The Paradox of Driving-Related Distraction: Driver Monitoring Systems Trigger Warnings During Overtaking Maneuvers

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ABSTRACT

Driver Monitoring Systems (DMS) detect visual distraction and alert drivers to maintain focus on the road. The European New Car Assessment Programme developed an algorithm that triggers warnings upon detecting distraction. Previous research showed that off-road glances during lane changes triggered warnings and drivers had difficulties understanding why these warnings occurred. Therefore, a simulator study was conducted in which drivers performed an overtaking maneuver in dense traffic. The DMS was either inactive and did not generate any warnings, or it was active and triggered warnings with or without being instructed beforehand. Results revealed that in 50 % of the overtaking maneuvers driving-related distraction was recorded. There was a significant difference between whether the DMS was inactive, active or instructed with regards to warnings. It was observed that side mirror glances, prior to overtaking, paradoxically prompted warnings. Findings indicated the necessity to refine DMS algorithms to discern safety-relevant behaviors from genuine distractions.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**; **Empirical studies in interaction design**.

KEYWORDS

Driver Monitoring; Driving Related Distraction; Visual Attention Time Sharing; Warnings; Distraction; Glance behaviour

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1 INTRODUCTION

There is a trend to implement Driver Monitoring Systems (DMS) into both automated and manual vehicles to detect signs of driver impairment. Most DMS monitor the driver via cameras [10]. Based on the collected glance data, algorithms identify driver states like distraction or fatigue. If the driver is classified as inattentive or fatigued by the DMS, the system issues a visual-auditory warning [10]. Therefore, DMS have the potential to improve road safety, prevent accidents and become an established safety system in vehicles [9]. For driver distraction, there are various algorithms which use different glance metrics and thresholds to identify visual distraction during driving [3, 6, 12–14, 19, 21].

1.1 Background on Driver Monitoring

Lee and Regan [17] state that driver distraction can be defined as "the diversion of attention away from activities critical for safe driving toward a competing activity". For safe driving visual distraction and manual distraction, are particularly relevant (e.g., [5]). Visual distraction is also referred to as "eyes off the road". Following this definition, any glance that is not directed through the windscreen, and therefore not directed at the road ahead, is classified as visual distraction. Present DMS are based on this assumption [19], although there is research indicating that distraction is highly context dependent, meaning that a glance cannot be classified as attentive or distracted without considering the context [1].

The European New Car Assessment Programme (Euro NCAP) proposed a distraction detection algorithm in their latest safety protocol [19], which distinguishes two types of distraction: non-driving-related distraction and driving-related distraction. Non-driving-related distraction includes glances, e.g. to the infotainment display or any area in the vehicle, which are not related to the driving task. Driving related distraction includes glances, e.g. to the side or rear-view mirror and any other area that is relevant for driving. Further, they distinguish between two metrics of glance behavior that contribute to distraction [19]: visual attention time sharing and long distraction. Visual attention time sharing, is defined by multiple short glances away from the road ahead for a total of 10 s within a time period of 30 s [19]. Long distractions, are defined as single long glances away from the road ahead (i.e., windscreen) for a period of ≥ 3 s [19]. For driving- and non-driving-related distraction, a visual-auditory warning is triggered by the algorithm, when threshold for a long distraction or visual attention time sharing is exceeded. This means that glances to the side mirrors during an overtaking maneuver can also potentially result in a warning if they accumulate to 10 s or exceed 3 s.

From a research perspective, the design of the warning algorithm outlined above has some shortcomings. There is no valid empirical evidence that a series of short off-road glances accumulated over time leads to distraction or increased crash risk. The values of 10 s within 30 s appear arbitrary, and it remains unknown whether such warnings are necessary to address safety issues. Further, triggering warnings when drivers engage in safety-related behaviors prior to lane changes (e.g., mirror checking) seems paradoxical. While checking a mirror prior to a lane change is likely relevant to the driving task, the glance is still classified as a distraction. Previous work pointed out that attention is largely context-dependent, and a deterministic algorithm like the one proposed by EuroNCAP could lead to false classification of behavior, triggering invalid warnings to the driver [1].

1.2 Related Studies

The literature supports the assumption that checking mirrors before lane changes is a common safety behavior. According to Lee et al. [18] and Tijerina et al. [20], the driver switches their glances from the windscreen to the side and rear-view mirrors. Further it was found, that a glance to the left mirror can serve as a predictor for a lane change [11]. Literature indicates that the duration of mirror glances before lane changes is between 0.8 and 1.6 s [18]. Therefore, glances are usually shorter than the critical threshold for a long distractions (3 s), defined by the Euro NCAP. Consequently this work focuses exclusively on visual attention time sharing as a cause of driving-related distraction.

In a previous study the Euro NCAP algorithm was implemented and warnings were triggered accordingly, whenever driving-related distraction was detected [8]. Participants performed several realistic lane change and overtaking maneuvers in a driving simulator. The results showed that 86.67 % and thus the majority of participants received warnings. This suggests that the glances observed during the maneuver were categorized as driving-related distraction and consequently triggered a warning. However, data is missing on what glances caused the warnings.

Further, interview data from the study indicated that participants had difficulties understanding what behavior triggered a warning. Even after experiencing multiple warnings, drivers were not able to name the reason for the warning correctly. In line with this Koniakowsky et al. [15] showed that participants had difficulties forming a correct mental model of the warnings triggered by the DMS. Drivers commonly assume, that solely prolonged glances to the display in the vehicle cause warnings [15]. Consequently, there is reason to suggest that drivers have difficulties understanding that also multiple short glances and even glances at mirrors can be triggers for a warning.

1.3 Study objectives

Previous research suggests that the Euro NCAP distraction detection algorithm triggers warnings during driving maneuvers like lane changes. However it remains unclear, whether actually multiple short glances to the mirrors trigger these warnings. Further, drivers have difficulties understanding the cause of these warnings. However, this is a prerequisite for successful behavioral adaption in terms of glance behaviour. Therefore, the aim of this paper is twofold; first, investigate how often and through which glance behavior driving-related distraction causes warnings. Second, examine whether drivers' glance behavior changes if drivers had a better understanding of the DMS and warnings, e.g. by instructing the DMS beforehand. To bring forth evidence, a static driving simulator study with N = 62 participants was conducted. Drivers performed an overtaking maneuver of a lead vehicle. The Euro NCAP algorithm was used to detect driving-related distraction during the overtaking maneuver. Only driving-related distraction caused by visual attention time sharing was analyzed, which is why, for the sake of readability, the present paper uses the term driving-related distraction to refer to visual attention time sharing.

2 METHOD

2.1 Sample

The final sample comprised N= 62 participants after excluding three for insufficient eye-tracking data quality (18 female, 44 male). The average participant age was M = 38.21 (SD = 10.83). All participants held a valid German driver's license and had normal or corrected to normal vision. The mean time since obtaining a driver's license was M = 20.34 (SD = 10.41).

2.2 Study Design

In the present study, a between-subjects experimental design was utilized to investigate the impact of the DMS on driver behavior. The DMS conditions were systematically varied between participants as follows: DMS inactive, in which the DMS monitored glance behavior but did not trigger warnings; DMS active, in which the DMS triggered warnings; and instructed, in which the DMS triggered warnings and participants received instructions regarding the DMS functionality before their drive. Participants were randomly assigned to one of the three groups (DMS inactive: n = 21; DMS active: n = 22; DMS instructed: n = 19).

2.3 Procedure

Upon arrival, participants gave informed consent and were instructed about the driving simulator. The group with the inactive and the active DMS were neither informed about the DMS nor the occurrence of warnings. One third of the participants were instructed about the DMS, the behavior would trigger a warning and were made familiar with the warning. All participants were told that driving safety and compliance with traffic rules always had priority.

Participants were instructed to drive on the far right lane of a three-lane highway, following a van. The van's speed was programmed to decrease from 100 km/h to 60 km/h at a predetermined point during the drive. Subsequently, drivers were told to overtake the van when they feel safe to do so, taking into account the rear traffic. The traffic scenario was designed in such way that vehicles on the middle lane passed by, traveling at approximately 100 km/h, which precluded immediate lane changing. The gap between passing vehicles increased progressively, requiring participants to continuously reassess whether the emerging gap was sufficient for a a lane change. Approximately 30 s into the scenario, the first substantial gap appeared, enabling a lane change to be executed. An overtaking maneuver was deemed successful once the participant had safely changed to the middle lane.

2.4 Driving Simulation and DMS

The study was conducted in a stationary driving simulator featuring a panoramic view of 220°. The driver's rear view was represented by three LED displays integrated in the mirrors. The simulation of a three-lane motorway environment was generated using the SILAB® driving simulation software [16]. To capture participants' glances, the SmartEye® remote eye-tracking system with three cameras was employed. Following the Euro NCAP protocol, solely glances directed at the windshield were categorized as attentive, whereas glances toward any other Areas of Interest (left mirror, rear mirror) were deemed indicative of distraction [19]. The DMS issued immediate visual-auditory warnings as soon as a driving-related distraction was detected (Figure 1). Multiple short glances away from the road ahead for a total of 10 s within a time period of 30 s triggered a warning [19]. The 30-second time period was reset if drivers directed their glance back to the road ahead for a duration of ≥ 2 s. Warnings occurred only at vehicle speeds ≥ 20 km/h. The warning appeared in the instrument cluster above the speed indicator in the drivers line of sight for a duration of 4 s. An icon of an eye along with the message "Glance aversion detected. Stay attentive." served as the warning.

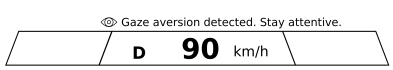

Figure 1: Schematic illustration of the warning display, triggered by the DMS. Warnings were displayed in the instrument cluster above the speed indicator in the driver's line of sight.

2.5 Data preparation and analysis

Eye-tracking data was recorded during the overtaking maneuver from the onset of the lead vehicle decelerating, to the completion of the lane change by the ego vehicle, i.e., crossing the middle lane marking. All instances of driving-related distraction were counted per overtaking maneuver. Furthermore, the percentage of glances in three predefined areas of interest (windshield, left mirror, rear mirror) was calculated. A glance comprised the transition and temporary maintenance of the eye in an area of interest [7]. A chi-square test compared glance behaviors across the DMS conditions (active, inactive, instructed). Since only for one driver two instances of drivng related distraction were recorded, the variable was dichotomized for the analysis (driving-related distraction: yes/no). Analysis and visualization was performed using R version 4.3.3 and RStudio version 2023.06.2. Inferential statistical tests were conducted at a significance level of α=.05.

3 RESULTS

Across all conditions (DMS inactive, DMS active, and DMS instructed), driving-related distraction was recorded in 50 % (n = 31) of the overtaking maneuvers. For the group with the active DMS, in 59 % (n = 13) of the overtaking maneuvers a driving-related distraction was recorded and triggered a warning (see Figure 2). When the DMS was inactive, driving-related distraction was recorded in 62 % (n = 13) of the maneuvers. As the DMS was inactive, no warnings were triggered. When the DMS was instructed prior to the drive, only in 26 % (n = 5) of overtaking maneuvers participants triggered a warning due to driving-related distraction.

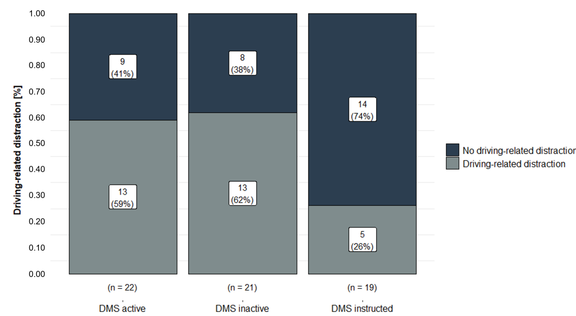

Figure 2: For all conditions (DMS active, inactive, instructed), instances of driving-related distraction were counted during the overtaking maneuver. The number of maneuvers in which no driving-related distraction occurred (grey) were compared against the number of maneuvers in which a driving-related distraction (navy) occured by DMS condition.

Inferential statistics, by means of a chi-square test, revealed a significant effect between the conditions and the frequency of driving-related distraction. Thus, there was a significant difference between the frequency of driving-related distraction depending on whether the DMS was inactive, active, or instructed ($\chi^2(2)$ = 6.18, p = .045, w = 0.32). According to Cohen [2], this difference corresponds to a moderate effect size.

However, post-hoc tests with Bonferroni correction were not significant. This means that post-hoc there was no significant difference between the observed and expected frequency of driving-related distraction in the condition with a inactive, active, or instructed DMS. Therefore, it did not reveal further information in which of the conditions the expected and observed frequency of driving-related distraction differed significantly from another. On a descriptive level, when the DMS was instructed, the number of warnings triggered by participants due to driving-related distraction was less (n = 5), compared to when it was active (n = 13) or inactive (n = 13).

In a second step, the glance locations causing the recorded driving-related distractions (n = 32) during the overtaking maneuvers were investigated more closely (see Figure 3). Eye-tracking data revealed that predominantly glances directed towards the left side mirror (M = 41.98 %, SD = 20.52 %) and to a smaller share, glances to the rear-view mirror (M = 12.88 %, SD = 21.07 %) led to instances of driving-related distraction. On average, drivers still spent 45.14 % of the time looking through the windshield prior to a recorded driving-related distraction (see Figure 3).

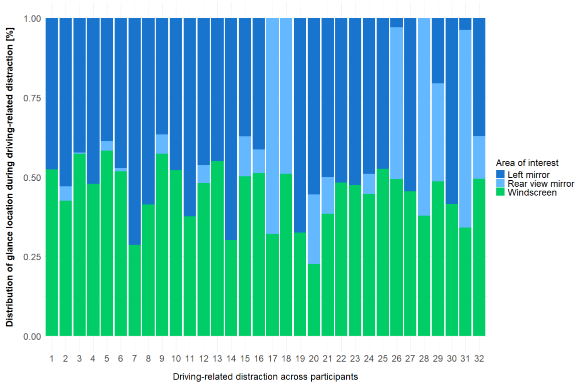

Figure 3: Distribution of glance location during the overtaking maneuver in the time period of driving-related distraction. The numbers on the x-axis represent the all recorded driving-related distraction independent of DMS condition.

4 DISCUSSION

The aim of the present experiment was twofold. First, examine whether the instances of driving-related distraction differ depending on whether participants are instructed about the DMS before the drive or not. Second, investigate which glances during an overtaking maneuver cause driving-related distraction as specified by the Euro NCAP. Sixty-two participants were randomly assigned to one of the three conditions (DMS inactive, active, instructed) and performed the same overtaking maneuver once. In all three conditions, multiple short glances away from the road ahead were observed during the overtaking maneuver that added up to the threshold of a driving-related distraction (10 s). As a result, more than half of the drivers received a warning, in the condition with the active DMS. This is in line with previous research which has reported multiple warnings during driving maneuvers [8]. It can be reasonably assumed that overtaking maneuvers, such as the one implemented in this experiment, are likely to occur in real traffic. Drivers are likely to divide their attention between the rear-view mirrors and the forward roadway, whether intentionally or not. It is difficult to justify that warnings in such cases are a beneficial factor for driving safety.

The results of the chi-square test revealed a significant difference between the frequency of driving-related distraction for the overtaking maneuver with the inactive, active, and instructed DMS. However, the post-hoc tests with Bonferroni correction did not reach significance. This could be explained by a lack of power, due the relatively small sample size per group. Nevertheless, on a descriptive level, participants who received instructions regarding the DMS (i.e., DMS instructed) showed less driving-related distraction than participants who had received warnings but no instructions (i.e., DMS active). Furthermore, on a descriptive level, it was apparent that it does not make a difference in terms of the frequency of driving-related distraction whether the DMS was inactive or active but uninstructed, as the number of driving-related distraction was descriptively the same. In line with previous research, this descriptive finding could be attributed to the fact that participants have difficulty in acquiring a correct mental model of the DMS based on the sole interaction with the DMS [8, 15], so that the mere warning itself does not influence the driver's glance behavior in the short term, which is unsurprising. This explanatory approach is consistent with the results of this study. Solely an instruction on the functioning of the DMS led to a change in participants' glance behavior and thus to a reduction in the occurrence of driving-related distraction, at least descriptively.

Furthermore, the results showed that driving-related distraction, as defined by the Euro NCAP, occurred due to mirror glances when overtaking a vehicle in dense traffic. More precisely, they were caused by glances into the side mirror, when drivers were checking for rear traffic prior to the lane change. This is in live with previous research, which showed that a considerable proportion of glances are directed to the side mirror prior to a left lane change [18, 20]. The safety-related glance behavior of drivers, prior to a lane change, was often classified as driving-related distraction by the Euro NCAP algorithm. However, it is not possible to derive from the presented data whether fewer warning also mean less or poorer safeguarding. To determine this, the gaze behavior needs to be examined with regards to the number and duration of mirror glances. The subsequent question is whether it is preferable to receive fewer warnings during an overtaking maneuver if that means drivers conduct fewer mirror checks. If long-term behavioral changes may result in drivers making fewer mirror glances, this would be contrary to the intended outcome of the DMS, and could paradoxically lead to a reduction in safety rather than an increase. Therefore, the question arises as to whether, in the case of overtaking maneuvers, it is appropriate for the algorithm to consider driving-related distractions (e.g., mirror checking) to be relevant distractions for the triggering of warnings.

4.1 Limitations

The study was conducted in a static driving simulator, which limits the external validity of the present study results. Investigating driving-related distraction in a field study would be sensible next step as participants rather overestimate their own safety in driving simulators [4] and therefore it could be that the participants in the present study showed less safety-related glance behavior than they would do in real traffic. Thus, the number of driving-related distraction in the present study may even have been underestimated.

Furthermore only one overtaking maneuver was considered in the present analysis. Therefore, it is not possible to draw any conclusions about the effect over time. However, since each overtaking maneuver is unique in real traffic, it does not seem appropriate to analyze the same overtaking maneuver multiple times. To shed light on this issue, future research therefore needs to consider different overtaking maneuvers over time.

In the present study, the participants' mental model of the DMS was not examined. Therefore, attributing the found effects to a better understanding is the most logical conclusion but cannot be supported by data on the mental model. Future work should therefore elaborate whether a better understanding of the DMS leads to a reduction in driving-related distraction by assessing and comparing the mental model of instructed and uninstructed participants.

4.2 Conclusion

In the present study the DMS frequently elicited warnings due to mirror glances during overtaking maneuvers. Findings indicated the necessity to refine DMS algorithms to discern safety-relevant behaviors from genuine distractions. Further, data revealed that implementing a DMS without further instructions does not seem promising. Findings provide insights for researchers and practitioners in the field of distraction by investigating the interplay between the driver's understanding of the DMS and the occurrence of driving-related distraction.

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REFERENCES

[1] Christer Ahlström, George Georgoulas, and Katja Kircher. 2021. Towards a context-dependent multi-buffer driver distraction detection algorithm. *IEEE transactions on intelligent transportation systems* 23, 5 (2021), 4778–4790.

[2] J. Cohen. 1992. A power primer. *Psychological Bulletin* 112, 7 (1992), 155–159. https://doi.org/10.1037/0033-2909.112.1.155

[3] European Commission. 2022. *Technical support to assess the upgrades necessary to the advanced driver distraction warning systems.* Publications Office of the European Union.

[4] Joost C. F. de Winter, P. M. Leeuwen, and Riender Happee. 2012. Advantages and Disadvantages of Driving Simulators: A Discussion. In *Proceedings of Measuring Behavior 2012*, A.J. Spink, F. Grieco, O.E. Krips, W.S. Loijens, L.P.J.J. Noldus, and P.H. Zimmerman (Eds.). s.n., Utrecht, The Netherlands, 47–50.

[5] Thomas A. Dingus, Melissa C. Hulse, Jonathan F. Antin, and Walter W. Wierwille. 1989. Attentional demand requirements of an automobile moving-map navigation system. *Transportation Research Part A: General* 23, 4 (1989), 301–315.

[6] Birsen Donmez, Linda Ng Boyle, and John D. Lee. 2007. Safety implications of providing real-time feedback to distracted drivers. *Accident Analysis & Prevention* 39, 3 (2007), 581–590. https://doi.org/10.1016/j.aap.2006.10.003

[7] International Organization for Standardization. 2020. ISO 15007:2020 Road vehicles—Measurement and analysis of driver visual behaviour with respect to transport information and control systems—Part 1: Defnitions and Parameters (ISO 15007:2020). https://www.iso.org/obp/ui/en/#iso:std:iso:15007:ed-1:v1:en

[8] Yannick Forster, Nadja Schoemig, Christina Kremer, Katharina Wiedemann, Sebastian Gary, Frederik Naujoks, Andreas Keinath, and Alexandra Neukum. 2024. Attentional Warnings caused by driver monitoring systems: How often do they appear and how well are they understood? *Accident Analysis & Prevention* 205 (2024), 107684. https://doi.org/10.1016/j.aap.2024.107684

[9] Amina Guettas, Soheyb Ayad, and Okba Kazar. 2019. Driver State Monitoring System: A Review. In *Proceedings of the 4th International Conference on Big Data and Internet of Things.* Association for Computing Machinery, New York, NY, USA, 1–7. https://doi.org/10.1145/3372938.3372966

[10] Anaïs Halin, Jacques G. Verly, and Marc Van Droogenbroeck. 2021. Survey and Synthesis of State of the Art in Driver Monitoring. *Sensors* 21, 16 (2021), 5558. https://doi.org/10.3390/s21165558

[11] Matthias J. Henning, Oliver L. Georgeon, and Josef F. Krems. 2007. The quality of behavioral and environmental indicators used to infer the intention to change lanes. In *Fourth International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design.* University of Iowa, Stevenson, Washington, 231–237. https://doi.org/10.17077/drivingassessment.1242

[12] Katja Kircher and Christer Ahlström. 2009. Issues Related to the Driver Distraction Detection Algorithm AttenD. In *First International Conference on Driver Distraction and Inattention.* Swedish National Road and Transport Research Institute (VTI), Gothenburg, Sweden, 1–15.

[13] Katja Kircher and Christer Ahlström. 2013. *The driver distraction detection algorithm AttenD.* Vol. 1. CRC Press, London, 327–348. https://doi.org/10.1201/9781315578156

[14] S. G. Klauer, T. A. Dingus, V. L. Neale, J. D. Sudweeks, and D. J. Ramsey. 2006. *The Impact of Driver Inattention on Near-Crash/Crash Risk: An Analysis Using the 100-Car Naturalistic Driving Study Data.* Technical Report. National Highway Traffic Safety Administration. https://rosap.ntl.bts.gov/view/dot/62931

[15] Ina Koniakowsky, Yannick Forster, Josef F. Krems, and Andreas Keinath. n.d.. The Role of Mental Models on the Effectiveness of Driver Monitoring Systems in Reducing Driver Distraction: Insights from a Driving Simulator Study. (n.d.). under review.

[16] Hans-Peter Krueger, Martin Grein, Armin Kaussner, and Christian Mark. 2005. SILAB-A task-oriented driving simulation. In *Driving Simulation Conference.* University of Iowa, Orlando FL, United States, 323–331.

[17] John D. Lee and Michael A. Regan. 2008. *Defining driver distraction.* CRC Press, Boca Raton, 31–40.

[18] Suzanne E. Lee, Erik C. B. Olsen, and Walter W. Wierwille. 2004. *A Comprehensive Examination of Naturalistic Lane-Changes.* Technical Report. National Highway Traffic Safety Administration.

[19] Euro NCAP. 2023. *Assessment Protocol-Safety Assist - Safe Driving. Implementation 2023. V. 10.2.* Euro NCAP, Leuven, Belgium.

[20] Louis Tijerina, William Riley Garrott, Duane Stoltzfus, and Edwin Parmer. 2005. Eye Glance Behavior of Van and Passenger Car Drivers During Lane Change Decision Phase. *Transportation Research Record* 1937, 1 (2005), 37–43. https://doi.org/10.3141/1937-06

[21] Trent Victor. 2005. System and method for monitoring and managing driver attention loads. Google Patents.