returns. Drivers can initiate the unmasking whenever and as often as they want. The assumption is that there is a small effort in demanding the information by pressing the button and therefore, the drivers only press when the information is actually required for solving the driving task. Studies in other contexts showed that even though the motoric effort is low, participants abstain from pressing buttons to retrieve information if it is not necessarily required (Gray & Fu, 2004). For the MARS method, more stimulus unmaskings represent a higher information demand for the stimulus. Figure 1 shows examples for the usage of the MARS method.

Figure 1. Examples for the application of the MARS method for information in the cluster display and information embedded in the driving scene (traffic signs, traffic lights).

In a first driving simulator study, we applied the MARS method to the traffic light phasing as an action relevant stimulus (Rittger, et al., 2014). Two criteria indicated that the MARS method is applicable for measuring information demand. First, the information demand varied depending on the environmental conditions. Second, these variations were qualitatively similar to the variations in information demand measured by fixations. However, the study revealed that drivers fixated on the traffic light more often than they pressed the button to unmask the traffic light phasing. In the study, the MARS method and the eye tracking were applied in separate conditions. Two hypotheses were discussed. The number of button presses measured by the MARS method might underestimate the information demand because drivers could have fixated the stimulus multiple times during single unmasking intervals. Alternatively, it might be that drivers fixated on the traffic light more often than necessary because the traffic light was a salient stimulus in the experimental setting.

The current research addresses this discussion in a further driving simulator study. We applied a full factorial within design. Two main conditions distinguished between driving with and without the MARS method. In the GAZE condition, we recorded fixations while the relevant stimulus was always visible. In the MARS condition, the relevant information was masked and drivers unmasked whenever and how often they wanted. Importantly, we expanded the methodology of the previous study by measuring driver fixations during the MARS condition. With this approach, we determined how unmasking intervals and fixations related and justified a direct comparison of button presses and fixations.

In order to generalize the applicability of the MARS method to a different stimulus and test case, we applied the masking to a dynamic in-vehicle display showing recommendations of a traffic light assistance system. Via car to infrastructure communication in the simulation, the vehicle approaching the traffic light received information about the phase duration. Based on this information, the system calculated driving speeds and behaviors supporting an efficient approach to the intersection.

In line with our previous research, we then considered different criteria to evaluate the MARS method. First, we varied the complexity of the information presented in the display and expected that more detailed information leads to higher information demand. Additionally, the traffic light phasing varied in the simulated test track. Recently, we observed that the potential for changes in driving behavior differs between different traffic light phases (Rittger, Schmidt, Maag, & Kiesel, 2015). Therefore, we expected that the information demand for the display varies between intersection approaches with green, red to green, red, or green to red traffic lights. The MARS method should be able to reflect these differences qualitatively similar to the fixations measured by eye tracking.

Second, we compared driving behavior by means of driving speed between the MARS and the GAZE condition. The MARS method should show low primary task intrusion, which means that it should not vary driving behavior compared to driving without the MARS method.

Third, we recorded subjective evaluations of the MARS method and the display concepts. By that, we could determine if participants were able to distinguish between the MARS method as a research method and the variation of display concepts in terms of research on an actual vehicle application.

We report this study as a starting point for the development of a new method that might relate to driver fixations. In terms of validating the method, we expected that the MARS method leads to results comparable to the eye tracking method in the current setting. In case our hypothesis is right, the MARS method could supplement or replace the eye tracking method in settings that are prone to the disadvantages of eye tracking for specific research questions. Therefore, the study will give insight into driver fixations during masking and unmasking events and might demonstrate the advantage of the MARS method from a methodological point of view.

that in the current setting, the MARS and the GAZE method lead to similar results in terms of information demand, which allows us to interpret the comparison between driver fixations and button presses in terms of a valiation of the method.

2. Material and Methods

2.1 Participants

Eighteen participants (ten female) took part in the study. Their mean age was 31.1 years (sd = 9.6). All drivers were well experienced with driving in the static driving simulator and had normal or corrected to normal vision. Data of one participant were excluded from the analysis, because of major problems in understanding the instructions.

2.2 Apparatus and materials

The study took place in the static driving simulator of the Wuerzburg Institute for Traffic Sciences (WIVW GmbH) which runs with the simulation software SILAB. The steering wheel had two buttons positioned at the left and the right side on the level of the conventional thumb position. The simulator had a 300° horizontal field of vision, visualized by five projectors distributed over five screens. Three LCD displays presented the rear view mirror, the left outside mirror and the speedometer display including the recommendations of the traffic light assistant. Four infrared cameras of the eye tracker Smart Eye AB allowed recording fixations.

For the evaluation of the MARS method, drivers were asked to respond to the following questions provided as paper-pencil questionnaire after completing the respective experimental drives: It was difficult to comply with the information when the display was masked; It bothered me that the display was masked; The longer I drove with the masked display, the easier was driving. Drivers responded to six questions evaluating the display versions: I frequently looked at the display; I got along well with the information in the display; I performed well in adapting to the expected behavior; The display contained enough information; The information in the display was helpful; The information in the display was complex. Participants answered on a verbal-numeric scale with six verbal categories (no agreement, very low agreement, low agreement, medium agreement, strong agreement, very strong agreement), with all but the no agreement category dividing into three numeric categories, resulting in a scale from 0 to 15.

2.3 Traffic light assistant and HMI (Human Machine Interface)

The cluster display contained the HMI of the traffic light assistant. We compared two versions. The simple HMI showed the current traffic light phase (Figure 2, left). The complex HMI contained three dynamic information units: traffic light phase information, action and speed recommendations (Figure 2, right). This information supported crossing the intersection at green without a stop. In case of unavoidable stops, the system assisted with efficient stops at red. The traffic light phase information contained the depiction of the current traffic light phase along with a marking for the phase at arrival based on the current driving speed. Eight seconds before termination of the current traffic light phase, a countdown timer dynamically started and the filling of the current traffic light phase reduced by quarters, with one quarter representing two seconds. Icons recommended to accelerate (▲), to brake (▼), to coast (▽) or to keep speed (⧗). The numeric speed recommendations indicated which speed participants should drive. The maximum and minimum recommended speeds were 50 km/h and 30 km/h, respectively. The major unit was 5 km/h. Previous research showed that recommending lower speeds leads to the feeling of bothering other drivers (Rittger, Muehlbacher, Maag, & Kiesel, 2014). All information units in the complex HMI version dynamically considered the current driving speed of the participants. The HMI was activated approximately 300 m in front of the intersection. No lead vehicles hindered drivers in following the recommendations.

Figure 2. HMI versions as used in the experiment. The simple version showed the current traffic light phase (left). The complex version showed dynamic information on the traffic light phase duration by changes in the filling of the respective color, phase at arrival, action and speed recommendations (right).

In the MARS condition, the HMI display was masked while the traffic light assistant was active. To unmask the information in the display, drivers pressed at least one of two buttons at the steering wheel. After pressing the button, the information in the HMI was unmasked for 1000 ms, before the masking returned (Figure 3). Pre-tests had shown that 1000 ms offered sufficient time to process the information in the display. Drivers could press the button to unmask whenever they wanted and as often as they wanted. Longer or repeated presses within an unmasking interval did not lead to longer unmasking intervals. After termination of the 1000 ms interval, drivers had to press the button again to unmask the display again. In the GAZE condition, the HMI was unmasked constantly.

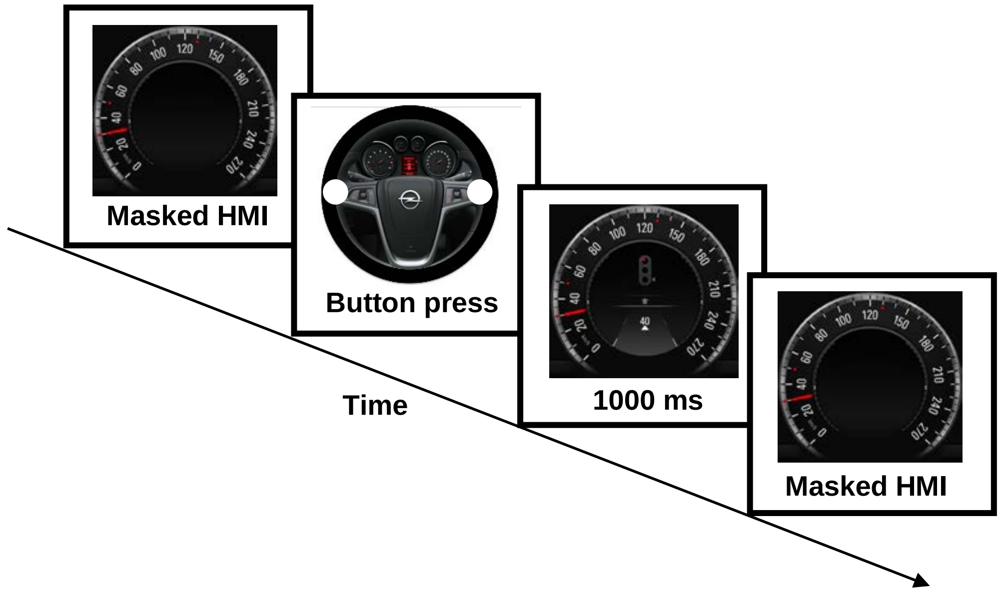

Figure 3. Schematic depiction of the MARS method as applied in the current study. The HMI is masked while driving. When pressing one of two buttons located at the steering wheel (white dots), the HMI unmasks for 1000 ms before the masking returns. Note that the display is located behind the steering wheel.

2.4 Design

The study had a full within-subjects design. Each participant drove through the simulated test track with the conditions MARS and GAZE and the simple and the complex HMI version. The two drives with the same HMI version were conducted consecutively.

The order of the two HMI versions and the order of the two method conditions alternated between participants. Fixations were recorded in all drives.

The traffic light phases varied between solid green, changing red to green, solid red and changing green to red. The order of the traffic light phases was permuted as a Latin square, resulting in four versions of the simulated test track. To repeat each of the traffic light approaches, the second half of each simulated test track consisted of the reversed order of its first half, resulting in eight traffic light approaches. The order of the four simulated test tracks was the same for all drivers. Hence, drivers experienced each combination of condition and HMI version with a different permutation of traffic light approaches.

The dependent variable was the percentage of time the information was demanded, i.e., the total length of unmasking intervals in the MARS condition and the total length of fixations on the display in the GAZE condition, both in relation to the total duration of each traffic light approach. Further, we measured fixations in all conditions, driving speed, and subjective evaluations according to the questionnaires.

2.5 Simulated test track

The simulated urban test track consisted of eight intersections with the same four-way intersection layout and was approximately 4.8 km long. The road environment varied by buildings, landmarks and plants. Participants always drove straight. There was traffic at the intersection, but no traffic on drivers' own lane. The traffic light phasing was according to German road regulations. The red phase ended with a combined presentation of red and yellow, the green phase ended with a single yellow state. Traffic light changes occurred when drivers were approximately 40 m in front of the intersection (i.e., 4.3 s in the red to green condition and 3.9 s in the green to red condition). For the analysis, we considered the approach area of 300 m. The speed limit was 50 km/h.

2.6 Procedure

Participants completed a data privacy statement and received instructions about the objectives of the study. Before the first drive with a new HMI version, the experimenter explained the display thoroughly, followed by a short practice track with a constantly unmasked display. During the whole experiment, the instruction was to follow the traffic rules and to stick to the recommendations in the HMI. After each drive, participants filled in the questionnaires. The procedure took approximately 1 h. Participants took breaks whenever they wanted between drives.

3. Results

For the analysis of fixations, the cluster display was the area of interest. The display included the HMI and the speedometer. A fixation on the area of interest lasted at least 100 ms. As soon as a fixation ended, any further fixation on the display counted as new fixation. We conducted the Analyses of Variance (ANOVAs) according the repeated measurements design.

3.1 Fixations in the MARS condition

To justify a comparison of information demands measured by button presses and fixations, we investigated the relation between fixations and unmasking intervals in the MARS condition. Hence, the following analysis was based only on data recorded in the MARS condition. Figure 4 visualizes the relevant parameters. We determined the number of fixations starting before an unmasking interval (A), starting and ending within an unmasking interval (D) and starting within an unmasking interval and lasting into the masking interval (C). Additionally, the analysis contained the number of unmasking intervals without (E) and with fixation (F). (B) describes fixations on the display while the display was masked.

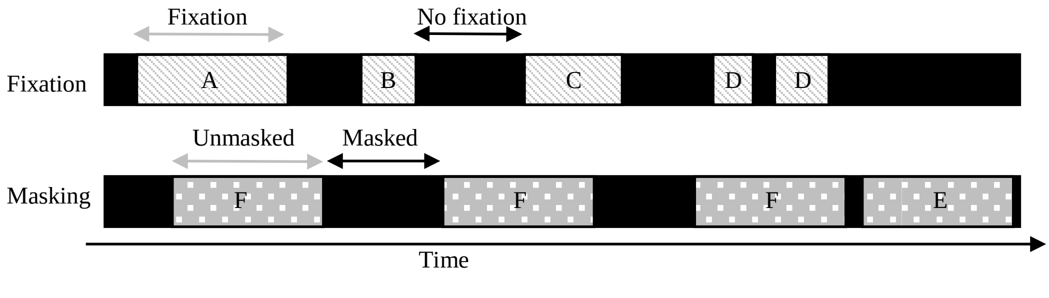

Figure 4. Visualization of relevant parameters for the analysis of fixations when driving with the MARS method.

Table 1 presents the respective number of observations accumulated for all participants and all traffic light approaches in each condition. It shows that only 2.33 % of the unmasking intervals came along without any fixation. In total, 1.05 fixations occurred per unmasking interval. 56.73 % of the fixations on the display in the MARS condition occurred while the display was masked.

Table 1.

Parameters describing the number of unmasking intervals and number of fixations separated for the two different HMI versions and the four different traffic light phases.

HMI version	Traffic light phase	Number of unmasking intervals (E+F)	Number of fixations (A+B+C+D)	Number of fixations per unmasking interval (A+C+D)/(F+E)	Percentage of unmasking intervals without fixation (E)/(E+F) *100	Percentage of fixations during masking (B)/(A+B+C+D)*100
Simple	Green	n=75	n=232	1.15	4.0 %	62.9 %
	Red to green	n=91	n=210	1.01	0.0 %	56.2 %
	Red	n=98	n=246	1.01	4.1 %	59.8 %
	Green to red	n=88	n=234	1.00	5.7 %	62.4 %
Complex	Green	n=106	n=279	1.12	0.9 %	57.3 %
	Red to green	n=146	n=361	1.09	0.0 %	56.0 %
	Red	n=165	n=316	1.01	3.0 %	47.2 %
	Green to red	n=134	n=315	1.04	2.2 %	55.9 %
Total		∑n=903	∑n=2193	1.05	2.3 %	56.7 %

3.2 Percentage of time demanding the information in the display

Based on the observation that one unmasking interval came along with on average one fixation on the display, we evaluated the percentage of information demand in the MARS and the GAZE condition in one analysis. The ANOVA compared the percentage of time demanding the information in the display in relation to the total duration of each intersection approach. The independent factors were the method condition (MARS, GAZE), the HMI version (simple, complex) and the traffic light phase (green, red to green, red, green to red).

In line with the previous studies, the percentage of time demanding the information in the display was higher in the GAZE compared to the MARS condition, $F(1,16) = 72.523$, $p < .001$, $\eta^2_{partial} = .819$. As expected, with the complex HMI version, the information demand was higher compared to driving with the simple HMI, $F(1,16) = 46.810$, $p < .001$, $\eta^2_{partial} = .745$. Supporting our assumptions, the main effect traffic light phase indicates that the percentage of time demanding the information was larger in the green and red to green condition compared to the red or the green to red condition, and larger in the red to green condition compared to the solid green condition, $F(3,48) = 56.586$, $p < .001$, $\eta^2_{partial} = .780$. The interaction between the method condition and the HMI version shows that there is no significant difference between simple and complex HMI version in the MARS condition, but in the GAZE condition $F(1,16) = 28.129$, $p < .001$, $\eta^2_{partial} = .637$. The interaction between the method and the traffic light phasing shows that there is no difference between the green and the red to green condition for the MARS method, while all other effects remain valid in the MARS and the GAZE condition, $F(3,48) = 10.917$, $p < .001$, $\eta^2_{partial} = .405$. The interaction between the HMI version and the traffic light phase shows that the differences between the traffic light phasing is mainly based on the percentage of information demand occurring with the complex HMI version, $F(3,48) = 19.061$, $p < .001$, $\eta^2_{partial} = .544$. Finally, there was a three-way interaction of all three factors, $F(3,48) = 7.286$, $p < .001$, $\eta^2_{partial} = .313$. The differences in information demand between simple and complex HMI and the differences in information demand between traffic light phases when driving with the complex HMI are stronger in the GAZE compared to the MARS condition (Figure 5).

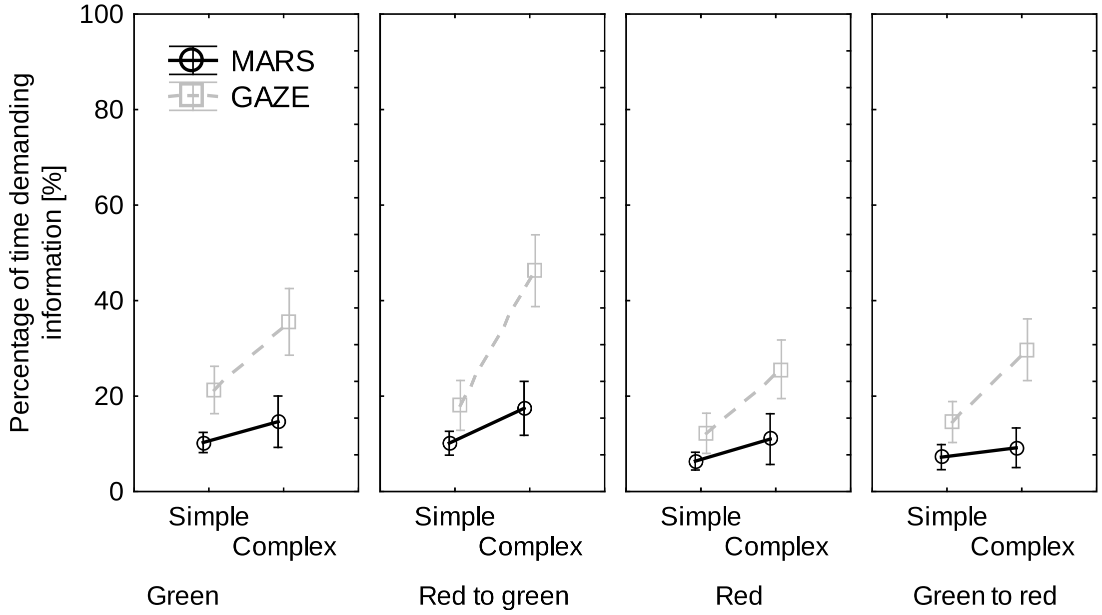

Figure 5. Percentage of time demanding the information in the MARS and the GAZE condition depending on the factors HMI version and traffic light phase. The graph shows means with 95% confidence intervals.

3.3 Driving behavior in the MARS and the GAZE condition

In order to evaluate whether driving with the MARS method changes normal driving behavior, we compared mean driving speed between the MARS and the GAZE condition.

Figure 6 visualizes the mean driving speed averaged over all HMI and traffic light phase conditions and differentiated by distance segments. An ANOVA with the independent factors method condition, HMI version and traffic light phase compared the mean driving speed. Neither significant main effects nor interactions with the factor method were found, all *ps* > .973. The method for measuring information demand did not influence driving behavior.

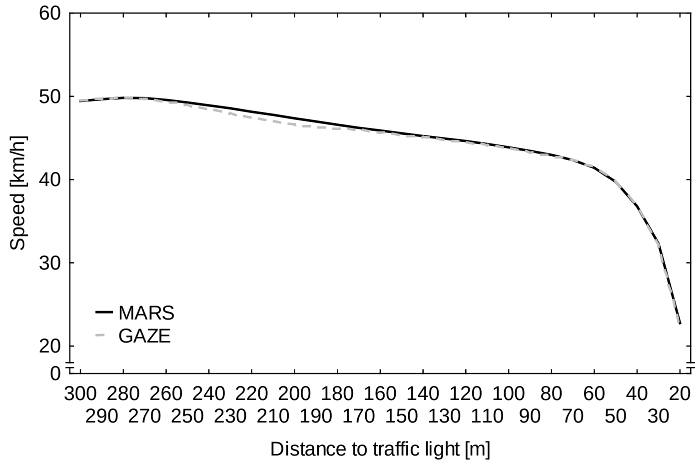

Figure 6. Mean driving speed during the 300 m traffic light approach for the MARS and the GAZE condition. The respective upper boarders (e.g., 300 for the distance segment 290-300 m in front of the intersection) label the distance segments.

3.4 Subjective evaluation

Participants evaluated driving with the MARS method (Figure 7). We conducted t-tests for dependent groups with the factor HMI version. In general, it was not very difficult to drive with the masked display, with higher difficulty ratings in the complex HMI compared to the simple HMI condition, $t(16) = 3.622$, $p = .002$. Drivers expressed that they were not very disturbed by the masked display, but that they were more disturbed by the masked information with the complex HMI compared to the simple HMI, $t(16) = 2.368$, $p = .031$. Participants agreed medium strongly that driving with the masked lights became easier with time, with no differences between HMI versions, $t(16) = 1.241$, $p = .233$.

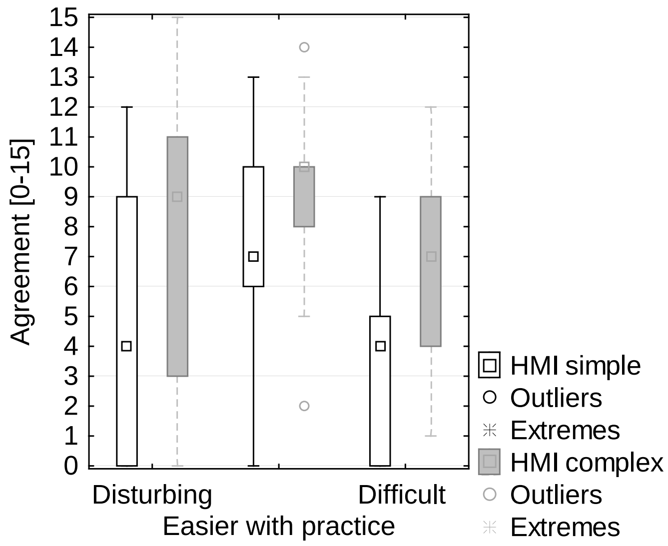

Figure 7. Driver's agreement to the statements evaluating if driving with the masked display was disturbing, if it was easier with practice and if it was difficult to stick to the recommendations with the masking. The graph shows boxplots with medians.

Finally, drivers evaluated the two different HMI versions. For each of the six questions, we conducted separate ANOVAs with the factors method condition and HMI version. Neither significant main effects nor significant interactions with the factor method were found in driver's agreement to the statements, all *ps* > .067, (Figure 8).

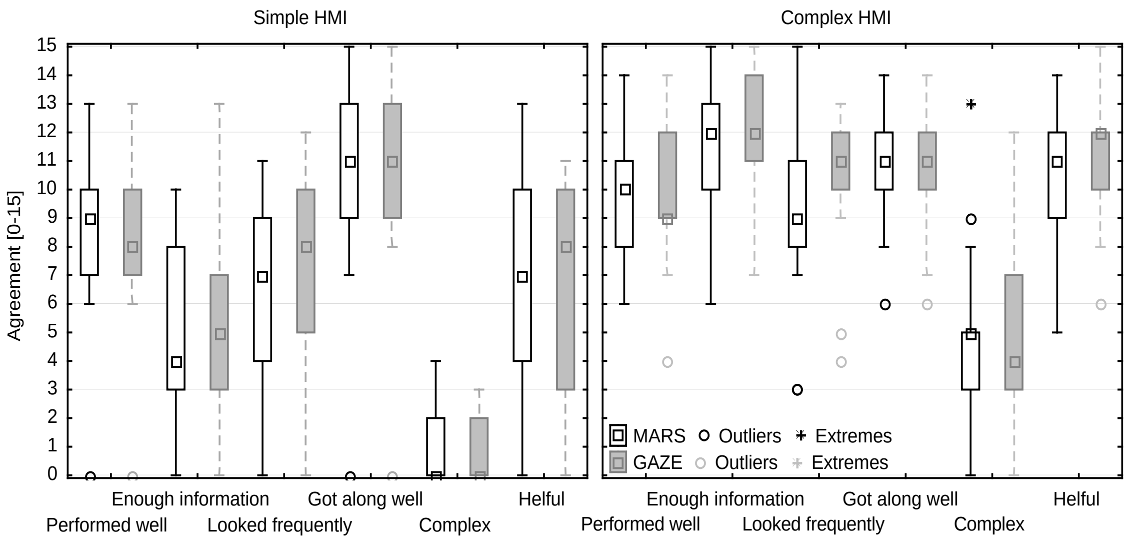

Figure 8. Driver's agreement to the statements evaluating the HMI versions in the MARS and GAZE condition for the simple (left) and the complex (right) HMI version. The graphs show boxplots with medians.

4. Discussion

The goal of the present study was to show if the MARS method is applicable for measuring information demand for dynamic information in an HMI display in the vehicle. The information demand is an indicator for the attention allocation to a stimulus due to action relevance. This is the second study evaluating the MARS method in a driving simulator setting. We compared button presses as the dependent variable of the MARS method to fixations collected with an eye tracker in the GAZE condition.

As expected, with the complex HMI version the information demand for the display showing the recommendations of a traffic light assistant was higher than with the simple HMI version. With more and dynamic information in the complex display, drivers needed to retrieve information from the display frequently in order to fulfil the task of sticking to the recommendations. When driving with the complex HMI version the information demand for the display was especially large for changing red to green traffic lights. When the traffic light changed during the approach, the traffic light phase at arrival marked in the display differed from the currently active traffic light phase in the road. Therefore, drivers might have felt that it is necessary to check frequently if the arrival at green status was still correct or if the display adapted and a stop at red was recommended.

The results showed that the experimental variations influenced the information demand in the MARS and the GAZE condition qualitatively similar: Situations with high information demand measured in the GAZE condition also resulted in high information demand measured in the MARS condition. This indicates that the MARS method is able to measure differences in information demand between the experimental conditions as expected and in the same direction as the eye tracking method.

We replicated our previous findings by showing that the number of fixations measured in the GAZE condition was higher than the number of button presses in the MARS condition. In line with this, the differences in information demand between the experimental conditions were lower in the MARS compared to the GAZE condition. Due to the lower number of unmasking events, the MARS method reflected less strong differences between the introduced variations compared to the eye tracking method.

Importantly, the investigation of fixations during the MARS condition provides an explanation. Button presses and fixations related to each other. Drivers hardly ever pressed the button without fixating the display. One button press came along with on average one fixation on the display. There were hardly any multiple fixations during a single unmasking interval. This is the case even though drivers had time to fixate multiple times during a single 1000 ms unmasking interval.

Yet, around 56% of the fixations on the display during the MARS condition occurred during display masking. The analysis of eye tracking data did not allow distinguishing between fixations on the HMI and fixations on the speedometer, as both information units were presented in the same display. While the button presses in the MARS method only measured information demand for the HMI display, the fixations measured information demand for the HMI and the speedometer.

Consequently, it might be that driver fixations overestimated the information demand and that the eye tracking measured effects not related to the HMI (but to the speedometer). In case our interpretation is right, the difference in information demands between the MARS and the GAZE condition would decrease, if the complete display were masked rather than just the traffic light information. In future research the MARS method could be applied to both stimuli, the speedometer and the HMI, within one experiment. We could then determine the information demand for multiple stimuli within the same area of interest. Comparing the results with eye tracking data that distinguishes between the two areas might clarify this discussion.

As expected, the MARS method did not change driving behavior. The drivers solved the driving task similarly, independent of masked or permanently unmasked displays. The number of times the drivers requested the information in the MARS condition was sufficient with respect to driving performance and no more or longer fixations on the HMI were required.

Additionally, the subjective evaluations of the HMI versions did not differ between the MARS and the GAZE condition. We consider this as important for a potential future usage of the MARS method in the development of in-vehicle systems. The participants were able to distinguish between the MARS method as experimental tool and the actual HMI evaluation.

In the assessment of the method, drivers expressed that the MARS method was more difficult when driving with the complex compared to the simple HMI. This is a possible limitation, because the MARS method should be applicable similarly to all experimental conditions with no variations in task demands. Future research needs to show how these differences influence the measurement of information demand. Along with this, the investigated stimuli could include more than two levels of complexity, in order to allow for a richer comparison between the MARS and the GAZE condition.

Comparing the practicability of the eye tracking and the MARS method for simulation studies, we observed benefits for the MARS method. The set-up only requires the availability of an input device, e.g. a button easy to reach for participants. No camera set-up with expensive equipment is necessary. Eye tracking requires calibration and individual characteristics of drivers might challenge an efficient data recording. The MARS method offers stable data quality throughout the experiment, while due to participant's movements and adaptions of seat position, as well as changing lighting conditions, the quality of fixation data might vary during the experiment. The button press events were recorded in the data streams of the SILAB software and no further processing or post-hoc data control was necessary.

The preparation of future MARS method experiments requires careful consideration of the duration of the unmasking interval. Unlike fixations, the duration of the unmasking intervals is pre-defined and does not change during the experiment. The unmasking duration and characteristics of the masked stimulus, as well as the demands in the environment, might interact. Especially, in more variable and complex driving situations drivers might divide their information demand into more and shorter fixations. The 1000 ms unmasking intervals as defined in the current study then only allow for coarser measurements of information demand compared to eye tracking. A possible approach could be that drivers determine the length of the unmasking intervals by the length of the button presses. We abstained from this solution because due to the low effort, we expected that drivers could keep the button constantly pressed. Future research could also provide more details about the frequency and distribution of button presses, if frequent re-presses occur in specific areas, and how variations in the frequency of button presses relate to driver attention.

Finally, the current data does not show if the MARS method solves the possible flaws of the eye tracking method in terms of driver attention (i.e., fixation without attention, attention without fixation). Nevertheless, assume that due to the higher effort of pressing the button compared to fixating the display, button presses might be a valid indicator for information demand for a specific action relevant stimulus. More research is needed to determine the relation between button presses, fixation behavior and the actual attention to the display.

5. Conclusion

We believe that the MARS method is a promising tool for the assessment of information demand to dynamic stimuli. Extending previous results, the current study allowed explaining fixations during unmasking intervals: Unmasking the stimulus includes that drivers fixate the stimulus, with one unmasking coming along with one fixation. A possible application in the development of driver interfaces could be head-up displays, as the discrimination of fixations on the display and the road environment represents a challenge for eye trackers.

Acknowledgements

This research was conducted in the research project UR:BAN Urbaner Raum: Benutzergerechte Assistenzsysteme und Netzmanagement funded by the German Federal Ministry of Economic Affairs and Energy (BMWi) in the frame of the third traffic research program of the German government. The authors thank the staff of the Würzburg Institute of Traffic Sciences for the support in setting up the driving simulator study.

References

Corbetta, M. (1998). Frontoparietal cortical networks for directing attention and the eye to visual locations: Identical, independent, or overlapping neural systems? *Proceedings of the National Academy of Sciences, 95,* 831-838.

Engström, J. (2011). *Understanding attention selection in driving: From limited capacity to adaptive behaviour*: Chalmers University of Technology. Doctoral Dissertation, Vehicle Safety Division Department of Applied Mechanics Chalmers University of Technology, Sweden.

Galpin, A., Underwood, G., & Crundall, D. (2009). Change blindness in driving scenes. *Transportation Research Part F: Traffic Psychology and Behaviour, 12*, 179- 185.

Gelau, C., & Krems, J. F. (2004). The occlusion technique: a procedure to assess the HMI of in-vehicle information and communication systems. *Applied Ergonomics, 35,* 185-187.

Gray, W.D., & Fu, W.T. (2004). Soft constraints in interactive behavior: The case of ignoring perfect knowledge in-the-world for imperfect knowledge in-the-head. *Cognitive Science, 28(3),* 359-382.

Greenberg, J., Tijerina, L., Curry, R., Artz, B., Cathey, L., Grant, P., Kochhar, D., Kozak, K., Blommer, M., . (2003). Driver distraction: Evaluation with event detection paradigm. *Transportation Research Record: Journal of the Transportation Research Board, 1843,* 1-9.

Horrey, W. J., Wickens, C. D., & Consalus, K. P. (2006). Modeling drivers' visual attention allocation while interacting with in-vehicle technologies. *Journal of Experimental Psychology: Applied*, *12*, 67.

Just, M. A., & Carpenter, P. A. (1980). A theory of reading: from eye fixations to comprehension. *Psychological review, 87*, 329-354.

Kircher, K., Fors, C., & Ahlstrom, C. (2014). Continuous versus intermittent presentation of visual eco-driving advice. *Transportation Research Part F: Traffic Psychology and Behaviour, 24*, 27-38.

Konstantopoulos, P., Chapman, P., & Crundall, D. (2010). Driver's visual attention as a function of driving experience and visibility. Using a driving simulator to explore drivers' eye movements in day, night and rain driving. *Accident Analysis & Prevention, 42*, 827-834.

Mack, A. (2003). Inattentional Blindness Looking Without Seeing. *Current Directions in Psychological Science, 12*, 180-184.

Posner, M. I. (1980). Orienting of attention. *Quarterly journal of experimental psychology, 32*, 3-25.

Pradhan, A. K., Hammel, K. R., DeRamus, R., Pollatsek, A., Noyce, D. A., & Fisher, D. L. (2005). Using eye movements to evaluate effects of driver age on risk perception in a driving simulator. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 47*, 840-852.

Rittger, L., Kiesel, A., Schmidt, G., & Maag, C. (2014). Masking Action Relevant Stimuli in dynamic environments – The MARS method. *Transportation Research Part F: Traffic Psychology and Behaviour, 27,* 150-173. doi: 10.1016/j.trf.2014.10.002.

Rittger, L., Muehlbacher, D., Maag, C., & Kiesel, A. (2015). Anger and bother experience when driving with a traffic light assistant: A mulit-driver simulator study. D. de Waard, J. Sauer, S. Röttger, A. Kluge, D. Manzey, C. Weikert, A. Toffetti, R. Wiczorek, K. Brookhuis, and H. Hoonhout (Eds.) (2015). Proceedings of the Human Factors and

Ergonomics Society Europe Chapter 2014 Annual Conference. ISSN 233-4959 (online). Availabe from http://hfes-europe.org.

Rittger, L., Schmidt, G., Maag, C., & Kiesel, A. (2015). Driving behaviour at traffic light intersections. *Cognition, Technology & Work, 17,* 4, 593-605.

Senders, J.W., Kristofferson, A.B., Levison, W.H., Dietrick, C.W., and Ward, J.L. (1967). The Attentional Demand of Automobile Driving. *Highway research Record, 195,* 15-33.

Shinar, D. (2008). Looks are (almost) everything: where drivers look to get information. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 50*, 380-384.

Shinoda, H., Hayhoe, M. M., & Shrivastava, A. (2001). What controls attention in natural environments? *Vision research, 41,* 3535-3545.

Sullivan, B. T., Johnson, L., Rothkopf, C. A., Ballard, D., & Hayhoe, M. (2012). The role of uncertainty and reward on eye movements in a virtual driving task. *Journal of vision, 12*, 19. doi: 10.1167/12.13.19.

Underwood, G., Chapman, P., Bowden, K., & Crundall, D. (2002). Visual search while driving: skill and awareness during inspection of the scene. *Transportation Research Part F: Traffic Psychology and Behaviour, 5*, 87-97.

Van Der Horst, R. (2004). Occlusion as a measure for visual workload: an overview of TNO occlusion research in car driving. *Applied Ergonomics, 35*, 189-196.